

## Exam

### Hour Exam 2: Wednesday, October 25th

- In-class, covering waves, electromagnetism, and relativity
- Twenty multiple-choice questions
- Will cover: Chapters 8, 9 10 and 11  
Lecture material
- You should bring
  - 1 page notes, written single sided
  - #2 Pencil and a Calculator
  - Review Monday October 23rd
  - Review test will be available online on Monday (see exams page)

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1

## Topics covered in Exam 2

- Waves, interference, resonance, and electromagnetism
- EM radiation, light, color
- Special Relativity time & space
- Special Rel. mass & energy
- General Relativity

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2

## Wave properties

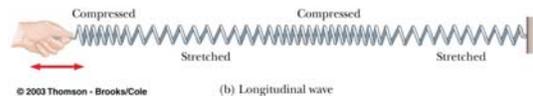
- **Amplitude** is the maximum displacement of string above the equilibrium position
- **Wavelength**,  $\lambda$ , is the distance between two successive points that behave identically
- **Period**: time required to complete one cycle
- **Frequency** =  $1/\text{Period}$  = rate at which cycles are completed
- **Velocity** =  $\text{Wavelength}/\text{Period}$ ,  
 $v = \lambda / T$ , or  $v = \lambda f$

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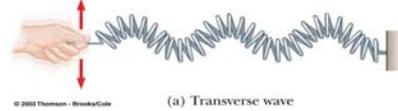
3

## Types of wave motion

- Longitudinal wave
  - Vibrations are in the direction of motion



- Transverse wave
  - Vibrations are perpendicular to the direction of



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4

## Waves Questions

When both transverse and longitudinal waves are present (such as  $s$  and  $p$  seismic waves in the Earth), the longitudinal wave usually travels faster.

*If the longitudinal wave travels about twice as fast as the transverse wave of the same frequency, how are their wavelengths related?*

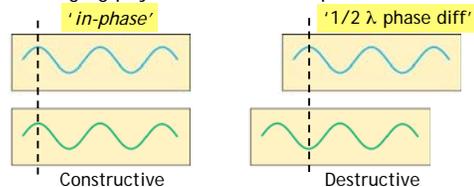
- A. Longitudinal wavelength twice as long
- B. Longitudinal wavelength half as long
- C. Both same.

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5

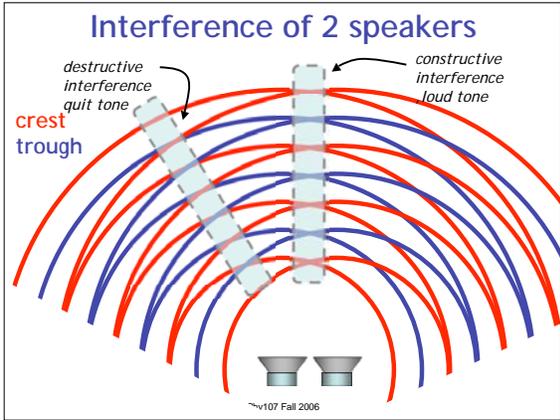
## Interference of sound waves

- Interference arises when waves change their 'phase relationship'.
- Can vary phase relationship of two waves by changing physical location of speaker.



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6



### Interference question

You are standing at a point where the signals from two radio antennas cancel exactly. The towers broadcast at 1000 kHz. You walk around with a constant distance from tower 1. How much closer to tower 2 do you need to go to get full constructive interference (strong radio signal)?

Speed of sound: 340m/s

A. 300 meters  
**B. 150 meters**  
 C. 75 meters

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### Interference summary

- Important quantity is distance difference in number of wavelengths.
- A distance difference of a half wavelength leads to destructive interference.
- Whole wavelength differences lead to constructive interference.

*But destructive interference also for 3 half wavelengths, 5 half-wavelengths, etc.*

*Constructive interference also occurs at differences of 2 whole wavelengths, 3 whole wavelengths*

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### Doppler Effect

- As the source moves toward the observer (A), the wavelength appears shorter and the frequency increases
- As the source moves away from the observer (B), the wavelength appears longer and the frequency appears to be lower

Phy107 Fall 2006 10

### Most objects resonate, Closed tube

(a)

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### Resonance on string

- First three natural vibrational modes of a string fixed at both ends (e.g. a guitar string).
- A normal pluck excites primarily the first vibrational mode.

Phy107 Fall 2006 12

### Force between charges

*Opposite charges attract  
Like charges repel.*

*Force on positive particle due to negative particle*



- Other than the polarity, they interact much like masses interact gravitationally.
- Force is along the line joining the particles.

Charge on 1 electron or proton =  $1.6 \times 10^{-19}$  Coulomb

**Electrostatic force:**  $F_E = k Q_1 Q_2 / r^2$   
 $k = 9 \times 10^9 \text{ Nm}^2/\text{C}^2$

**Gravitational force:**  $F_G = GM_1 M_2 / r^2$   
 $G = 6.7 \times 10^{-11} \text{ Nm}^2/\text{kg}^2$

Phy107 Fall 2006 13

### Coulomb force question

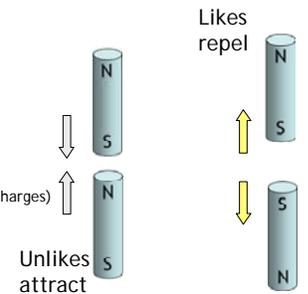
If the distance between two positive charges is increased by a factor of two, the force between them

- A. Increases by a factor of 2
- B. Decreases by factor of 2
- C. Decreases by a factor of 4

Phy107 Fall 2006 14

### Magnetic forces

- North Pole and South Pole
- This is the elementary magnetic particle
- Called magnetic dipole (North pole and south pole)
- There are no magnetic 'monopoles' (magnetic charges)



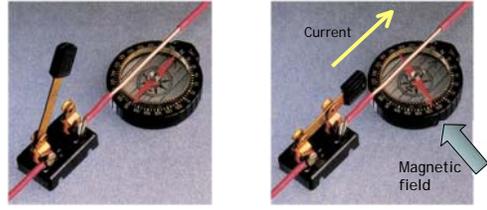
Unlikes attract

Likes repel

Phy107 Fall 2006 15

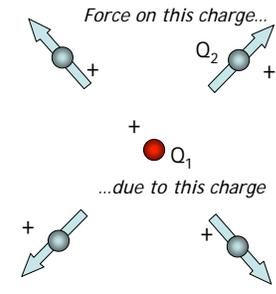
### Source of magnetic field

- Current in wire produces magnetic field.
- That magnetic field aligns compass needle



Phy107 Fall 2006 16

### The electric force and field



**$F = \frac{kq_1q_2}{r^2}$**

**$E = \frac{kQ}{r^2}$**

**$F = Eq$**

- Charge  $q_1$  can exert a force on any number of charges. Would like to understand just the part from  $q_1$ .
- Similar relationship between work and Voltage

Phy107 Fall 2006 17

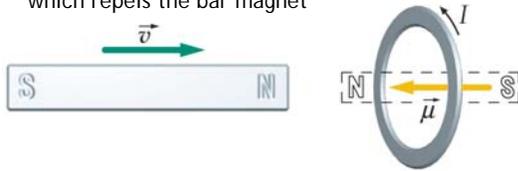
### Magnetic Force

- What does the magnetic force act on?
  - Electric field is from a charge and exerts a force on other charges
  - Magnetic field is from a moving charge and exerts a force on other moving charges!
- Magnetic field B
- Magnetic force  $F = qvB$ 
  - F perpendicular to both v and B

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## Faraday's law of induction and Lenz's Law

- A changing (moving) magnetic field causes a current in a metal. However, electric fields are what causes electrons to move in a metal
- Changing magnetic fields produce electric fields
- The current produces a magnetic field, which repels the bar magnet



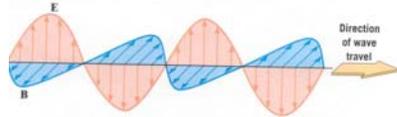
## Ampere's Law and Light

- Finally: Changing electric fields cause magnetic fields!
- Electric fields are from charges
- Magnetic fields are from moving charges
- Changing Magnetic fields cause Electric fields
- Changing Electric fields cause Magnetic fields
- All this was expressed in Maxwell's equations
- Maxwell and others realized that a changing magnetic/electric field could cause a changing magnetic/electric field. The condition for one to cause the other and vice-versa was for the two to change in a sin wave pattern and move at the velocity of light!

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20

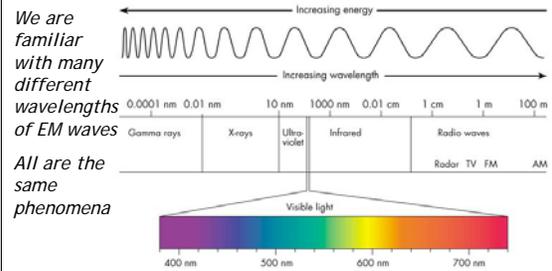
## Properties of EM Waves



- Light is a set of electric and magnetic fields where the changing electric field creates the magnetic field and the changing magnetic field creates the electric field
- Only works when the fields change from up to down and back again at the speed of light
- The speed of light is a special value - we'll see this again in Einstein's relativity.
- Has all properties of a wave: wavelength, frequency, interference...  $c = v = \lambda f$
- Can be generated by spark jumping a gap.

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21



## EM wave question

As an EM wave travels through empty space, its speed can be increased by

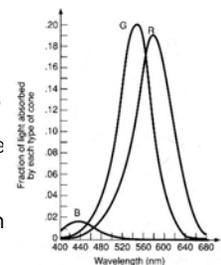
- Increasing its frequency
- Increasing its energy
- Neither

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23

## Eye spectral sensitivity

- Eye's sensitivity to EM radiation is through three cones sensitive to different spectral ranges.
- Overlapping ranges means that different light sources can be seen as the same color
- Three cones suggests we can synthesize colors from three primary sources.



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24

## Einstein's principle of relativity

- Galilean Relativity
  - Laws of mechanics identical in all inertial ref. frames
- Einstein's Relativity
- Principle of relativity:
  - All the laws of physics are identical in all inertial reference frames.
- Constancy of speed of light:
  - Speed of light is same in all inertial frames (e.g. independent of velocity of observer, velocity of source emitting light)

(These two postulates are the basis of the special theory of relativity)

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25

## Space & time relativistic effects

- Einstein's Relativity
  - All laws of physics identical in inertial reference frames
  - Speed of light =  $c$  in all inertial reference frames
- Consequences
  - Simultaneity: events simultaneous in one frame will not be simultaneous in another.
  - Time dilation
  - Length contraction
  - Relativistic invariant:  $x^2 - c^2 t^2$  is 'universal' in that it is measured to be the same for all observers

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26

## Review: Time Dilation and Length Contraction

Time in other frame

→

$$T = \gamma T_p = \frac{T_p}{\sqrt{1 - v^2/c^2}}$$

Time in object's rest frame

←

Times measured in other frames are longer (time dilation)

Length in other frame

→

$$L = \frac{L_p}{\gamma} = L_p \sqrt{1 - \frac{v^2}{c^2}}$$

Length in object's rest frame

←

Distances measured in other frames are shorter (length contraction)

- Need to define the rest frame and the "other" frame which is moving with respect to the rest frame

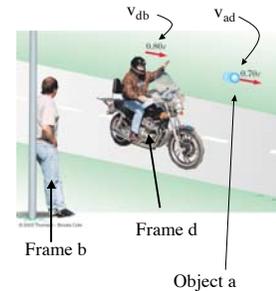
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27

## Relativistic Addition of Velocities

- As motorcycle velocity approaches  $c$ ,  $v_{ab}$  also gets closer and closer to  $c$
- End result: nothing exceeds the speed of light

$$v_{ab} = \frac{v_{ad} + v_{db}}{1 + \frac{v_{ad} v_{db}}{c^2}}$$



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28

## Time dilation

I am on jet traveling at 500 mph and throw a ball up and catch it in my hand. I time it.  
 You are on the ground and watch me. You time it.  
 How do the measurements compare for you and I?

- A.  $t_{jet} = t_{Earth}$
- B.  $t_{jet} > t_{Earth}$
- C.  $t_{jet} < t_{Earth}$

Proper time is measured in the jet frame (rest frame of object where events occur at same spatial location).

Times measured in other frames are longer (time dilation). Since my time measurement of interval between same two events is less, you could say that my clock runs slow. If you look at my clock through a telescope, it appears to run slow.

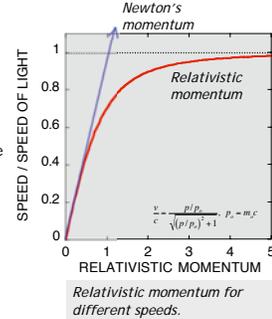
My heartbeat is a kind of clock, so you observe it to be beating more slowly. All my biological processes have slowed down.

Hence you will measure that I age more slowly.

## Relativistic Momentum

- Momentum can be increased arbitrarily, but velocity never exceeds  $c$
- We still use  $\frac{\text{change in momentum}}{\text{change in time}} = \text{Force}$  so for constant force we still have momentum = Force x time, but the velocity never exceeds  $c$
- Momentum has been redefined.

$$p_{relativistic} = \gamma m v = \frac{m v}{\sqrt{1 - (v/c)^2}}$$

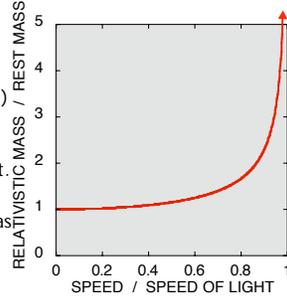


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30

## Momentum gets large, but speed does not?

- Can understand this by saying particle becomes extremely massive as speed increases ( $m = \gamma m_0$ )
- Constant force has less and less affect as speed approaches speed of light
- Same as saying that relativistic momentum has new form ( $p = \gamma m_0 v$ )



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31

## Relativistic Mass and Energy

$$E = \gamma m_0 c^2 = KE_{rel} + m_0 c^2$$

$$E = \gamma m_0 c^2, \text{ or } E = mc^2$$

- The total energy of a particle is dependent on it's kinetic energy and its mass.
- Even when the particle is not moving it has energy.
- **Mass is another form of energy**
  - Moreover, energy can show up as mass.
  - The energy to put all the protons together in a nucleus gives the nucleus more mass!

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32

## Space/Time - Energy/Momentum

- Relativity mixes up space and time - also energy and momentum
  - When converting from one inertial frame to another
  - In the time dilation and length contraction formulas
    - time is in the length formula and length is in the time formula
    - through the velocity (length/time)
  - In the total energy formula momentum(or kinetic energy) and mass energy are related
- There are combinations of space/time and energy/momentum that observers in any inertial frame will measure the as the same
  - For energy and momentum this invariant says that all observers can agree on mass an object has when it's at rest!

$$x^2 - c^2 t^2 \quad E^2 - c^2 p^2 = (m_0 c^2)^2$$

33

## General Relativity and Gravity

- General relativity motivated by Equivalence Principle
  - No experiment can distinguish between force of gravity and an accelerated reference frame.
- General relativity does not consider gravity to be a force between massive objects
  - Mass tells space-time how to curve
  - Curvature of space-time dictates how objects move.
  - Objects move along straight line in space-time
  - Motion independent of mass of object (even light bends)
- Leads to effects such as
  - Light bending in gravitational fields
  - Black holes...

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34

## Paradox?

Now we each throw our own balls to the same height, and we each measure the time interval of our own ball with our own wristwatch.

- We agree that wristwatch on the jet runs slow.
- We agree that the wristwatch on the earth runs slow.
- We both say that the *other* person's wristwatch is slow.

Problem is exactly symmetric:

Earth perspective - jet flies forward at 500 mph  
Jet perspective - earth moves backwards at -500 mph

So must each come to the same conclusion - that the other wristwatch runs slow. But this also means we say that biological processes of the *other* person run slow, hence they age less! Who is correct?

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35

## Spaceship twins

A 30 yr old astronaut leaves Earth, travels at speeds close to that of light, and then returns to Earth after 20 yrs as measured on Earth. What is the astronaut's biological age upon returning?

- Less than 50 years.
- More than 50 years.
- Exactly 50 years.

The observer on the earth is in an inertial frame. The astronaut is not, since she must turn around and come back (acceleration).

So special relativity applies to the earth observe, who sees the astronaut's clock running slow. Hence the astronaut ages less than the earth observer.

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36