Hour Exam 2: Wednesday, March 8
- In-class, covering waves, electromagnetism, and relativity
- Twenty multiple-choice questions
- Will cover: March Chap 6-7, 9-12
  Griffith Chap 12, 15, 16
- All lecture material
- You should bring
  - 1 page notes, written double sided
  - #2 Pencil and a Calculator
  - Review Monday March 6
  - Review questions online under "Review Quizzes" link

Topics covered in Exam 2
- Waves, interference, resonance, and electromagnetism
- EM radiation, light, color
- Special Relativity time & space
- Special Rel. energy, & General Relativity

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** = Wavelength/Period, $v = \lambda / T$, or $v = \lambda f$

Types of wave motion
- **Longitudinal wave**
  - Vibrations are in the direction of motion
- **Transverse wave**
  - Vibrations are perpendicular to the direction of motion
- **Doppler effect**
  - Change in apparent frequency due to motion of source or observer

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

*If the longitudinal wave travels 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.

Superposition & interference
- **Superposition of waves**
- **Interference of waves on a string**
- **Interference of sound waves**
  - Constructive interference
  - Destructive interference
- **Doppler effect**
  - Change in apparent frequency due to motion of source or observer
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.

Constructive  
Destructive

\[ \text{in-phase} \]
\[ \frac{1}{2} \lambda \text{ phase diff} \]

Interference of 2 speakers

- crest
- trough
- constructive interference (loud tone)
- destructive interference (quit tone)

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)?

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

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

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.
Resonance

Vibrational modes are accurately shown by means of holographic interferometry, which displays a contour map of the vibration. Several modes of vibration of a wine glass are shown in the photo below. Points of maximum motion, which occur around the rim, appear as "bull's eyes." The vibrational amplitude changes by half a wavelength of light (316 nm) in moving from one bright fringe to the next one. The fundamental mode, designated as the (2,0) mode, has four such regions, with the glass moving in alternate directions as it vibrates.

Electricity and magnetism

- Coulomb force between charged particles
  - Same form as gravitational force
- Electric field lines: path followed by charged particle
- Electric current: flow of charged particles

- Magnetic field:
  - Arises from electric currents (moving charges)
  - Also results in force on an electric current
- Faraday effect:
  - Changing magnetic field induces electric current
  - Magnetic field from induced currents opposes change in applied field

Electrical Charge

- Only the negative charge moves around. These are the electrons.
- The positive charges are protons. Protons and electrons form a ‘planetary’ atom.
- Electrons orbit around a nucleus containing the protons. Compare planets orbiting around a sun.
- Atoms are bound together, forming solid materials. Electrons can be torn from atoms, transferred to other materials.

Force between charges

Electrostatic force: \( F = \frac{kQ_1Q_2}{r^2} \)
- \( k = 9 \times 10^9 \) N m^2 / C^2

Gravitational force: \( F = \frac{GM_1M_2}{r^2} \)
- \( G = 6.7 \times 10^{-11} \) N m^2 / kg^2

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

The idea of electric fields

- EM wave made up of oscillating electric and magnetic fields.
- But what is an electric field?
- Electric field is a way to describe the force on a charged particle due to other charges around it.
- Force = charge \( \times \) electric field
- The direction of the force is the direction of the electric field.
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)

Electromagnetic waves

- EM radiation is a transverse wave
  - Contains both electric field and magnetic field
  - Amplitudes are perpendicular to propagation dir.
- EM radiation propagates at $c$, speed of light
- EM radiation generated by accelerating charges
- Visible light is a narrow band of entire EM spectrum.
- Radio waves are EM radiation. Can be generated by spark jumping a gap.

EM wave question

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

A. Increasing its frequency
B. Increasing its energy
C. Neither
Visible light is only a narrow range of the entire EM spectrum.

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 suggest we can synthesize colors from three primary sources.

Eye spectral sensitivity

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Galilean Relativity
- Laws of mechanics identical in all inertial ref. frames.

Einstein's Relativity
- All laws of physics identical in inertial ref. frames.
- Speed of light= c in all inertial ref. Frames (e.g. independent of velocity of observer, velocity of source emitting light).

Space & time relativistic effects

- Events observed to be simultaneous in one frame may not be simultaneous in another.
- Measured interval between events different for different observers.
  - Time dilation. Proper time is that measured in frame where events occur at same spatial location.
  - All other measured times are longer by factor γ.
- Measured distance between events different for different observers.
  - Length contraction. Proper length is that measured in rest frame of object.
  - All other lengths are shorter by factor γ.

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. \( t_{\text{jet}} = t_{\text{Earth}} \)
B. \( t_{\text{jet}} > t_{\text{Earth}} \)
C. \( t_{\text{jet}} < t_{\text{Earth}} \)

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. Hence you will measure that I age more slowly.

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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 - 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?
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?

A. Less than 50 years.
B. More than 50 years.
C. 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 observer, who sees the astronaut’s clock running slow. Hence the astronaut ages less than the earth observer.

Space-time diagrams
- World line: path of particle through space-time, is a sequence of events, plotted as points (events) in space-time.
- Observers use different axes, so events appear different.
- But event itself is “universal”, just appears different in different frames.
- For instance $x^2 - ct^2$ is “universal” separation between events in space-time: all observers get same result.

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

Mass-energy equivalence
- This results in Einstein’s famous relation $E = mc^2$
- This says that the total energy of a particle is related to its mass.
- Even when the particle is not moving it has energy.
- We could also say that mass is another form of energy - Just as the text talks of chemical energy, gravitational energy, etc, we can talk of mass energy.
Energy-mass equivalence

Suppose we convert all of the mass of a 1 kg object to energy in order to accelerate a 180,000 kg spaceship from rest. How fast is the spaceship going?

Total energy from 1 kg object = mc²
= (1 kg) x (3x10⁸ m/s)²
= 9x10¹⁶ J

This energy is transferred to train, which finally moves at velocity v. The transferred energy appears as kinetic energy = (1/2)mv²
=(1/2) x (18x10⁴ kg) x v²
= 9x10¹⁶ J

This says velocity must by 10⁶ m/s
Since this is only a little more than 1% of the speed of light, we didn’t need to use the relativistic form for the kinetic energy.

A. 1 x 10⁶ m/s
B. 2 x 10⁵ m/s
C. 1 x 10⁴ m/s

Energy and momentum

• Relativistic energy is

\[ E = \gamma mc^2 \]

• Since \( \gamma \) depends on velocity, the energy is measured to be different by different observers

• Momentum also different for different observers
  - Can think of these as analogous to space and time, which individually are measured to be different by different observers

• But there is something that is the same for all observers:

\[ E^2 - c^2 p^2 = (mc^2)^2 \]

= Square of rest energy

• Compare this to our space-time invariant

\[ x^2 - c^2 t^2 \]

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
  - 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
  - Gravitational lensing
  - Black holes