“Light thinks it travels faster than anything but it is wrong. No matter how fast light travels, it finds the darkness has always got there first, and is waiting for it.”

“They say a little knowledge is a dangerous thing, but it's not one half so bad as a lot of ignorance”

— Terry Pratchett

Darkness cannot drive out darkness: only light can do that. Hate cannot drive out hate: only love can do that.”

— Martin Luther King Jr.
Announcements

• Schedule has been revised
  • Second Midterm moved out one week
• Midterm will be graded Thursday
  • Other grades up to date as well, with any luck and lots of coffee
  • You should have received an email from Thinkwave Gradebook
• You will need to set up an account to view your grades
Last Class

- Midterm
- Before that: History Ancients-Galileo
This Class

- History Galileo, Newton (right?)
- Gravity & Tides
- Intro to light
- LT EM Spectrum
Galileo Galilei: Falling Rocks, Observations, the Telescope and the Inquisition
Galileo Galilei

• 1564-1642
  • Tycho 1546-1601
  • Kepler 1571-1630

• Greatly improved the newly telescope, (did NOT invent the telescope!)

• First to report telescope observations of the sky
  • support the Copernican Model of the Universe
Biographical Notes

• Born in Pisa, son of a musician
• Roman Catholic, considered the priesthood
• Had 2 daughters and a son (out of wedlock)
  • “Galileo’s Daughter” by Dava Sobel
• Studied Medicine at Pisa but wound up a Mathematician
• Contemporary of Kepler, but dismissed his ideas about tides and elliptical orbits
• Got in trouble with the Inquisition over Heliocentrism
  • “It is surely harmful to souls to make it a heresy to believe what is proved.” (Galileo Galilei via Brainyquote.com)
  • Herin hangs a fascinating tale, for which we don’t have time...
  • Ultimately recanted and spent the last 10 years of his life under house arrest
Galileo

- Galileo is also credited with
  - Playing a major role in making science science rather than philosophy (aka the Scientific Revolution)
  - "Philosophy is written in this grand book, the universe ... It is written in the language of mathematics, and its characters are triangles, circles, and other geometric figures;...." Galileo Galilei in The Assayer
  - Demonstrating that two objects fall at the same rate regardless of their mass (if you can neglect air resistance)
    - Actual experiment probably apocryphal
    - But illustrative of his approach
Galileo

- http://www.biography.com/people/galileo-9305220
- http://www.history.com/topics/galileo-galilei
Galileo’s Observations

- Built telescope in 1609
- Published Sidereus Nuncius (Sidereal Messenger) in 1610
  - Moon has mountains & valleys.
    - Heavens are not perfect
  - Milky way is made up of individual stars.
    - Stars must be far away...and not on a fixed sphere
  - Four “planets” orbiting Jupiter.
    - The Earth is not the only “center of revolution”
- Subsequent important observations
  - The sun had spots. g d
    - Heavens are not perfect
  - Venus had phases.
    - Venus MUST orbit the Sun
Galileo’s Observations

- Built telescope in 1609
- Published Sidereus Nuncius (Sidereal Messenger) in 1610
- Moon has mountains & valleys.
  - Heavens are not perfect
- Milky way is made up of individual stars.
  - Stars must be far away...and not on a fixed sphere
- Four “planets” orbiting Jupiter.
  - The Earth is not the only “center of revolution”
- Subsequent important observations
  - The sun had spots.
    - Heavens are not perfect
  - Venus had phases.
    - Venus MUST orbit the Sun
Galileo’s Observations

- Built telescope in 1609
- Published Sidereus Nuncius (Sidereal Messenger) in 1610
- Moon has mountains & valleys.
  - Heavens are not perfect
- Milky way is made up of individual stars.
  - Stars must be far away...and not on a fixed sphere
- Four “planets” orbiting Jupiter.
  - The Earth is not the only “center of revolution”

- Subsequent important observations
- The sun had spots.
  - Heavens are not perfect
- Venus had phases.
  - Venus MUST orbit the Sun
Galileo’s Observations

- Built telescope in 1609
- Published Sidereus Nuncius (Sidereal Messenger) in 1610
  - Moon has mountains & valleys.
    - Heavens are not perfect
  - Milky way is made up of individual stars.
    - Stars must be far away… and not on a fixed sphere
  - Four “planets” orbiting Jupiter.
    - The Earth is not the only “center of revolution”
- Subsequent important observations
  - The sun had spots.
    - Heavens are not perfect
  - Venus had phases.
    - Venus MUST orbit the Sun
NEWTON’S LAW OF UNIVERSAL GRAVITY
Newton on History Channel

Newton’s Law of Universal Gravity

- Maybe it was an apple, maybe it was Kepler
- But Newton realized something causes all objects to be attracted to one another
  - The Moon to the Earth
  - The Earth to the Sun
  - The Apple to the Earth
- this force increases with the masses of the objects and decreases with their distance from one another.
- He also realized that it depended very strongly on distance
Newton’s Law of Universal Gravity

\[ F = \frac{GMm}{r^2} \]

F is gravitational force (in Newtons, 1N is about 0.2 pounds)
M,m are masses of two objects (in kg)
r is distance between two objects (in m)
G is universal gravitational constant (a # that makes the units work out)
\[ G = 6.67 \times 10^{-11} \frac{Nm^2}{kg^2} \]

- The gravitational force between two bodies is proportional to their masses and inversely proportional to the square of the distance between them
TED-ED Gravity

Let's Practice
If the mass of Mars’ moon Deimos tripled, the gravitational exerted by Deimos on Mars would____.

A. increase to 3x what it was
B. increase to 9x what it was
C. decrease to 1/3 what it was
D. decrease to 1/9 what it was
If the distance between Deimos and Mars became three times what it is currently, the gravitational force exerted by Mars on Deimos would ____.

A. increase to 3x what it was
B. increase to 9x what it was
C. decrease to 1/3 what it was
D. decrease to 1/9 what it was
If an asteroid knocked the Moon so that it’s orbit was twice the distance from the Earth that it is now, the gravitational force of the Earth on the Moon would become _____.

A. 1/4 as large
B. 1/2 as large
C. the same
D. 2x as large
E. 4x times as large
TIDES
Gravity & Tides

- Gravity strongest on nearest stuff, weakest on farthest
- Water distorts — bulge
- Both Sun and Moon do this
- Which is stronger?

![Diagram showing the effect of gravity and tides on the Earth's ocean.](diagram.png)
Tides

Spring Tide

- Gravitational pull of Moon & Sun creates a bulge of water
- Earth rotates through the bulge

Neap Tide
What IS Physics?.... er, Light?
In astronomy, we usually cannot perform experiments with our objects of study.

We observe them = we collect & analyze light.

White light is made up of all the visible colors of light.

Wavelength determines color.
What is light?

- Electromagnetic radiation
- Coordinated variation of electric & magnetic fields
- Sometimes also behaves like a stream of particles
Light: Information from Space

- Visible light is only a small fraction of all electromagnetic radiation
  - visible light, infrared light, UV light, radio, microwave, Xray, Gamma ray...
  - When astronomers refer to “light” they often mean all of the above, not just visible light
  - The color, intensity, timing, etc. all provide information about the object observed
The Speed of Light

- Electromagnetic radiation is the fastest thing known to exist
- All light moves at the “speed of light” in empty space regardless of source or wavelength
- The speed of light is a fundamental property of the universe
- speed of light = c = $3 \times 10^8$ m/s = 300,000 km/s
TED-Ed Light Visible & Invisible

what is light
The Electromagnetic Spectrum

- All these are the same thing as visible light
- Gamma rays -- highest frequency, shortest wavelength, greatest energy per photon
- Radio waves -- lowest frequency, longest wavelength, least energy per photon
WARMUP QUESTION
Which of the following has the shortest wavelength?

A. A photon of ultraviolet light.
B. Blue electromagnetic radiation.
C. An X-ray.
D. A radio wave.
E. Infrared radiation.
Which of the following has the shortest wavelength?

A. A photon of ultraviolet light.
B. Blue electromagnetic radiation.
C. An X-ray.
D. A radio wave.
E. Infrared radiation.
Let’s Practice
Consider green light with a wavelength of 550 nm (0.00000055 cm). Light with a wavelength 1000 times longer than this is most likely to be _____.

A. Infrared  
B. Ultraviolet  
C. Gamma Ray  
D. Radio (excluding microwave)
Consider Xrays with frequency $10^{17}$ Hz. Light with a frequency one millionth of this (i.e. $10^{11}$ Hz) is most likely to be _____.

- A. Ultraviolet
- B. Gamma Ray
- C. Microwave
Evil aliens have kidnapped you and placed you in a chamber with a light source. There is a large dial in front of you marked “wavelength”. It’s currently flooding the room with light and the dial reads $10^{-12}$ m. Which way do you turn the dial?

A. Toward larger numbers -- fast!

B. Toward smaller numbers -- fast!

C. I leave it where it is.
WAVE- PARTICLE DUALITY
Light behaves like both wave and particle

- **A wave** is disturbance or oscillation (of a physical quantity), that travels through matter or space, accompanied by a transfer of energy
  - example: water waves, sound waves
  - characterized by wavelength, frequency, speed
  - key property is interference

- **A particle** in the physical sciences is a small localized object to which can be ascribed physical properties.
  - example: bullets, pebbles, sand grains, electrons, protons
  - characterized by size, shape, speed, specific amount of energy, mass, etc.
  - particles do not display interference
Particles Waving
The Original Double-slit Experiment
Light behaves like both wave and particle

- Light displays interference
  - Double-slit experiment
  - Wave behavior
- Light deposits energy in discrete (quantized) amounts
  - depending only on wavelength
  - photoelectric effect
- The “particle of light” or “quantum of light” is called a photon
  - Particle behavior
Topic for Next Class

• Midterm
Reading Assignment

- Ch 3&4 in Astro
- Ch 3,4&10 in the Astropedia
Homework

- none yet