Astronomy 122

This Class (Lecture 7):

Gravity and Light

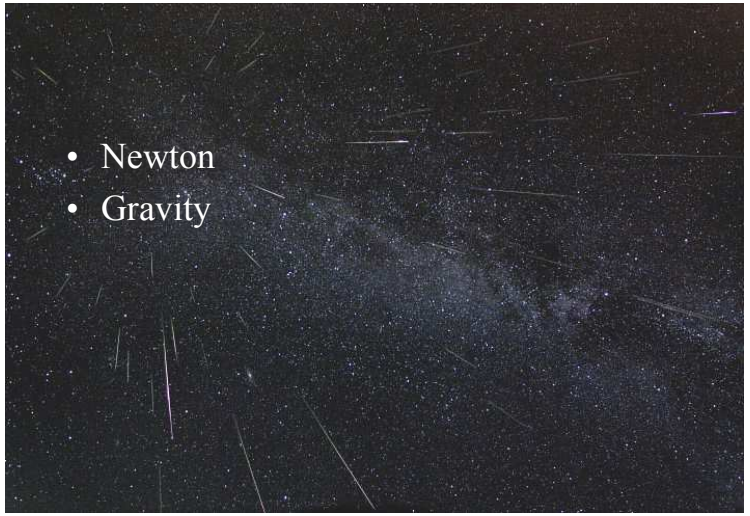
Homework #3 due Fri at 11:59pm!

Next Class:

Optics and Telescopes

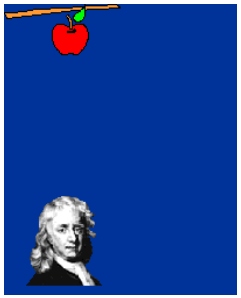
Music: Earthbound – Darrin Drda

Outline

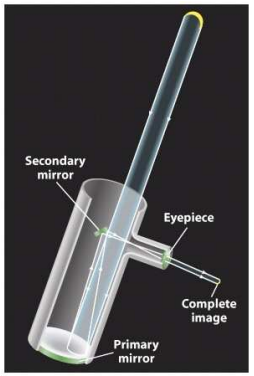


- Newton
- Gravity

Isaac Newton (1642-1727)



$$\int_a^x f(t)\,dt$$



Isaac Newton (1642-1727)

- Developed fundamental laws of nature
- Gave us a reason why the heliocentric system works – **GRAVITY**
- Designed the reflecting telescope
- Discovered that white light is a mix of all colors
- Also invented calculus

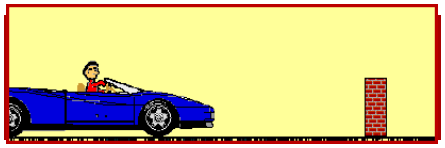
The Laws of Motion

- Until the mid-17th century, scientists worked *empirically*
  - Building a mathematical formula that fit the data
  - No reason *why* the Universe worked
- Newton found fundamental laws that govern the motion of bodies
  - Both on Earth and in the heavens
  - Another blow to Aristotle's physics

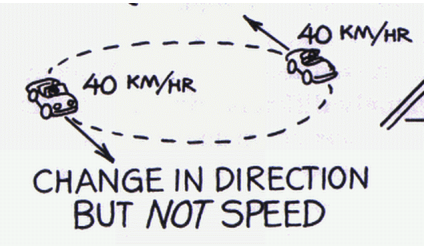
Newton's 1st Law of Motion

- Law of Inertia

  "An object at rest will remain at rest and an object in motion will remain in motion in a straight line at constant speed, unless acted upon by an unbalanced force."



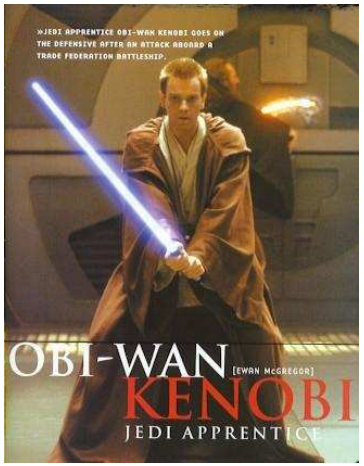
- Motion is described by *velocity*, which measures speed **and** direction



What is a Force?

- No, not THE Force…
- Force in the simplest sense is a push or pull. It may be from gravity, electrical, magnetic, or muscle efforts
- Measured in Newtons

You must learn the ways of the force.



Why was it so hard to see this?

- Usually we have Friction!
- Friction is a possible net outside force that Newton was talking about!
- Remember the feather/hammer experiment? Air Friction dominates the feather causing this to fail in the classroom.

Newton's 2nd Law of Motion

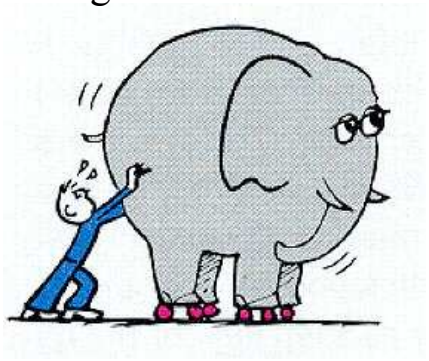
- Law of Acceleration
  - The net force acting on an object is proportional to the object's mass and its resulting acceleration.

a = F / m or **F = m a**

- *Acceleration* is a change in velocity (in speed and/or direction, think of the 1st law)
  - Measured in meters per second per second
  - To accelerate something you have to apply a force
- *Mass* is amount of matter in an object
  - Measured in grams or kilograms, *not pounds!*

Elephant at rest stays at rest

Takes a big force, or the Elephant stays at rest. Or an anvil in space– even if it is "weightless".



http://sol.sci.uop.edu/~jfalward/physics17/chapter2/chapter2.html

Newton's 3rd Law of Motion

- Law of Action-Reaction
  - "Every action has an equal and opposite reaction"
  - Action: Guy jumps forward out of the boat
  - Reaction: Boat moves away from the pier

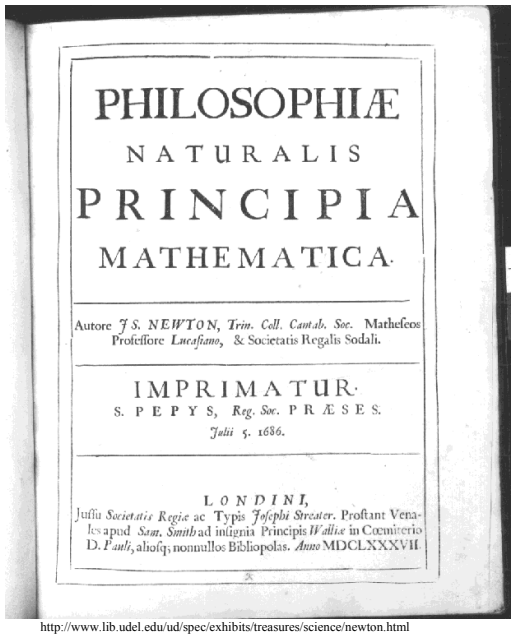
Newton's 3rd Law of Motion

- Law of Action-Reaction
  - "Every action has an equal and opposite reaction"
  - Action: Player makes a shot.
  - Reaction: He moves backwards slightly.

Think-Pair-Share

You are an astronaut taking a space walk to fix your spacecraft with a hammer. Your lifeline breaks and you are left floating in space. To return safely to your spacecraft, you should

a) Throw the hammer at the spacecraft to get someone's attention.
b) Throw the hammer away from the spacecraft.
c) Use a swimming motion with your arms & legs.
d) Reach down and kiss your ship goodbye.


PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore *J S. NEWTON, Trin. Coll. Cantab. Soc.* Matheseos Professore *Lucasiano*, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, *Reg. Soc.* PRÆSES.
Julii 5. 1686.

LONDINI,
Jussu *Societatis Regiæ* ac Typis *Josephi Streater*. Prostant Venales apud *Sam. Smith* ad insignia Principis *Walliæ* in Cœmiterio D. *Pauli*, aliosq; nonnullos Bibliopolas. *Anno* MDCLXXXVII

http://www.lib.udel.edu/ud/spec/exhibits/treasures/science/newton.html

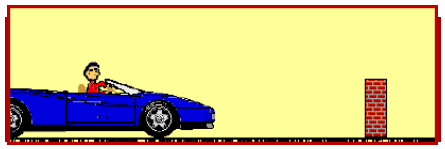
Newton

Principia is one of great science works. By demonstrating that the motion of all bodies was controlled by the same universal laws, Isaac Newton brought to the scientific community a vision of an orderly, harmonious universe.

Newton's 1st Law of Motion

- Law of Inertia

  "An object at rest will remain at rest and an object in motion will remain in motion in a ***straight line*** *at constant speed, unless acted upon by an unbalanced force."*



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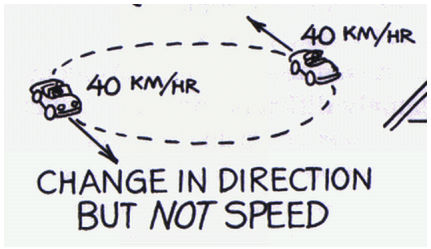
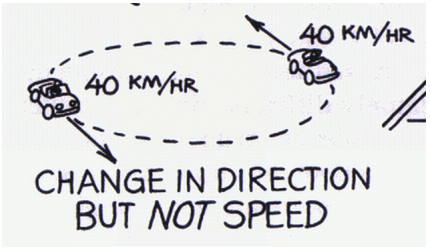


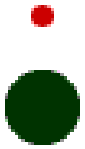
Going in a Circle

- Circle (or orbit) not equal to a straight line.
- The object is constantly changing direction.



Newton and the Planets

Newton's ideas can/should be applied to the heavens as well as the Earth. Right?

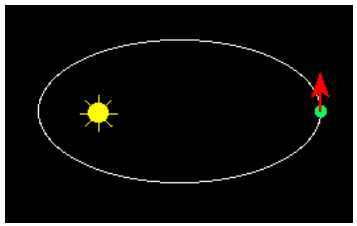


Planetary Motion… By Newton

- A planet going around the Sun (or a moon going around a planet) is always accelerating
  - The direction of motion is changing
- There must be a force acting on the planet! (F = ma)
  - Imagine it as a string
- If we "cut the string", what happens?
  - According to Newton's 1st Law, the ball moves in a straight line

Nature of Gravity

- Newton's Law of Acceleration then tells us that the Sun MUST be applying a **force**

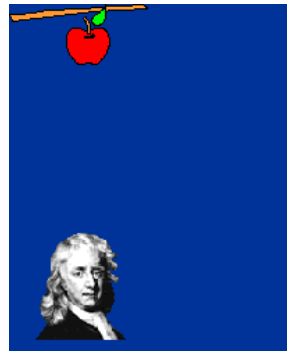


- Ah GRAVITY!

Newton's Law of Gravity

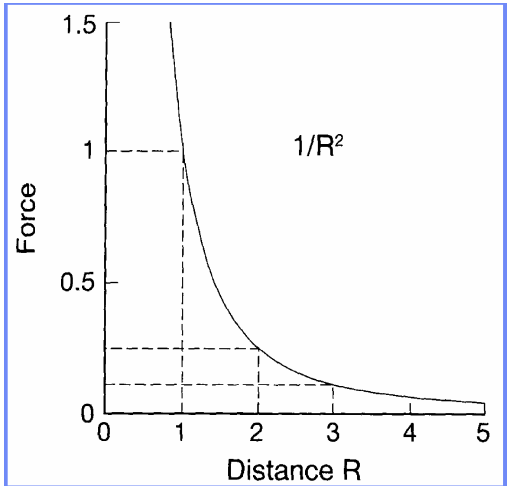
- Any two masses have a gravitational force between them:

$$F = G\frac{m_1 m_2}{r^2}$$



- m_1 and m_2 are the masses
- r is the distance between the two masses
- G is the "gravitational constant" ($G = 6.67 \times 10^{-11}$ when kg and meters are used)

Inverse Square Law

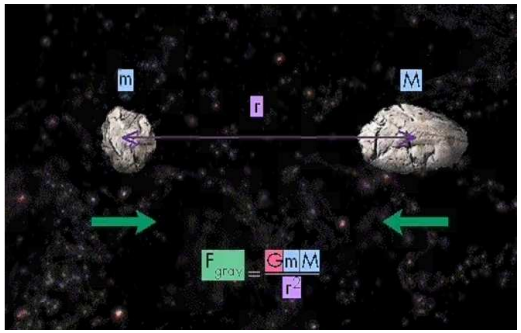


Strong function of separating distance!

Half the distance makes four times the force!

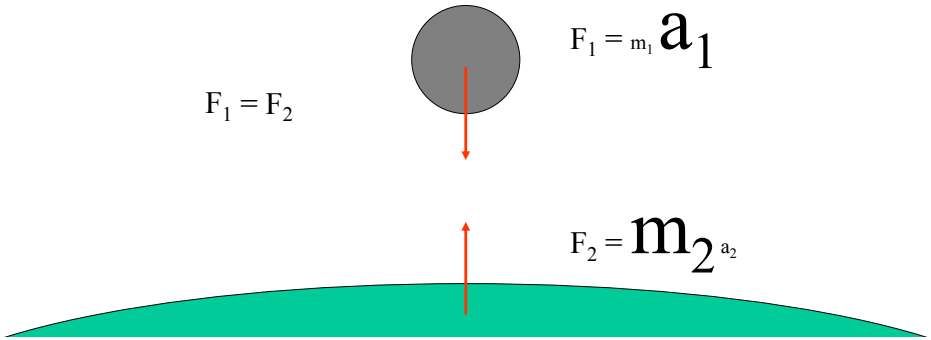
Newton's Law of Gravity

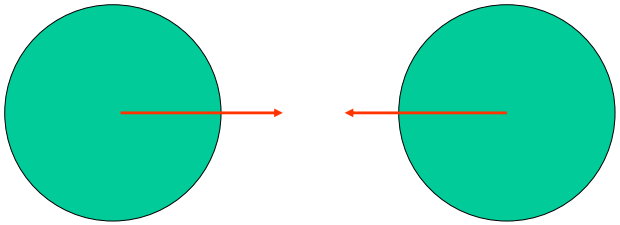
Two bodies attract each other with a force that is directly proportional to the product of the their masses and inversely proportional to the square of the distance between them.



Newton's Universal Law of Gravity

The Earth pulls you and you pull it. But the Earth wins, inertial-wise.





What is Weight?

- What we feel as weight is actually the force we feel from Newton's Law of Gravity.

$$Weight = \frac{GM_{Earth}M_{you}}{R_{Earth}^{2}}$$

- It is confusing since social convention has made weight and mass the same at the earth's surface, but what happens to your weight elsewhere?

Think

Question: When you fly in an airplane, does your weight:

1. Increase.
2. Decrease.
3. Stay the same.

But only a little….

And your mass?

Weight in an Airplane?

Question: When you fly in an airplane, you increase your distance from the center of the Earth.

If the distance increases, d^2 is larger, so your weight is reduced.

$$Weight \propto \frac{1}{d_{Earth}^{2}}$$

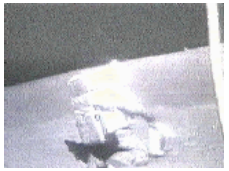
Gravity on the Moon

- Is there gravity on the moon?

- **Yes!**
- But your weight is $1/6^{th}$ of your Earth weight

Moon Gravity

- See you next fall..



http://btc.montana.edu/ceres/html/Weight/weightstudentactivity.htm

Moon weight

- The Moon is around 3.7 times smaller and 81 times lighter than the Earth

$$Weight = \frac{GM_{Moon}M_{you}}{R_{Moon}^{2}}$$

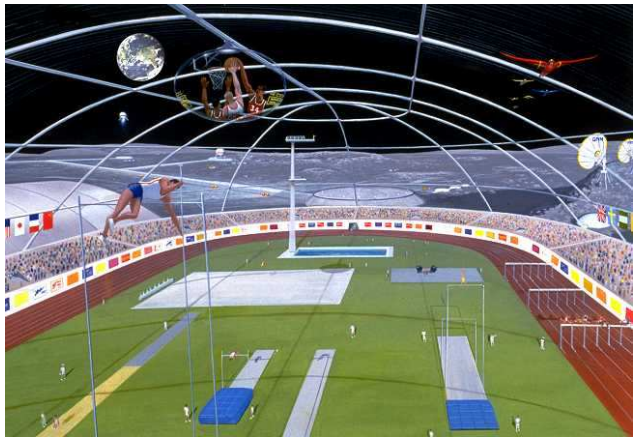
- Your mass would be exactly the same, but your weight would be around 1/6th of your weight on Earth.

Moon weight

$$Weight = \frac{GM_{Moon}M_{you}}{R_{Moon}^{2}} = \frac{G\left(\frac{M_{Earth}}{81}\right)M_{you}}{\left(\frac{R_{Earth}}{3.7}\right)^{2}}$$

$$or\ldots = \frac{1}{81}(3.7)^{2}\frac{GM_{Earth}M_{you}}{R_{Earth}^{2}} \approx \frac{1}{6}Weight_{Earth}$$

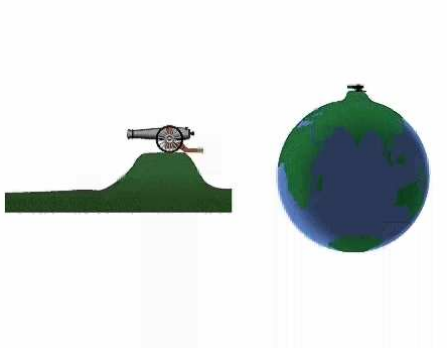
Moon Olympics?



http://www.astronomy.org/programs/moon/moon.html

Newton's Great Insight

- The same force makes things fall down on Earth **and** keeps the planets in their orbits



Orbiting bodies are falling bodies!

Or http://spaceplace.jpl.nasa.gov/orbits1.htm

Why was this important?

- Remember, the ancients believed that there were two sets of rules
  - One for Earth
  - One for the Heavens
- Newton showed that the same laws of nature applied everywhere!
- Earth is not a "special place"
- We are a part of the **Universe**

"Zero-G"

- Why are astronauts "weightless" when in orbit? Are they out of the Earth's gravity?
  - No! Gravity is what keeps them in orbit
  - Astronauts feel weightless because they are falling at the same speed as the spacecraft
  - There is no force pressing them against the floor

Free Falling Objects

"weightless" : not beyond influence of gravity

- Astronaut is just another orbiting body
- Earth's pull is what keeps astronaut in orbit
- Astronaut feels "weightless" because she and spacecraft are experiencing gravity together

Newton's Orbits

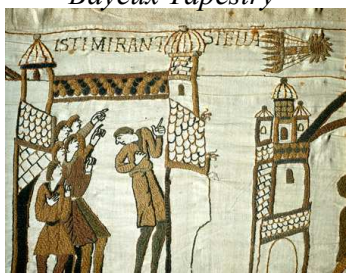
- Kepler had produced his three laws by trying to fit mathematical formulae to his data
- Newton found he could derive Kepler's Laws from his Law of Gravity and Laws of Motion!

Testing: Halley's Comet

Halley's Comet was known to often reappear. Edmund Halley used Newton's formulism to find next arrival.

http://seds.lpl.arizona.edu/nineplanets/nineplanets/halley.html

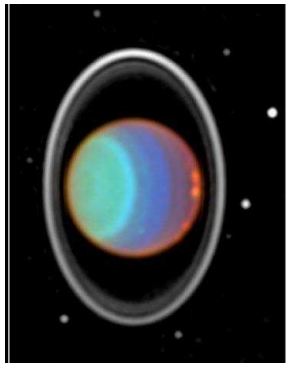
Bayeux Tapestry



http://www.getty.edu/artsednet/resources/Space/Stories/halleys.html

Problem with Gravity?

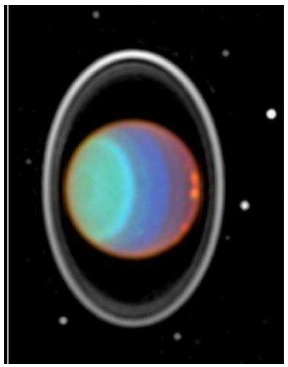
- 1830's: Uranus observed orbit did not follow predictions of Newtonian solar system model.
- Was this the death of Newton's gravity?
- Not good. Theory has to agree with all data, not just some.
- So despite great job with planets, moons, other stars, even one clear failure is enough. (e.g. Mars forced us to throw out circular orbits.)

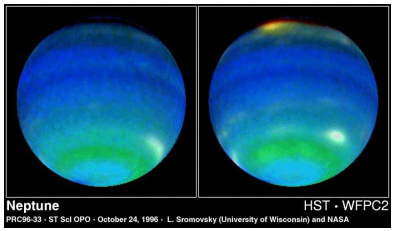


http://lyra.colorado.edu/sbo/hubble/ss/ss.html

Problem with Gravity?

- What's going on?
- What do you think?
- Throw out Newton? No one complained when I threw out Ptolemy (around longer)





Unknown mass, right at predicted location in 1846.

Victory snatched from jaws of defeat!!!!

http://lyra.colorado.edu/sbo/hubble/ss/ss.html

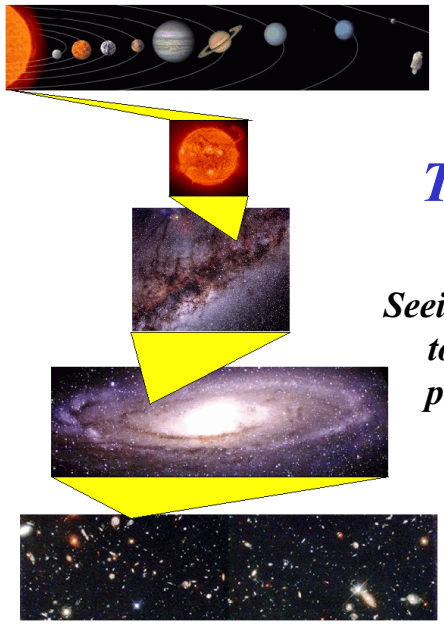
Escape Velocity

We talked about the horizontally aimed cannon, but if we fired it vertically, what velocity do we have to fire it so that it doesn't fall back down?

At some velocity the cannonball outruns gravity's pull. That number is 11.2 km/s or 25,000 m/hr.

Jules Verne: Moon Ship

http://vesuvius.jsc.nasa.gov/er/seh/earlysf.html

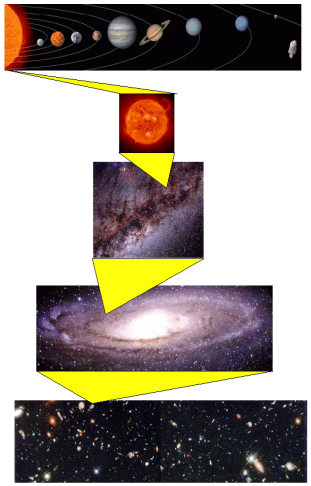


Astronomy: The Big Picture

Seeing how all these pieces fit together into a coherent picture of our Universe!

How to Understand this

- Aside from few places where we put landers...
- From earth, what can we measure about planets /stars/ galaxies?

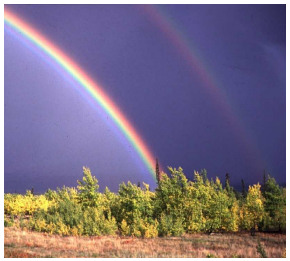


Lighten Up

- In astronomy, we usually **cannot** perform experiments.
- The only way to get information from our subject of study (stars, planets, galaxies) is by ***observing*** their light
- We use telescopes to collect the light that comes to the Earth from distant objects
- To be able to extract the valuable information out of the light we collect, we must understand light.

Come On Light my Fire

- Human beings are *visual*
- We have relied mostly on sight in our existence
  - In ancient times, to find food and shelter
  - Today, to interact with our modern world
- But what is light?
  - Why does light come in different colors?
  - How does light behave?
  - What is infrared? Ultraviolet? X-rays? Radio waves?



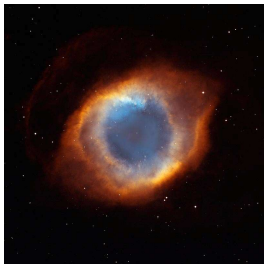
What is Light?

- Light is ***radiant energy***
- On a nice sunny day, you can feel the energy of the sunlight as it warms your skin.

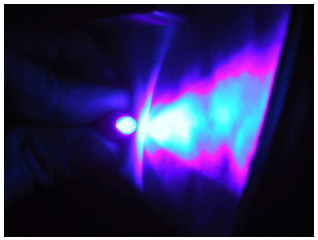
Name Some things that shine by (emit) their own light?

Light bulbs

Stars



Nebulae



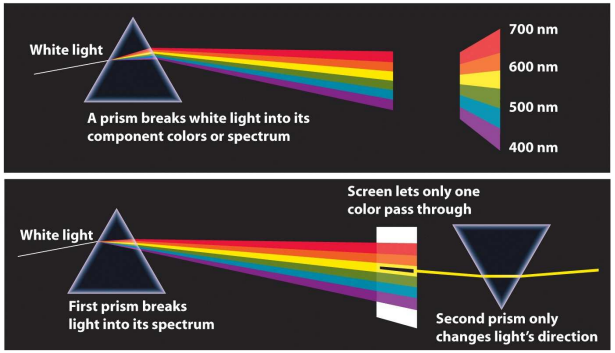
Light-emitting diodes (LEDs)

The Colors of Light

- In ancient times, it was thought that light's fundamental color was *white*
- Colors were created by interactions with objects
  - For example, light would be "colored" by the flowers
- It wasn't until the 1600's that Isaac Newton discovered that "white light" is a *mixture* of all the colors of the rainbow

Colors of the Rainbow

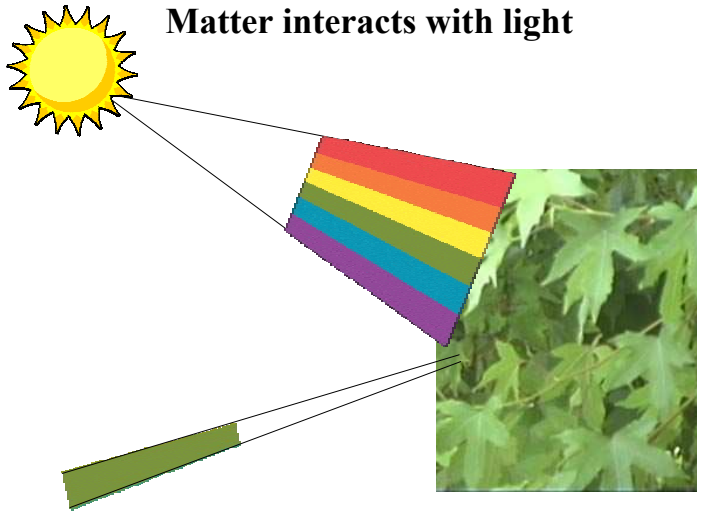
- Newton used a prism to separate white light into its component colors
  - Called a **spectrum**
- Then used a second prism to recombine the spectrum back into white light
- Showed white light is a mixture of many colors



Where Do Colors Come From?

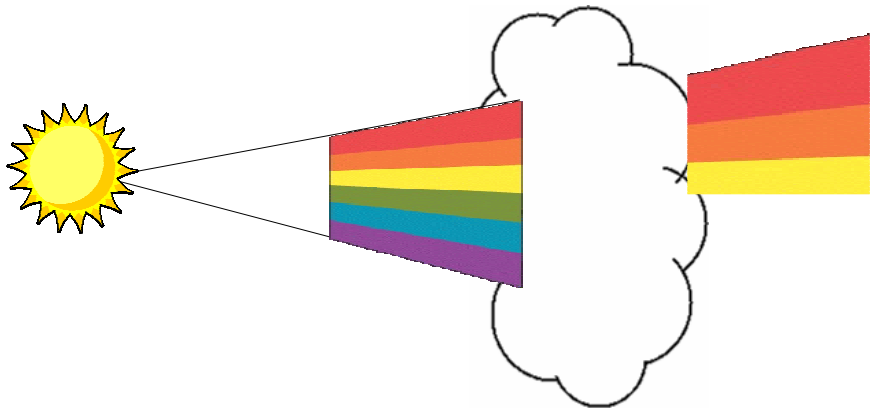
- The color of light is determined by its wavelength
- Visible light has extremely small wavelengths
  - Wavelengths range from 400 nm (violet light) to 700 nm (red light)
- Colors, from longest wavelength to shortest: **red**, **orange**, **yellow**, **green**, **blue**, **violet**

Matter interacts with light



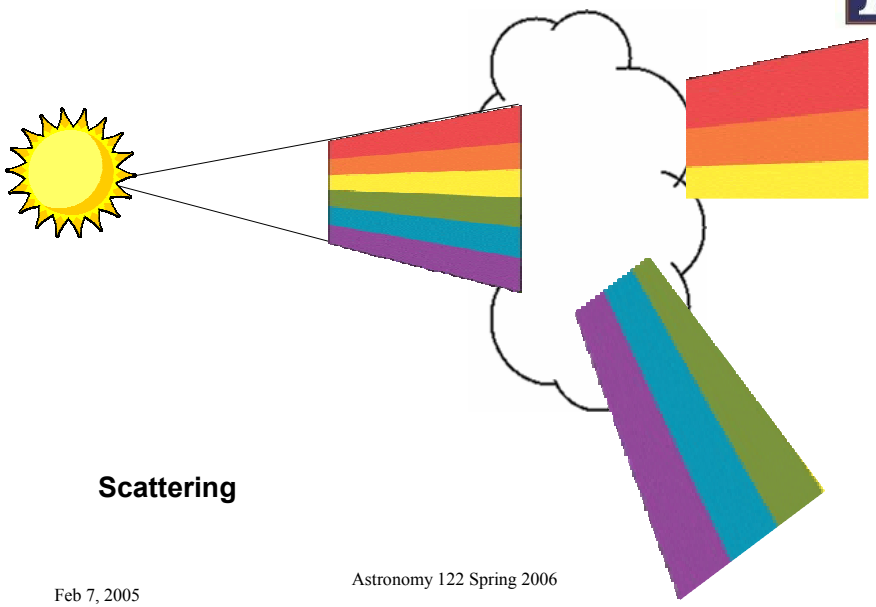
Reflection

Matter interacts with light



Absorption

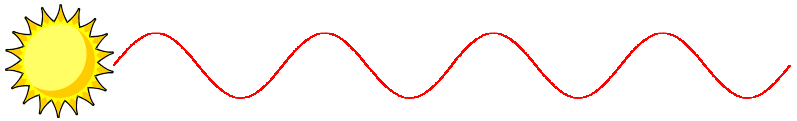
Matter interacts with light



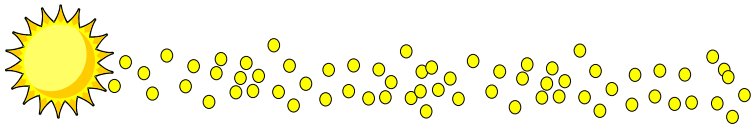
Scattering

Particle or Wave?

- So, how does light behave?



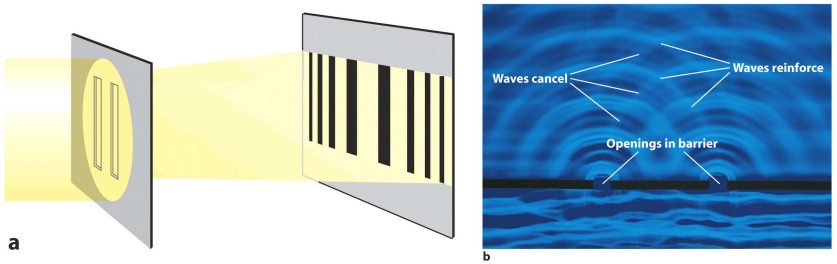
- **Huygens:** light travels in the form of waves of energy



- **Newton:** light is composed of a large number of particles

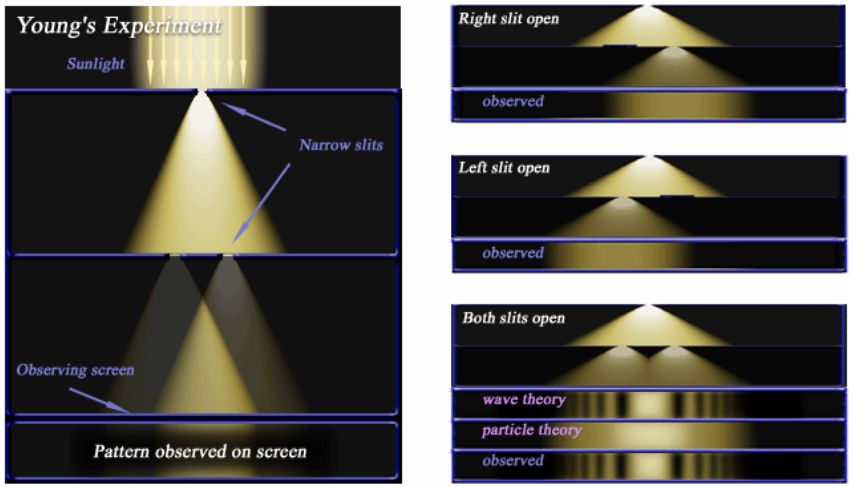
Light is a Wave!

- In 1801, an English physicist demonstrated that light travels as a wave
- When a single color of light is passed through a double slit, a pattern light and dark bands is produced
- Can only be explained by wave-like behavior



Thomas Young: Light is a wave

Double-slit experiment (1801)



Wikipedia