The Copernican Revolution

- The Copernican Revolution is about astronomers struggling with two related problems
  - Earth's place in the cosmos
  - The motion of the planets
- Copernicus revolutionized humanity's view of Earth's place in the Universe
  - By placing the Sun at the center, Copernicus made Earth move along an orbit like the other planets
- The problem of planetary motion was partly solved by Kepler's Laws
  - Kepler figured out laws to describe **how** the planets move, but not the reasons **why**

Kelper's Three Laws

- 1st: The orbit of a planet about the Sun is an ellipse with the Sun at one focus.
- 2nd: A line drawn from the planet to the Sun sweeps out equal areas in equal times
- 3rd: The size of the orbit determines the orbital period

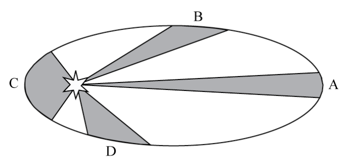
According to Kepler's second law, a planet with an orbit like Earth's would:

a) move faster when further from the Sun.
b) move slower when closer to the Sun.
c) experience a dramatic change in orbital speed from month to month.
d) experience very little change in orbital speed over the course of the year.
e) none of the above.

The planet in the orbit shown below obeys Kepler's Laws.

During how many portions of the planet's orbit (A, B, C and D) would the planet be speeding up the <u>entire time?</u>

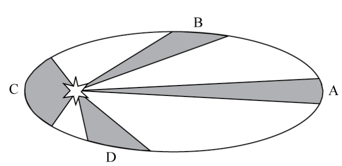
A. Only during one of the portions shown.
B. During two of the portions shown.
C. During three of the portions shown.
D. During four of the portions shown.
E. None of the above.



The planet in the orbit shown below obeys Kepler's Laws.

During which of the portions of the planet's orbit would the planet experience an increase in speed for <u>at least a moment</u>?

A. Only during one of the portions shown.
B. During two of the portions shown.
C. During three of the portions shown.
D. During four of the portions shown.
E. None of the above.



Which of the following best describes what would happen to a planet's orbital speed if it's mass were doubled but it stayed at the same orbital distance?

a) It would orbit half as fast.
b) It would orbit less that half as fast.
c) It would orbit twice as fast.
d) It would orbit more than twice as fast.
e) It would orbit with the same speed.

If a small weather satellite and the large International Space Station are orbiting Earth at the same altitude above Earth's surface, which of the following is true?

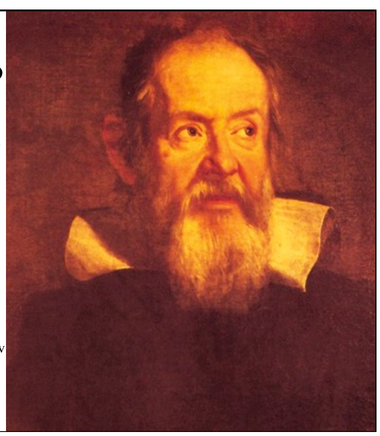
a) The large space station has a longer orbital period.
b) The small weather satellite has a longer orbital period.
c) Each has the same orbital period

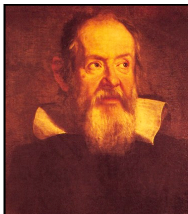
An asteroid orbits the Sun at an average distance a = 4 AU. How long does it take to orbit the Sun?

A. 4 years
B. 8 years
C. 16 years
D. 64 years

The great scientist Galileo made discoveries that strongly supported a heliocentric cosmogony

http://en.wikipedia.org/wiki/Galileo_Galilei#Church_controversy





Galileo (1564-1642) was Italian

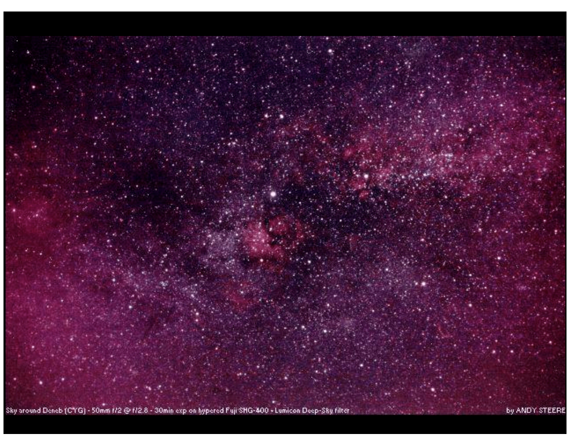
- Was blind at the time of his death
- Was labeled a heretic by the church

Galileo is known for first observations of the Sun, the Moon, etc…with a telescope

How did Galileo solidify the Copernican revolution?

- Italian mathematician & scientist in early 17th century
- **Misconception Alert:** Galileo did not invent the telescope
  - He did observe the heavens
  - He applied his observations to the question of Earth's place in the cosmos
  - His discoveries supported Copernicus' hypothesis

Galileo and his telescope



Milky Way

- There are thousands (billions) more stars in the Milky Way than are visible to the naked eye.
- Universe is bigger than imagined.

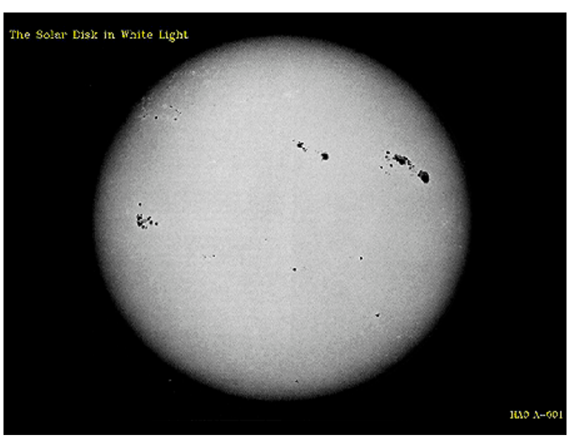
A Being with Ears

The Bulge of Saturn

- Saturn is not a sphere.
- Circles and spheres do not dominate the heavens.

The Moon

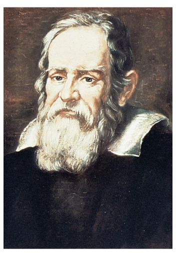
- The moon has craters.
- The moon is not a perfect heavenly body.



Sunspots

- The Sun is not a perfect heavenly body.
- The Sun rotates about its own axis.

How did Galileo solidify the Copernican revolution?



Galileo (1564–1642)

Galileo (1564-1642) overcame major objections to Copernican view. Three key objections rooted in Aristotelian view were:

1. Earth could not be moving because objects in air would be left behind.
2. Non-circular orbits are not "perfect" as heavens should be.
3. If Earth were really orbiting Sun, we'd detect stellar parallax.

Overcoming the first objection (nature of motion):

Galileo's experiments showed that objects in air would stay with a moving Earth.

- Aristotle thought that all objects naturally come to rest.
- Galileo showed that objects will stay in motion unless a force acts to slow them down (Newton's first law of motion).

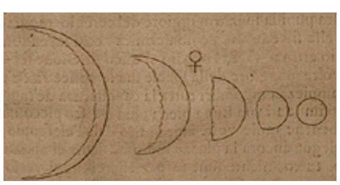
Overcoming the second objection (heavenly perfection):

- Tycho's observations of comet and supernova already challenged this idea.
- Using his telescope, Galileo saw:
  - Sunspots on Sun ("imperfections")
  - Mountains and valleys on the Moon (proving it is not a perfect sphere)

Overcoming the third objection (parallax):

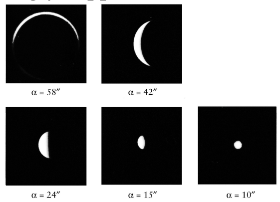
- Tycho *thought* he had measured stellar distances, so lack of parallax seemed to rule out an orbiting Earth.
- Galileo showed stars must be much farther than Tycho thought — in part by using his telescope to see the Milky Way is countless individual stars.

✓ If stars were much farther away, then lack of detectable parallax was no longer so troubling.

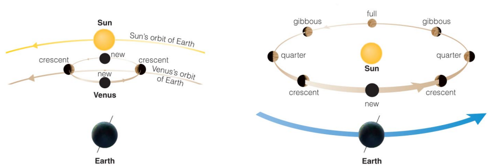


Galileo discovered that Venus, like the Moon, undergoes a series of phases as seen from Earth

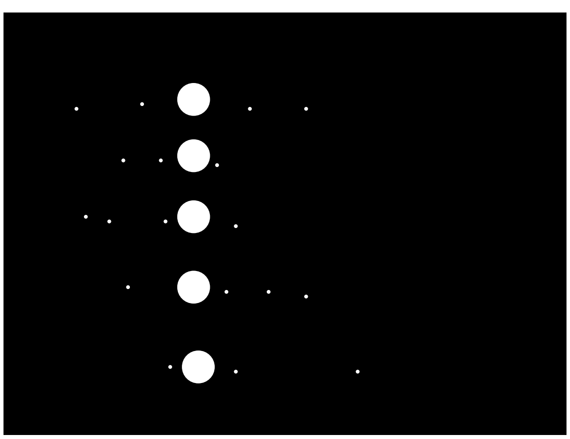
Galileo's discoveries of the phases of Venus with his telescope showed that Venus must orbit the Sun and strongly supported a heliocentric model

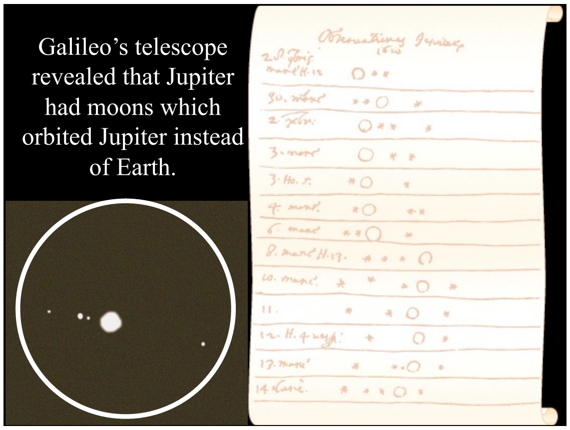


Venus is clearly smallest when it in the full phase and largest when it is in the new phase. Then Venus must be very far from Earth when it is in the full phase and quite closes to Earth when in the new phase – which supports the argument that Venus is orbiting the Sun not Earth.



Galileo's observations of phases of Venus proved that it orbits the Sun and not Earth.





The moons of Jupiter supported the Copernican model

- Aristotle's model was **Earth-centered**
  - But, Jupiter's moons revolve around Jupiter
  - There are centers of motion other than Earth
- Jupiter's innermost moon had the shortest orbital period and the moons further from Jupiter had longer periods
  - The periods obeyed Kepler's 3rd Law

Galileo's discoveries made him famous… and infamous

Published *"Dialogue Concerning the Two Chief World Systems"* in 1632
- Compared the Copernican system with the Ptolemaic system
- Directly challenged the Earth-centered view held by the authorities of the day

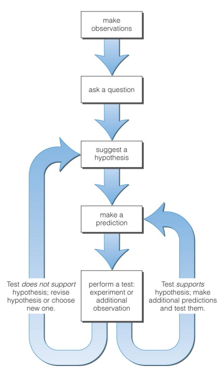
In 1633, Galileo was brought before the Inquisition
- He was forced to recant his support of the Copernican system
- Placed under house arrest until his death in 1642

His book on the subject was removed from the Church's index of banned books in 1824

Galileo was formally vindicated by the Church in 1992

How can we distinguish science from non-science?

- Defining science can be surprisingly difficult.
- *Science* from the Latin *scientia*, meaning “knowledge.”
- But not all knowledge comes from science…



The idealized scientific method

- Based on proposing and testing hypotheses
- **hypothesis** = educated guess

But science rarely proceeds in this idealized way… For example:

- Sometimes we start by “just looking” then coming up with possible explanations.
- Sometimes we follow our intuition rather than a particular line of evidence.

Hallmarks of Science: #1

Modern science seeks explanations for observed phenomena that rely solely on natural causes.

(A scientific model cannot include divine intervention)

Hallmarks of Science: #2

Science progresses through the creation and testing of models of nature that explain the observations as simply as possible.

(Simplicity = “Occam’s razor”)

Hallmarks of Science: #3

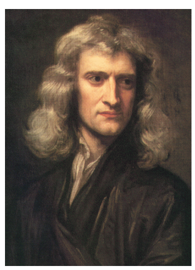
A scientific model must make testable predictions about natural phenomena that would force us to revise or abandon the model if the predictions do not agree with observations.

Isaac Newton (1642 – 1727) was British

Is known for creating first theoretical model for explaining gravity and …..

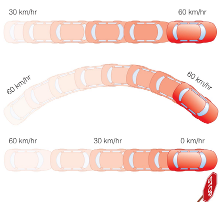
How did Newton change our view of the Universe?

- Realized the same physical laws that operate on Earth also operate in space
  - **One universe**
- Worked out fundamental laws of motion and gravity
- Designed the reflecting telescope
- Discovered that white light is a mix of all colors
- Also invented calculus



Isaac Newton formulated three laws of motion and the law of gravitation – these laws describe the motion of our physical world

How do we describe motion?



Precise definitions to describe motion:

- Speed: Rate at which object moves

  $\text{speed} = \frac{\text{distance}}{\text{time}} \left(\text{units of } \frac{\text{m}}{\text{s}}\right)$

  example: speed of 10 m/s

- Velocity: Speed and direction
  example: 10 m/s, due east

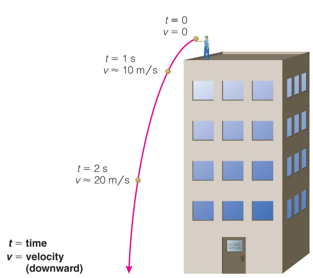
- Acceleration: Any change in velocity
  units of speed/time (m/s^2)

What produces *acceleration* in a car?

A. The gas pedal
B. The brake
C. The steering wheel
D. A and B
E. All of the above

The Acceleration of Gravity

- All falling objects accelerate at the same rate (not counting friction of air resistance).
- On Earth, $g \approx 10$ m/s^2: speed increases 10 m/s with each second of falling.



The Acceleration of Gravity (g)

- Galileo showed that g is the *same* for all falling objects, regardless of their mass.

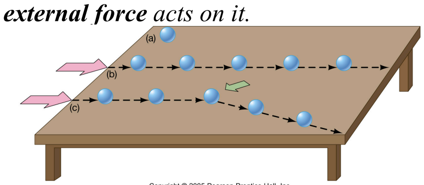
Apollo 15 demonstration

http://www.youtube.com/watch?v=5C5_dOEyAfk

What are Newton's three laws of motion?

Newton's 1st law of motion:

An object at rest will remain at rest, and an object moving in a straight line at constant speed will not change its motion, unless an ***external force*** *acts on it.*



What is a force?

- No, not THE Force…
- A force in the simplest sense is a push or pull
- May be from gravity, electrical, magnetic, or muscle efforts
- Causes an object to *accelerate*
- Acceleration in science means a change in velocity, in speed and/***or*** direction

Newton's First Law

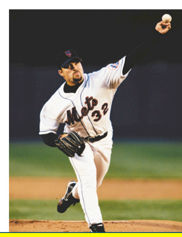
- A body remains at rest or moves in a straight line at a constant speed unless acted upon by an outside (net) force.
- A rockets will coast in space along a straight line at constant speed.
- A hokey puck glides across the ice at constant speed until it hits something

What are Newton's three laws of motion?

Newton's 2nd law of motion:

The acceleration of an object is proportional to the force acting on it and inversely proportional to its mass.

F = ma



A baseball accelerates as the pitcher applies force by moving his arm

Newton's Second Law of Motion

- (net)Force = mass * acceleration or $F_{net} = m * a$
- Acceleration is the rate of change in velocity – or how quickly your motion is changing.

What are Newton's three laws of motion?

Newton's 3rd law of motion:

For every force, there is always an ***equal and opposite*** *reaction force*

A rocket is propelled upward by a force equal and opposite to the force with which gas is expelled out the back

Newton's Third Law of Motion

- Whenever one body exerts a force on a second body, the second body exerts an equal and opposite force on the first body.
- Don't need a rocket launch pad!
- The Bug and the Windshield – who is having the worse day?

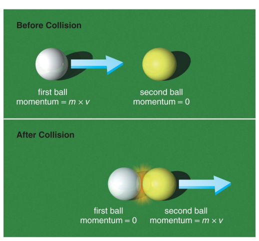
A 4.0-kg object is moving across a friction-free surface with a constant velocity of 2 m/s. Which one of the following horizontal forces is necessary to maintain this state of motion?

A. 0 N
B. 0.5 N
C. 2 N
D. 8 N

Momentum and Force

- Momentum is "mass in motion"
- An object's momentum is the product of its mass and velocity
- Momentum = mass × velocity
- The only way to change an object's momentum is to apply a force to it

Conservation of Momentum



- Newton's first law
- The total momentum of interacting objects cannot change unless an external force is acting on them
- Interacting objects exchange momentum through equal and opposite forces

A car possesses 20 units of momentum. What would be the car's new momentum if

a) its velocity were doubled.
b) its velocity were tripled.
c) its mass were doubled.
d) both its velocity were doubled and its mass were doubled

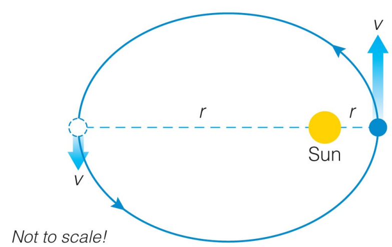
If a planet travels in a circular orbit without speeding up or slowing down, is it accelerating?

A. Yes
B. No

If a planet travels in a circular orbit without speeding up or slowing down, does it have a force on it?

A. Yes
B. No

What keeps a planet rotating and orbiting the Sun?



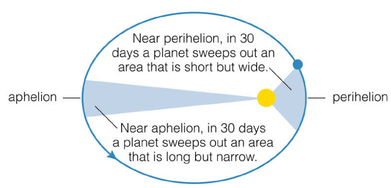
Conservation of Angular Momentum

angular momentum = mass x velocity x radius

- The angular momentum of an object cannot change unless an external twisting force (torque) is acting on it
- Earth experiences no twisting force as it orbits the Sun, so its rotation and orbit will continue indefinitely

Conservation of Angular Momentum

- Angular momentum = $m \times v \times r$
- Orbital – Kepler's 2nd law



Angular momentum conservation also explains why objects rotate faster as they shrink in radius:

Conservation of Energy

- Energy can be neither created nor destroyed.
- It can change form or be exchanged between objects.
- The total energy content of the Universe was determined in the Big Bang and remains the same today.

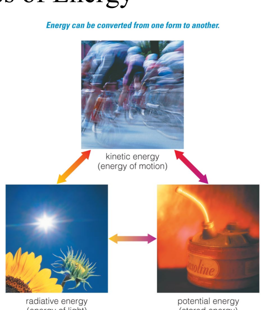
Where do objects get their energy?

- Energy makes matter move.
- Energy is conserved, but it can:
  - Transfer from one object to another
  - Change in form

Basic Types of Energy

- Kinetic (motion)
- Radiative (light)
- Stored or potential

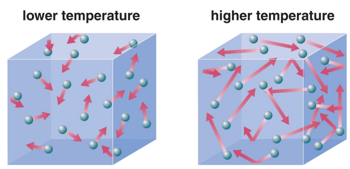
Energy can change type but cannot be destroyed.



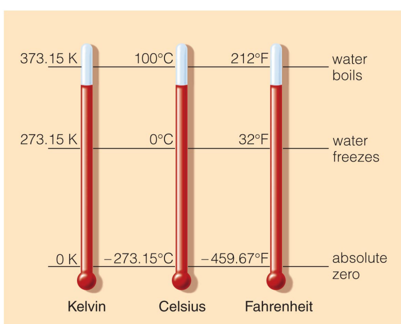
Thermal Energy:

the collective kinetic energy of many particles
(for example, in a rock, in air, in water)

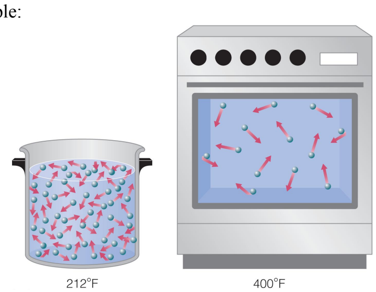
Thermal energy is related to temperature but it is NOT the same.
Temperature is the *average* kinetic energy of the many particles in a substance.



Temperature Scales

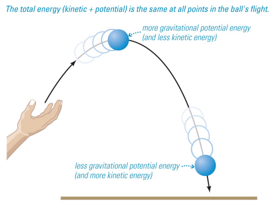


Thermal energy is a measure of the total kinetic energy of all the particles in a substance. It therefore depends both on *temperature* AND *density*
Example:



Gravitational Potential Energy

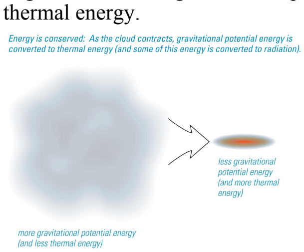
- On Earth, depends on:
  - object's mass (m)
  - strength of gravity (*g*)
  - distance object could potentially fall



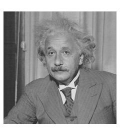
Gravitational Potential Energy

- In space, an object or gas cloud has more gravitational energy when it is spread out than when it contracts.

⇒A contracting cloud converts gravitational potential energy to thermal energy.

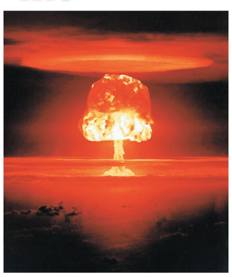


Mass-Energy



- Mass itself is a form of potential energy

$$E = mc^2$$



- A small amount of mass can release a great deal of energy
- Concentrated energy can spontaneously turn into particles (for example, in particle accelerators)