Astro 110-01 Lecture 10
Newton's laws

http://umbra.nascom.nasa.gov/comets/movies/SOHO_LASCO_C2.mpg
What have we learned?

• How do we describe motion?
  — Speed = distance / time
  — Speed and direction => velocity
  — Change in velocity => acceleration
  — Momentum = mass × velocity
  — Force causes change in momentum, producing acceleration/deceleration
Newton’s first law of motion

An object moves at constant velocity unless a net force acts to change its speed or direction.

That explains why we don’t feel any sensation of motion when we are traveling in an airplane (flying at constant velocity, no net force is acting on it or on us)

a spacecraft needs no fuel to keep moving in space (when in same orbit)
Newton’s second law of motion

\[
\text{Force} = \text{mass} \times \text{acceleration} \\
\text{or } F = m \times a \text{ or } F = m \times g
\]

Jupiter is more massive than Earth, therefore exerts a stronger gravitational force on passing asteroids and comets, and therefore sends them scattering with a greater acceleration.

e.g. a baseball accelerates as the pitcher applies a force by moving his arm (until the ball is released).
Newton’s 2\textsuperscript{nd} law: Example

- Example: pushing a cart
Newton’s third law of motion

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

That explains why astronomical objects always attract each other through gravity. It’s also true for our body and the Earth.

e.g. a rocket is propelled upward by a force equal and opposite to the force with which gas is expelled out its back
Understanding Newton’s 3\textsuperscript{rd} law: Apparent weight

You are weightless in free-fall!
Understanding Newton’s 3rd law

Weight = force that acts upon an object due to acceleration of gravity

Let \( R = \) reaction force = \(- ma\) (a= acceleration of elevator)

\[
F = m(g + R)
\]

\[
F(elev) = ma
\]
Caution on the term ‘weightless’

• You are weightless in free fall does not mean there is no force of gravity acting upon you
• Free fall is the state of falling without any resistance to the fall
• Objects in free fall are weightless because they are not pushing against anything to give them weight

Astronauts in the Space Station are in constant free-fall as they fall around Earth, so they are weightless
Why are astronauts weightless in space?

- There *is* gravity in space.
- Weightlessness is due to a *constant state of free-fall*.

> An object orbiting the Earth continually *falls* around the Earth.
What have we learned?

• How did Newton change our view of the universe?
  — He discovered laws of motion and gravitation.
  — He realized these same laws of physics were identical in the universe and on Earth.

• What are Newton’s Three Laws of Motion?
  1. An object moves at constant velocity if no net force is acting.
  2. Force = mass × acceleration.
  3. For every force, there is an equal and opposite reaction force.
Conservation Laws in Astronomy [Section 4.3]

Our goals for learning:

• What keeps a planet rotating and orbiting the Sun?
• Where do objects get their energy?
1. Conservation of Momentum: Linear momentum

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.
1. Conservation of Momentum: 

Linear momentum (cont’d)

• Newton’s 2\textsuperscript{nd} law:
  – Object 1 exerts a force that will change the momentum of object 2

• Newton’s 3\textsuperscript{rd} law:
  – Object 2 exerts an equal and opposite force on object 1
  \[ \text{momentum}(1) = - \text{momentum}(2) \]

Total momentum of colliding objects is conserved
Conservation of Angular Momentum

\[ m \times v \times r = \text{constant} \]

or What keeps a planet rotating and orbiting the Sun?

\[ v = \text{velocity} \]
\[ r = \text{average distance from the Sun} \]

- \( r \) greater so \( v \) is smaller
- \( r \) smaller so \( v \) is greater
Angular momentum conservation also explains why objects rotate faster as they shrink in radius.

Extending arms means larger radius, so smaller velocity of rotation.

"Bringing arms in reduces the radius, so increases rotational velocity."
Conservation of Angular Momentum

• 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 rate and orbit must stay about the same
  – But Earth is very gradually transferring some of its rotational angular momentum to the Moon, and is gradually slowing down

• Clouds of gas, spinning disks orbiting young stars: They will start to spin faster as gravity makes them shrink in size
2. Conservation of Energy

- Energy cannot appear out of nowhere or disappear into nothingness.
- Objects can gain or lose energy only by exchanging energy with other objects
  - All actions in the universe involve exchanges of energy or the conversion of energy from one form to another
- The total energy content of the universe was determined in the Big Bang and remains the same today.

⇒ Energy can change type but cannot be destroyed.
Basic Types of Energy

- **Kinetic (motion):**
  - Moving objects
  - Thermal energy

- **Radiative energy:**
  - carried by light

- **Potential or Stored energy:**
  - Gravitational potential energy
  - Mass energy
  - Chemical energy
Thermal Energy, a form of Kinetic Energy

the collective/total kinetic energy of many particles moving randomly within a substance, like a rock, the air or the gas within a distant star

Thermal energy is related to temperature but it is NOT the same.

Temperature is a measure of the average kinetic energy of the many particles in a substance.
Thermal energy is a measure of the total kinetic energy of all the particles in a substance. ➔ It therefore depends on both temperature AND density.

But water in the pot contains more thermal energy because of its much higher density.

Air in oven at 400 F is hotter than the boiling water (212 F) in the pot.
Common Temperature Scales

Absolute zero Kelvin is when all motion stops