Astro 110-01 Lecture 9
Closing the Loop on the Copernican Revolution:
The genius of Isaac Newton
How did Isaac Newton change our view of the universe?

- He realized the same physical laws that operate on Earth also operate in the heavens: 
  - one universe

- He discovered the laws of motion and gravity

- And much more:
  - Experiments with light; first reflecting telescope, calculus…

Sir Isaac Newton
(1642–1727)
Some basic concepts:
How to describe motion

• Speed versus velocity
• Acceleration
• Mass versus weight
• Momentum
• Force
Speed and Velocity

- Speed = how fast something is moving
- Velocity = speed + direction

Direction → a vector quantity

Example: Circular orbit around Earth = constant speed but not constant velocity, because direction is changing in a circular motion
Acceleration

Acceleration = rate of change of velocity in time

Example: acceleration of gravity, $g$, is rate of change of velocity in time due to gravity
Speed, velocity and acceleration

**Speed:** Rate at which object moves

\[
\text{speed} = \frac{\text{distance}}{\text{time}} \quad \text{(units of } \frac{\text{m}}{\text{s}})\]

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/s²)
How is mass different from weight?

**Mass**—the amount of matter in an object

\[ m \]

**Weight**—the *force* that acts upon an object

\[ F = m \text{ (mass)} \times a \text{ (acceleration)} \]

- A vector quantity, affected by direction of acceleration
Momentum

Momentum = mass x velocity

→ A vector quantity, affected by direction
Force

Force = mass x acceleration

Example: it takes a lot more force to push a car forward than a bicycle at the same acceleration

For every force, there is an equal and opposite force.

Example: The recoil someone feels when firing a gun: the gun is applying a force to the bullet, but the bullet applies a force back on the gun
Momentum and Force

Momentum = mass \times \text{velocity}

A net force (or sum of all forces) changes momentum
- Change of momentum = change in acceleration (since change in velocity).
If sum of all forces = 0 \rightarrow \text{no change in momentum}

- The only way to change an object’s momentum is to apply a force.

- The rotational momentum of a spinning or orbiting object is known as angular momentum.
Thought Question

Is there a net force for each of the following? (Answer yes or no.)

- A car coming to a stop.
- A bus speeding up.
- An elevator moving up at constant speed.
- A bicycle going around a curve.
- A moon orbiting Jupiter.
Thought Question

Is there a net force for each of the following? (Answer yes or no.)

- A car coming to a stop. Yes
- A bus speeding up. Yes
- An elevator moving up at constant speed. No
- A bicycle going around a curve. Yes
- A moon orbiting Jupiter. Yes
Acceleration of Gravity

• All falling objects accelerate at the same rate
  (not counting friction of air resistance).

• On Earth:
  \( g \approx 10 \text{ m/s}^2 \)
  or: speed increases 10 m/s with each second of falling.
Acceleration of Gravity ($g$)

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

On the Moon,

• your weight is the same, your mass is less
• your weight is less, your mass is the same
• your weight is more, your mass is the same
• your weight is more, your mass is less
Clicker Question

On the Moon,

• your weight is the same, your mass is less
• your weight is less, your mass is the same
• your weight is more, your mass is the same
• your weight is more, your mass is less
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
What have we learned?

• How is mass different from weight?
  — Mass = quantity of matter
  — Weight = force acting on mass
  — Objects are weightless in free-fall
Clicker Question

Is the force the Earth exerts on you larger, smaller, or the same as the force you exert on it?

- Earth exerts a larger force on me.
- I exert a larger force on Earth.
- Earth and I exert equal and opposite forces on each other.
Clicker Question

Is the force the Earth exerts on you larger, smaller, or the same as the force you exert on it?

- Earth exerts a larger force on me.
- I exert a larger force on Earth.
- **Earth and I exert equal and opposite forces on each other.**
Thought Questions

A compact car and a Mack truck have a head-on collision. Are the following true or false?

• The force of the car on the truck is equal and opposite to the force of the truck on the car.

• The momentum transferred from the truck to the car is equal and opposite to the momentum transferred from the car to the truck.

• The change of velocity of the car is the same as the change of velocity of the truck.
Thought Questions

A compact car and a Mack truck have a head-on collision. Are the following true or false?

• The *force* of the car on the truck is equal and opposite to the force of the truck on the car. **T**
• The *momentum* transferred from the truck to the car is equal and opposite to the momentum transferred from the car to the truck. **T**
• The *change of velocity* of the car is the same as the change of velocity of the truck. **F**
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

\[
\text{Force} = \text{mass} \times \text{acceleration}
\]

That explains why large planets such as Jupiter have a greater effect on asteroids and comets than small planets such as Earth.

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 of 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
How is mass different from weight?

- **Mass**—the amount of matter in an object
- **Weight**—the *force* that acts upon an object

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

Weight = \textit{force} that acts upon an object due to acceleration of gravity

Let \( R \) = reaction force = \(- ma\)

\[ F = mg + R \]

\[ F = mg \]

\[ F = mg + R \]

\[ F = mg + R \]

\[ F = 0, \text{ since person not touching scale} \]
Caution on the term ‘weightless’

• You are weightless in free fall does not mean there is no force of gravity acting upon you
• It really means that it is the only force 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.