Making Sense of the Universe: Understanding Motion, Energy, and Gravity

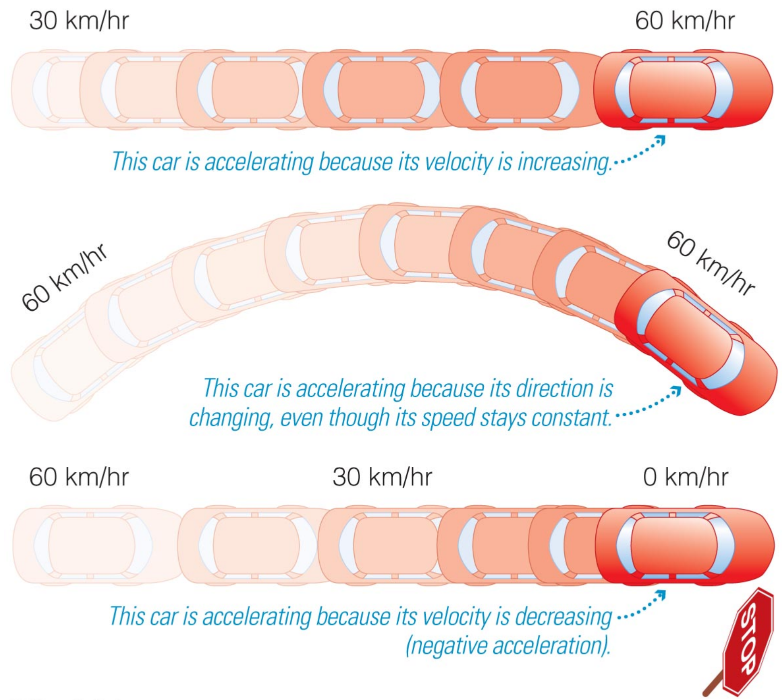
4.1 Describing Motion: Examples from Daily Life

- Our goals for learning:
  - **How do we describe motion?**
  - **How is mass different from weight?**

How do we describe motion?

- Precise definitions to describe motion:
- **Speed**: Rate at which object moves

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



Example: 10 m/s

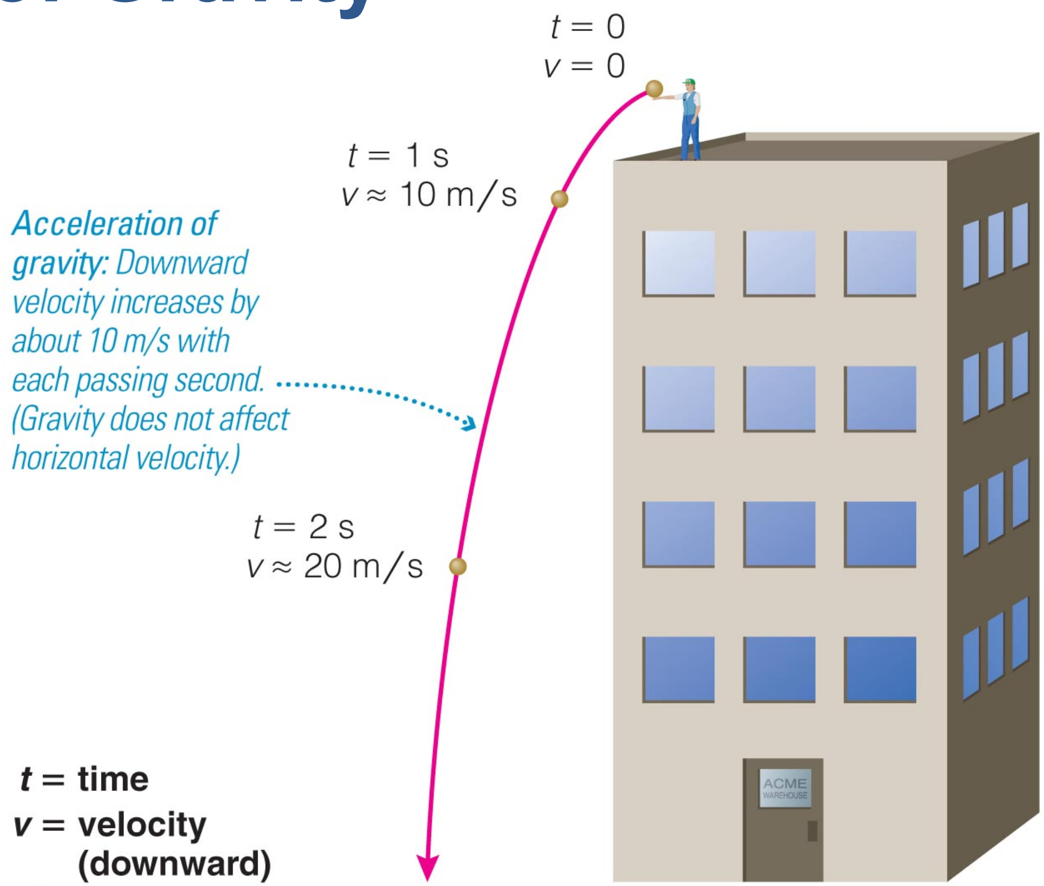
- **Velocity**: Speed and direction
  Example: 10 m/s, due east

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

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.



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

Momentum and Force

- **Momentum** = mass x velocity
- A **net force** changes momentum, which generally means an acceleration (change in velocity).
- Rotational momentum of a spinning or orbiting object is known as **angular momentum**.

Thought Question

For each of the following is there a net force? Y/N

1. A car coming to a stop
2. A bus speeding up
3. An elevator moving up at constant speed
4. A bicycle going around a curve
5. A moon orbiting Jupiter

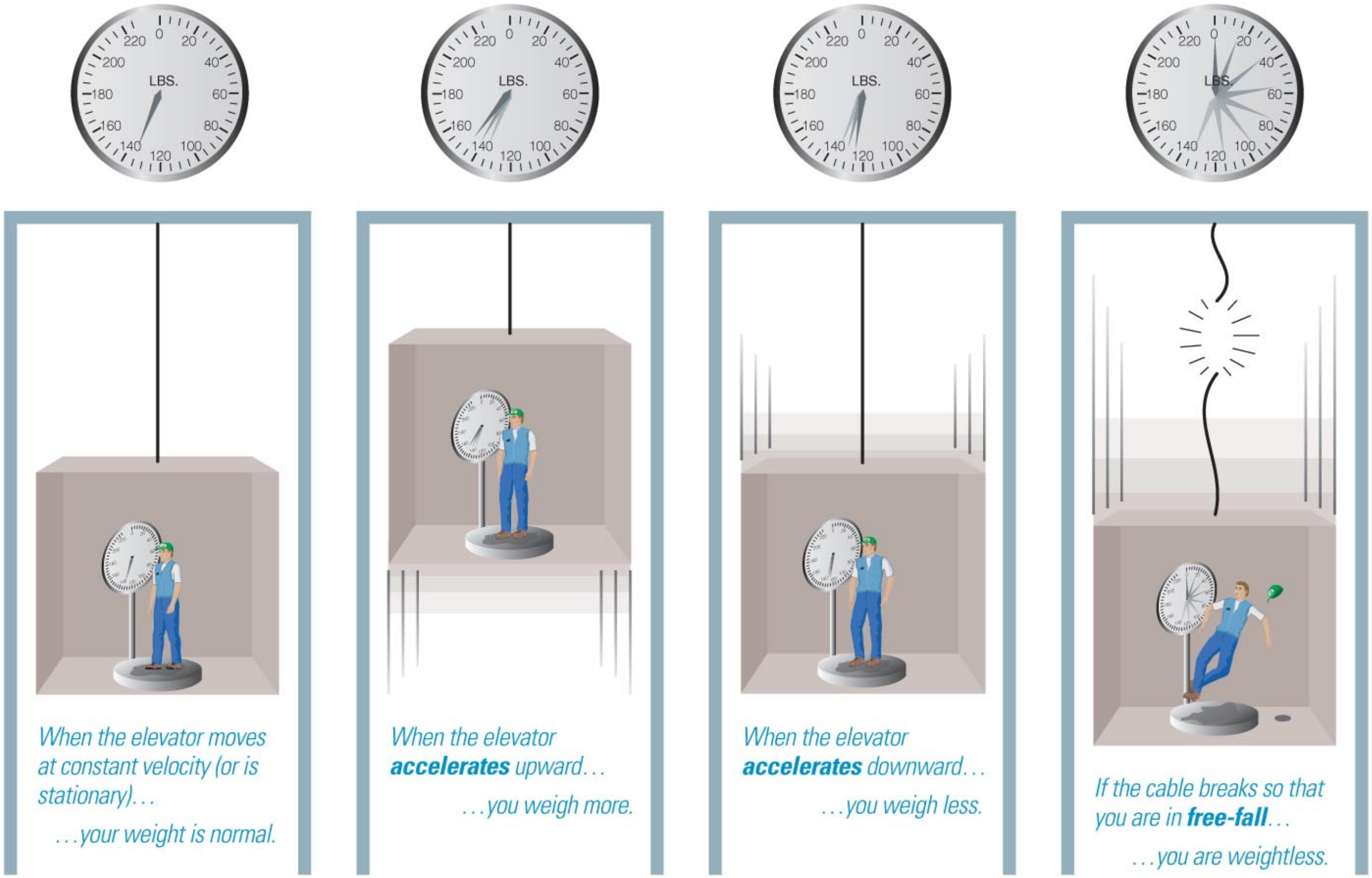
Thought Question

For each of the following is there a net force? Y/N

1. A car coming to a stop: Y
2. A bus speeding up: Y
3. An elevator moving at constant speed: N
4. A bicycle going around a curve: Y
5. A moon orbiting Jupiter: Y

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!

Thought Question

On the Moon, where the gravitational acceleration (g) is less, which one is true?

A. My weight is the same, my mass is less.
B. My weight is less, my mass is the same.
C. My weight is more, my mass is the same.
D. My weight is more, my mass is less.

Thought Question

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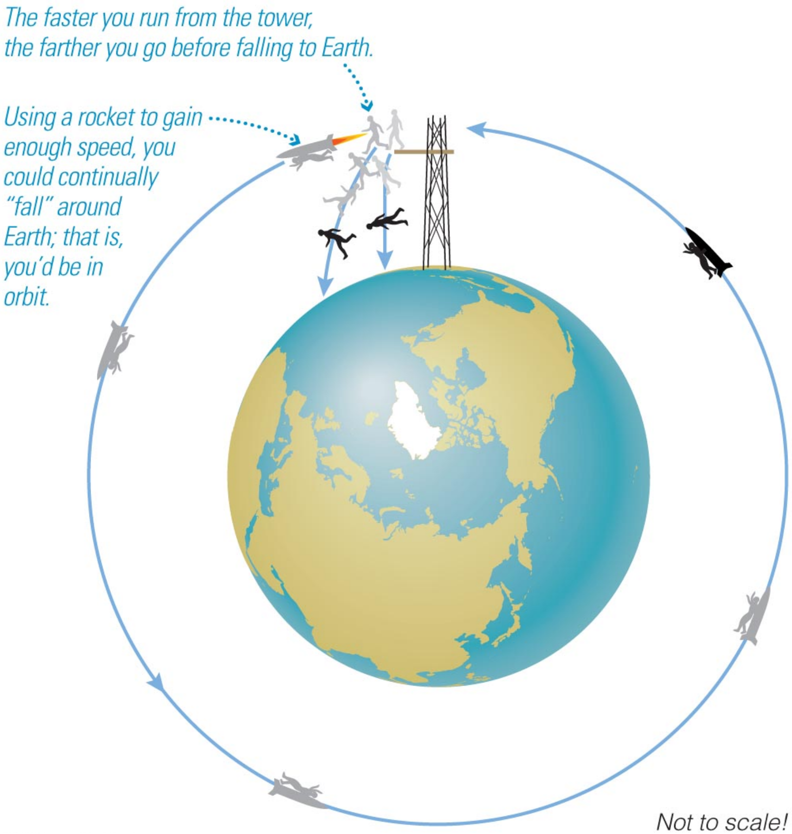
Why are astronauts weightless in space?

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



Interactive Figure

What have we learned?

- **How do we describe motion?**
  - **Speed** = distance/time
  - Speed and direction => **velocity**
  - Change in velocity => **acceleration**
  - **Momentum** = mass x velocity
  - **Force** causes change in momentum, producing acceleration.

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.

4.2 Newton's Laws of Motion

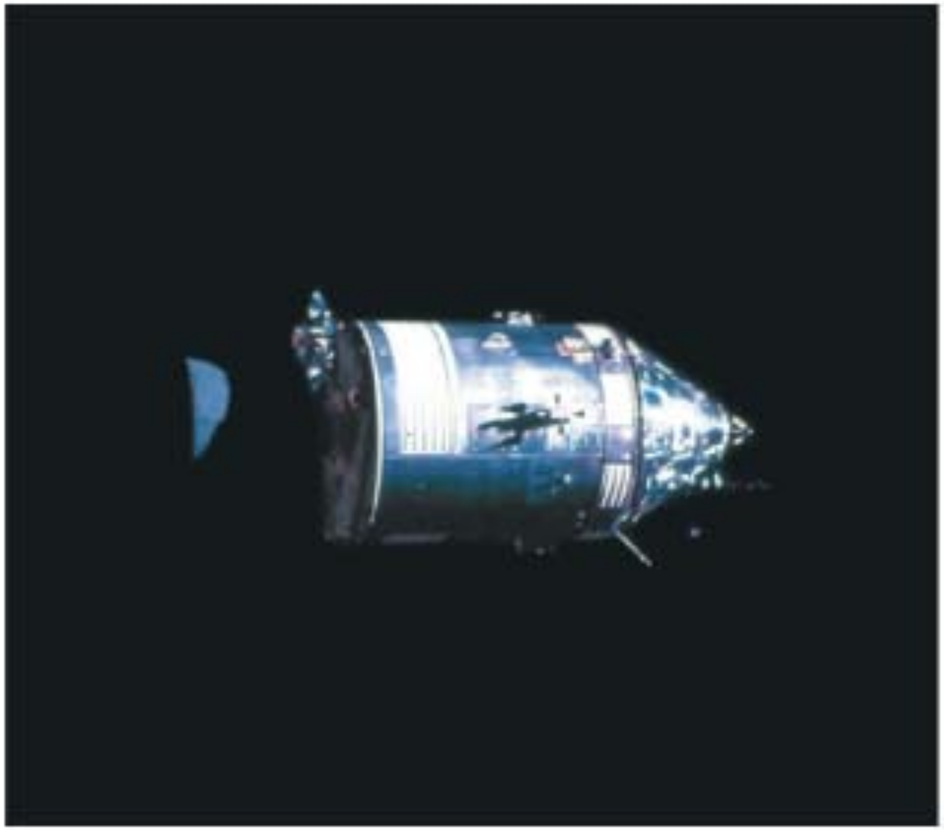
- Our goals for learning:
  - **How did Newton change our view of the universe?**
  - **What are Newton's three laws of motion?**

How did Newton change our view of the universe?

- Realized the same physical laws that operate on Earth also operate in the heavens
  - one *universe*
- Discovered laws of motion and gravity
- Much more: experiments with light, first reflecting telescope, calculus…

Sir Isaac Newton
(1642–1727)

What are Newton's three laws of motion?



- **Newton's first law of motion:** An object moves at constant velocity unless a net force acts to change its speed or direction.

Newton's Second Law of Motion

- There are two equivalent ways to express Newton's Second Law of Motion
  – Force = mass x acceleration
  – Force = rate of change in momentum

Newton's third law of motion:

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

Thought Question

How does the force the Earth exerts on you compare with the force you exert on it?

A. Earth exerts a larger force on you.
B. You exert a larger force on Earth.
C. Earth and you exert equal and opposite forces on each other.

Thought Question

How does the force the Earth exerts on you compare with the force you exert on it?

A. Earth exerts a larger force on you.
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Thought Question

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

1. The *force* of the car on the truck is equal and opposite to the force of the truck on the car.
2. The *momentum* transferred from the truck to the car is equal and opposite to the momentum transferred from the car to the truck.
3. The *change of velocity* of the car is the same as the change of velocity of the truck.

Thought Question

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

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

What have we learned?

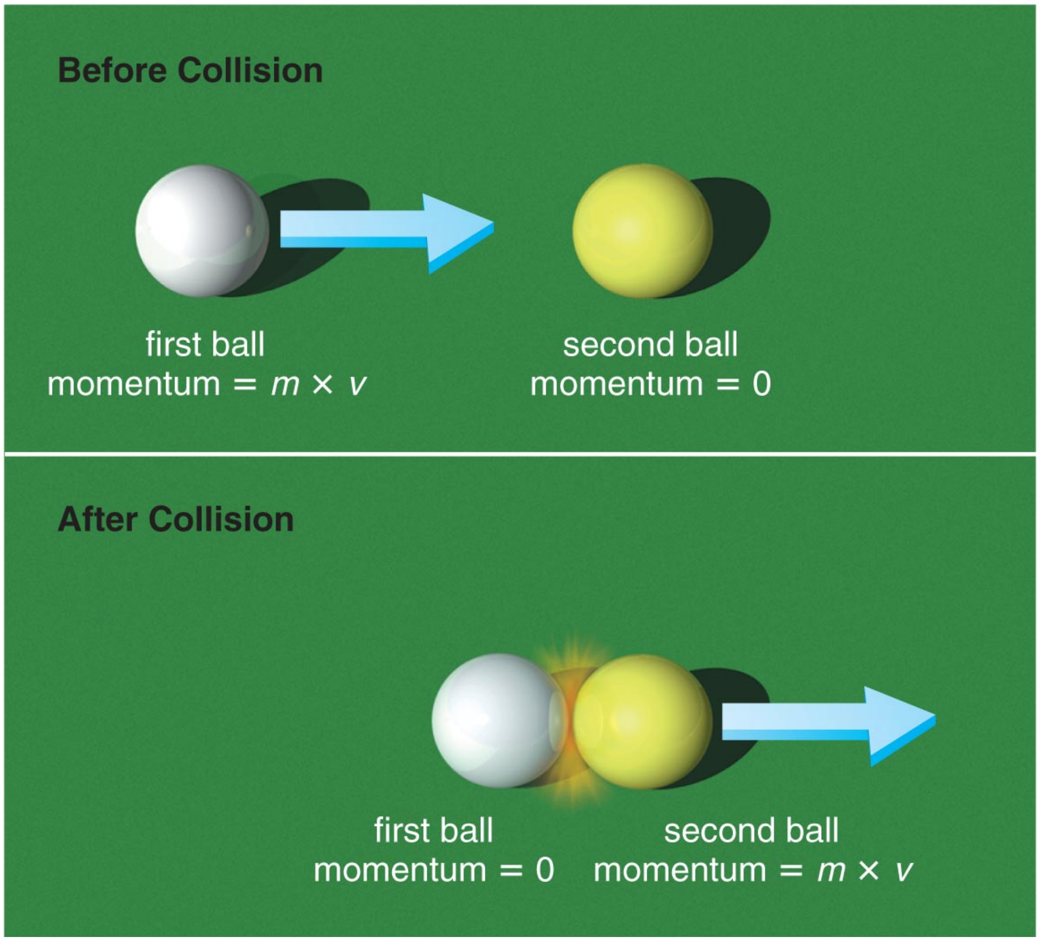
- **How did Newton change our view of the universe?**
  - He discovered laws of motion and gravitation.
  - He realized these same laws of physics were identical in the universe and on Earth.
- **What are Newton's three laws of motion?**
  1. Object moves at constant velocity if no net force is acting.
  2. Force = mass x acceleration
  3. For every force there is an equal and opposite reaction force.

4.3 Conservation Laws in Astronomy

- Our goals for learning:
  - **Why do objects move at constant velocity if no force acts on them?**
  - **What keeps a planet rotating and orbiting the Sun?**
  - **Where do objects get their energy?**

Why do objects move at constant velocity if no force acts on them?

Objects continue at constant velocity because of **conservation of 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.