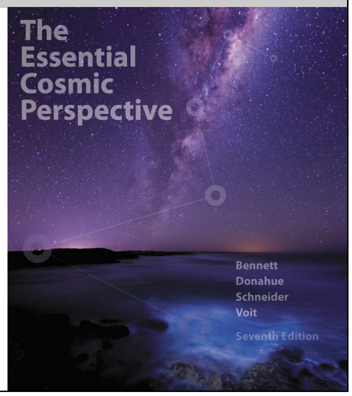
Lecture Outline

Chapter 4: Making Sense of the Universe Understanding Motion, Energy, and Gravity

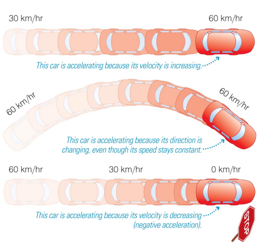


4.1 Describing Motion: Examples from Everyday Life

Our goals for learning:

- ➢ How do we describe motion?
- ➢ How is mass different from weight?

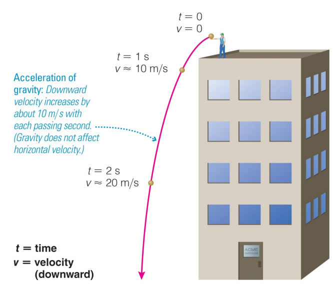
➢How do we describe motion?



- **Speed**: Rate at which object moves
  Example: speed of 10 m/s
- **Velocity**: Speed and direction
  Example: 10 m/s, due east
- **Acceleration**: Any change in velocity
  Example: 10 m/s^2

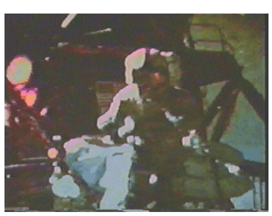
Acceleration of Gravity

- 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.



Acceleration of Gravity (*g*)

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



Apollo 15 demonstration

PLAY Feather and Hammer Drop

Momentum and Force

- Momentum = mass x velocity.
- A **net force** changes momentum, which generally means an acceleration (change in velocity).
  - An object must accelerate whenever a net force acts on it.
- The rotational momentum of a spinning or orbiting object is known as **angular momentum.**

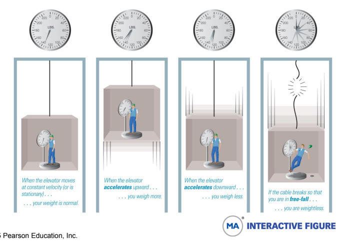
Thought Question

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

- A car coming to a stop
- A bus speeding up
- A bicycle going around a curve
- A moon orbiting Jupiter

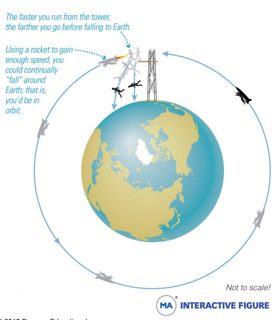
How is mass different from weight?

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



You are weightless in free-fall!

Why are astronauts weightless in space?



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

Recap

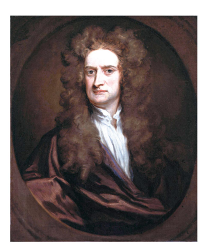
- **Speed** = distance/time
- Speed and direction => **velocity**
- Change in velocity => **acceleration**
- **Momentum** = mass x velocity
- **Force** causes change in momentum, producing acceleration.
- **Mass** = quantity of matter
- **Weight** = force acting on mass
  = mass x gravity

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?

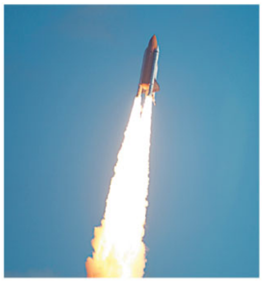


Sir Isaac Newton (1642–1727)

- He realized the same physical laws that operate on Earth also operate in the heavens:
  - ⇒ one *universe*
- He discovered laws of motion and gravity.
- Much more: Experiments with light; first reflecting telescope, calculus…

➢What are Newton's three laws of motion?

1. An 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:

- ➢ What keeps a planet rotating and orbiting the Sun?
- ➢ Where do objects get their energy?

1. Conservation of Momentum

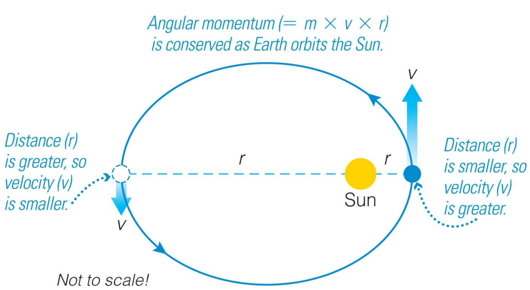
- ❑ The total momentum of interacting objects cannot change unless an external force is acting on them.

2. Conservation of Angular Momentum

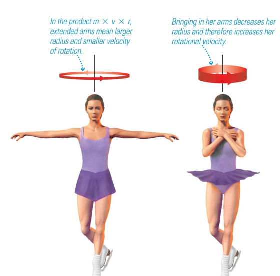
angular momentum = mass x velocity x radius

- ❑ 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.

➢What keeps a planet rotating and orbiting the Sun?



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



3.Conservation of Energy

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

(1st law of thermodynamics)

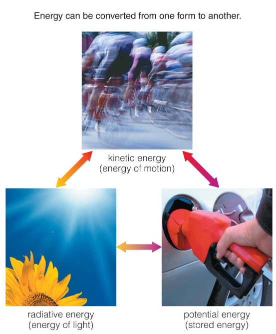
➢Where do objects get their energy?

- ❑Objects can gain or lose energy only by exchanging energy with other objects.
- ❑Energy makes matter move

Basic Types of Energy

- ❑Kinetic (motion)
- ❑Radiative (light)
- ❑Potential (stored)

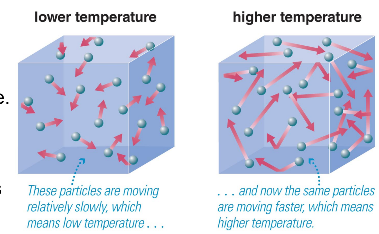
Energy can change type but cannot be destroyed.



Thermal Energy:

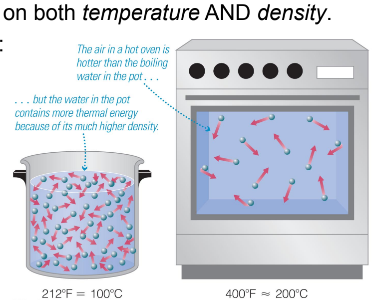
The collective kinetic energy of many particles (for example, in a rock, in air, in water)

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.

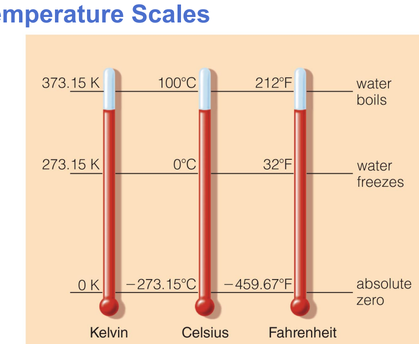


Thermal energy is a measure of the total kinetic energy of all the particles in a substance. It therefore depends on both *temperature* AND *density*.

Example:

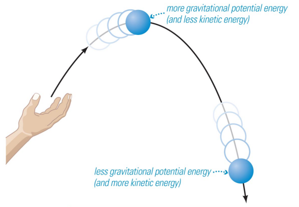


Temperature Scales



Gravitational Potential Energy

- On Earth, it depends on…
  - an object's mass (m).
  - the strength of gravity (g).
  - the distance an object could potentially fall.

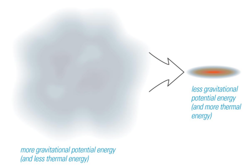


a The ball has more gravitational potential energy when it is high up than when it is near the ground.

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.



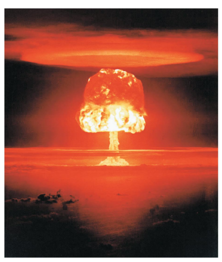
b A cloud of interstellar gas can contract because of its own gravity. It has more gravitational potential energy when it is spread out than when it shrinks in size.

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).



4.4 The Force of Gravity

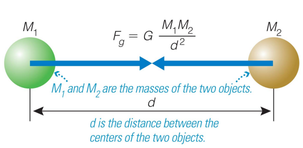
Our goals for learning:

- What determines the strength of gravity?
- How does Newton's law of gravity extend Kepler's laws?
- How do gravity and energy together allow us to understand orbits?
- How does gravity cause tides?

What determines the strength of gravity?

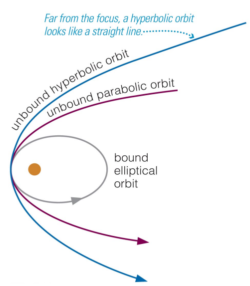
The **Universal Law of Gravitation:**

1. Every mass attracts every other mass.
2. Attraction is *directly* proportional to the product of their masses.
3. Attraction is *inversely* proportional to the *square* of the distance between their centers.



How does Newton's law of gravity extend Kepler's laws?

- 1. Kepler's first two laws apply to all orbiting objects, not just planets.
- 2. Ellipses are not the only orbital paths. Orbits can be:
  - bound (ellipses)
  - unbound
    - parabola
    - hyperbola



- 3. Newton generalized Kepler's third law:

which allows us to calculate the mass of distant objects.

Newton's version of Kepler's third law

$$p^2 = \frac{4\pi^2}{G(M_1 + M_2)} a^3$$

p = orbital period

a = average orbital distance (between centers)

$(M_1 + M_2)$ = sum of object masses

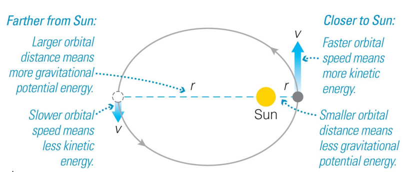
➢How do gravity and energy together allow us to understand orbits?

- Newton's extension of Kepler's laws explain stable orbits.
- But orbits do not always stay the same.

Orbital Energy

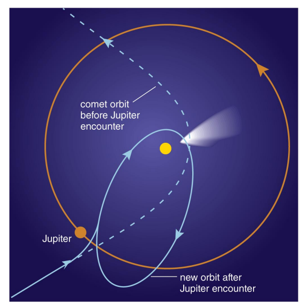
- Total orbital energy (gravitational + kinetic) stays constant if there is no external force.
  - Gravitational potential → orbital distance
  - Kinetic energy → orbital speed
- Orbits cannot change spontaneously → change orbital energy.

Total orbital energy = gravitational potential energy + kinetic energy



Gravitational Encounters

- Exchange of orbital energy
- Orbits can lose so much orbital energy they become bound
- Orbits can gain orbital energy and be "kicked out"
  - *New Horizons*

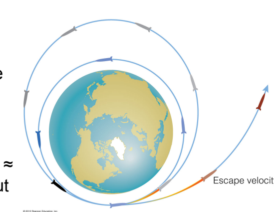


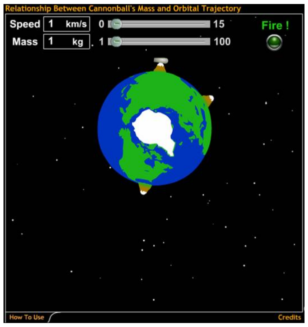
Atmospheric Drag / Friction

- Friction can cause objects to lose orbital energy
- Loss of orbital energy is converted to thermo energy in the atmosphere

Escape Velocity

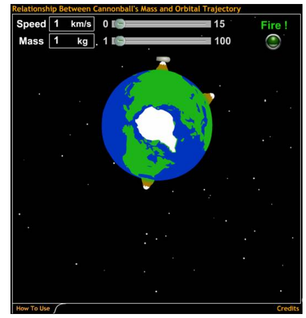
- If an object gains enough orbital energy, it may escape (change from a bound to unbound orbit).
- **Escape velocity** from Earth ≈ 11 km/s from sea level (about 40,000 km/hr).
- Chemical potential energy from the rocket is converted to orbital energy





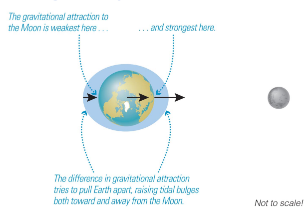
PLAY Relationship Between Cannonball's Mass and Orbital Trajectory

Escape and orbital velocities don't depend on the mass of the cannonball.



PLAY Relationship Between Cannonball's Mass and Orbital Trajectory

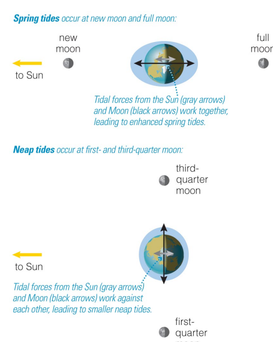
➢How does gravity cause tides?



- The Moon's gravity pulls harder on near side of Earth than on far side.
- The difference in the Moon's gravitational pull stretches Earth (**Tidal Force**).

Tides and Phases

Size of tides depends on the phase of the Moon.



PLAY Tides

Why does the moon always show us the same face?

- Moon once orbited faster; tidal friction caused it to "lock" in synchronous rotation.