Remember: Tom Burbine is in charge of all LAB issues

Astronomy Help Desk

Mon through Thu, 7-9pm in Hasbrouck 110

Read: Chaps 4 & 5
Announcements

- Remember: Tom Burbine is in charge of all LAB issues
- Astronomy Help Desk
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- For next week: Chapter 4, Light!

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For next week: Chapter 4, Light!

Today’s topic: Conservation laws, Newton’s Law of Gravity

- Where do objects get their energy?
- What determines the strength of gravity?
- How does Newton’s Law of gravity extend Kepler’s Laws?

Read: Chaps 4 & 5

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- For next week: Chapter 4, Light!
- Today’s topic: Conservation laws, Newton’s Law of Gravity
  - Where do objects get their energy?
  - What determines the strength of gravity?
  - How does Newton’s Law of gravity extend Kepler’s Laws?
- Questions?

Read: Chaps 4 & 5
First Law: Law of Inertia

- The motion of an object has speed and direction
- An object’s resistance to changes in motion is known as *inertia*
- Contradicted the still popular theories of Aristotle that objects will eventually come to rest
Second Law of Motion

\[ F = ma \]

- \( F \) describes the force acting
- \( m \) is the mass of the object
- \( a \) is its acceleration, the change in its motion.

Like motion, force has both a value or strength, and a direction in which it acts.

Acceleration refers to any change (e.g. both “speeding up” or “slowing down”)

Implies First Law of Motion
Second Law of Motion: examples

- The larger the force $\Rightarrow$ the larger the acceleration
- For equal force, a larger mass must have a smaller acceleration
- Larger mass has greater inertia. Can use this to measure mass of an object
- Unit of force (metric) is called a Newton (N):
  1 Newton is equal to $1 \text{ kg} \cdot \text{m/s}^2$
- Inertial mass
Newton’s 3 Laws of Motion

Third Law: equal and opposite force

- **Example:** smack an object
  - Object moves as a result
  - Your hand also feels a force and bounces back (and hurts)
Newton’s 3 Laws of Motion

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- Example: small object hits a large object
  - If the forces are equal, why does the smaller object bounce back faster?
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  - \[ m_{small} a_{small} = F = m_{large} a_{large} \]
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\[
a_{\text{small}} = \left( \frac{m_{\text{large}}}{m_{\text{small}}} \right) a_{\text{large}}
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Is the force the Earth exerts on you larger, smaller, or the same force you exert on it?

- Earth exerts a larger force on you.
- You exert a larger force on Earth.
- You and the Earth exert equal and opposite forces on each other.
Thought question

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A compact car and a Mack 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.
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   change of velocity of the truck.  \( F \)
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.

The momentum of interacting objects is conserved. For example, before the collision:
- First ball momentum: $m \times v$
- Second ball momentum: $0$

After the collision:
- First ball momentum: $0$
- Second ball momentum: $m \times v$
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.

Same holds true for angular momentum.
What keeps a planet rotating and orbiting the Sun?
Conservation of Angular momentum

\[ \text{angular momentum} = \text{mass} \times \text{velocity} \times \text{radius} \]

- 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.
- Bicycle wheel with perfect bearings will turn indefinitely.

Read: Chaps 4 & 5

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Conservation of Angular momentum

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

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

Energy can change type, but cannot be destroyed!

Read: Chaps 4 & 5
Thermal energy

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

- Temperature is the *average* kinetic energy of the many particles in a substance
- Thermal energy is *total* amount of kinetic energy in a substance
Temperature scales

- Kelvin
- Celsius
- Fahrenheit

- 0 K = -273.15°C = -459.67°F
- 273.15 K = 0°C = 32°F
- 373.15 K = 100°C = 212°F

- Water boils
- Water freezes
- Absolute zero

Read: Chaps 4 & 5

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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:
On Earth, depends on:

- objects mass (m)
- strength of gravity (g)
- distance object could potentially fall

The total energy (kinetic + potential) is the same at all points in the ball’s flight.

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

- 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.
Newton’s Law of Gravity

Every body in the Universe attracts every other body with a force proportional to the product of their masses and inversely proportional to the square of the distance between them:

\[ F_{\text{gravity}} = \frac{G M_1 M_2}{d^2} \]

\( G \) is the same here as it is in a distant galaxy. It is a physical constant of the Universe.
Gravity is an attractive force, and in accordance with Newton’s Third Law, the two masses feel equal and opposite forces.

Gravity is relatively weak because of the small value of the gravitation constant $G$; in metric units:

$$G = 6.7 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2$$

Large masses are required to provide an appreciable force, e.g. the mass of the Earth is $6.0 \times 10^{24}$ kg.
Newton’s Law of Gravity

- On the surface of a planet:

\[
F_{\text{gravity}} = M_1 \times \frac{GM_2}{d^2}
\]

\[
F_{\text{gravity}} = M_1 \times a_{\text{Earth's surface}}
\]

*Acceleration caused by the Earth on any object placed on its surface is the same: its value is 9.8 m/sec/sec.*

- Acceleration on the surface determines weight of object

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Read: Chaps 4 & 5
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**Acceleration caused by the Earth on any object placed on its surface is the same: its value is 9.8 m/sec/sec.**

- Acceleration on the surface determines **weight** of object
- On another planet

\[
\frac{a_{\text{planet}}}{a_{\text{Earth}}} = \frac{M_{\text{planet}}}{M_{\text{Earth}}} \times \frac{d_{\text{Earth}}^2}{d_{\text{planet}}^2}
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Newton’s Law of Gravity

On the surface of a planet:

\[ F_{\text{gravity}} = M_1 \times \frac{GM_2}{d^2} \]

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*Acceleration caused by the Earth on any object placed on its surface is the same: its value is 9.8 m/sec/sec.*

Acceleration on the surface determines weight of object.

On Mars

\[ \frac{a_{\text{Mars}}}{a_{\text{Earth}}} = \frac{M_{\text{Mars}}}{M_{\text{Earth}}} \times \frac{d_{\text{Earth}}^2}{d_{\text{Mars}}^2} = \left( \frac{0.11}{1} \right) \times \left( \frac{1}{0.53} \right)^2 = 0.39 \]
Gravity and Orbits

- Announcements
- Thought question
- Thought question
- Momentum
- Angular Momentum
- Energy!
- Types of energy
- Thermal energy
- Temperature scales
- Potential Energy
- Mass-Energy
- Energy conservation
- Law of Gravity
- Gravity and Orbits
- Orbits
- Escape velocity
- Center of Mass
- Orbits revisited
- Changing an orbit
- Tides

Gravity combined with Laws of Motion explains:

- Orbits
- Kepler’s Three Laws

Read: Chaps 4 & 5
Newton discovered that orbiting bodies may follow any one of a family of curves called *conic sections*. The ellipse is only one possibility.
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The ellipse is only one possibility.

Orbits may be bound (circle, ellipse) or unbound (parabola, hyperbola)

Read: Chaps 4 & 5
If an object gains enough orbital energy, it may escape (change from a bound to unbound orbit)

Escape velocity from Earth $\approx 11 \text{ km/s}$ from sea level (about 40,000 km/hr)
Because of momentum conservation, orbiting objects orbit around their center of mass.
Summary

- Planets obey the same laws as objects on Earth
**Summary**

- Planets obey the same laws as objects on Earth
- Kepler’s laws: explained by force of gravity
  - Planets orbit around the center of mass of the Solar System
  - Since most of the mass is the Sun, Sun is very close to center of mass
  - Third law depends on the sum of the two masses:

\[
P^2 = \left[ \frac{4\pi^2}{G(m_1 + m_2)} \right] a^3
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Summary

- Planets obey the same laws as objects on Earth
- Kepler’s laws: explained by force of gravity
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- New types of unbound orbits — hyperbolas and parabolas — in addition to ellipses

Read: Chaps 4 & 5
How do gravity and energy together allow us to understand orbits?

- Total orbital energy (gravitational + kinetic) stays constant if there is no external force.
- Orbits cannot change spontaneously.
What can make an object gain or lose orbital energy?

- Friction or atmospheric drag
- A gravitational encounter.
How does gravity cause tides?

- Moon’s gravity pulls harder on near side of Earth than on far side
- Difference in Moons gravitational pull stretches Earth
Size of tides depends on phase of Moon.
• Tidal friction gradually slows Earth rotation (and makes Moon get farther from Earth).

• Moon once orbited faster (or slower); tidal friction caused it to lock in synchronous rotation.

Read: Chaps 4 & 5