**AST 105**

**Introduction to Astronomy:**
*The Solar System*

Announcement:
First Midterm on Thursday 02/25

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**Newton’s 3 Laws of Motion**

1. An object moves at constant velocity if there is no net force acting on it.
2. When a force, $F$, acts on a body of mass $M$, it produces in it an acceleration, $A$, equal to the force divided by the mass. Or $A = F/M$.
3. For any force, there is always an equal and opposite reaction force.

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**Universal Law of Gravity**

$$ G = \frac{M_1 M_2}{d^2} $$

$G = 6.67 \times 10^{-11} \text{ m}^3/(\text{kg s}^2)$ “BIG G”

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**Same equation applies to $M_2$ standing on $M_1$**

$$ F_g = G \frac{M_1 M_2}{d^2} $$

$d$ is the distance between the centers (which we take to just be the distance to the center of the planet).
Acceleration Due to Earth's Gravity

\[ F = G \frac{M_1 M_2}{d^2} \]
\[ A = \frac{F}{M} \]

\[ A_c = \frac{G M_{\text{Earth}} M_{\text{cabbage}}}{R_{\text{Earth}}^2} \]
\[ d = \text{radius of Earth} = R_E \]

What is the ratio between the gravitational acceleration on the Moon and that on Earth?

(M_E=81M_M; R_E=3.7R_M)

A. 1/8
B. 1/4
C. 2
D. 1/6
E. 6

A. 1/8
B. 1/4
C. 2
D. 1/6
E. 6
Acceleration on the Moon

\[ g_{\text{planet}} = \frac{G M_{\text{planet}}}{R_{\text{planet}}^2} \]

\[
\begin{align*}
g_{\text{Moon}} &= \frac{GM_{\text{Moon}}}{R_{\text{Moon}}^2} \\
g_{\text{Earth}} &= \frac{GM_{\text{Earth}}}{R_{\text{Earth}}^2} \\
g_{\text{Moon}} &= g_{\text{Earth}} \left( \frac{M_{\text{Moon}}}{M_{\text{Earth}}} \right) \left( \frac{R_{\text{Earth}}}{R_{\text{Moon}}} \right)^2 \\
g_{\text{Moon}} &= g_{\text{Earth}} \left( \frac{181}{13.7} \right)^2 \\
g_{\text{Moon}} &= \frac{1}{6} g_{\text{Earth}}
\end{align*}
\]

How much does the Earth accelerate due to the cabbage?

\[
\begin{align*}
F &= MA \\
A_{\text{Earth}} &= \frac{GM_{\text{Earth}}M_{\text{cabbage}}}{R_{\text{Earth}}^2} \\
A_{\text{Earth}} &= \frac{G M_{\text{Earth}}}{R_{\text{Earth}}^2} \\
A_{\text{Earth}} &= \frac{G M_{\text{E}}}{R_{\text{E}}^2} \\
A_{\text{Earth}} &= 2 \times 10^{-24} \text{ meters/sec}^2 \\
&= \text{Tiny!}
\end{align*}
\]

How is mass different from weight?

- Mass = the amount of matter in an object
- Weight = the force that acts upon an object (based on acceleration and mass)

Your weight can change a lot depending on where you are but your mass doesn’t.

The Acceleration of Gravity

- All falling objects accelerate at the same rate (not counting friction of air resistance).
- On Earth, \( g \approx 10 \text{ m/s}^2 \)
  - Speed increases 10 m/s with each second of falling.

\[
\begin{align*}
F &= MA \\
M_1 &= \text{Earth} = M_{\text{E}} \\
M_2 &= \text{cabbage} = M_{\text{c}} \\
d &= \text{radius of Earth} = R_{\text{E}}
\end{align*}
\]
Poll Question (ungraded)

At exactly the same time that you drop a glass, your roommate throws a bottle perfectly horizontally at your professor. The bottle lands at the feet of your professor. Which smashes first, the glass or the bottle?

A. The glass  
B. The bottle  
C. Depends on how hard he threw the bottle  
D. Both at same time

The harder you throw, the farther it goes... horizontally.

But the downward force of gravity remains the same.
Into Orbit!

Objects in orbit are simply falling constantly around the Earth.

What is orbit?

Does the object move along path A, B, C, D, or E?

Clicker Question

What happens if he lets go of the string at exactly the moment pictured?

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What happens if he lets go of the string at exactly the moment pictured?

Does the object move along path A, B, C, D, or E?
What keeps an orbiting object in orbit?

- Gravity!
  - Since the direction is changing, there must be an acceleration
  - Newton's 1st law
  - If there is acceleration, there must be a force
  - Newton's 2nd law
- Gravity is a constant force pulling inward

Why are astronauts weightless in space?

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

How Fast Do Things Orbit?

Orbital Speed

- Planets (orbiters) are constantly trying to get away
  - Gravity (from the orbitee) is constantly pulling them back
- We can use Newton's law of gravity to calculate how fast they move

\[ V_{circular} = \sqrt{\frac{GM_{orbitee}}{r}} \]
Orbital Speeds for Satellites Around Earth

\[ V_{\text{circular}} = \sqrt{\frac{GM_{\text{orbitee}}}{r}} \]

\[ V_{\text{circular}} = \sqrt{\frac{GM_{\text{Earth}}}{R_{\text{earth}}}} \]

\[ V_{\text{circular}} = \sqrt{\frac{6.67 \times 10^{-11} \text{ m}^3/\text{kg} \cdot \text{s}^2 \cdot 6 \times 10^{24} \text{ kg}}{6378 \text{ km}}} \]

\[ V_{\text{circular}} = \sqrt{\frac{6.67 \times 10^{-11} \text{ m}^3/\text{kg} \cdot \text{s}^2 \cdot 6 \times 10^{24} \text{ kg}}{6378000 \text{ m}}} \]

\[ V_{\text{circular}} \approx 8000 \text{ m/s} \approx 18,000 \text{ mph} \]

Clicker Question

An astronaut and camera are floating outside the Space Shuttle, which moves fastest?

A. Shuttle has greatest speed due to greatest mass
B. Astronaut experiences greatest acceleration (and therefore greatest speed) since they just exited the SS.
C. Camera’s speed is fastest due to lowest mass
D. Astronaut, shuttle and camera all have same orbital speed

All orbitERS have same orbital speed

\[ V_{\text{circular}} = \sqrt{\frac{GM_{\text{orbitee}}}{r}} \]

• Depends only on:
  • mass of orbitEE
  • orbital distance, r
Orbital Times for Satellites Around Earth

\[ V_{\text{circular}} = 8000 \text{m/s} = 18,000 \text{mph} \]

speed = distance / time

time = distance / speed

time = \frac{\text{circumference}}{\text{speed}}

\[ \text{time} = \frac{2\pi r_{\text{earth}}}{V_{\text{circular}}} \]

\[ \text{time} = \frac{2\pi \times 6400000 \text{m}}{8000 \text{m/s}} \]

\[ \text{time} \approx 5000 \text{s} \approx 84 \text{ min} \]

Escape Velocity

The velocity needed to escape the gravity of the Earth

Earth

\[ V_{\text{cirk}} = 8 \text{ km/s} \]

\[ V_{\text{esc}} = 11 \text{ km/s} \]

Orbital velocity

\[ V_{\text{circular}} = \sqrt{\frac{GM_{\text{Earth}}}{r}} \]

Escape velocity

\[ V_{\text{escape}} = \sqrt{\frac{2GM_{\text{Earth}}}{r}} \]