AST 105

Introduction to Astronomy: The Solar System

Announcement:
First Midterm on Thursday 09/24
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.
Universal Law of Gravity

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

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

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

\[ A = F/M \]

\[ A_c = \frac{G M_{\text{Earth}}}{R_{\text{Earth}}^2} \]

\[ A_c = \frac{G M_E}{R_E^2} \]

\[ M_1 = M_{\text{Earth}} \]

\[ d = \text{radius of Earth} = R_E \]

\[ M_2 = M_c \]
Acceleration Due to Earth's Gravity

\[ A_c = G \frac{M_{Earth}M_{cabbage}}{R_{Earth}^2} \]

\[ A_c = \frac{GM_E}{R_E^2} \]

= 9.8 meters/sec²

Does not depend on the mass of the falling object!!!
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. \(\sim 1/10\)
B. \(\sim 1/4\)
C. \(\sim 2\)
D. \(\sim 1/6\)
E. \(\sim 6\)
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. \( \sim 1/10 \)
B. \( \sim 1/4 \)
C. \( \sim 2 \)
D. \( \sim 1/6 \)
E. \( \sim 6 \)
Acceleration on the Moon

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

\[
\frac{g_{\text{Moon}}}{g_{\text{Earth}}} = \frac{\frac{GM_{\text{Moon}}}{R_{\text{Moon}}^2}}{\frac{GM_{\text{Earth}}}{R_{\text{Earth}}^2}}
\]

\[
\frac{g_{\text{Moon}}}{g_{\text{Earth}}} = \left(\frac{M_{\text{Moon}}}{M_{\text{Earth}}}\right)^{1/2}
\left(\frac{R_{\text{Earth}}}{R_{\text{Moon}}}\right)^2
\]

\[
g_{\text{Moon}} = g_{\text{Earth}} \left(\frac{1}{81}\right)^{1/2} \left(\frac{1}{3.7}\right)^2
\]

\[
g_{\text{Moon}} \sim \frac{1}{6} g_{\text{Earth}}
\]

d = radius of Moon

Oops!
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.
How much does the Earth accelerate due to the cabbage?

\[ A_{\text{Earth}} = \frac{GM_{\text{Earth}}M_{\text{cabbage}}}{R_{\text{Earth}}^2} \]

\[ A_{\text{Earth}} = \frac{GM_{\text{cabbage}}}{R_{\text{Earth}}^2} \]

\[ F = MA \]
\[ A = \frac{F}{M} \]

\[ M_2 = \text{cabbage} = M_c \]
\[ M_1 = \text{Earth} = M_E \]
\[ d = \text{radius of Earth} = R_E \]

= 2x10^{-24} \text{ meters/sec}^2

= Tiny!
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.
    - 10 m/s per s
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
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$A_h = \frac{F_{\text{muscle}}}{M_{\text{bottle}}}$

Bottle

$A_v = g$

Glass

$A_h = 0$

$A_v = g$

Separating horizontal and vertical motions
The harder you throw, the farther it goes ... horizontally. But the downward force of gravity remains the same.
Into Orbit!

orbital velocity
Clicker Question

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?
Clicker Question

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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**

Analogy between radially inward force by string and by gravity
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

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

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

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

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

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

\[ V_{\text{circular}} \approx 8000 \text{ m/s} \approx 18,000 \text{ mph} \]
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
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\[ V_{circular} = \sqrt{\frac{GM_{orbitee}}{r}} \]

- Depends only on:
  - mass of orbitEE
  - orbital distance, \( r \)

All orbitERS have same orbital speed
Orbital Times for Satellites Around Earth

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

\[ \text{speed} = \frac{\text{distance}}{\text{time}} \]

\[ \text{time} = \frac{\text{distance}}{\text{speed}} \]

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

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

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

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

The velocity needed to escape the gravity of the orbit of Earth

Earth

\[ V_{\text{circ}} = 8 \text{ km/s} \]
\[ V_{\text{esc}} = 11 \text{ km/s} \]