Announcement:
First Midterm on Thursday 02/25
Newton’s view of the Universe

• **Motion**
  - Stating the obvious, but doing it scientifically
    - Including, how to launch yourself into space

• **Gravity**
  - It’s not just a good idea, it’s the Law
I derive from the celestial phenomena the forces of gravity with which bodies tend to the Sun and the several planets. Then from these forces, by other propositions which are also mathematical, I deduce the motions of the planets, the comets, the Moon and the sea.

--Isaac Newton

"If I have seen far, it is because I have stood on the shoulders of giants" - the giant he meant was Galileo
Velocity = space/time [characterized by speed and direction]

Acceleration is a change of velocity [change in speed or change in direction or change in both]
Newton’s 3 Laws of Motion

1. An object moves at constant velocity if there is no force acting upon it.

   In other words:
   An object at rest tends to stay at rest. An object in motion tends to continue in motion at constant speed in a straight line.
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.

$$F = MA$$
$$A = F/M$$
Newton’s 3 Laws of Motion

\[ F = MA \quad A = F/M \]

The more force on an object, the more it accelerates. But the more massive it is, the more it resists acceleration.

Acceleration = Force / Mass
Nothing Happens If the Forces Are Balanced

A body accelerates only when an \textit{unbalanced force} is applied
Newton’s 3 Laws of Motion

3. For every force/action, there is always an equal and opposite force/reaction.
Newton’s 3 Laws of Motion

To every action there is an equal and opposite reaction.
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 $M_1$

$d$ is the distance between the centers

(which we take to just be the distance to the center of the planet)
Clicker Question

Is the force the Earth exerts on you larger, smaller, or the same as 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 the same force on each other.
D. It depends on how far above the Earth's surface you are.
Is the force the Earth exerts on you larger, smaller, or the same as 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 the same force on each other.
D. It depends on how far above the Earth’s surface you are.
Same equation applies to $M_1$ pulled by $M_2$

$d$ is the distance between the centers

(which we take to just be the distance to the center of the planet)
What is the ratio between the gravitational forces acting on Darth Vader on the bottom and on the top of the ladder?
Ratios: The mathematical way

\[ F_{\text{top}} = \frac{GM_1M_2}{d_{\text{top}}^2} = \frac{GM_1M_2}{(2d)^2} = \frac{GM_1M_2}{4d^2} \]

\[ F_{\text{bot}} = \frac{GM_1M_2}{d_{\text{bot}}^2} = \frac{GM_1M_2}{d^2} \]
Ratios: The mathematical way

\[ F_{\text{top}} = \frac{GM_1 M_2}{4d^2} \]

\[ F_{\text{bot}} = \frac{GM_1 M_2}{d^2} \]
Ratios: The mathematical way

\[ F_{\text{top}} = \frac{GM_1 M_2}{4d^2} \]

\[ F_{\text{bot}} = \frac{GM_1 M_2}{d^2} \]

\[ \frac{F_{\text{top}}}{F_{\text{bot}}} = \frac{GM_1 M_2}{GM_1 M_2} \cdot \frac{4d^2}{d^2} = 4 \]
Ratios: The mathematical way

\[ F_{\text{top}} = \frac{GM_1 M_2}{4d^2} \]

\[ F_{\text{bot}} = \frac{GM_1 M_2}{d^2} \]

\[ \frac{F_{\text{top}}}{F_{\text{bot}}} = \frac{4d^2}{GM_1 M_2} \]

\[ \frac{GM_1 M_2}{4d^2} \]
Ratios: The mathematical way

\[ F_{\text{top}} = \frac{GM_1 M_2}{4d^2} \]

\[ F_{\text{bot}} = \frac{GM_1 M_2}{d^2} \]

\[ \frac{F_{\text{top}}}{F_{\text{bot}}} = \frac{\frac{GM_1 M_2}{4d^2}}{\frac{GM_1 M_2}{d^2}} = \frac{1}{4} \]
Ratios: The mathematical way

\[ F_{\text{top}} = \frac{GM_1 M_2}{d_{\text{top}}^2} = \frac{GM_1 M_2}{(2d)^2} = \frac{GM_1 M_2}{4d^2} \]

\[ F_{\text{bot}} = \frac{GM_1 M_2}{d_{\text{bot}}^2} = \frac{GM_1 M_2}{d^2} \]

\[ \frac{F_{\text{top}}}{F_{\text{bot}}} = \frac{\frac{GM_1 M_2}{4d^2}}{\frac{GM_1 M_2}{d^2}} = \frac{1}{4} \]
Ratios: The mathematical way

So the gravitational force at the top of the ladder is only \( \frac{1}{4} \) as strong as at the bottom.
Ratios: The logical way

$F = \frac{GM_1M_2}{d^2}$

What variable changes when Vader moves from the bottom to the top?

$d \uparrow 2$

$d^2 \uparrow 4$

$1/d^2 \downarrow 4$

$F \downarrow 4$

So if $d$ (distance) goes up by a factor of 2, $F$ (Force of gravity) goes down by a factor of 4
Clicker Question

How strong would gravity be at the surface if Earth were replaced by a styrofoam ball of the same mass but 10 times the radius?

A. 100 times stronger
B. 10 times stronger
C. unchanged
D. 10 times weaker
E. 100 times weaker

\[ F_g = G \frac{M_1 M_2}{d^2} \]
How strong would gravity be at the surface if Earth were replaced by a styrofoam ball of the same mass but 10 times the radius?

A. 100 times stronger
B. 10 times stronger
C. unchanged
D. 10 times weaker
E. 100 times weaker
How strong would gravity be at the surface if Earth were replaced by a ball of iron with 10 times the mass but the same radius (as regular Earth)?

A. 100 times stronger  
B. 10 times stronger  
C. unchanged  
D. 10 times weaker  
E. 100 times weaker

\[ F_g = G \frac{M_1 M_2}{d^2} \]
How strong would gravity be at the surface if Earth were replaced by a ball of iron with 10 times the mass but the same radius (as regular Earth)?

A. 100 times stronger
B. 10 times stronger
C. unchanged
D. 10 times weaker
E. 100 times weaker

\[ F_g = G \frac{M_1 M_2}{d^2} \]
Which of the following would cause the force on the Moon by Earth to increase by the largest amount?

A. Double the mass of the Moon.
B. Double the mass of the Earth.
C. Move the Moon two times closer to Earth.
D. Move the Moon two times further from the Earth.
E. Due to Newton’s third law, the Moon’s force on Earth will always be the same size as the Earth’s force on the Moon so none of the changes listed above could cause the force to increase.
Which of the following would cause the force on the Moon by Earth to increase by the largest amount?

A. Double the mass of the Moon.
B. Double the mass of the Earth.
C. Move the Moon two times closer to Earth.
D. Move the Moon two times further from the Earth.
E. Due to Newton’s third law, the Moon’s force on Earth will always be the same size as the Earth’s force on the Moon so none of the changes listed above could cause the force to increase.
So far we’ve only been talking about the FORCE of gravity

- How do we find out the acceleration due to gravity?
  - I.e. How fast does a cabbage fall towards the Earth?
**Acceleration Due to Earth's Gravity**

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

\[ A = F/M \]

\[ \frac{GM}{M_{\text{cabbage}}} \]

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

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

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

\[ M_2 = M_c \]
Which falls faster - a cabbage or an apple?

A. The cabbage will fall faster and hit the ground first
B. The apple will fall faster and hit the ground first
C. They both hit at the same time
D. It depends on which one is heavier
Which falls faster - a cabbage or an apple?

A. The cabbage will fall faster and hit the ground first
B. The apple will fall faster and hit the ground first
C. They both hit at the same time
D. It depends on which one is heavier
Why did they hit at the same time?

A. The masses of the cabbage and the apple were tiny compared to the mass of the Earth.

B. The mass of the falling object doesn’t matter.

C. They actually fell at slightly different speeds but over that small distance it wasn’t noticeable.

D. Prof. Perna has jedi powers.
Clicker Question

Why did they hit at the same time?

A. The masses of the cabbage and the apple were tiny compared to the mass of the Earth.
B. The mass of the falling object doesn’t matter
C. They actually fell at slightly different speeds but over that small distance it wasn’t noticeable
D. Prof. Perna has jedi powers.
Acceleration Due to Earth's Gravity

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

\[ A = F/M \]

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

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

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

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

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

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

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

= 9.8 meters/sec^2

Does not depend on the mass of the falling object!!!