Mon: HW by 5pm

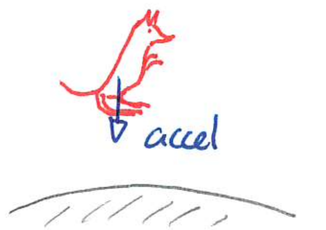
Weds: Review

Fri: Test 1 in class

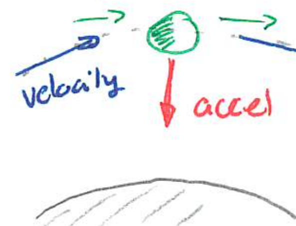
Motion of celestial objects

We have seen that both freely falling objects and objects orbiting Earth have acceleration. Thus there must be a force acting on each object.

The only object that can produce such a force is Earth



speeds up as it falls ⇒ acceleration ≠ 0



direction of velocity changes ⇒ acceleration ≠ 0

↳ Earth exerts a force on each ↲

Quiz 1

Consider the motion of objects near Earth's surface. They do not necessarily fall in straight lines.

Quiz 2 90%

DEMO: PhET Projectile Motion - launch horizontally various speeds

Quiz 3 40%

DEMO: Newton's Cannon with speeds 2000, 5000, 6000, 7000

The conclusion from such thought experiments is:

> The gravitational force that produces freely falling motion is the same as the gravitational force that produces the orbiting motion of the Moon and the planets

Newton's Law of Gravitation

Newton proposed that any object with mass will exert a gravitational force on any other object with mass. This is now called Newton's Universal Law of Gravitation Quiz 4 70%

> Any object with mass will exert a gravitational force on any other object with mass. The size of the gravitational force is given by
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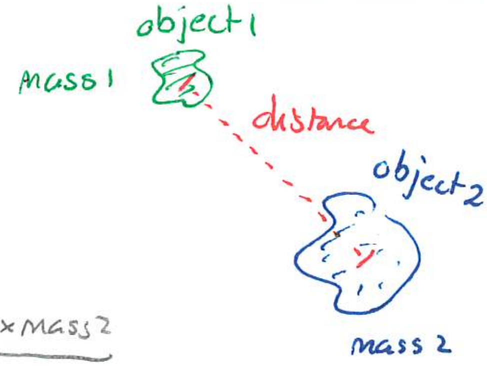
> 
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>
> $$\text{force exerted by 1 on 2} = \text{constant} \times \frac{\text{mass 1} \times \text{mass 2}}{\text{distance}^2}$$

The constant was eventually measured by Cavendish and is (in metric units)

$$6.67 \times 10^{-11} \ \text{N m}^2/\text{kg}^2$$

This universal law of gravitation is used to:

1) predict + explain the motion of planets in our solar system
2) predict + explain how free-fall and projectile motion occurs
3) decide on the paths of satellites and spacecraft
4) determine Earth's mass

The universal law of gravitation claims that any object with mass exerts a gravitational force on any other object with mass. What about "normal" scale objects like people?

1 Gravitational force between people

Suppose you and a friend sit on an ice skating rink, where you can easily slide.

a) Will you exert a gravitational force on your friend? Have you ever noticed such a force in your life?

In order to clarify the situation, assume that your mass is 60 kg (about 130 lb) and your friend's mass is 70 kg (about 155 lb) and that your centers are 2.0 m apart.

b) Calculate the gravitational force that you exert on your friend.

c) Assuming all other forces cancel each other, calculate the acceleration of your friend as a result of the gravitational force that you exert.

d) To get an idea of how small this is, we can determine how far your friend will move toward you. Assuming the acceleration is constant (not exactly true here, but close enough) and an object is initially at rest, then it will travel a distance

$$\text{distance} = \frac{1}{2} \times \text{acceleration} \times (\text{time elapsed})^2 .$$

Calculate how far your friend will travel in one hour.

e) Does the gravitational force that you exert on your friend result in appreciable motion?

Answer: a) Not really

b) $\text{Force} = 6.67\times10^{-11}\ Nm^2/kg^2 \times \dfrac{60\,kg \times 70\,kg}{(2.0m)^2}$

$= 6.67\times10^{-11}\ Nm^2/kg^2 \times \dfrac{4200\,kg^2}{4.0m^2} = 7.0\times10^{-8}N$

c) $\text{Accel} = \text{net force}/\text{mass} = \dfrac{7.0\times10^{-8}N}{70\,kg} = 1\times10^{-9}m/s^2$

Do for class on board using Windows calc.

d) one hour = 3600s

$\text{distance} = \frac{1}{2}\times10^{-9}\times(3600s)^2 = 0.0065m$

e) In one hour you would move about 6mm

DEMO: Chain fountain - defying gravity?

Discovery of Neptune

The theory of gravitation has been used to find previously unknown objects. A famous example was the discovery of Neptune.

The genesis of this was the discrepancy between the predicted and observed orbits of the planet Uranus, discovered in the 1780s.

The orbit of Uranus could be:

Predicted

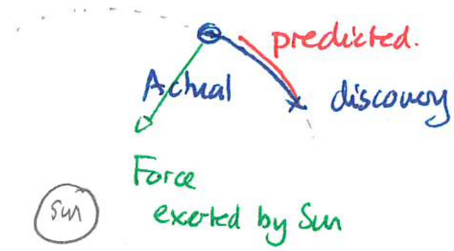
Using:

* Newton's mechanics
* Universal Law of Gravity
* Existing known planets + Sun

Observed

Using:

* Star charts
* telescopes



→ These did not match in the early 1800s

One explanation was that there must be another planet whose gravitational force perturbed Uranus' motion. Using the Universal Law of Gravitation one could predict where this planet should be. The prediction was passed on to astronomers who identified it in 1846

DEMO: AstroAddict Neptune Discovery.

Could this result in the discovery of other planets.

DEMO: Planet Nine Video