Phys 100 2023

Lecture 16

Mon: HW by 5pm

Weds: Review Test 1

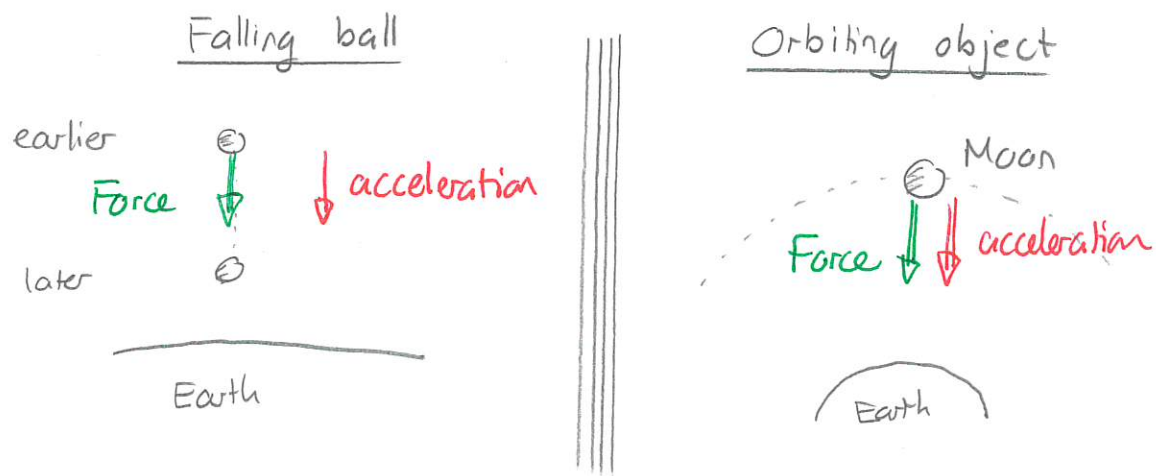
Fri: Test 1 - see previous test 1
- covers all material including Monday

Motion of Celestial Objects

One of the earliest questions addressed by Newton's system of mechanics concerned the motion of celestial objects (Moon, planets, ...). The same framework that is used to describe freely falling objects can successfully describe celestial motion

Quiz! 50%

These both have non-zero acceleration and both of the accelerations are directed to Earth's center



In each case the net force is only provided by Earth. What causes these forces?

Newton proposed that the two forces have the same origin and are of the same type. This can be illustrated via a hypothetical projectile launched from a mountain at various speeds

DEMO: PhET Projectile launch horizontally

Quiz 2

DEMO: Newton's Cannon Speeds 2000, 5000, 6500, 7000

The conclusion from these thought experiments was:

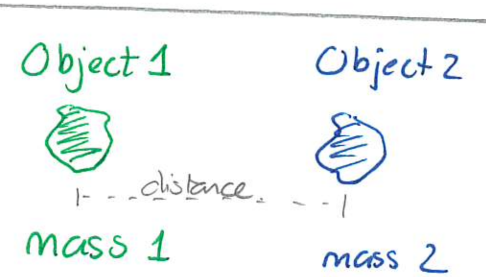
> The gravitational force that produces freely falling motion is the same as the gravitational force that produces the orbits of celestial bodies

Newton's Universal Law of Gravitation

The gravitational force exerted by Earth was extended to all objects

Quiz 3 50% → 70%

Newton's Universal Law of Gravitation states:

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

The constant was eventually measured by Cavendish and, in standard SI units is

$$6.7 \times 10^{-11}$$

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, suppose that your mass is 60 kg and your friend's mass is 70 kg and that your centers are 2.0 m apart.

b) Calculate the 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) Yes, according to Newton's universal gravitational law.

b) $$\text{Force} = 6.7\times10^{-11} \frac{\text{mass 1} \times \text{mass 2}}{(\text{distance})^2}$$

$$= 6.7\times10^{-11} \frac{60\times70}{2^2} = 6.7\times10^{-11}\times1050$$

$$= 6.7\times10^{-11}\times1.05\times10^{3}$$

$$= 7.0\times10^{-8}\ N$$

c) $$\text{accel} = \frac{\text{force}}{\text{mass}} = \frac{7.0\times10^{-8}}{70\,kg} = 10^{-9}\ m/s^2$$

d) $$\text{distance} = \frac{1}{2}\times10^{-9}\times(3600\,s)^2 = ~~1.8\times10^{-6}\,m~~\ 0.0065\,m$$

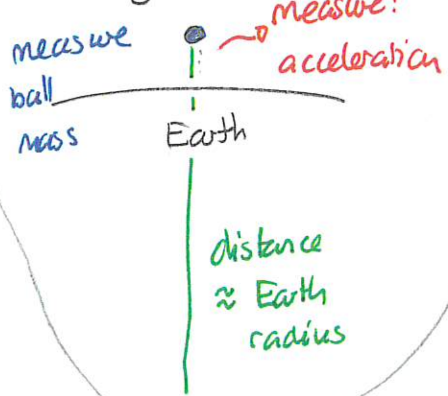
e) Not in one hour ~ only ~~2 millionths of a meter.~~ 6 mm.

Mass of Earth

Newton's Second Law and the Law of Gravitation can be combined to

Calculate mass of Earth

We can do this by observing a freely falling ball



Get net force

Net force = (mass ball) x accel

↓

Get gravitational force = net force

↓

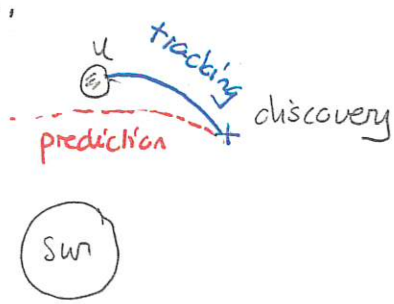
$$\text{gravitational force} = 6.7\times10^{-11}\,\frac{\text{mass ball} \times \text{mass Earth}}{(\text{distance})^2}$$

↳ solve for mass Earth

One can also do this by observing Moon's orbit and relating orbital period to orbital radius. This is a way in which we can determine the mass of a star around which planets orbit.

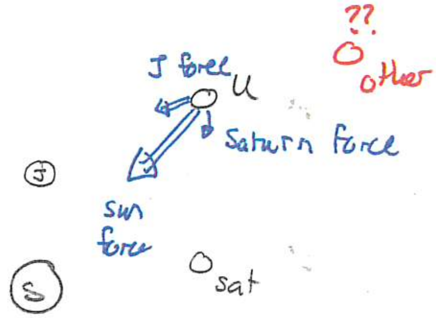
Discovery of Neptune

By the 1780s the planet Uranus was discovered by observation using telescopes. In the following years the position could be tracked,



We can ask whether the orbit could be predicted using gravitational forces and Newtons second law. We can determine:

* the gravitational forces exerted by Sun, Jupiter, Saturn....
* the effects of these on the orbit.



These predictions deviated from the actual observations. One explanation was that there must be another planet that exerts its own gravitational force on Jupiter. By comparing the observed to predicted orbits one could determine the location of this planet. Telescopes were used to check this and this is how Neptune was discovered (1846).

Could this result in the discovery of other planets.

Demo: Planet 9 video