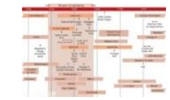
<u>Isaac Newton & Gravity</u>

Isaac Newton was born in England in 1642 – the year that Galileo died.

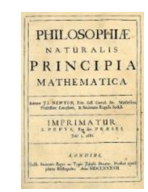


Newton would extend Galileo's study on the motion of bodies, formulate a workable model of the gravitational force, and combine the two into a modern description of orbital motion that would contain Kepler's Laws as a necessary consequence.

During our next class, we'll see a video on Newton that covers his life more completely, but we should discuss two important dates in his life:

1665 – 1667: Newton was a student at Cambridge, but when the black plague struck, school was closed, and Newton had to return to his family home in Woolsthorpe. ***During this extended break, he discovered his three laws of motion, law of gravity, and invented calculus – at the age of ~23!***

LC



1687: Edmund Halley convinced Newton to write up his discoveries which were published in The Principia (*A singularly unreadable work)*

Why the delay? We'll see in the next class in the video: "**Newton's Dark Secrets**."

Did an Apple Fall on Newton's Head?


That's the myth – we'll likely never know the truth. Probably the source of the story is **Newton's own words later in life**:

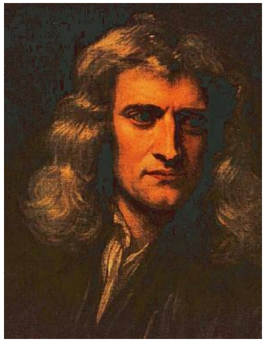
- **"We know that there is a force of Gravity that causes the apple to fall from the tree.**
- **Could this same force reach out and hold the Moon in its orbit?**
- **. . . And could a similar force between the Sun and the Planets hold them in their orbits?"**

Of course, Newton would answer his own questions in the affirmative, and his three laws of motion and law of gravity show how it works.

But what is really revolutionary about this idea?

Newton was proposing that the same laws of nature operate in the heavens as operate on Earth. Since Aristotle, it was believed that the heavens had to obey a different set of laws from those on Earth. **This changed everything!**

Newton's Laws of Motion



First Law of Motion (in Newton's own words*):

"Every body perseveres in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed thereon."

Translation:

An object at rest will remain at rest unless a net force acts on it.
An object in motion in a straight line will remain in that state unless a net force acts on it.

Compare this to Aristotle's view: "the natural state for all objects is a state of rest." Why did Aristotle think this?

*translated from Latin in The Principia

Newton's Laws of Motion

Second Law of Motion (in Newton's own words):

"The alteration of motion is ever proportional to the motive force impressed; and is made in the direction of the right line in which that force is impressed."

Translation:

A body subject to a net force will accelerate in the direction of the net force with an acceleration equal to the net force divided by the mass of the object. (a = F/m)

If you have studied some physics and calculus, then you know that this is the **Central Law of Classical Physics**:

$$\vec{F} = m\vec{a} = m\frac{d^2\vec{r}}{dt^2}$$

If you haven't studied physics or don't know what this is – *don't worry about it!*

<u>Newton's Laws of Motion</u>

<u>**Third Law of Motion (in Newton's own words)**</u>:

"To every action there is always opposed an equal reaction: <u>OR</u> the mutual actions of two bodies upon each other are always equal, and directed to contrary parts."

<u>**Translation:**</u>

When body A exerts a force on body B, then B exerts an equal but oppositely directed force on A.

<u>**Consequence of Newton's Laws of Motion**</u>:

If: We know all of the forces acting on an object and its position and velocity at some time,

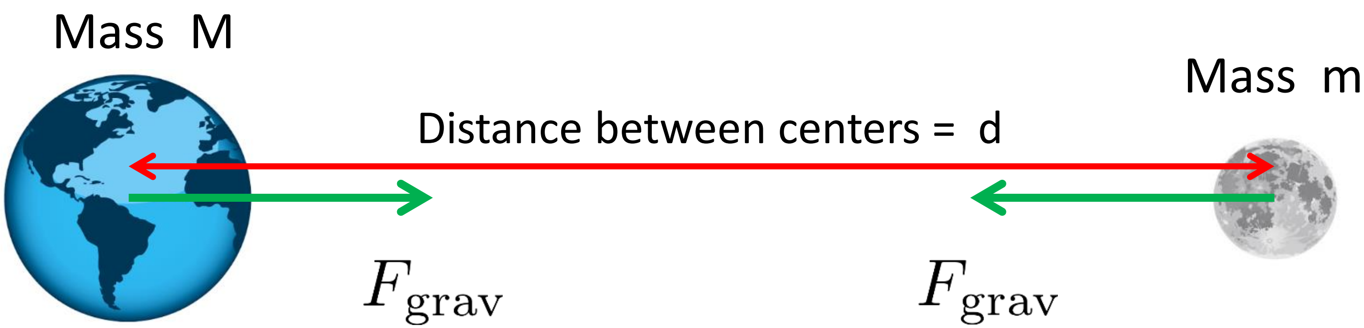
Then: We can calculate the object's future motion.

<u>**Note**</u>**: this is entirely general; the object could a planet, a galaxy, a golf ball, a speck of dust, or a molecule of gas!**

Law of Universal Gravitation

For the problem of planetary motion, Newton proposed that an attractive force of gravity exists between all objects that have mass.

For example: the Earth and the Moon:



Gravitational force of the Earth on the Moon and the Moon on the Earth

$$F_{\text{grav}} = G\frac{mM}{d^2}$$

(along the line between the two masses)

G = Gravitational Constant

This is an example of what's called an **"Inverse Square Force,"** which means that the strength of the force decreases as the square of the distance.

e.g. By what factor does the force of gravity that a planet exerts on a spacecraft change if the distance between the spacecraft and the planet is doubled? ***(LC)***

Answer: Reduced by 1/4

Law of Universal Gravitation

What's the big deal about an inverse square force law?

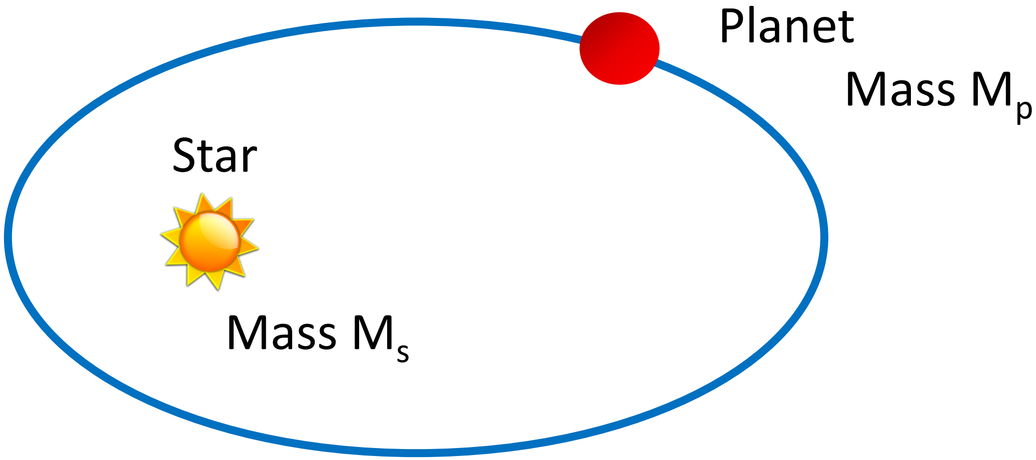
If someone stops you on the street someday and asks, *"Kepler says that planetary orbits are ellipses; why are they ellipses?"*

The simplest and most mathematically correct answer is:

Planetary orbits are ellipses because the gravitational force falls off as $1/(\text{distance})^2$.

Although we won't go into the details, Newton could use his three laws of motion and his law of gravity and derive exactly all of Kepler's Laws.
One that will be important to us later is Newton's Form of Kepler's 3rd Law.

Newton's Form of Kepler's 3rd Law



Recall how Kepler stated his 3rd Law: $(\text{Period})^2 \propto (\text{Semimajor axis})^3$

$$T^2 \propto a^3$$

Newton was able to find the proportionality constant and write this as an equation:

$$T^2 = \frac{4\pi^2}{G(M_s + M_p)} a^3$$

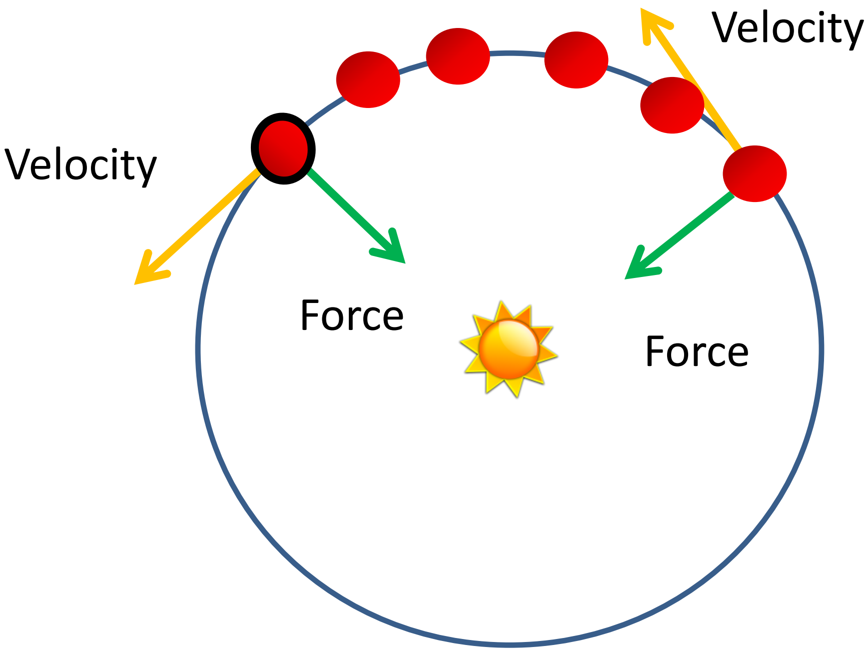
e.g. For the planet and star above, if we can measure T and a, and $M_s >> M_p$,
What can we can calculate? **(LC)**

Answer: *Mass of the star (this works for all kinds of orbits)*

Orbital Motion & Newton's Laws

Let's see if we can understand how an orbit works according to Newton:

Circular Orbit:



The Force is always perpendicular to the velocity, so gravity just bends the path around in a circle at constant speed

(G & O)

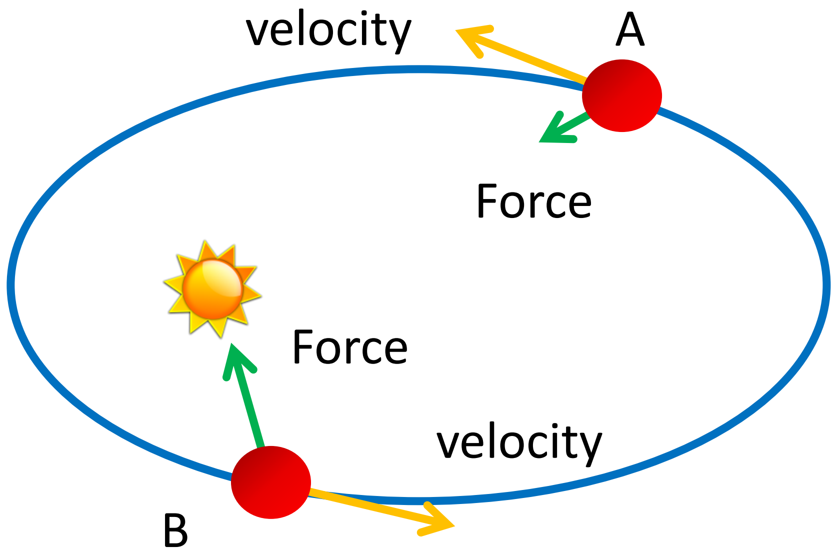
Only one force acts on the planet to hold it in its orbit - - not two.

But to get something into orbit, you need another force to accelerate it up to the necessary speed. But once you reach orbital speed, that force is no longer necessary.

(canon)

Orbital Motion & Newton's Laws

Elliptical Orbit:



Here the force is not always perpendicular to the velocity.

So at A, gravity is speeding the planet up, and at B gravity is slowing it down.

(G & O)

This is Kepler's Second Law.

What happens if the velocity keeps increasing?

(canon)

At some point, you will be in an unbound orbit that is shaped like either a parabola (right at the escape speed) or hyperbola for speeds greater than the escape speed.

Orbital Motion & Newton's Laws

Of course, just looking at simple one planet orbits is a bit misleading because all objects exert gravitational forces on each other - the motion can get pretty complicated.

- **Sun, planet, and comet**
- **Binary star, planet**
- **Four star ballet**

(MySS)

Amazingly enough, this isn't all that Newton did. He did pioneering work in optics and proposed a theory of light. He built the first reflecting telescope and he had some other interests that we'll see about in the video.
Your author includes some other elements of physics in this chapter; we'll cover those as we need them.