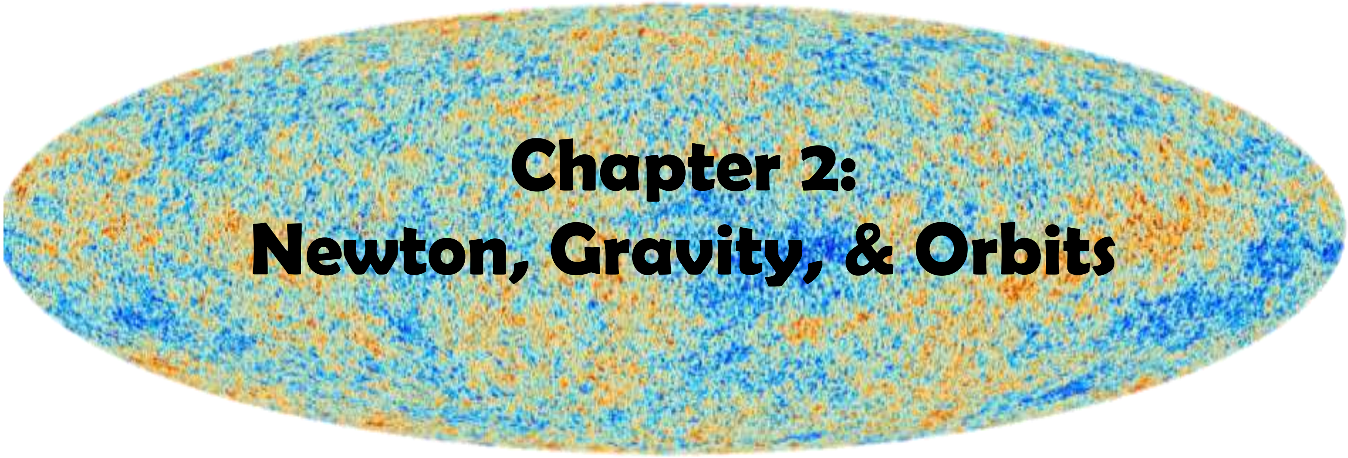
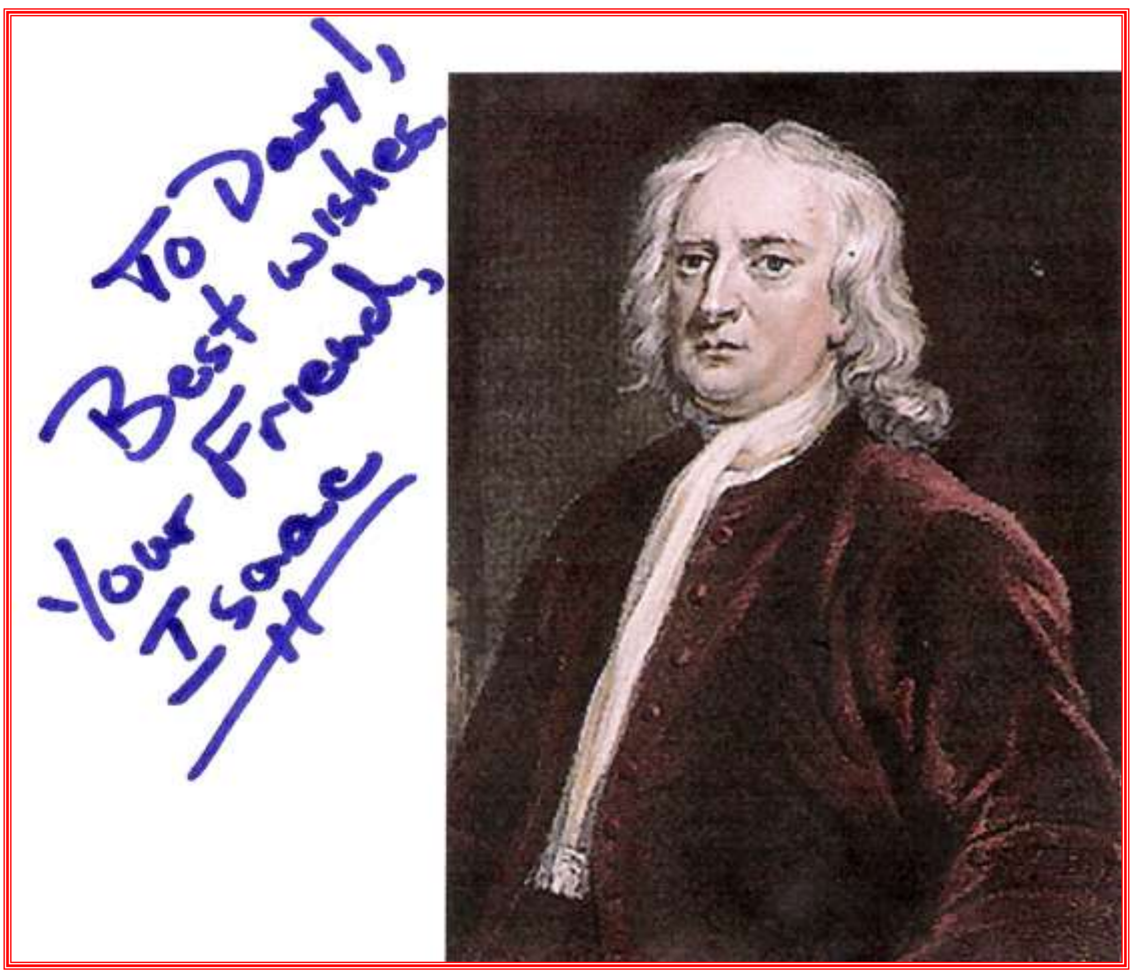


Chapter 2:
Newton, Gravity, & Orbits

Updated 09/04/2015



Newton's Laws of Motion Gravity. Where would we be without it? Floating around in empty cold space as individual atoms, that's where. Gravity is a topic that was never "discovered" or "invented". It's not like one day, Fred Flintstone woke up, fell out of bed, and said, "Wilma! I just discovered gravity! " However, Newton, pictured above, did indeed develop a mathematical model that explained gravity. Working upon the ground work that Galileo found, Newton decided that gravity is an instantaneous force acting between any two masses at any place in the Universe. In science-speak:

> *The force of gravity is proportional to the product of the masses and inversely proportional to the square of the distance between the masses.*

Remember from Chapter 1, that in math-speak, the force of gravity is written as: $F_G = G\frac{M_1 M_2}{R^2}$. We will get back to this later in the chapter. Right now, we have to take a step back and take a close look at what is lovingly called Newton's ***Laws of Motion***. You have been taught these three *Laws* probably since 4^{th} grade or so. It is time to *really* learn them. Here they are in summary form then we will look at each on in detail.

1. An object at rest will remain at rest and an object in motion will remain in motion in a straight line unless an outside force acts upon it.
2. The acceleration an object experiences is directly proportional to the force acting upon it and inversely proportional to the mass of the object.
3. For every force acting between two objects there is an equal opposing force.

Sounds weird simply because most of the language used is science-speak. Most folks don't use science-speak. This is one reason most folks are afraid of science; most of the time, scientists use their own language. Well, let's translate these three Laws into common good old American.

1. An object will keep doing what it wants to without outside interference.
2. Common sense: The change in motion an object feels depends on its mass (big mass, small change) and the force acting on it (big force, big change).
3. The famous action-reaction thingee.

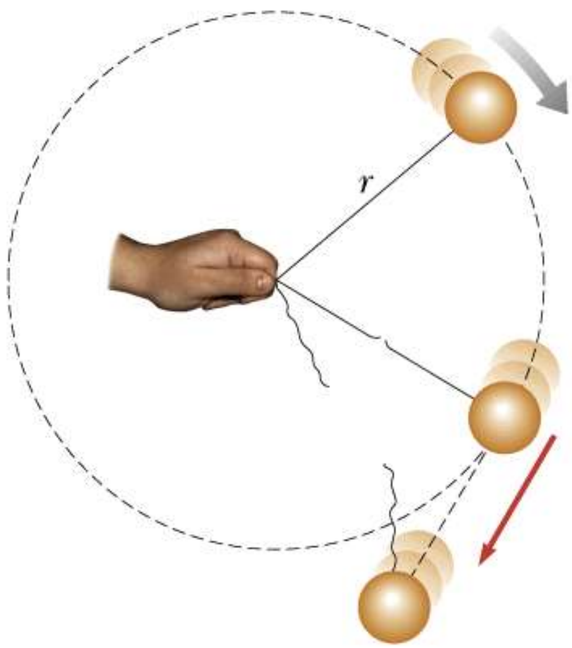
So, hopefully, you see these are not really abstract ideas. They are everyday statements that you already know. ***NL1*** (Newton's 1^{st} Law) and ***NL2*** (2^{nd} Law) are why it's easy to kick a soccer ball, but you wouldn't want to kick a bowling ball. ***NL3*** is why if you do something stupid, like kick a bowling ball, your foot breaks; the bowling ball applies an equal force to your foot. Let's take a close look at each Law individually.

Newton's 1^{st} Law *DO NOT CALL THIS THE LAW OF INERTIA*! It is not! It is, however, a description of just what ***inertia*** is. By definition, ***inertia*** is the property of ALL objects that resists a change in its motion. Inertia is a property, not anything mysterious like most science teachers try to make it.
[IMAGE: Shot & car]

A massive object, like my yellow grapefruit, has a lot of mass, therefore a lot of inertia. A “light” object, like my yellow Hot Wheels car, has little mass thereby little inertia. It is easy to make the car change its motion. Just flick it, it moves. Try flicking the grapefruit. What happens? Well, since the grapefruit is actually an indoor shot put that weighs 16 pounds (7 kg), your finger is the thing that gets affected. The shot put sits there are laughs at your puny little mortal finger.

Now, what does NL1 have to do with astronomy? Orbits. Newton knew that is you twirled an object attached to a string around and around and let go the object would travel off in a straight line path. Try it.

Serway, Physics for Scientists and Engineers, 5/e
Figure 6.2



Notice how the ball was moving in a circular path, sorta like David & Goliath slingshot weaponry. When the string breaks, the force holding the ball in the circle is no longer there and the ball will then, according to NL1, ***move in a straight line***.

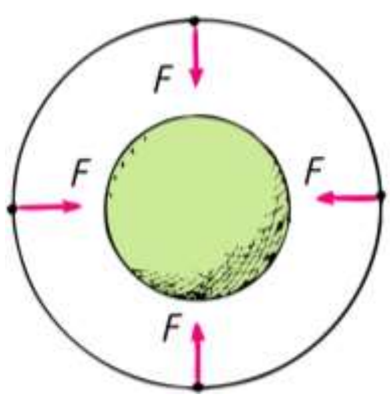
Other examples of 1st Law motion: Take a look at the home turn at a racetrack:

Notice the majority of the tire tracks follow the curve. However, what happens when a race car hits that turn a little too fast and can't stay moving in the curve needed? Yep, those straight line marks are the unfortunate result of "moving in a straight line".

Remember this example from class?

And the one below of the German teenage idiots?

So, what would happen to our earth if, all of a sudden, the sun disappeared? We would move at 31 km/s *in a straight line in the direction we were moving at the instant the gravity disappeared*. Bye bye us. This shows us that an object that is moving in a circular path needs a force that acts toward the center of the circle in order to keep moving in that circle. What causes the force in the case of the ball above? The tension in the string. Once that is gone, there is no reason for the ball to move in a circle. What causes the force that keeps the earth moving in a circular orbit? Gravity from the sun. It always acts toward the sun, pulling us. Notice in the next image, the force of gravity, ***F***, is always acting toward the center of the circle.



So, what is an orbit anyway and why doesn't the earth just fall into the sun? Orbits are nothing more than specialized projectiles. Follow this progression from Galileo to which Newton applied math to prove it was true. Galileo imagined a very VERY high mountain on which he could shoot progressively faster projectiles from a hugely huge cannon. Here is his original diagram:

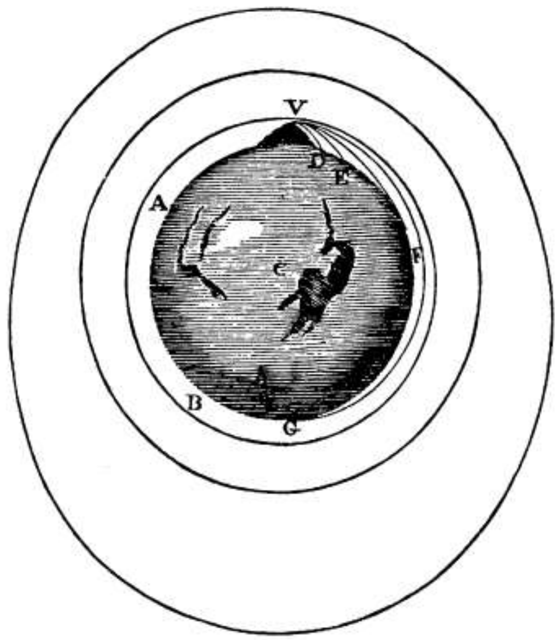
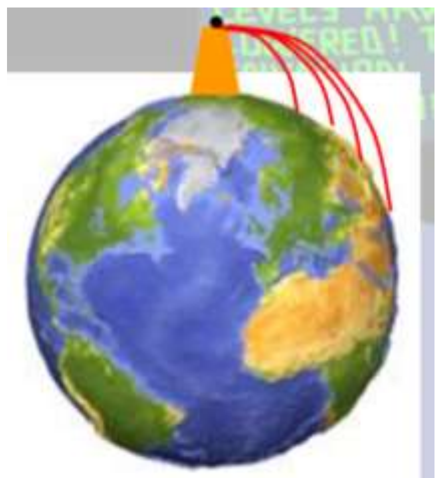


Image credit: *The MacTutor History of Mathematics*[23]

That diagram looks a little confusing, so let's take this one step at a time. First, fire the cannon with just a little bit of gunpowder. Where will be cannon shell go? It will plop down close to the mountain because the gravity from the earth will pull it down pretty quickly. The red line in the image below (from my own Projectile PPTX) is what would happen. From this very tall mountain, the cannon ball will follow a curved path downward just like any and all projectiles thrown near the surface of the earth - footballs, soccer balls, baseballs, spit balls at teachers, jello in the Student Center…

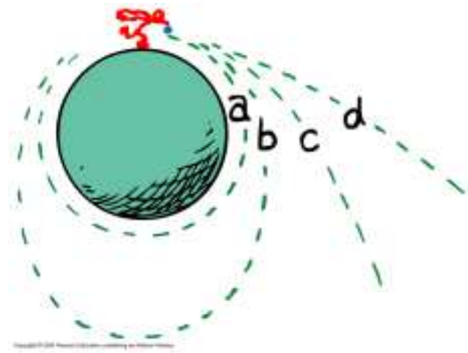
What would happen with a cannon that has more “umph”? This:

Notice, the 2nd cannon ball will travel further, but will still fall downward in a curved path. More ‘umph”?



Notice the 3rd & 4th shots are still going to fall back down to the earth, but each one travels a little further. So, if you can guess where this is going, what happens if you fire that cannon with so much speed that when it falls it actually follows the curvature of the earth’s surface? Orbit!

Notice the last cannon ball, located over western Africa in the image, does, indeed, keep falling. However, every time it tries to fall back to the earth, the earth surface has curved out away from under it. The cannon ball is constantly trying to play catch up with the surface of the earth. Gravity from the earth keeps tugging at the ball so it stays in a curved path just like the ball at the end of a string. What would happen to this cannon ball if it slowed down a little? Yep, it would fall to the earth. What would happen if it went faster? It leaves.

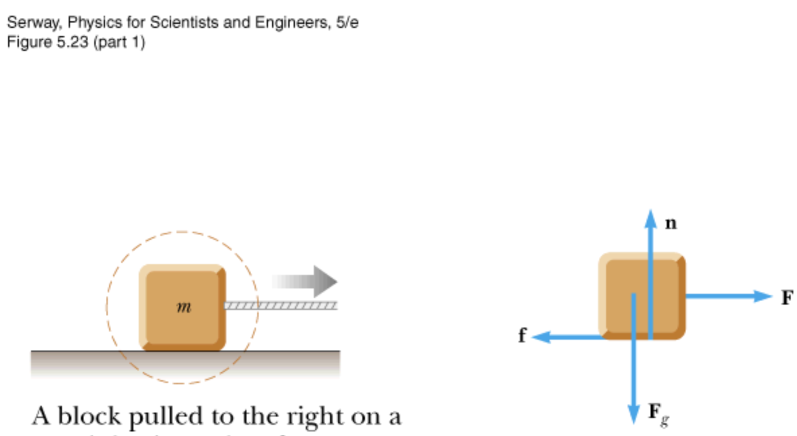


Path 'a' has just the right speed to stay in a circular orbit. Path 'b' is faster and will follow an elliptical path. Path 'c' and 'd' are simply too fast and will leave the gravitation influence of the earth. So, when NASA or Dr. Evil and Mini-Me put something in "orbit", all they are doing is going to a certain height above the surface and pushing the "satellite" sideways with enough speed so that it will follow the desired path; circular or elliptical.

Newton's 2nd Law: FMA Newton's 2nd Law of Motion is, more or less, simply a mathematical statement of the 1st Law. It says that the change in an objects motion (acceleration) is defined by the object mass and the force applied to the mass. In mathematical equation form, it is

$$\Sigma F = ma$$

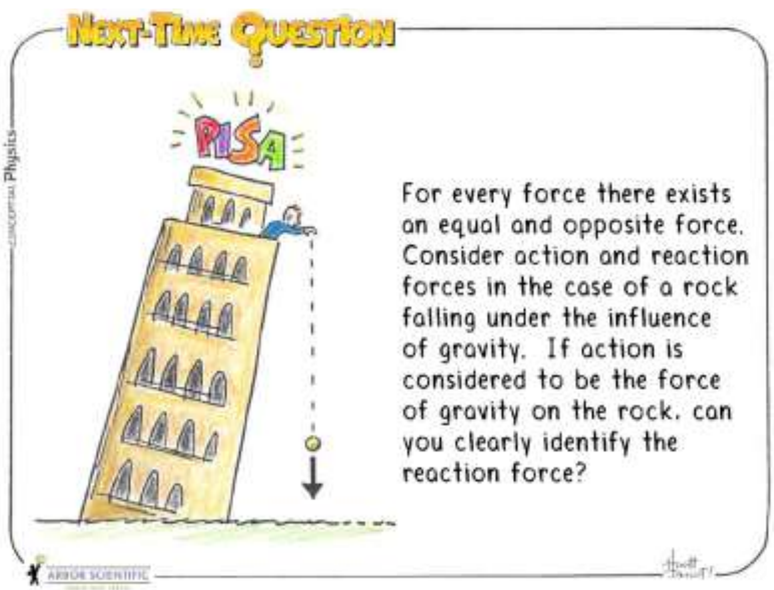
Looks innocent enough, but what the heck is that funky symbol in front of the "F"? It's a "sigma" symbol used in math to mean the "sum of" things. All that means is you have to consider all the forces acting on an object, not just one. Take a look below.



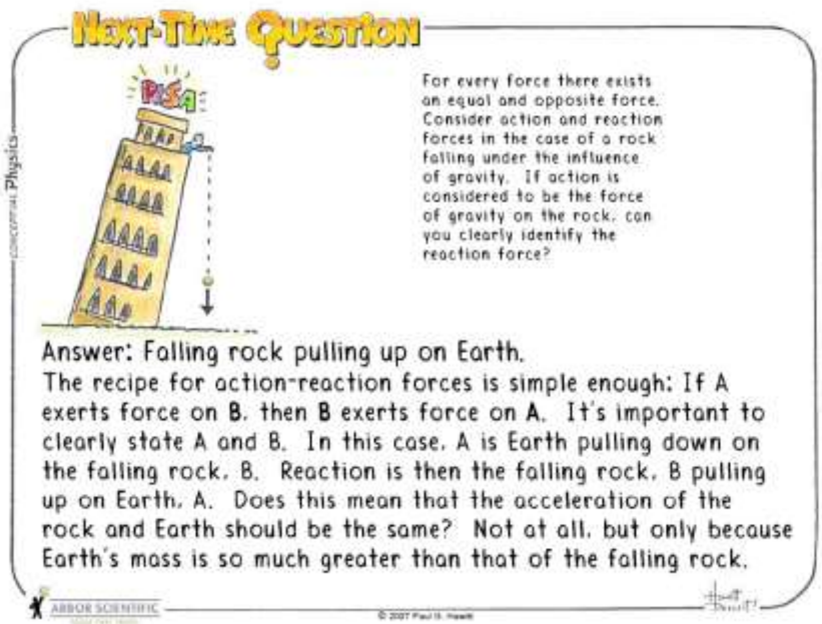
A block pulled to the right on a rough horizontal surface

Notice a few weird things? F_g, the force of gravity most folks would call the weight of the block, is pointed downward toward the center of earth, and that '***n***'? What's up with that? We'll chat more about that weirdo in a minute, but that '***n***' stands for the "***Normal***" force that is the force of the tabletop surface fighting back against gravity; it's an example of NL3. Now, look at ***F***. If we want to find the acceleration, ***a***, of the block, do we put ***F*** into NL2, $\Sigma F=ma$? Nope! Keep in mind, the ΣF is important. It is the sum of the forces in the direction of motion. So, $\Sigma F = ma$ becomes $F - f = ma$. Get it? Got it? Good.

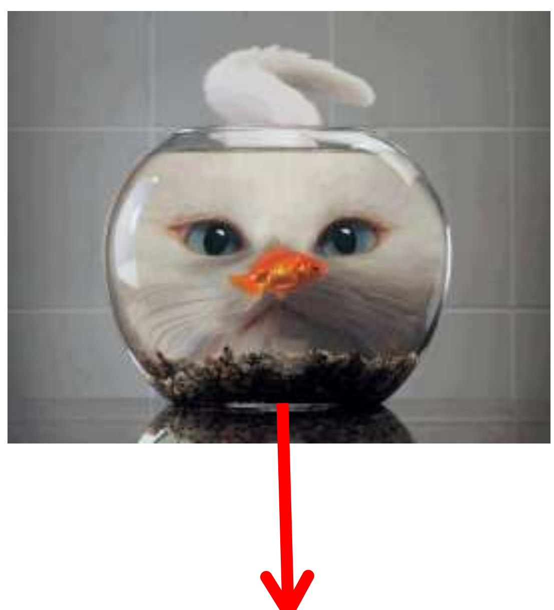
Newton's 3rd Law: The Famous Action/Reaction_This is the easy one, but it is also the hard one. What? It is easy to say that for every action there is an equal and opposite reaction. It is easy to push against a wall and feel the wall pushing back on your hand. However, a key point to NL3 is the fact that there has to be two objects involved. Examples:



NL3 specifically states that every force has an opposing force. So, what's the answer to the above cartoon situation? Well, opposite means opposite, right? Just turn the statement around. If the action is force of gravity from earth on rock, then the reaction is the force of gravity from rock to earth! Yes, that rock wants to attract the earth upward! So, why doesn't the earth move up toward the rock? Duh. It's the big kid on the block.



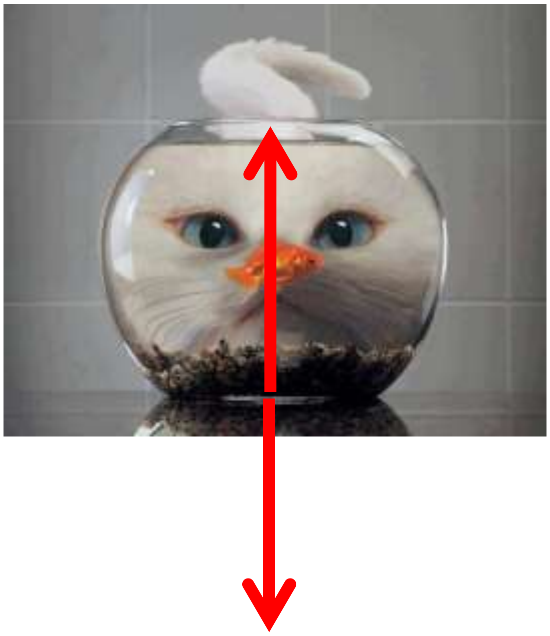
You see that there are two objects involved, not one! The rock falls because of earth's gravity, but the earth is also attracted to the rock with an equal and opposite (direction) force. Clear? No? OK, how about this example?



Action: Gravity from earth pushes cat/aquarium into tabletop. Reaction?

Rection is the tabletop fighting back against the weight of the object. This up force is called the "Normal" force. "Normal" is an old math term that means *perpendicular*.

So, you should see that the action force, weight, is canceled by the reaction force, the normal.



Newton & Astronomy? We already chatted about ***NL1*** & ***NL2*** with orbits. Now, let's investigate a few other things we can thank Newton for. WARNING: Some scary math ahead. ***HONORS NECESSARY***.

Speed of Orbit Following the same type of math/algebra we did when we talked about Newton's Synthesis where he proved Kepler's Laws, follow this.

Remember that Newton realized that an orbiting object must feel a centripetal force cause by gravity from the central object?

$$F_G = F_c$$

$$G\frac{M_1 M_2}{R^2} = \frac{Mv^2}{R}$$

Let's use the earth and sun:

$$G\frac{M_E M_S}{R^2} = \frac{M_E v^2}{R}$$

Mass of earth, M_E, cancels out:

$$G\frac{M_S}{R^2} = \frac{v^2}{R}$$

Now, one of the R's cancels:

$$G\frac{M_S}{R} = v^2$$

Take the square rootage of both sides and we end up with:

$$v = \sqrt{\frac{GM_S}{R}}$$

So, let's calculate the speed, v, of the earth in orbit.

$$v_{Earth} = \sqrt{\frac{GM_S}{R}} = \sqrt{\frac{\left(6.67x10^{-11}\, N\cdot m^2/kg^2\right)\left(2x10^{30}\,kg\right)}{1.5x10^{11}\,m}} = 30{,}000\, m/s \cong 75{,}000\, mi/hr$$

Wow! We be fast!

Mass of Orbiting Object Using the same equation, we can find the mass of any central object just by knowing how fast (or how big) its orbit is. As a shortcut, remember Kepler's 3rd Law and Newton's Synthesis?

$$\frac{4\pi^2}{GM_S} = \frac{T^2}{R^3}$$

Using this info, find the mass of the earth based on the moon's motion. Solve for M first…

$$\frac{4\pi^2 R^3}{GT^2} = M_E = \frac{4\pi^2\left(3.84x10^8\,m\right)^3}{\left(6.67x10^{-11}\, N\cdot m^2/kg^2\right)\left(27.33 days\right)^2} \cong 5.98x10^{24}\,kg$$

WOWZERS! We not only be fast, but we be heavy!

So, now, go to your room and do your homework.

Chapter 2 Resources

Powerpoint: http://dtfizzix.com/AstroPPTs.html

DIRECT LINKS: Full PPTX - http://www.dtfizzix.com/PPTs/Ch2-Gravity.pptx

PDF Format (Smaller) - http://www.dtfizzix.com/PPTs/Ch2-Gravity.pdf

Narrated Video – Coming Soon To A Computer Near You!

Homework:

Complete List: http://dtfizzix.com/AstroHWSchedule.html

Chapter 2 Specific:

1. 5 Questions – GOOGLE FORM

2. View 12 minute videos: ***PART7 & PART8 –*** *Gravity & Tides* at Astronomy Crash Course

-Just watch, no write-up.

LABS:

Newton's Laws Inquiry Multi-Day Lab-A-Palooza