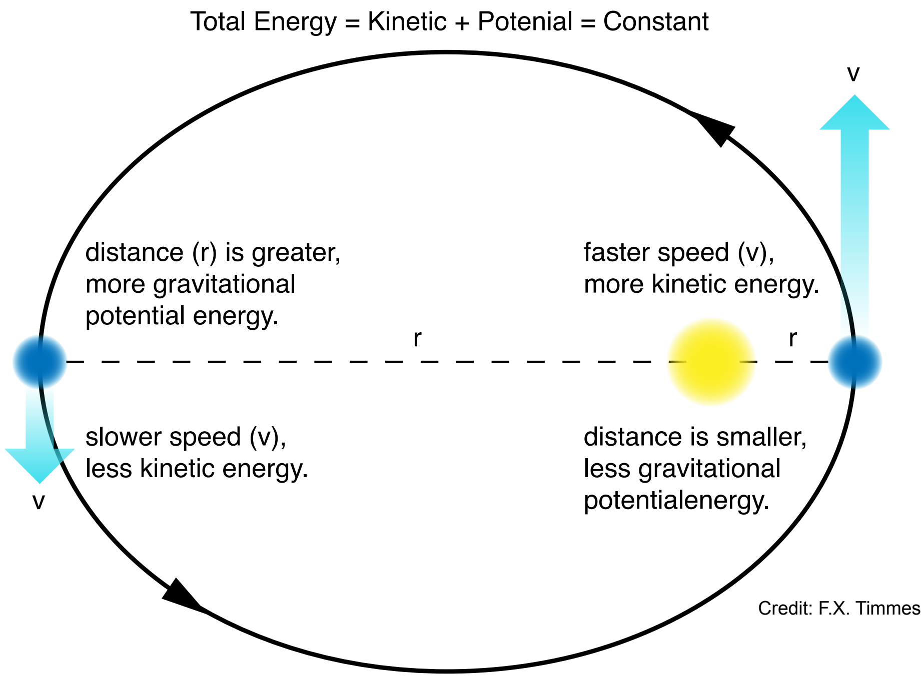
How quickly we grow accustomed to wonders. I am reminded of the Isaac Asimov story "Nightfall," about the planet where the stars were visible only once in a thousand years. So awesome was the sight that it drove people mad. We who can see the stars every night glance up casually at the cosmos and then quickly down again, searching for a Dairy Queen.

Roger Ebert

Into the Tides

Hi there. in this module we'll cover how gravity causes tides.

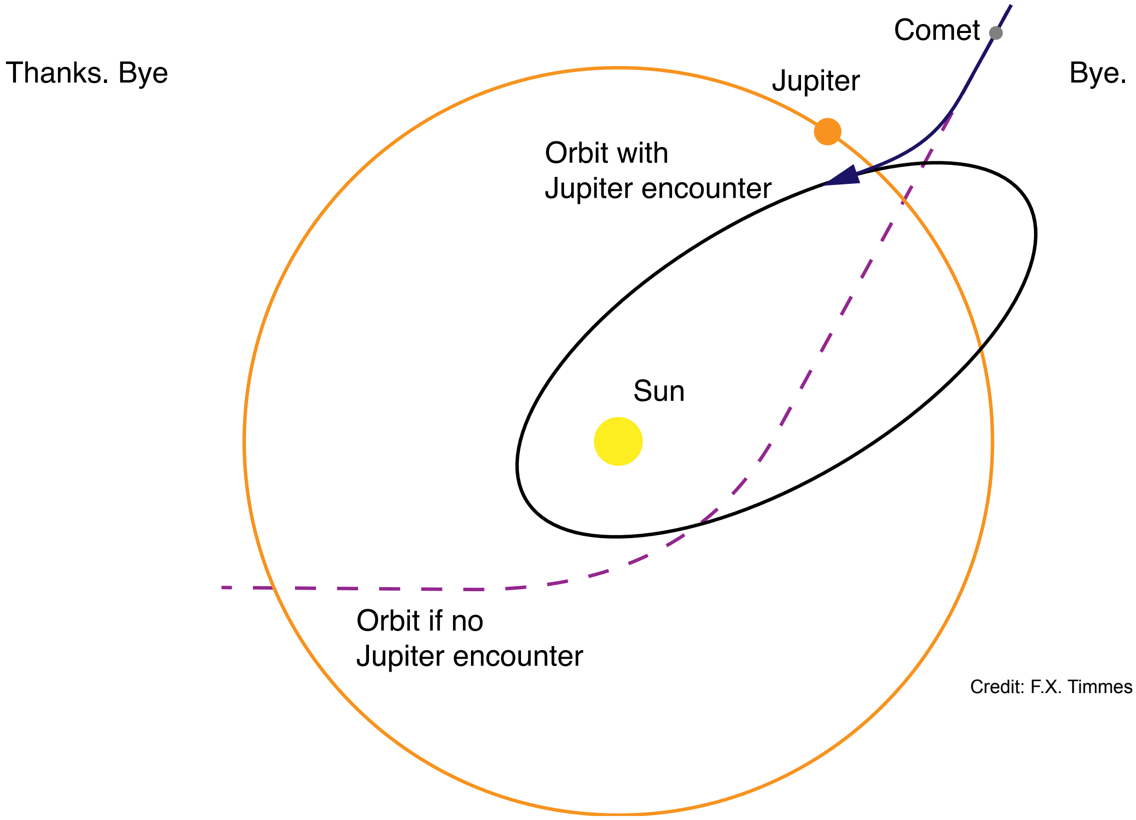
Gravity determines the orbits. You get bound orbits such as circles and ellipses, or unbound orbits such as parabolic or hyperbolic orbits. An object isn't going to change its orbit unless it gains or loses energy. Remember, energy is conserved, so the sum of the kinetic energy and the potential gravitational energy is going to be the same when you add them up.



The image above is showing a conservation of energy as it goes around, as it converts gravitational energy into kinetic energy.

We talked about this orbit in terms of conservation of angular momentum before. That's one way of looking at it. Another way to look at, getting to the exact same conclusions, is to think about it in terms of energy, the conservation of energy.

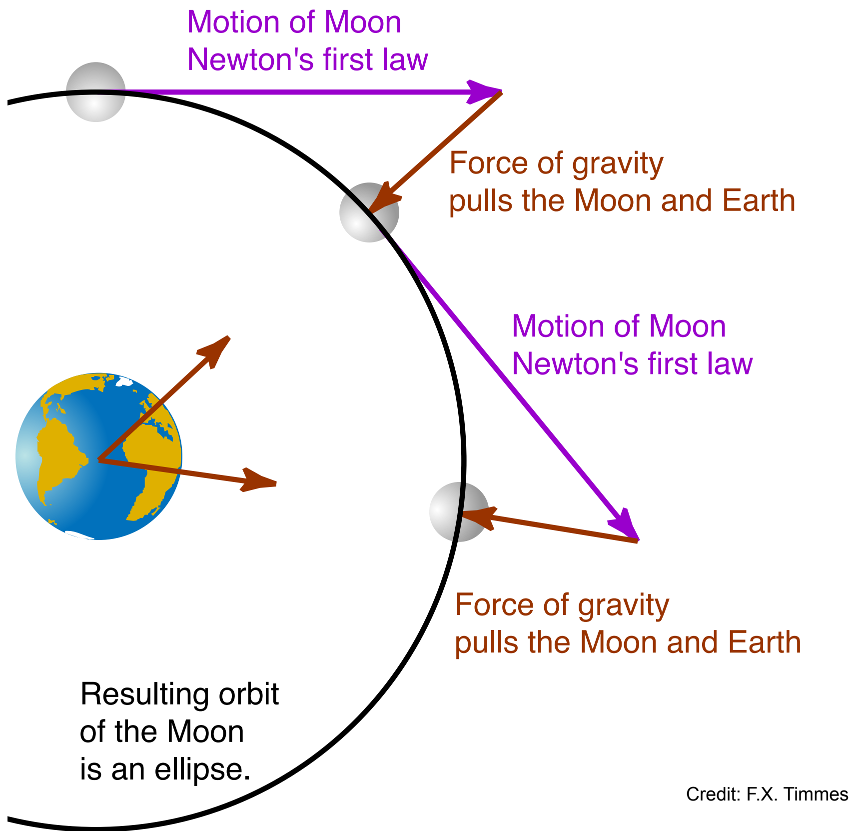
So as you get closer to the Sun, your speed goes up, so your kinetic energy is going up, but your potential energy is going down. And conversely, on the other side, you've got a great deal of potential, gravitational potential energy, but not much speed. So that would be your kinetic energy. But the sum of those two is always the same.



The only way you're ever going to change your orbit is if you change the energy - which basically means an interaction with a third body. That's what's shown in the image above, where you can have a comet or an asteroid coming in. Generally, those comets and asteroids are going to be coming in on hyperbolic or parabolic orbits, but they may have an interaction with Jupiter, the third body, which can transfer orbital energy away from the comet or the asteroid and capture the asteroid or comet.

In the case shown above, energy is taken from the comet and added to Jupiter. This changes the comet's orbit from an unbound orbit to an bound orbit - a captured comet. This is the origin of many of the comets and asteroids that are trapped inside our solar system. And of course, those are the ones we have to watch the most for near Earth impacts. The energy added to Jupiter is minuscule since its so massive, but at a tiny level Jupiter's semimajor axis becomes a smidgeon larger.

So you basically need a third body in order to change the energy, to change the orbit, of an object.



When you're in orbit, you're always falling, but you never hit the surface. In particular, the Moon or a satellite is always falling towards the Earth, but it never quite gets there. Yes, we covered a little bit of this when we were talking about weightlessness. The image above shows the Moon, and it's going around in its orbit around the Earth there in this image. And what does the Moon want to do? The Moon wants to obey Newton's first law. An object in motion remains in motion along a straight line.

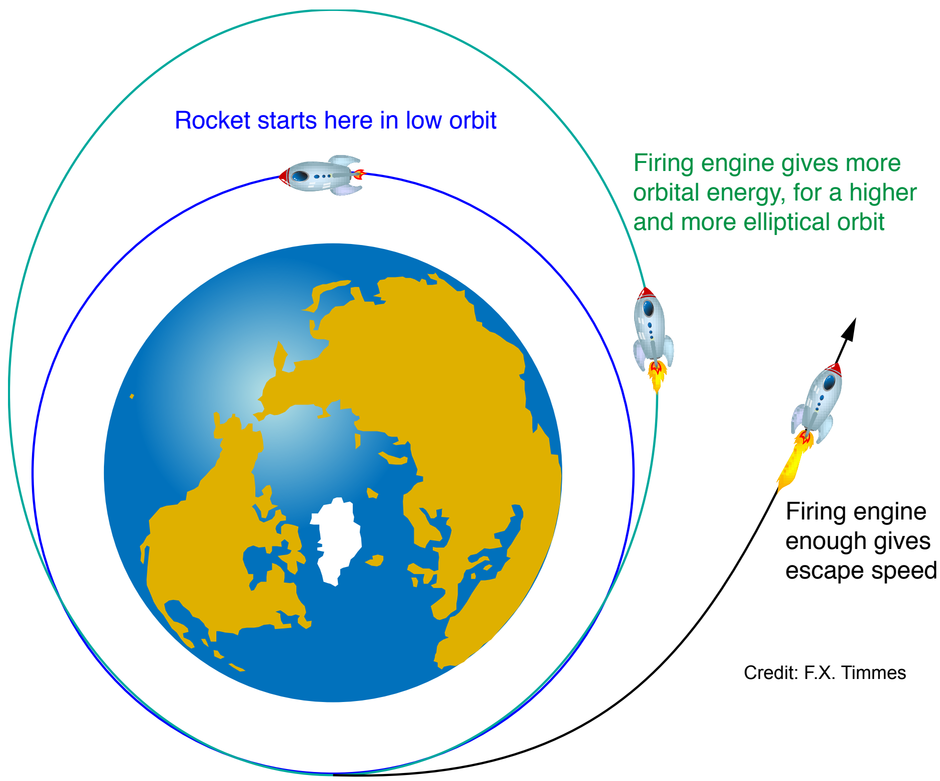
But there's an extra force, a gravitational force. And that extra force says no straight line for you, get back here. And so it pulls the object back. What does the Moon want to do now? It wants to go on a straight line. Gravity says, no, back you go.

When you go through this continually - I want to go in a straight line, no you don't - the path that you carve out is an orbit, an ellipse in general but shown above as a circle.

And so, the Moon is always falling. Gravity is always pulling the Moon. It's always falling back toward us, but it never reaches the us.

Say you have rocket in orbit, maybe like the Space Station, such as in the image below. If you hit the thrusters a little bit some chemical energy will be into increasing the kinetic energy of the rocket. This will “raise” the orbit of the rocket - make its semi-major axis larger. But still in orbit.

But if you crank up the thrusters to give the rocket even more kinetic energy, there comes a point when the rocket will escape Earth's gravitational field. That's referred to as achieving escape velocity. The escape velocity on Earth is about 11 kilometers per second. So if you can get up that speed, then you can escape Earth's gravitational pull altogether and go to the Moon, or to go Mars, or wherever you like to go, but you'll be out of the gravitational well of the Earth.

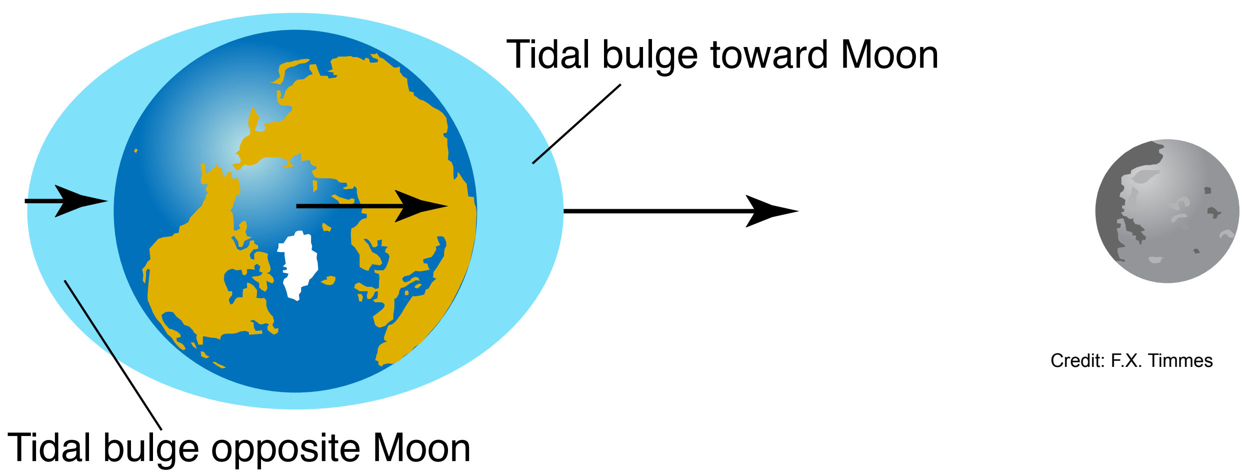


Credit: F.X. Timmes

Credit:Wikipedia, Creative Commons

So, tides. What causes tides? Well, did you know that the Earth pulls on your feet harder than it pulls on your head, because your feet are closer to the center the Earth than your head is? You don't feel that effect because it's relatively small on your scale. You're just a couple meters high so you don't feel it, but it's there.

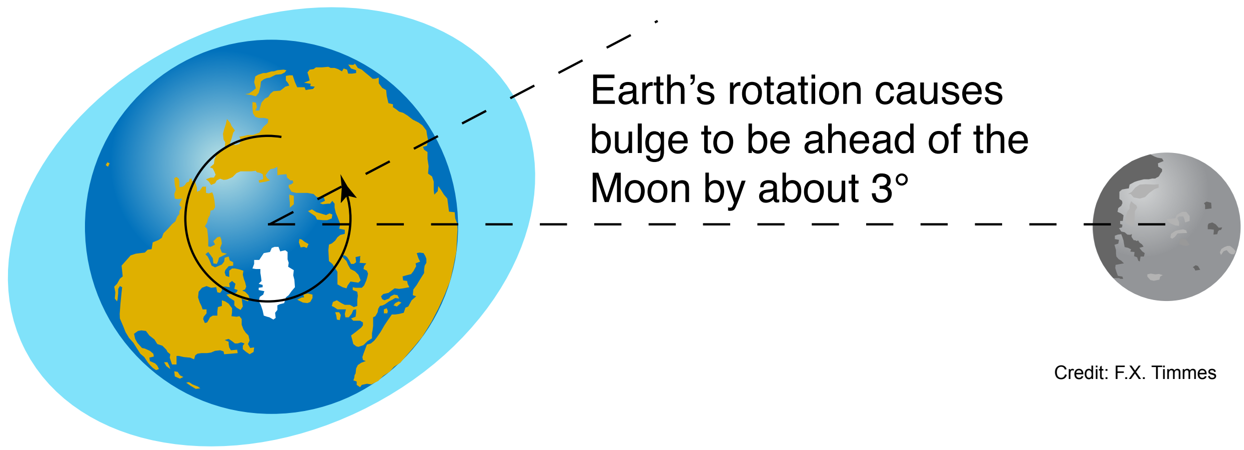
On the scale of planets, however, the effect of pulling stronger on nearer objects is quite noticeable. And this is what drives tides on the Earth's oceans and other planets. The image above is from the Bay of Fundy and you can see the difference between low and high tide. Relatively extreme in this place. Tides are all caused by gravity pulling on something stronger that is nearer.



For example, our Moon. The Moon is the largest source of tides on Earth. And the Moon pulls on the near side of the Earth stronger than it does the middle. This creates one tidal bulge. Generally, we're a water planet so water piles up on the tidal bulge toward the Moon.

The Moon also pulls on the center of the Earth harder than it does on the backside of the Earth because the center is closer. This creates a second tidal bulge.In some sense, this is material that is “left behind”. If you've ever thrown a water balloon, you throw the water balloon, and the water goes to the back of the balloon. Kind of the same effect here.

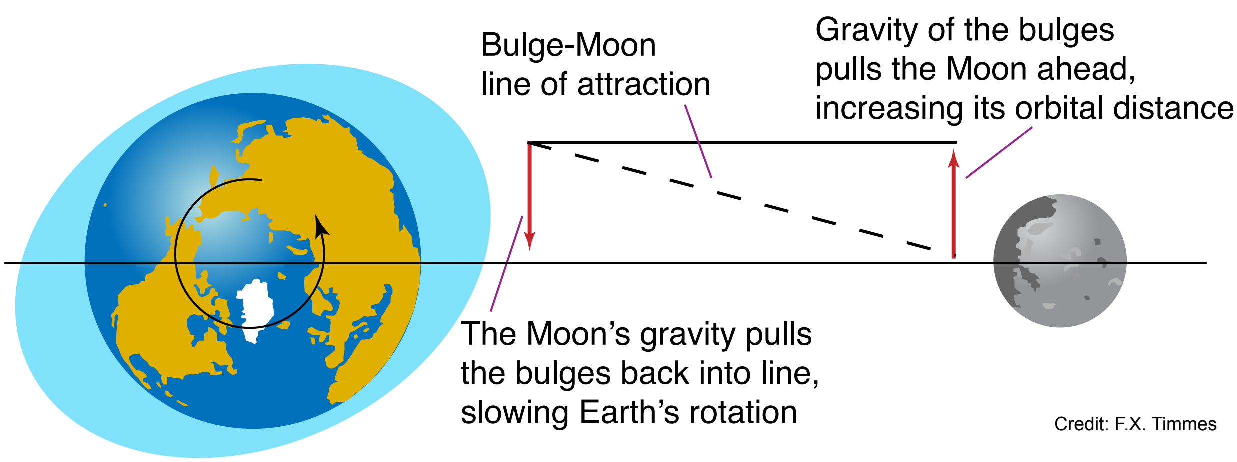
So you end up with two tidal bulges, one generally toward the Moon, one generally away from the Moon. That's a wee bit of a simplification, as we will see next.



The tidal bulge doesn't point directly at the Moon, as the illustration above shows. Why? Because Earth completes a rotation in 24 hours and the Moon has an orbital period of 27.3 days. This difference causes the bulge to lead the Moon by about 3°.

So the Moon is controlling the tidal bulges on a 27.3 day time scale. The Earth is rotating once every 24 hours. So we have two high tides and two low tides within a 24 period because we are rotating into the tidal bulges.

When we're standing at the beach, we use this curious turn of phrase. “Oh, look, the tide's coming in.” High tide isn't coming in. We're rotating *into* high tide. So it's a little bit of residual geocentricness even in our language - the tides coming in. Nope, we're going into the tides.

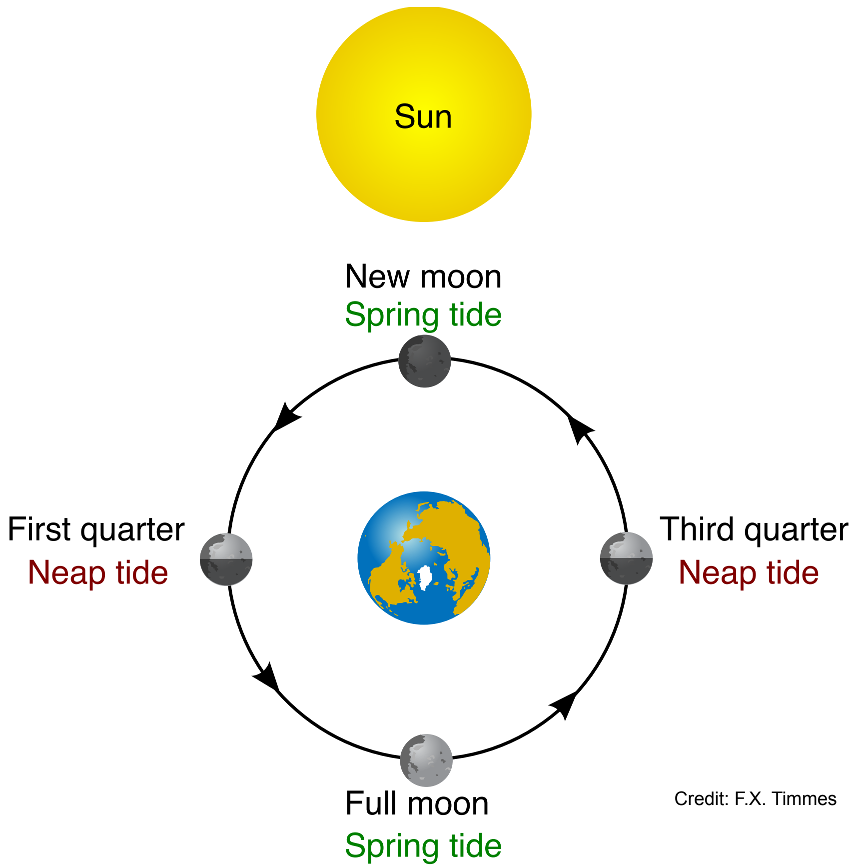


The tidal bulge has a two interesting effects, because the masses are not lined up. First, the bulge's gravitational attraction pulls the Moon forward, causing the Moon to move further away from Earth at a rate of about 4 cm/year. So every year, the Moon gets a little farther away.

Second, the Moon’s gravitational attraction on the bulge pulls the bulge backward, slowing the Earth down at a rate of about 0.002 seconds per century.

If left on its own, on time scales of about 5 billion years, the Earth would rotate at the same period in which the Moon goes around. Estimates are uncertain, but around 40 days (yes the “day” would be 40 times longer) is the canonical value. By then though, the Sun will be undergoing its final phases, swelling out to likely engulf the Earth and Moon.

This phenomena is called tidal locking. Tidal locking is quite common in planets and moons. We'll see it when we cover Jupiter, when we cover Saturn. So this basic idea is tidal locking causes the rotation period to be equal to the orbital period.



The Moon is the major driver of our tides, but the Sun also causes tides. The Sun is a lot more massive than the moon, but it's also a lot farther away. The net effect is that tides from the Sun are about one third as strong as they are from the Moon.

These two tide drivers can either line up to help one another or be at cross purposes to fight with one another. At either a full Moon or a new Moon, as the image above shows, the tidal effect from the Moon and the Sun is lined up. They're both working together, and the tides are extra high at high tides and extra low at low tides. These are called spring tides.

On the other hand, at the quarter Moon phases, first quarter and third quarter, the Moon and the Sun are working at cross purposes to one another. They're fighting each other. The high tides and low tides are not as pronounced, the tides are more equal. These are called neap tides.

Thanks! Bye Bye.