MITOCW | gravity

You know gravity as the force that keeps us from falling off this planet. But it's so much more than that. Gravity predicts the formation of planets, explains why they are spherical and why the orbits of planets around the sun are elliptical. It helped us discover one of the planets in our own solar system, and the formation of Saturnâ€™s rings. Gravity can bend and even trap light, and it governs some of the behavior of the universe itself. In this video, weâ€™ll look at the different models of gravity and explore how each helps us understand these diverse phenomena. This video is part of the Governing Rules video series. A small number of rules describe the physical and chemical interactions that are possible in our universe. Hello. My name is Nergis Mavalvala. I am a professor in the physics department at MIT, and today I'll be talking with you about gravity. After watching this video, you should be able to recognize several different expressions for gravity, and to analyze situations involving gravity in preparation for problem-solving. We also hope that you gain an appreciation for the universal nature of gravity and the many places its effects can be seen. There are three expressions of gravity that scientists find useful. We're going to talk about all three of them today: gravity near the earth's surface, Newton's universal law of gravity, and Einstein's gravitational field equations, which are the core of general relativity. We'll be spending most of our time with the second one, but we're going to start with the simplest item and build upward and outward from there. You should make sure that the first two equations are in your notes. Let's start with the basics: gravity near Earth's surface. In studying Newton's Laws we all learn that F = ma. Near Earth's surface, that "a," acceleration, is provided by Earth's gravity. The value is almost constant, so we use this small "g" constant to represent it. We're all familiar with the most basic applications of gravity - that we stay on the ground, that objects fall downward, that we have to work harder walking up a hill than down. There are also many applications of gravity that are hidden from us in our day-to-day experience. For instance, elevators use counterweights to ease the load on the motor. As gravity pulls on the counterweight, the tension it puts on the cable pulls the elevator upward and helps to balance the force of gravity on the elevator itself. Some older mountain railways also use counterbalancing, with one train car moving upward as the other moves down. Pile drivers are construction machines that rely on the pull of gravity to slam large weights into the ground, digging holes and driving foundations for buildings. As useful as this simple view of gravity is, it's fairly limited - it can't explain why the planets are spherical instead of, say, cube-shaped. It also can't explain the orbits of the planets, or the action of the tides. Let's move to a more complex expression for gravity that can help us understand these things. Newton's law of universal gravitation is a powerful model that can explain many different phenomena. Let's dive right in. Unlike the most basic view of gravity, in which it pulls straight down, leaving Canadians to wonder why penguins don't fall off the planet, Newton's gravity shows that all objects are pulled toward each other's centers. Thus, we all stay firmly planted on Earth's surface. Because the gravitational force pulls equally in all directions, large bodies in space tend to be spherical. The Sun, all planets, and even larger moons tend towards a spherical shape for this reason. Newton's law of gravity also means that all objects are pulled toward each other, such as planets toward the sun. By solving the differential equations that come from this law, we can obtain the elliptical orbits that all planets have as they move around their stars. We can get all sorts of ellipses, from the near-circles we see in the inner planets, to Pluto's elongated orbit, to comets that swing far out of the solar system. The smaller pulls that planets have toward each other can be useful too. They're what allowed us to discover Neptune, by looking at the disturbances in the orbit of Uranus. Newton's law of gravity also gave us new insight into events on Earth, like our tides. Objects on one side of the Earth are pulled more strongly toward the moon than objects on the other side, in a phenomenon called tidal forces. Our own galaxy, the Milky Way, has gravitational interactions with other smaller galaxies nearby. Its disc-like shape and spiral arms may have come from tearing those galaxies apart. We see other galaxies colliding in many other places in the universe, as gravity pulls them together. It actually seems to be fairly common. Speaking of galaxies, Newton's law also tells us how fast galaxies should rotate. We can predict a particular A curve for how fast the stars will be moving according to their distance from the center - that's curve A here. But when we measure the actual velocity of those stars, we get B curve B instead. This was our first indication of the existence of dark matter - some sort of substance that produces gravity but doesn't interact with light. We couldn't see it, but we could see its effects. Dark matter surrounds and is part of every galaxy. In fact, there's so much that it makes up most of the galaxy! Physicists are still trying to figure out what this dark matter might be. We can also use Newton's law of gravity to look beyond the structure of individual galaxies - we can look at clusters of galaxies, superclusters, and even the entire visible universe. Fair enough. When we do look at things on that scale, where individual galaxies become just dots, we can see massive structures of galaxies, like this Great Wall here, or these empty intergalactic voids. In recent years supercomputers have become powerful enough to simulate the formation of such structures in our universe. Here you can see the result of one such simulation, with each speck of light representing a galaxy worth of stars or dark matter. Using Newton's law of gravity, superclusters of galaxies and intergalactic voids appear naturally! A real triumph of Newton's approach was that it worked for everything from people on Earth out to some of the most distant objects we can see. But it couldn't handle everything, and that's why we need this next part. The most powerful model of gravity is described by Einstein's field equations, which are the core of general relativity. This equation may not make sense to you now, but later in your career you may learn about something called tensors, which are related to vectors. In this equation, tensors describe the gravitational effects of both matter and energy on all things around them. This equation is very hard to solve, even for experts. Some of the cases we know how to solve tell us about black holes and gravitational lensing, and give us insight into the universe when it was very young. Black holes were one of the first solutions to Einstein's field equations. You've probably heard of black holes, which are objects so massive that they warp space and time, and even light cannot escape their gravitational pull. At the center of our galaxy, and of many large galaxies, are supermassive black holes. We can see their effects as stars near the center of the galaxy whip around them at high speed. While black holes trap light, other massive objects can have an effect too. Light bends in its path as it moves past heavy objects like stars. This can lead to gravitational lensing, in which light from a distant object is bent around both sides of a heavy object. This lets us see multiple views of an object, or even warped images. Einstein's field equations also include this lambda value: the cosmological constant. This value can be used to describe a universe that collapses or holds steady, expands slowly, or expands at an accelerating rate. Astronomers are working to measure this value, and we seem to be in the third case - a universe that expands faster and faster. Einstein's theory of gravity remains one of the best-tested and most accurate theories in all of science. It can explain everything that Newtonian gravity can and more, things we wouldn't otherwise be able to predict or understand, it can even make predictions about how the universe will end. You can see why people would be interested in studying it. These three gravitational equations describe a huge range of phenomena in our natural world, from things in our own home to the farthest objects we can see. I hope that you will be motivated to learn more about them. Understanding these laws and being able to use them will lead you to a greater appreciation of the natural world. Now it's time to take some of the examples we saw and examine them in a different way. You will need paper and something to write with for this part of the video. Knowing that gravity causes a particular phenomenon is good, but we also want to know how to describe these phenomena mathematically. We'll be giving you some situations that can be described through gravity. Your job, working in pairs or groups of three, is to determine what information you would want in order to solve a particular problem. For instance, let's say that we drop a rock and want to know how long it would take to fall. We would want to know the rock's initial height and whether air resistance would be important. We might also want to double-check the value for gravity on Earth. That example is pretty simple. Let's do a more complicated one. Given an asteroid headed toward Earth, and its velocity and location, which approach would we need to find out whether the asteroid will hit the Earth, and if so, how long it will be before the impact? To understand an object's trajectory we need to know about its starting point - the position of the asteroid as compared to Earth. We also want to know how fast it's moving and in what direction. We'll need to know the mass of the Earth and of the asteroid, because both will factor into the force applied on the asteroid. Some things are arbitrary choices - for instance, we can pick any coordinate system we like. Since gravity pulls objects together, we might want to choose polar coordinates centered on the Earth to make things easier. Finally, there are some things that we'll want to know that are of a more general nature. For instance, how do we take into account gravity from the Sun? Can we measure all of our positions and velocities from the Earth's reference frame as if it were moving with constant velocity? Should we track the Earth as it moves in its orbit? These are things we might not know when we start to solve a problem, and it's important to write them down. Now it's your turn. We'll put four problems on the screen. Your instructor will assign problems to different groups. Each group's job is to write up a list of what information you would need in order to solve the problem. Remember, you don't need to actually solve it - just write down what you would need to know in order to find a solution. Here are the problems. Thank you for watching our video, and good luck with your class.