Whiteboard: 1/60, f5.6, iso 1000, **WB Use Grey Card**, Manual Audio at level 11, focal length ½ way to ∞. H4n **INPUT** @ **95%** gain.

BBB 1/60, f5.6, iso 320, **WB Use Grey Card**, Manual Audio at level 11, focal length ½ way to ∞. H4n **INPUT** @ **95%** gain.

BBB Check Horizontal Level & Billy's Lights!! Middle line at bottom 1/3 of desk & remember Billy and Bo chair locations!

Title: Universal Gravitation Potential Energy Introduction

Mr.p: Good morning. We have already worked with gravitational potential energy. Today we are going to introduce universal gravitational potential energy. [intro] Bobby, what is the equation we already have for gravitational potential energy?

- Bobby: Gravitational potential energy equals the mass of the object times acceleration due to gravity times h, where h is the vertical height above the horizontal zero line.
- Billy: That's right. We have to decide where to set

the horizontal zero line in order to use this equation.

Mr.p: [$PE_g = mgh$ (remember zero line)] Correct. And Bo, where is this equation applicable?

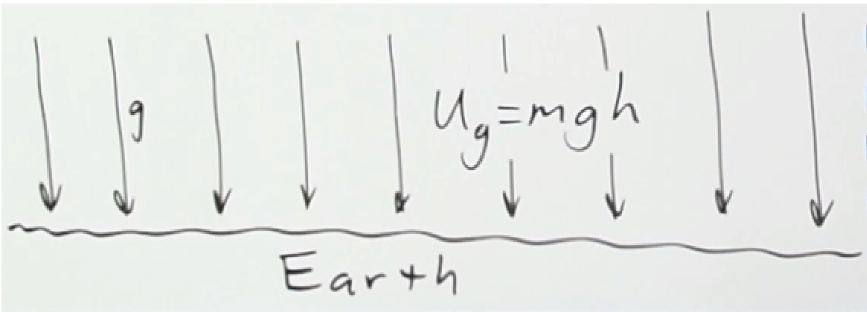
- Bo: Where is this equation applicable?
- **Mr.p: (Yes. When can we use this equation?)**
- Bo: … We have always used this equation for gravitational potential energy. So, I don’t really understand your question.

Mr.p: That is a fair point. How about this instead? Billy, if this equation represents your gravitational potential energy, then this is the gravitational potential energy which exists between you and what other object?

Billy: That is the gravitational potential energy between me and … well, little g is the acceleration due to gravity here on planet Earth, so that must be the gravitational potential energy which exists between me and the Earth.

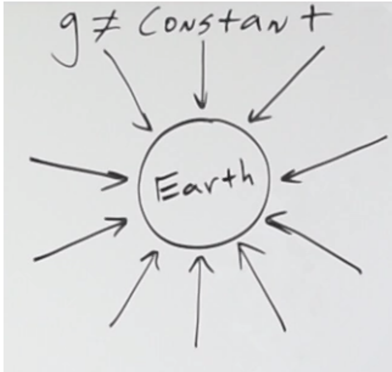
Mr.p: Correct. So back to the question for you Bo, where is this equation applicable?

Bo: Oh, so we can use gravitational potential energy equals the mass of the object times the acceleration due to gravity times the vertical height above the horizontal zero line when the object is on the surface of a planet.

Mr.p: [Constant g field] That is correct. More generally speaking, we can use this equation when the gravitational field is constant. [

] When you look at the surface of a planet on a local level, like where we are right now, the acceleration due to gravity has a constant magnitude of 9.81 meters per second squared. We live our lives in a constant downward gravitational field which has a magnitude of 9.81 meters per second squared. Any object we drop while standing on the surface of this planet will, in the absence of air resistance, increase its velocity by 9.81 meters per second down every second.

Bo: Did we not recently prove the acceleration due to gravity at the top of Mt. Everest to be 9.77 meters per second squared and therefore show the gravitational field on the surface of the Earth actually is not constant?

Mr.p: Okay, sure, right. It varies ever so slightly, however, for our purposes we can assume the acceleration due to gravity on the surface of the planet is constant. {hear Bo} Again, this equation is valid when the object is in a constant gravitational field. [

] When we look at the Earth from a non-local, or a global perspective, you can see the acceleration due to gravity is not constant.

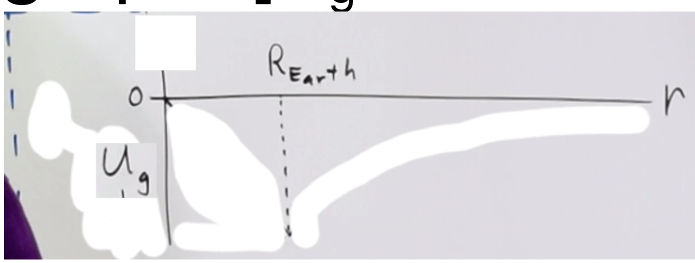
Bo: (okay.)

Bobby: That's right. Previously we determined the acceleration due to gravity on the International Space Station was 8.6 meters per second squared.

Mr.p: Correct. The farther apart the gravitational field lines are in the gravitational field drawing, the smaller the gravitational field. As we get farther from the Earth the magnitude of the gravitational field decreases and, therefore, the gravitational field lines in the drawing get farther apart. [$U_g = -\frac{Gm_1m_2}{r}$ (always true) Universal Gravitational Potential Energy. $G = 6.67 \times 10^{-11} \frac{N \cdot m^2}{kg^2}$] The equation for Universal Gravitational Potential Energy is the negative of the quantity, big G or the universal gravitational constant which has a value of 6.67 times ten to the negative 11 newtons times meters squared divided by kilograms squared, times mass 1 times mass 2, all divided by r, the distance between the centers of mass of the two objects.

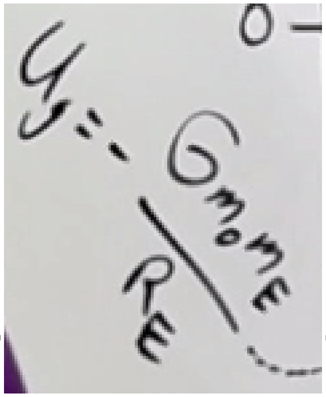
- Billy: Isn't that Newton's Universal Law of Gravitation?
- Bo: What's up with the negative?
- Bobby: Where did the capital U for gravitational potential energy come from? I thought it was capital PE sub g.

Mr.p: Okay. One thing at a time. I use a capital U sub g for universal gravitational potential energy, because that is what is typically done. I don't know why it is a capital U. Sorry. [$F_g = m_o g$ (planet specific) & $F_g = \frac{Gm_1m_2}{r^2}$ (always true)] Second, no, this is not

Newton’s Universal Law of Gravitation, however, it is similar. … I think it would be helpful to compare these two equations for gravitational potential energy to the two equations we have for the force of gravity. Remember, we have an equation for the force of gravity which is planet specific, which means it is valid where the acceleration due to gravity is constant, just like we have an equation for gravitational potential energy where the gravitational field is constant. And then we have Newton’s Universal Law of Gravitation which is the force of gravity which exists between any two objects and is an equation we can always use for the force of gravity. Now, we also have Universal Gravitational Potential Energy which is the equation we can always use for the gravitational potential energy which exists between any two objects. … Now let's talk about the negative sign. … The easiest way to understand the negative is via a graph. [U_g between object and Earth 

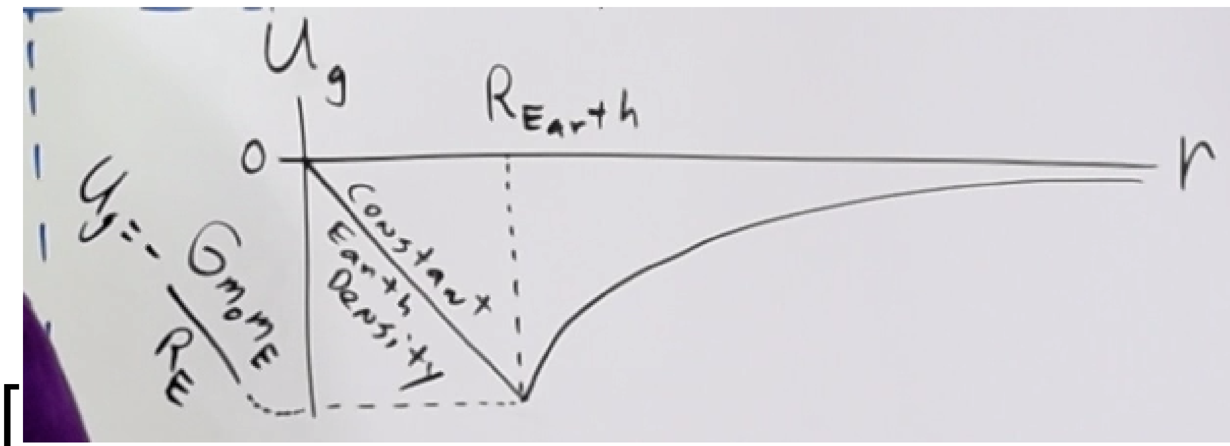
] Let's graph the gravitational potential energy which exists between an object and the Earth. On the y-axis we have the gravitational potential energy and on the x axis we have, r, the distance between the centers of mass of the two objects. Let’s start with an object on the surface of the planet. Bobby, what would the gravitational potential energy which exists between the Earth and an object which is on the surface of the Earth be equal to?

Bobby: Using the equation, it would be equal to the negative of the universal gravitational constant times the mass of object one, which would be the object, times the mass of object two, which would be the Earth, all divided by, r, the distance between the center of mass of the object and the center of mass of the Earth, which is the radius of the Earth.

Mr.p: [

] And, Bo, how about the universal gravitational potential energy of the Earth-object system when the object is infinitely far away from the Earth?

- Bo: The object is infinitely far away from Earth?
- **Mr.p: (yes)**
- Bo: Then r, the distance between their centers of mass would be infinitely large and anything over infinity is zero, so the universal gravitational potential energy would be zero.

Mr.p: [] And because the equation is proportional to one over r, the curve would have a concave downward shape and look like this. [

] If we assume the Earth has a constant density, then the gravitational potential energy graph from the center of the Earth to the radius of the Earth has a constant, negative slope. I’m not going to get in to details about that part of the graph today. Instead, notice that, for universal gravitational potential energy, we do not need to set the zero line because the zero line is already set for us. The zero line is where both objects are infinitely far away from one another. Also, class, can universal gravitational potential energy ever be positive?

Billy: No. **Bobby: No?** **Bo: No.**

Mr.p: Because the zero line is where both objects are infinitely far away from one another, universal gravitational potential energy will never be positive. This is because the zero line is where the two objects are infinitely far away from one another. This predetermined location for the zero line is why the negative is in the equation for universal gravitational potential energy. [at r = R_E, $g_{Earth} = \frac{Gm_E}{R_E^{\ 2}}$ & $U_g = -\frac{Gm_o m_E}{R_E} = -\left(\frac{Gm_E}{R_E^{\ 2}}\right) m_o R_E = -m_o g R_E$ similar to $PE_g = mgh$ Point to graph] One other item to notice about the gravitational potential energy which exists between an object and the Earth when the object is on the surface of the planet, in other words, when r equals the radius of the earth. At this point the acceleration due to gravity equals the universal gravitational constant times the mass of the Earth divided by the radius of the Earth squared. We derived this equation twice previously and you definitely need to know how to do that derivation and show me that derivation when you use this equation. Also, we can multiply the universal gravitational potential energy by the radius of the Earth over the radius of the Earth because it equals 1 and then we have the equation for the acceleration due to gravity on the surface of the Earth inside the parenthesis. So we can substitute in little g and we get that the universal gravitational potential energy of an object on the surface of the planet equals the negative of the mass of the object times the acceleration due to gravity times the radius of the Earth. Note the similarity between that and the gravitational potential energy equation we use in a constant gravitational field. [Be careful of: 1) $U_g < 0$, 2) U_g needs 2 objects, 3) r is not squared]… Three things to be careful of: 1) Please do not forget the negative. It's easy to forget and, sadly, often is. 2) Remember it requires two objects to have gravitational potential energy: object 1 and object 2. A single object, by itself, cannot have gravitational potential energy. And 3) The variable "r" is ***not*** squared in universal gravitational potential energy. It is in Newton's Universal Law of Gravitation, which means students have a tendency to add a square, it is not there, beware. Again, do not add a square, it is not there, beware. … Thank you for learning with me today, I enjoyed learning with you.