0660 – Electric Potential - But, What IS It?
{FILM POSES FOR THUMBNAIL!!}
{Mr.p needs bright, colored paper.}
FYI: My plan is for this video to go after 0658 Electric Potential and before 0659 Equipotential Surfaces.

Mr.p: Mr.p: Good morning. (Previously we learned about electric potential. But I know there are probably a lot of you who want to ask, …)

- BBB: But, … what is it?
- Billy: What is electric potential?

Mr.p: Well, (today I am going to do my best to answer that question.) ♪ Flipping Physics! ♪ {6.8 kg ball} Okay, let's take a step back and look at gravitational potential energy. … Let's set the horizontal zero line at the ground. … Now, when I hold a 6.8-kilogram ball at a height of 1.5 meters above the ground, above the zero line, … we can determine the gravitational potential energy of the Earth-ball system. … Billy, please do that.

$$PE_{g_1} = m_1 gh = (6.8)(9.81)(1.5) = 100.062 \approx 1.0 \times 10^2 J$$

Billy: {calc} Absolutely! … Gravitational potential energy in a constant gravitational field equals the mass of the object in the field times the gravitational field strength times the vertical height of the object relative to the zero-reference line. … So, it’s 6.8 times 9.81

times 1.5 or {calc} 100.062 or … 100, … actually 1.0 times ten to the 2nd joules with 2 sig figs!

$$\Rightarrow \frac{100.062J}{6.8kg} = 14.715 \approx 15\frac{J}{kg}$$

Mr.p: {6.8 and 2.7 kg balls} Thank you Billy. Now, … notice that, when we divide the 100.062 joules by the mass of the ball or 6.8 kilograms, we get 14.715, or roughly 15 joules per kilogram. {drop, switch} Now I am holding a 2.7-kilogram ball at a height of, again, 1.5 meters above the zero line. … Bo, please do what Billy and I just did, only for this ball.

$$PE_{g_2} = m_2gh = (2.7)(9.81)(1.5) = 39.7305 \approx 4.0 \times 10^1 J$$

$$\Rightarrow \frac{39.7305J}{2.7kg} = 14.715 \approx 15\frac{J}{kg}$$

Bo: Sure. … Uh, … we just use the same equations, only substituting in the mass of that second ball of 2.7 kilograms instead of 6.8 kilograms, … and we get … 39.7305 or 40 … or 4.0 times 10 to the 1st joules. … And if we divide that by the mass of the second ball or 2.7 kilograms, we get … well we get 14.715 or 15 joules per kilogram, just like you got with the first ball.

Mr.p: {2.7 kg and 0.145 kg balls} Correct Bo, thanks. {drop, switch} Now I am holding a 0.145-kilogram ball at a height of 1.5 meters above the zero line. … Bobby, please do what Bo just did.

$$PE_{g_3} = m_3 g h = (0.145)(9.81)(1.5) = 2.1337 \approx 2.1J$$

$$\Rightarrow \frac{2.1337J}{0.145kg} = 14.715 \approx 15\frac{J}{kg}$$

Bobby: {calc} Okay. … Uh, well, … again we just substitute in the new mass of 0.145 kilograms instead of the other masses and we get {calc} 2.1337 or roughly 2.1 joules with 2 sig figs. … And when we divide that by 0.145 kilograms, … I do not have to put that in my calculator, because I already know it will equal 14.715 or 15 joules per kilogram with 2 sig figs.

Mr.p: {0.146 kg ball} That is absolutely right, thank you Bobby. … We have just determined that, as long as the object is located 1.5 meters above a horizontal zero line here on the surface of planet Earth, the gravitational potential energy of the Earth-object system per kilogram is always the same, it is always 15 joules per kilogram. … In fact, But, what if there is nothing there? {drop ball} What if there is nothing in this spot, 1.5 meters above the horizontal zero line? Billy, could you please do that calculation?

- Billy: Certainly! … Substituting in a mass of zero, gives us zero gravitational potential energy. … And then divide, zero by … zero. … Uh?

- Bobby: Sure, but, given all the other mass values gave us 15 joules per kilogram…
- Billy: Sure. That makes sense. Is it still 15 joules per kilogram?

Mr.p: Yes, that is correct. … Even with no mass at that location, … we can still define the gravitational potential energy per unit mass … as the gravitational potential at that location, … and, in this case, this empty spot right here, … has a gravitational potential of 15 joules per kilogram. … To be clear, the ratio of the gravitational potential energy to the mass at a location, we call that gravitational potential.

- Bobby: Okay, so that spot, 1.5 meters above the zero line, … even when no object is located there, … has the gravitational potential … to have a gravitational potential energy of the Earth-object system.
- Billy: And in order to determine the gravitational potential energy of the Earth-object system, all we have to do is multiply the mass of the object by the gravitational potential … of 15 joules per kilogram.

Mr.p: Exactly. … And we started with gravitational potential energy and gravitational potential, … but now let's bring it back to electric potential energy and electric potential. … If we have two, 12 nanocoulomb point charges a distance of 2.0 meters apart, Bo, please calculate their electric potential energy.

$$q_1 = q_2 = 12nC\left(\frac{1C}{1\times10^9 nC}\right) = 1.2\times10^{-8}C$$

$$U_e = \frac{kq_1q_2}{r} = \frac{\left(9\times10^9\right)\left(1.2\times10^{-8}\right)\left(1.2\times10^{-8}\right)}{2}$$

$$= 6.48\times10^{-7} \approx 6.5\times10^{-7}J$$

$$\Rightarrow \frac{6.48\times10^{-7}J}{1.2\times10^{-8}C} = 54\frac{J}{C} = 54V$$

$$V = \frac{kq}{r} = \frac{\left(9 \times 10^{9}\right)\left(1.2 \times 10^{-8}\right)}{2} = 54V$$

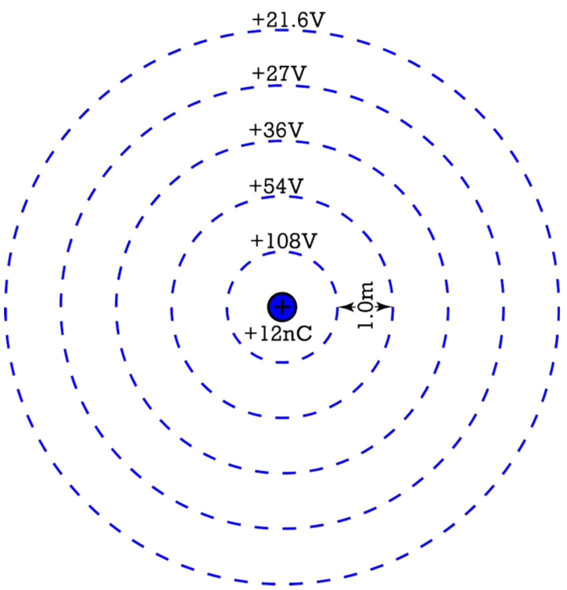
- Bo: Sure. … Because the Coulomb constant is in terms of coulombs, we need to convert the charges from nanocoulombs to coulombs. … There are 1 billion nanocoulombs in 1 coulomb, so multiply the charges by 1 coulomb over 1 times 10 to the 9th nanocoulombs to get … 1.2 times 10 to the negative 8 coulombs. … Electric potential energy equals the coulomb constant times charge 1 times charge 2 divided by the distance between centers of charge. …

Substitute in 9 times 10 to the 9th for the Coulomb constant, the charges I just figured out, and the distance of 2 meters. And we get … 6.48 times 10 to the negative 7 joules or 6.5 times 10 to the negative 7 joules with 2 sig figs.

- **Mr.p: (And, if we remove one of the two charges, please calculate the electric potential of a location 2.0 meters from the remaining charge.)**
- Bo: Uh, okay. … This is pretty much just like what we did to get gravitational potential, we can divide the electric potential energy by the

charge to get electric potential. … That is 6.48 times 10 to the negative 7 joules over 1.2 times 10 to the negative 8 coulombs equals … 54 joules per coulomb … or 54 volts, because a volt equals a joule per coulomb. … Oh, right, we could have just used the equation for the electric potential near a point charge which equals the coulomb constant times the charge of the point charge all divided by r, the distance from the center of the charge to the location of the electric potential. … Substituting in all the numbers we talked about gives us the same 54 volts for the electric potential at a distance of 2.0 meters from the point charge.

Mr.p: Exactly. And hopefully y'all recognize this calculation is valid for any location which is 2.0 meters from the point charge, … and that forms a concentric sphere with the charge that has an electric potential of 54 joules per coulomb or 54 volts. … And that, because r is in the denominator of the equation for electric potential, the magnitude of the electric potential increases as



you get closer to the point charge, … and the magnitude of the electric potential decreases as you get farther from the point charge.

- Billy: So, there is an imaginary sphere around the 12 nanocoulomb charge with an electric potential value of 54 joules per coulomb. … And, we can use that 54-volt electric potential value … to determine the electric potential energy of a two-charge system comprised of the 12 nanocoulomb charge … and any other second point charge … by just multiplying 54 joules per coulomb by the charge of the second point charge. That makes sense.

- Bobby: Just like there exists a spot 1.5 meters above a horizontal zero line near the surface of planet Earth … that has a gravitational potential of 15 joules per kilogram. … And we can use that 15 joules per kilogram gravitational potential value … to determine the gravitational potential energy of an Earth-object system consisting of the Earth … and any object … by just multiplying 15 joules per kilogram times the mass of the object.
- Bo: But, … actually, it's not just that single location which is 1.5 meters above the

horizontal zero line. … There is an entire two-dimensional plane which exists 1.5 meters above the horizontal zero line … or, I guess, horizontal zero plane, where the gravitational potential is 15 joules per kilogram, right?

Mr.p: {Bright, colored paper} Exactly. {paper parallel to screen} There exists a two-dimensional plane, which is oriented like this sheet of paper, {paper horizontal} parallel to the surface of the planet … that is 1.5 meters above a horizontal zero plane, which has a gravitational potential of 15 joules per kilogram.

Bo: So, the horizontal plane for the gravitational potential … and the concentric spherical surface for the electric potential … are surfaces where the potential is … uniform?

- o Mr.p: Exactly. … And that is what our next video is about.
- o **BBB: (Oh boy! Cool. Oh.)**
- o **Billy: (But, … wait a second.)**
- o **Mr.p: {Inquisitive look.}**

- Bo: What?
- Billy: That horizontal plane that is 1.5 meters above the horizontal zero plane at the surface of planet Earth … that has a uniform

gravitational potential of 15 joules per kilogram, … it is not actually a horizontal, two-dimensional plane, right?

- Bo: Uh, what do you mean?
- Billy: … At a local level we can treat it as a two-dimensional surface, … but the reality is that it extends all the way around planet Earth.
- Bo: Oh, I see what you are getting at here. … If we zoom out to look at it from a global perspective, … that two-dimensional plane of uniform gravitational potential is actually a spherical surface with a radius that is 1.5 meters larger than the radius of the Earth.

- Bobby: Yeah, so, … the Earth has concentric spherical surfaces of uniform gravitational potential just like a point charge has concentric spherical surfaces of uniform electric potential.
- Bo: Woah.
- Billy: Yeah.

$$U_g = -\frac{Gm_1m_2}{r} \Rightarrow \frac{-\frac{Gm_1m_2}{r}}{m_2} \Rightarrow \text{Gravitational Potential} = -\frac{Gm}{r}$$

Knowns: $R_E = 6.371 \times 10^6 m$; $M_E = 5.97 \times 10^{24} kg$

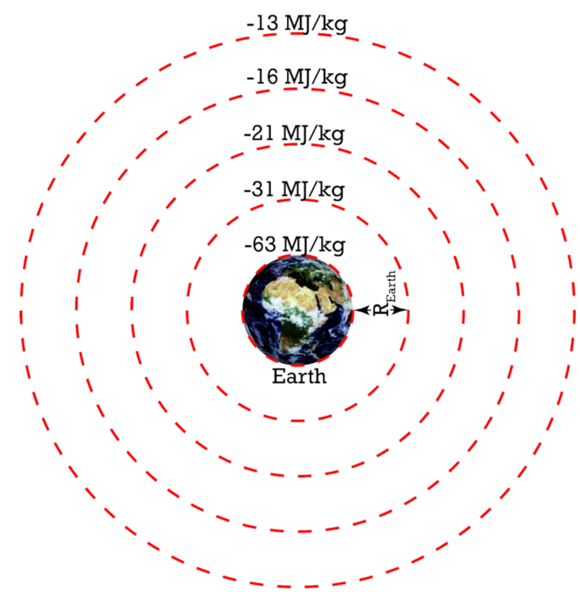
$$\text{Gravitational Potential}_{R_E} = -\frac{Gm}{R_E} = -\frac{\left(6.67 \times 10^{-11}\right)\left(5.97 \times 10^{24}\right)}{6.371 \times 10^6}$$

$$\Rightarrow \text{Gravitational Potential}_{R_E} = -62,501,805\frac{J}{kg}\left(\frac{1MJ}{1 \times 10^6 J}\right) \approx -63\frac{MJ}{kg}$$

$$\text{Gravitational Potential}_{3R_E} = -\frac{Gm}{2R_E} = -\frac{\left(6.67 \times 10^{-11}\right)\left(5.97 \times 10^{24}\right)}{(2)\left(6.371 \times 10^6\right)} \approx -31\frac{MJ}{kg}$$

$$\text{Gravitational Potential}_{3R_E} = -\frac{Gm}{3R_E} = -\frac{\left(6.67 \times 10^{-11}\right)\left(5.97 \times 10^{24}\right)}{(3)\left(6.371 \times 10^{6}\right)} \approx -21\frac{MJ}{kg}$$

Mr.p: Absolutely. But realize this requires that we switch from using the equation … gravitational potential energy equals mass times gravitational field strength times vertical height above the horizontal zero line … to the equation for universal gravitational potential energy. … That first equation requires a constant gravitational field, which is true near the surface of the planet, however, the gravitational field which surrounds the planet is not constant far from the surface of the planet. … That equation is … universal gravitational potential energy equals the negative of the universal gravitational constant, or Big G, {look at Billy} times mass 1 times mass 2 all over the distance between centers of mass of the two charges. … Realize, this equation does not use the same horizontal zero line we had before we did the calculations with the masses 1.5 meters above the horizontal zero line. … The universal gravitational potential energy equation has a predefined zero location which is infinitely far from the Earth. … And when we divide that equation by one of the two masses, … we can show that gravitational potential equals the negative of Big G times the mass of the object divided by the distance from the center of the mass of the object to the location of the gravitational potential. … Hopefully you can see that the equation for gravitational potential has the same shape as the equation for electric potential. … And we can calculate the gravitational potential at intervals of the radius of the Earth above the surface of the Earth. I'm not going to walk through all of those calculations, but you can see them on



the screen. … Again, please recognize that the Earth has concentric spherical surfaces of uniform gravitational potential around it, … just like a point charge has concentric spherical surfaces of uniform electric potential around it.

. … Thank you very much for learning with me today, I enjoy learning with you. {fade}