

## AN ENERGETIC STORY!

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So, I'm sure you're probably bored and wondering why do we need to know this stuff. Well, this is the stuff that everything in science and engineering is based on. Without understanding these basics, there's no way to understand the more advanced concepts.

Now that we understand a little about a force, and about units and why they are important, we can now ask the question, where does the force come from? That probably seems like a pretty silly question. Well, its obvious that when you apply a force on the rock by pushing the rock with your hand, the force comes from your hand. If you blow on the rock, the force comes from the air that you blow on it. When gravity acts to create a force on the rock, then the force came from gravity. But let's think a little deeper. Why does your hand have force? Why does the air have force? Why does gravity have force? Where does the force come from? Does it simply exist because it exists?

Believe it or not, that's what most people believed during the time of Newton. In fact, its quite likely that Newton believed that himself. There were a large number of bizarre theories at the time that tried to explain where the force comes from. For instance, some scientists thought there were invisible vortices that cause force, some thought that is was something called "the ether", and others thought it was something called energy. In fact, the theory that has survived, and that seems most correct, is the energy theory. The earliest explanations of this theory were vague, and stated that energy existed within all moving things, and that the energy was used up when the moving thing became stationary. However, we have come a very long way from those early theories, and we now know that energy is never created nor destroyed, but that energy just changes form. We'll explain that in a bit, but let's first figure out the simplest explanation of energy.

Remember that rock in space? Well, when it was sitting still, it must have no energy, but when we pushed it, it must have some energy right? Thus, the energy in the rock must be related to the velocity of the rock, right? Well, since the velocity essentially came from the force that we applied to the rock, the energy must also be related to the force, right? So, let's try to imagine how the energy ( $E$ ) can be related to ( $\sim$ ) both the velocity ( $v$ ) and the force ( $F$ ).

$$E \sim v$$

$$E \sim F$$

Since the energy is related to the velocity, and the energy is also related to the force, we can simply try to relate the velocity to the force. When relating things, the goal is to turn the relation ( $\sim$ ) into an equals ( $=$ ). The best way to do this is to consider the units of the

things that are being related. So, we must relate the velocity to the force, but we must also relate the unit of velocity to the unit of force.

$$v \sim F$$

$$\frac{\text{m}}{\text{s}} \neq \frac{\text{kg}\cdot\text{m}}{\text{s}^2}$$

So how do we manipulate each side to make them equal? Well, there are many ways, but what we are looking for is the simplest way of manipulating them. This is often referred to as Occam's razor, which states that the answer that is simplest, and has the fewest assumptions, is most correct. So, it looks like the left-hand-side needs a kilogram on top and a second on the bottom. Well, if we multiply the velocity by the mass, then we could get a kilogram on the left, and if we also multiply it by velocity again, we will get an extra meter on the top, and the second on the bottom that we need. So, it would look like this:

$$mvv \sim F$$

$$\frac{\text{kg}\cdot\text{m}^2}{\text{s}^2} \neq \frac{\text{kg}\cdot\text{m}}{\text{s}^2}$$

Looks somewhat confusing, but we know that anything multiplied by it's self, is just that thing raised to the second power. So the left-hand-side is just the mass multiplied by the velocity squared. However, the units are still not the same. It seems that the right hand side needs a meter on the top. Well, we can actually consider how we apply the force. Let's say that we push the rock to apply the force, and let's consider the case where we push it very, very softly. Thus, we are applying a very small force on the rock. In this case, we are able to push the rock for some time and over some distance as it accelerates away from us. Well, if we take the force that we apply, and multiply it by the distance ( $d$ ) that we apply it over, then we would get that extra meter on the top that we need.

$$mv^2 \sim Fd$$

$$\frac{\text{kg}\cdot\text{m}^2}{\text{s}^2} \neq \frac{\text{kg}\cdot\text{m}^2}{\text{s}^2}$$

And whammo!...we have found that the units of the left and right sides are the same. And in fact, this is the simplest way to relate the velocity of an object, to the force that was applied to that object to set it in motion. Thus, by the principle of Occam's razor, we have found the correct way to relate the velocity to the force. Notice that the unit of energy is also equal to a Newton-meter (N.m). For convenience, we name this unit after

a famous scientist names James Joule, and is therefore called a Joule, and abbreviated with a “J”. Thus:

$$\frac{\text{kg}\cdot\text{m}^2}{\text{s}^2} = \text{N}\cdot\text{m} = \text{J}$$

Since we started this discussion out with relating energy to both the velocity and the force, let’s return there. We can now explain how the energy is related to the velocity of an object in motion, and also how the energy is related to the force applied to an object over some distance.

$$E = \frac{1}{2}mv^2$$

$$E = Fd$$

There is one slight change that I made here, and that is the factor of one-half in front of the velocity term. This term has no unit of measure, and is a used for reasons that we can’t explain without using calculus. When you learn calculus, then you will understand why all the scientists put that one-half in front. For now, just know that it has no unit of measure, and that it is simply a convention used to make other things look nice when we use calculus.

So, that’s it...sort of. That basically describes two equations for energy. The first one describes the energy contained in the rock as it moves away from us at a constant velocity. The second one describes how much energy we put into it when we push the rock. For this case, these two energies are the same. Whatever energy you put in the rock, will be contained in the rock as it moves away from you. However, this is not always the case. For this reason, we give these two types of energy different names. The first is the energy of motion, or the “Kinetic Energy”. The word kinetic basically refers to anything in motion, or anything with non-zero velocity. The second equation is the equation for the energy due to work, or the “Work Energy”. Think of all those times you’ve had to push something along the floor (a couch or a bed), well the work energy that you expended is the amount of force you pushed with multiplied by the distance you pushed it.

So, why aren’t they always the same? Well, that’s a very good question. The best way to answer is probably to say that there are many different types of energy in this world. The form of energy that is easiest to see is the kinetic energy. However, all the other forms are difficult to visualize. For instance, it is difficult to visualize the work energy because after you have expended the work, there is often nothing to show for it. Let’s say you pushed a couch around the room, and then put it back in the same place. Did you do any work energy? Yes. Do you have anything to show for it? No. Everything looks the same. In fact, did you do any work energy? No. Believe it or not, since the couch

ended up in the same place it started, the distance that you moved it is exactly zero. Thus, the work energy that you did was exactly zero as well.

So, what did you do? You obviously did something because your muscles hurt right? Well, you did expend some energy, but you didn't expend any work energy. Instead, you expended what we call chemical energy. This is another type of energy, and it's the energy your body uses to generate the kinetic energy of your arms and legs moving. See, food has a lot of chemical energy in it. Different types of food have different amounts of chemical energy in it, and your body can access the energy of different foods in different ways. When you eat something with a lot of sugar (like a candy bar) you get a lot of chemical energy, and your body uses it very quickly. When you eat celery, you don't get very much chemical energy, and your body uses it very slowly. That's why you feel so energetic when you eat a candy bar, and that's why we call it a "sugar high".

So, when you push a couch around a room and end up in the same place, you have spent no work energy. However, you have spent a great deal of chemical energy, and you might have spent so much chemical energy that you're hungry for more! Think about when you push against a wall. Have you done any work energy? No, because the wall doesn't move. But have you spent some chemical energy? Yes, because your muscles are working and using up the chemical energy that you have eaten. To better understand where chemical energy comes from, you should take a course on chemistry and chemical engineering. To learn more about how our bodies convert chemical energy into kinetic energy, take courses on biology and biological engineering.

There are many other types of energy out there, and they are all sort of "invisible" like chemical energy. It's hard to see how much energy is in a candy bar, huh? It's also hard to see how much work energy you have done. One other type of energy is called gravitational energy (however it is often called gravitational potential energy, and sometimes even called just potential energy). This is energy that is caused by two objects that are separated, and gravity is trying to pull them back together. When an object is sitting on a high shelf, then it has gravitational potential energy. Gravity is trying to pull the object back down to the earth, but the shelf is holding it up. If someone pushes the object so that it falls off the shelf, then the gravitational force will convert the gravitational potential energy into kinetic energy as the object falls to the floor. This is why it is called potential energy, because the object has the potential to have a lot of kinetic energy simply by pushing it off the shelf.

Another type of energy is electro-magnetic energy. You've probably heard of this and understand the basics. The easiest way to visualize this is similar to the gravitational potential energy. Magnets attract certain types of metals that we call ferrous metals. When a magnet comes close enough to a piece of ferrous metal, it will cause the metal to move. When the ferrous metal moves, it has some kinetic energy. Where did this energy come from? Well, it came from the magnetic potential energy. It's really quite similar to the gravitational potential energy, where if an object is pushed into a certain location (eg. off the shelf) then its gravitational potential energy is converted to kinetic

energy through the application of the gravitational force. Same thing here, if the ferrous metal is pushed into a certain location (eg. close to the magnet) then its magnetic potential energy is converted to kinetic energy through the application of the magnetic force.

So, why call it electro-magnetic energy, why not just call it magnetic energy? Well, because scientists discovered that very small particles called electrons can also cause magnetic fields. When an electron moves, it somehow creates a magnetic field. This magnetic field can then cause ferrous metals to move just like a regular magnet does.

There is another type of energy associated with electrons that is quite possibly the most obvious form of energy in modern society. That form of energy is electrical energy. Electrical energy is also related to the motion of electrons, but is not related to the magnetic field generated by the motion of these electrons. Instead, it is related to the motion of the electrons themselves. See, when regular objects move, they have kinetic energy, and we measure it with the mass and velocity of the object. Well, when electrons move, not only do they have some kinetic energy and generate a magnetic field that has electro-magnetic energy, but they also have electrical energy. This is a special form of energy that is still not fully understood, but seems to be capable of very impressive feats. Electrical energy can turn the dark into light, and can cause cold things to become very hot. It can travel across huge distances in a very short time, and it can even travel through the air (eg. lightning). To learn more about electro-magnetic and electrical energy, take courses in physics and electrical engineering. Eventually, you'll be studying about the smallest particles that exist (and questioning what it means to "exist").

The final type of energy that we must discuss (and I alluded to it at the end of the last paragraph) is heat energy. This type of energy is exactly what you think it is. It's the energy contained in something that is warm. However, everything can be called warm compared to something else, right? For instance, the sun is warmer than an oven, which is warmer than toaster, which is warmer than a hot chocolate, which is warmer than tap water, which is warmer than an ice cube, which is warmer than the north pole, which is warmer than liquid nitrogen, which is warmer than the coldest thing ever create - a Bose-Einstein Condensed Super Fluid. Thus, everything has some heat energy depending on what we're comparing it to, right? The heat energy is related to temperature, but its not the same thing. We don't really have time to go into the details of that right now, but just remember that temperature isn't the same thing as heat energy. Two things can be the same temperature, but one can have more heat energy if it has a higher heat capacity.

One important thing to discuss about heat energy is a common source of heat energy...the friction force. Everyone knows what friction is right? Put your hands together and move them back and forth. Pretty easy right? Now, push your hands together really hard, and now move them back and forth. Pretty hard right? This is friction, and its caused by a friction force. Now, if you push you hands together really hard, and move your hands back and forth really fast, you're hands will warm up, and

the temperature will increase. This is because the friction force is causing much of the chemical energy that you are expending to be converted into heat energy. The heat energy is absorbed in your hands and increases the temperature of your hands. This is a very important type of energy to consider, because usually you want to minimize this type of energy. For instance, if I want to move a couch from point A to point B, would I want to push the couch over sandpaper, or over ice? Well, I'm trying to do a certain amount of work energy (applying a force over a distance). If that's all the energy I have to produce, then I would simply have to burn that much chemical energy. However, when I push the couch over the sandpaper, there will be a lot more friction (and hence a lot of heat energy produced) than if I push it over ice. Since that energy must have come from somewhere, and since the chemical energy is the only source of energy, it would have to come from my chemical energy. I would have to spend more energy to push the couch over sandpaper than I would if I pushed it over ice.

So, we've discussed 7 types of energy: kinetic, work, gravitational, chemical, electromagnetic, electrical, and heat. We also understand that energy is neither created nor destroyed, but that it is just converted from one form to another. When we push on a rock, we are converting chemical energy into kinetic energy. We also know the units of energy, and why we measure energy in that way.

So, what's the end story about all this energy stuff? Honestly, it's hard to say. The last chapter has not been written on the energy story. There will be new theories and new discoveries about energy for years to come. What we know now is small compared to what we are capable of knowing. However, we can use what we know to help us in designing a better world for ourselves to live in, and I think that is the proper goal of any scientist or engineering.