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We’ve now introduced three values that all have the same unit – kinetic energy, potential energy, and work. Since they have the same unit of measurement, we should be able to use them all together. We know there’s some correlation between these three values, but we don’t know how to use them to describe how an object changes after an action has been completed. This is where the law of conservation of energy comes in. In the following blog post, we’ll explain the law of conservation of energy, the formula that governs it, and common conservation of energy examples. Interested in an Albert school license? The Law of Conservation of Energy states that the energy in a system before an action plus the work done to complete the action will be equal to the energy in the system after the action. This doesn’t always play out perfectly in real life as some energy can be lost to the creation of noise and heat. For the time being, this law will play out perfectly in the problems you’re given in your physics courses. The catchier definition of this law you may have heard before is that energy cannot be created or destroyed. While that is true, it’s missing something. Energy can be transferred from one object to another. This is what allows one pool ball to set another into motion. It effectively tells us that an object or system needs energy from somewhere else in order to change or complete an action. This is also why a perpetual motion machine could never truly exist. The conservation of energy formula can be written as: Conservation of Energy Formula\sum E_{K1}+\sum E_{P1}+\sum W=\sum E_{K2}+\sum E_{P2} Recall that E_{K} represents kinetic energy, E_{P} represents potential energy, and W represents work. The reason we’ve added numbers to the subscripts is to show that the left side of the equation represents values from before an action was taken while the right side was after the action was taken. So, before and after something falls or before and after two things collide or something like that. The \sum might be new, though. \sum is a Greek letter sigma and is used to represent a sum. In this case, it would be the sum of all of the kinetic energies, potential energies, and work going into the system. For example, if you had two moving objects, you would have two kinetic energies to account for. Similarly, if an object has gravitational potential energy and elastic potential energy you would have two potential energies to account for. Explore Work and Energy on Albert We discussed kinetic energy, potential energy, and work in depth previously, but let’s check our understanding before we jump into some conservation of energy examples. First, kinetic energy is energy that comes from motion. It is determined by an object’s mass and velocity and is given by the equation E_{K}=\frac{1}{2}mv^{2}. So far, we’ve covered two types of potential energy – gravitational potential energy and elastic potential energy. Gravitational potential energy is determined by an object’s mass, gravitational field strength, and height above ground. It is given by the equation E_{P}=mgh. Elastic potential energy is determined by the spring constant of the elastic object and the distance it has been stretched or compressed. It is given by the equation E_{P}=\frac{1}{2}kx^{2}. Lastly, work is a measure of the effort needed from an external force to cause an action to occur and it is commonly found with the equation W=Fd\cos\theta. It’s also important to keep in mind that the work put into a system is equal to the change in energy of that system. This is what allows for the law of conservation of energy equation to work. Interested in an Albert school license? Let’s consider a fairly simple experiment that can be used to test the law of conservation of energy. You only need a scale, a stopwatch, and a few things you can drop. The idea of this experiment is simply to take the mass of a few different objects with notably different masses. You could use a pen, a notebook, and an empty water bottle – anything that will fall without gathering too much air resistance. We’ll be using some sample data below, but feel free to recreate this experiment to find your own data or try a simulation. Firstly, you’ll want to take the mass of each object and calculate the potential energy. ObjectMassGravitational Field StrengthHeightE_{P}=mghE_{P}Object 10.5\text{ kg}9.81\text{ m/s}^{2}3\text{ m}E_{P}=0.5\text{ kg}\cdot 9.81\text{ m/s}^{2}\cdot 3\text{ m}14.715\text{ J}Object 22\text{ kg}9.81\text{ m/s}^{2}3\text{ m}E_{P}=2\text{ kg}\cdot 9.81\text{ m/s}^{2}\cdot 3\text{ m}58.86\text{ J}Object 35\text{ kg}9.81\text{ m/s}^{2}3\text{ m}E_{P}=5\text{ kg}\cdot 9.81\text{ m/s}^{2}\cdot 3\text{ m}147.15\text{ J} Secondly, drop each object from the height you used above and time how long it takes each item to drop. Then, we’ll use this to figure out the average velocity of each object as it falls. You’ll want to drop each item a few times to make sure you have a good average to decrease any potential errors in the data. ObjectTimev=gtAverageObject 1: Trial 10.80\text{ s}v=9.81\text{ m/s}^2\cdot 0.80\text{ s}=7.84\text{ m/s}7.81\text{ m/s}Object 1: Trial 20.77\text{ s}v=9.81\text{ m/s}^2\cdot 0.77\text{ s}=7.55\text{ m/s}Object 1: Trial 30.82\text{ s}v=9.81\text{ m/s}^2\cdot 0.82\text{ s}=8.04\text{ m/s}Object 2: Trial 10.79\text{ s}v=9.81\text{ m/s}^2\cdot 0.79\text{ s}=7.75\text{ m/s}7.78\text{ m/s}Object 2: Trial 20.81\text{ s}v=9.81\text{ m/s}^2\cdot 0.81\text{ s}=7.95\text{ m/s}Object 2: Trial 30.78\text{ s}v=9.81\text{ m/s}^2\cdot 0.78\text{ s}=7.65\text{ m/s}Object 3: Trial 10.76\text{ s}v=9.81\text{ m/s}^2\cdot 0.76\text{ s}=7.46\text{ m/s}7.88\text{ m/s}Object 3: Trial 20.80\text{ s}v=9.81\text{ m/s}^2\cdot 0.80\text{ s}=7.84\text{ m/s}Object 3: Trial 30.84\text{ s}v=9.81\text{ m/s}^2\cdot 0.85\text{ s}=8.34\text{ m/s} Explore Conservation of Energy on Albert Thirdly, we’ll use our known mass and our calculated average velocities to find the final kinetic energy for each object. ObjectMassVelocityE_{K}=\frac{1}{2}mv^{2}E_{K}Object 10.5\text{ kg}7.81\text{ m/s}E_{K}=\frac{1}{2}\cdot 0.5\text{ kg} \cdot (7.81\text{ m/s})^{2}15.2\text{ J}Object 22\text{ kg}7.78\text{ m/s}E_{K}=\frac{1}{2}\cdot 2\text{ kg} \cdot (7.78\text{ m/s})^{2}60.5\text{ J}Object 35\text{ kg}7.88text{ m/s}E_{K}=\frac{1}{2}\cdot 5\text{ kg} \cdot (7.88\text{ m/s})^{2}155.2\text{ J} Once we’ve collected the above data, we can apply the law of the conservation of energy by comparing the potential and kinetic energy values that we calculated. It is important to realize that we can make this comparison directly from our conservation of energy formula. If we follow our standard problem-solving steps a bit, you’ll soon see why it works. E_{K1}=0\text{ J} E_{P1}=\text{known} W=0\text{ J} E_{K2}=\text{known} E_{P2}=0\text{ J} \sum E_{K1}+\sum E_{P1}+\sum W=\sum E_{K2}+\sum E_{P2} 0\text{J}+E_{P1}+0\text{J}=E_{K2}+0\text{J} E_{P1}=E_{K2} So, we can see that the potential energy we calculated for each object should be equal to the kinetic energy we calculated. Keep in mind that there was some error in our measured times and calculations. Let’s check the law of conservation of energy. ObjectE_{P1}E_{K2}Percent ErrorObject 114.715\text{ J}15.2\text{ J}3.3\% Object 258.86\text{ J}60.5\text{ J}2.9\% Object 3147.15\text{ J}155.2\text{ J}5.5\% As you can see, we have some error. Specifically, our kinetic energy values aren’t a perfect match to our potential energy values. Given our percent error values are around 3% to 5%, we can therefore assume they were created by inaccurate measurements, rounding errors through the problem, or other human factors. So, we have successfully conducted a lab that proves the Law of the Conservation of Energy. Interested in an Albert school license? Let’s take another example and look at how the conservation of energy applies to roller coasters. In this case, we’ll assume a roller coaster car filled with people has a mass of 700\text{ kg}. On this particular coaster, the car is brought up to its first hill, which is 75\text{ m} tall. Assuming the vehicle is at rest at the top of the hill and no work is done on the car as it falls, what will be its velocity at the bottom of the hill? Solution h_{1}=75\text{ m} g=9.81\text{ m/s}^{2} v_{1}=0\text{ m/s} h_{2}=0\text{ m} v_{2}=\text{?} At first, you may be feeling a little lost on how to solve this one. You probably know you need the formula for the conservation of energy given the context of this article. As for how to use it, we’ll need to break it down by substituting equations for our values. \sum E_{K1}+\sum E_{P1}+\sum W=\sum E_{K2}+\sum E_{P2} \frac{1}{2}mv_{1}^{2}+mgh_{1}+\frac{1}{2}kx_{1}^{2}+W=\frac{1}{2}mv_{2}^{2}+mgh_{2}+\frac{1}{2}kx_{2}^{2} That probably looks quite long and overwhelming because, well, it is. We can simplify it immediately, though. We were told to assume no work was done and no elastic potential energy was ever mentioned, so we can take out both of those values. \frac{1}{2}mv_{1}^{2}+mgh_{1}=\frac{1}{2}mv_{2}^{2}+mgh_{2} You can see that this looks a bit better and a bit more manageable. Now, we have a variable matching all of our knowns from our problem statement and the only variable we don’t know is the one we were told to find. You could jump in and rearrange to solve for the final velocity now, or you can simplify a little more. We have a couple of known values of zero, so let’s plug just those in and see what goes away as a result. \frac{1}{2}m(0\text{ m/s})^{2}+mgh_{1}=\frac{1}{2}mv_{2}^{2}+mg(0\text{ m}) mgh_{1}=\frac{1}{2}mv_{2}^{2} This is now as simple as we can get. Let’s finish following our usual problem-solving steps to find the answer to this question. mgh_{1}=\frac{1}{2}mv_{2}^{2} mv_{2}^{2}=2mgh_{1} v_{2}^{2}=\frac{2mgh_{1}}{m} v_{2}=\sqrt{2gh_{1}} v_{2}=\sqrt{2\cdot 9.81\text{ m/s}^{2}\cdot 75\text{ m}} v_{2}=38.36\text{ m/s} Explore Conservation of Energy on Albert The Law of Conservation of Energy is an important one in Physics. It gives engineers the knowledge they need to create things like roller coasters and rocket ships. It also allows us to combine seemingly unrelated ideas like the height of an object and the stretch of spring. Working with this equation can seem overwhelming at first, but it gets easier over time. The more problems you apply it to, the more patterns you’ll see in it, and before no time it will be more helpful than stressful. The law of conservation of energy states that energy is neither created nor destroyed, although it can change forms.Emilie Chatelet proposed and tested the law of conservation of energy.The law of conservation of energy is a physical law that states that the total energy of an isolated system is a constant, although energy can change forms. In other words, energy is conserved over time. The law of conservation of energy is the first law of thermodynamics. French mathematician and philosopher Émilie du Châtelet first proposed and tested the law in the 18th century.There are a few different ways of writing the formula for the law of conservation of energy. One of the most common formulas describes the relationship between kinetic energy (K) and potential energy (U):K1 + U1 = K2 + U2In this case, the total energy of the system is a constant, but energy converts between potential and kinetic energy.For calculations involving frictionless carts, swings, pendulums, throwing a ball, etc., there is another useful form of the equation for the conservation of energy, which uses the following formulas for potential and kinetic energy:U = mgh ; where U is potential energy, m is mass, g is acceleration due to gravity, and h is heightK = ½mv2 ; where m is mass and v is velocityTotal energy is the sum of potential and kinetic energy:Etotal = mgh + ½mv2This formula works well for physics problems where there is no friction. More complex equation cover the situation where some energy gets converted into heat via friction.Another form of the laws of conservation of energy states that the internal energy (ΔE) of a system is the sum of the heat flow (Q) across its boundaries (q) and the work done on the system (W).ΔE = Q + WThere are many examples of the law of conservation of energy in everyday life:The energy of a child on a swing changes between potential and kinetic energy. At the top of the swing, all of the energy is potential. At the bottom of the swing, it’s all kinetic. The energy is a mixture of kinetic and potential energy between these two points. In a frictionless system, the potential energy at the top equals the kinetic energy at the bottom, which equals the sum of the kinetic and potential energy at the other points.A swinging pendulum also illustrates a conversion between kinetic and potential energy, exactly like a swing. Of course, in both the swing and pendulum examples, friction plays a role. The conserved energy really is a mixture of kinetic energy, potential energy, and thermal energy or heat.A car converts chemical energy (gasoline) into kinetic energy. Here again, so energy is lost as heat, but the sum of the forms of energy remains constant.As an apple falls from a tree, it starts out with potential energy. As it falls, it has a mixture of kinetic and potential energy. In the instant it strikes the ground, all of its energy is kinetic. The sum of its potential and kinetic energy is a constant value.A flashlight converts chemical energy from its battery into electrical energy, which is then converted into light and heat.A speaker converts electrical energy into sound, which is another form of energy.Generators convert mechanical energy into electrical energy.Your body converts chemical energy from food into mechanical energy (moving muscles), different chemical energy molecules, and heat.An exploding firework converts chemical potential energy into kinetic energy, light, heat, and sound.In classical mechanics, the law of conservation of energy and the law of conservation of mass are two separate laws. However, they combine in relativity in Einstein’s famous equation:E = mc2This equation shows mass can convert into energy, and vice versa. The law of conservation of energy still holds true, as long as the reference from of the observer remains unchanged.One consequence of the law of conservation of energy is that is means perpetual motion machines of the first kind are impossible. These are machines that do work forever without any additional energy input. While perpetual motion that does work might look good on paper, it doesn’t work in the real world because some energy in a machine changes form into heat. Usually, this is from friction. So, to keep a machine running actually requires a continuous input of energy.Remember, the law of conservation of energy applies to a closed system. Sometimes it isn’t easy or even possible to define or isolate a system. This comes into play in general relativity, where systems don’t always have time translation symmetry. For example, conservation of energy isn’t necessarily defined for curved spacetime or time crystals.Feynman, Richard (1970). The Feynman Lectures on Physics Vol I. Addison Wesley. ISBN 978-0-201-02115-8.Gibney, Elizabeth (2017). “The quest to crystallize time”. Nature. 543 (7644): 164–166. doi:10.1038/543164aHagengruber, Ruth (ed.) (2011). Émilie du Chatelet: Between Leibniz and Newton. Springer. ISBN 978-94-007-2074-9.Kroemer, Herbert; Kittel, Charles (1980). Thermal Physics (2nd ed.). W. H. Freeman Company. ISBN 978-0-7167-1088-2.Serway, Raymond A.; Jewett, John W. (2004). Physics for Scientists and Engineers (6th ed.). Brooks/Cole. ISBN 978-0-534-40842-8.Related Posts by Chris Woodford. Last updated: November 28, 2022. Gobble down five bananas and you'll have enough energy to swim for about an hour. [1] That's because your body is a complex machine capable of turning one kind of energy (food) into another kind (movement). Cars can pull off the same trick. Depending on which make and model you own, you probably know that it does so many kilometers or miles to the gallon; in other words, using a certain amount of energy-rich gasoline, it can transport you (and a moderate load) a certain distance down the road. What we have here are two examples of machines—the human body and the automobile—that obey one of the most important laws of physics: the conservation of energy. Written in its simplest form, it says that you can't create or destroy energy, but you can convert it from one form into another. Pretty much everything that has ever happened in the universe obeys this fundamental law. But why, and what use is it anyway? Let's take a closer look! Photo: The conservation of energy: James Prescott Joule calculated that the water at the bottom of Niagara falls would be about a fifth of a degree warmer than the water at the top. Why? The water loses potential energy as it falls, which is converted into heat. [2] Photo courtesy of the Carol M. Highsmith Archive, Library of Congress, Prints and Photographs Division. Contents The first thing we need to note is that the law of conservation of energy is completely different from energy conservation. Energy conservation means saving energy through such things as insulating your home or using public transportation; generally it saves you money and helps the planet. The conservation of energy has nothing to do with saving energy: it's all about where energy comes from and where it goes. Write the law formally and it sounds like this: In a closed system, the amount of energy is fixed. You can't create any more energy inside the system or destroy any of the energy that's already in there. But you can convert the energy you have from one form to another (and sometimes back again). A "closed system" is a bit like a sealed box around whatever we're studying: no energy can leak into the box from the inside (or be introduced to the box from outside). There are some even simpler, more familiar ways of stating the conservation of energy. "No pain, no gain" is a rough everyday equivalent: if you want something, you have to work for it. "There's no such thing as a free lunch" and "You don't get anything for free" are other examples. Artwork: A closed system? This house is an example of a closed system: the energy that's inside the red dotted line stays as it is or gets converted into other forms. We can't create any new energy inside the house out of nothing at all, and we can't make energy inside the house vanish without trace, though we can turn it into other forms. So what if one room of the house suddenly starts getting hotter? The heat energy making that happen must be coming from energy that's already inside the house in a different form (maybe it's wood in a fire that's being burned to release the chemical energy locked inside it). If that's not the case, we don't have a closed system: the "extra" heat must be coming into the house from outside (maybe strong sunlight streaming in through the window). The conservation of energy (and the idea of a "closed system") sounds a bit abstract, but it becomes an awful lot clearer when we consider some real-life examples. Walking upstairs Walk upstairs and you have more potential energy when you get to the top than you had at the bottom—but you haven't created energy out of thin air. The muscles in your body have to work against the force of gravity to move you upwards and your body loses energy (that it made from food) as it climbs. This is the energy that your body regains as potential energy. Driving a car Fill a car up with gasoline and you have a closed system. All the energy you have at your disposal is locked inside the gas in your tank in chemical form. When the gas flows into your engine, it burns with oxygen in the air. The chemical energy in the gas is converted first into heat energy: the burning fuel makes hot expanding gas, which pushes the pistons in the engine cylinders. In this way, the heat is converted into mechanical energy. The pistons turn the crankshaft, gears, and driveshaft and—eventually—the car's wheels. As the wheels turn, they speed the vehicle along the road, giving it kinetic energy (energy of movement). If a car were 100 percent efficient, all the chemical energy originally locked inside the gasoline would be converted into kinetic energy. Unfortunately, energy is wasted at each stage of this process. Some is lost to friction when metal parts rub and wear against one another and heat up; some energy is lost as sound (cars can be quite noisy—and sound is energy that has to come from somewhere) Not all the energy the car produces moves you down the road: quite a lot has to push against the air (so it's lost to air resistance or drag), while some will be used to power things like the headlights, air conditioning, and so on. Nevertheless, if you measure the energy you start with (in the gasoline) and calculate how much energy you finish with and lose on the way (everything from useful kinetic energy and useless energy lost to friction, sound, air resistance, and so on), you'll find the energy account always balances: the energy you start with is the energy you finish with. Like everything else, cars must obey the law of conservation of energy. They convert the energy in fuel into mechanical energy that moves you down the road, but waste quite a lot of energy in the process. If you put 100 units of energy into a car (in the form of fuel), only 15 units or so move you down the road. The rest is wasted as heat losses in the engine (74 percent); parasitic losses (6%, making electricity, for example, to light the headlamps); and drivetrain losses (5%, sending power to the wheels). The 15 useful units of energy are used to overcome drag (air resistance), friction (in the brakes), and rolling resistance (in the tires). Every bit of energy we put into a car has to go somewhere, so the energy outputs (74% + 6% + 5% + 15%) must always exactly add up to the original energy input (100%). Artwork: Figures for city driving from Where the energy goes, fueleconomy.gov. Now this only applies if your car is a "closed system." If you're driving along the straight and the road suddenly starts going downhill, you're going to be able to go much further than you'd be able to go otherwise. Does this violate the conservation of energy? No, because we're no longer dealing with a closed system. Your car is gaining kinetic energy from the gasoline in its tank, but it's also gaining kinetic energy because it's going downhill. This isn't a closed system so the conservation of energy doesn't apply anymore. Boiling a kettle Photo: An electric kettle like this converts electrical energy into heat energy. That's the reverse of the process that happens in the power plant that supplies your home, where electricity is produced using heat energy released by burning a fuel such as coal, oil, or gas. Boil water with an electric kettle and you're seeing the conservation of energy at work again. Electrical energy drawn from the power outlet on your wall flows into the heating element in the base of your kettle. As the current flows through the element, the element rapidly heats up, so the electrical energy is converted into heat energy that gets passed to the cold water surrounding it. After a couple of minutes, the water boils and (if the power stays on) starts to turn to steam. How does the conservation of energy apply here? Most of the electrical energy that enters the kettle is converted into heat energy in the water, though some is used to provide latent heat of evaporation (the heat we need to give to liquids to turn them into gases such as steam). If you add up the total electrical energy "lost" by the electricity supply and the total energy gained by the water, you should find they're almost exactly the same. Why aren't they exactly equal? Simply because we don't have a closed system here. Some of the original energy is converted to sound and wasted (kettles can be quite noisy). Kettles also give off some heat to their surroundings—so that's also wasted energy. Pushing a car uphill In the everyday world, "work" is something you do to earn money; in physics, work has a different meaning. When you do a useful job with a force (a push or a pull), such as moving a car uphill, we say you're doing work, and that takes energy. If you push a car uphill, it has more potential energy at the top of the hill than it had at the bottom. Have you violated the conservation of energy by creating potential energy out of thin air? No! To push the car, you have to do work against the force of gravity. Your body has to use energy to do work. Most of the energy your body uses is gained by the car as you push it uphill. The energy your body loses is pretty much equal to the work it does against gravity. And the energy the car gains is the same as the work done. So no energy is created or destroyed here: you're simply converting energy stored as fuel inside your body into potential energy stored by the car (because of its height). Artwork: When you push a car uphill, the potential energy it gains comes from the energy your body loses in the process. Who discovered the conservation of energy? “... the quantity of heat produced by the friction of bodies, whether solid or liquid, is always proportional to the quantity of force expended.” James Prescott Joule, The Mechanical Equivalent of Heat, 1845. How do we know the conservation of energy is true? First, it sounds sensible. If you put a heavy log on a fire it might burn for an hour. If you put a second log, roughly the same size, on the fire, it's reasonable to suppose you'll get twice as much heat or the fire will burn twice as long. By the same token, if five bananas can supply your body with an hour's energy, ten bananas should keep you running for two hours—although you might not enjoy guzzling them all at once! In other words, the energy in (the logs you add to the fire or the bananas you eat) is equal to the energy out (the heat you get by burning logs or the energy you make by eating bananas). Reasonable guesswork doesn't quite cut the mustard in science. Really, we need to be sure that the energy we start with in a closed system is the same as the energy we end up with. So how do we know this? One of the first people to confirm the law of conservation of energy experimentally was English physicist James Prescott Joule (1818–1889), who used an ingenious bit of apparatus to find what he called "the mechanical equivalent of heat." He used a falling weight to drive a large paddle wheel sealed inside a container of water. He calculated the potential energy of the weight (the energy it had because of its height above Earth) and reasoned that, as the weight fell, it transferred pretty much all its energy to kinetic energy in the paddle wheel. As the paddle wheel turned, it stirred the water in the container and warmed it up by a small but significant amount. Now we know how much energy it takes to warm a certain mass of water by a certain number of degrees, so Joule was able to figure out how much energy the water had gained. To his delight, he found out that this figure exactly matched the energy lost by the falling weight. Joule's brilliant work on energy was recognized when the international scientific unit of energy (the joule) was named for him. Photo: The Mechanical Equivalent of Heat: In James Prescott Joule's famous experiment, a falling weight (1) pulls on a rope that passes over a pulley (2). The rope spins an axle (3) that turns a paddle inside a sealed container of water (4). As the paddle spins, the water heats up. Joule proved that the heat energy gained by the water was exactly the same as the potential energy lost by the weight. Joule built on earlier work by Anglo-American physicist Benjamin Thompson (1753–1814), also known as Count Rumford. While working in a Germany artillery factory, Rumford noted that cannon barrels got hot when they were being drilled out. He swiftly realized that the heat was not a magic property of the metal (as many people supposed) but came from the mechanical, frictional process of drilling: the more you drilled, the hotter the metal got. Rumford's simple calculations produced results that, according to Joule, were "not very widely different from that which I have deduced from my own experiments." That was a sign both men were on the right track. Back in the 19th century, charlatan inventors would pop up from time to time showing off miracle machines that seemed to be able to drive themselves forever. Inventions like this are called perpetual motion machines: they seem to be able to move forever without anyone adding any more energy. Often, machines like this were blatant tricks: the mechanisms were powered by a concealed assistant who sat in the shadows turning a hidden handle! Some of the machines sound plausible, but all of them unfortunately fall foul of the conservation of energy. In one version of perpetual motion, illustrated here, water (1) tips down onto a waterwheel, turning it around (2). The turning wheel drives gears (3) that power an Archimedes screw, which lifts the water back up to the top, theoretically allowing the whole cycle to repeat itself forever. Although you might think energy is being recycled as the water moves around, it's also being lost all the time. The water at the top has potential energy and that can indeed drive a waterwheel as it falls. But some energy will be lost to friction as the wheel turns. More energy will be lost to friction in the gears and the screw. So, between them, the wheel, gears, and screw will not have the same amount of energy as the potential energy the water lost originally. That means the screw cannot lift as much water back to the bath as fell down from it originally—so the machine will very quickly come to a stop. Find out more The Museum of Unworkable Devices: An excellent website about perpetual motion machines (and similar unworkable devices) compiled by Donald E. Simanek, former professor of physics at Lockhaven University. Nuclear reactions seem to create energy out of nothing breaking up or joining together atoms. Do they violate the conservation of energy? No! Albert Einstein's famous equation E=mc2 shows that energy and mass are different forms of the same thing. Loosely speaking, you can convert a small amount of mass into a large amount of energy (as in a nuclear power plant, where large atoms split apart and give off energy in the process). Einstein's equation shows us we sometimes need to factor mass into the conservation of energy. In a nuclear reaction, we start off with one set of atoms (a certain amount of energy in the form of mass) and end up with a different set of atoms (a different amount of energy locked in their mass) plus energy that's released as heat. If we factor in the mass of the atoms before and after the reaction, plus the energy released in the process, we find the conservation of energy is satisfied exactly. Since mass is a form of energy, it's clear that we can't destroy mass or create it out of nothing in the same way that we can't create or destroy energy. You'll sometimes see this referred to as the conservation of mass. Chris Woodford is the author and editor of dozens of science and technology books for adults and children, including DK's worldwide bestselling Cool Stuff series and Atoms Under the Floorboards, which won the American Institute of Physics Science Writing award in 2016. You can hire him to write books, articles, scripts, corporate copy, and more via his website chriswoodford.com. If you'd rather listen to our articles than read them, please subscribe to our new podcast on Apple Podcasts, Spotify, Audible, Amazon, Podchaser, or your favorite podcast app, or listen below: Find out more On this website Atomic energy Atoms Energy On other websites The Mechanical Equivalent of Heat: A good Wikipedia article about James Prescott Joule's famous experiment. The Conservation of Energy: In this short video clip from his MIT lectures, Professor Walter Lewin demonstrates very impressively that you can't finish up with more energy than you started off with. Luckily for him, as it turns out! Books For younger readers Eyewitness Energy by Jack Challoner and Dan Green. Dorling Kindersley, 2016. A simple introduction to the science, technology, and history of energy. Ages 9–12. Energy by Chris Woodford. Dorling Kindersley, 2007. My own colorful introduction explains what energy is, where it comes from, and how we use it in our everyday lives. Ages 9–12. Power and Energy by Chris Woodford. Facts on File. This longer book of mine is a history of human efforts to harness energy, from ancient technologies like water power to the latest forms of renewable energy. Suitable for most readers from about ages 10 upward. For older readers Great Experiments in Physics: Firsthand Accounts from Galileo to Einstein by Morris H. Shamos. Dover, 1959/1987. This utterly wonderful book (one of my favorite books ever!) contains reprints of papers reporting many of the greatest physics experiments of all time, including "Chapter 12. The Mechanical Equivalent of Heat" by James Prescott Joule. You may be able to read the whole paper via Google Books if you scroll through to page 166. Six Easy Pieces by Richard Feynman. Basic Books, 2011. Chapter 4 is a clear, simple, theoretical explanation of the conservation of energy. Articles Popular science More scholarly A few older articles from the archives explore the law in more depth: The Discovery of the Law of Conservation of Energy by G. Sarton et al, Isis, Vol. 13, No. 1 (Sep., 1929). This article traces the history of the conservation of energy back through Mayer, Joule, Carnot, and others. On the Principle of the Conservation of Energy by Ernst Mach, The Monist, Vol. 5, No. 1 (October, 1894), pp. 22–54 (33 pages). Mach discusses the broader significance of the law and in terms of our concepts of energy. Conservation of energy in the human body, Scientific American, Vol. 81, No. 6, August 5, 1899. ↑   Five medium ripe bananas contain about 500 calories according to the US Department of Agriculture database. How much energy you use during swimming varies according to stroke and vigor, and what your body's like, but 500 calories is a decent ballpark figure. Richard Muller explains the calculation more generally and notes that an hour's vigorous exercise of any kind burns off roughly 400 calories (I've rounded up) in Physics and Technology for Future Presidents (Princeton: Princeton University Press, 2008. p.26) ↑   I cover this story in my book Atoms Under the Floorboards, p.38. It's covered at greater length in James Joule, Letter to the editors, Philosophical Magazine 27 (1845): 205, quoted in Shamos, M. H. (ed.) (1987), Great Experiments in Physics (Dover, New York), p. 169. In physics, the Law of Conservation of Energy states that energy cannot be created or destroyed in an isolated system; it can only be transformed from one form to another. This fundamental principle is one of the key laws of physics and underscores the constancy of energy in all physical processes, whether it involves mechanical, thermal, chemical, or electrical energy transformations. The Law of Conservation of Energy is a fundamental principle in physics that asserts energy within a closed system remains constant, regardless of the transformations it undergoes. Essentially, this law means that energy can neither be created nor destroyed. Instead it merely shifts from one form to another. The Law of Conservation of Energy manifests in several forms, each relevant to different physical contexts: In mechanical systems, energy shifts between kinetic energy (movement energy) and potential energy (stored energy due to position). For example, a swinging pendulum exchanges its height (potential energy) for speed (kinetic energy) and back. This form deals with heat energy. When energy transforms into heat, as with friction, it remains within the system, complying with conservation principles, such as in insulated systems where heat does not escape. In chemical reactions, the energy stored in bonds of reactants transforms into products or releases as heat, yet the total energy remains constant. This principle is crucial for understanding reactions in batteries or metabolic processes in biology. In electrical circuits, energy converts from electrical potential to other forms like light or heat without loss of total system energy, important for power management and efficiency in electrical systems. The formula for the Law of Conservation of Energy is straightforward: $E_{\text{total}}=E_{\text{initial}}=E_{\text{final}}$ This equation states that the total energy E_{total} of an isolated system remains constant. Meaning the initial energy E_{initial} before any processes occur equals the final energy E_{final} after those processes. This encapsulates all forms of energy, including kinetic, potential, thermal, and others, ensuring their sum remains unchanged regardless of the transformations that occur within the system The derivation of the Law of Conservation of Energy formula is grounded in the fundamental principle that energy cannot be created or destroyed, only transformed from one form to another. Here’s a simplified explanation of how this principle leads to the conservation of energy equation: Energy can exist in various forms such as kinetic, potential, thermal, electrical, and chemical. Each form can be quantitatively described by specific equations. Like kinetic energy $KE=1/2mv^2$ and potential energy $PE=mgh$, where: m = mass, v = velocity, g = acceleration due to gravity, h = height above a reference point. Consider a closed system where energy transformations occur without any external energy input or loss to the surroundings. For instance, a pendulum swinging back and forth converts its energy from kinetic to potential and back without losing energy to the environment. In any process within a closed system, the total energy at any time can be represented by the sum of all forms of energy present. For the swinging pendulum: At the highest points, kinetic energy is zero, and potential energy is maximum. At the lowest point, kinetic energy is maximum, and potential energy is minimum. By setting up an equation that balances the total energies at different points in time or different states of the system. You acknowledge that the sum of energies remains constant. Mathematically, this is expressed as: Total Energy at Start=Total Energy at End $E_{\text{initial}}=E_{\text{final}}$ The Law of Conservation of Energy has wide-ranging applications across various fields, demonstrating its fundamental role in both theoretical and practical aspects: Engineering Design: Engineers design mechanical systems, such as engines and turbines. To maximize energy efficiency by minimizing energy losses to heat and friction. Environmental Science: Researchers analyze ecosystems to understand energy flow among organisms and use this information to study sustainability and conservation strategies. Building and Architecture: Architects incorporate energy-conserving principles into building designs to improve insulation and reduce heating and cooling costs. Physics Education: Educators use this law to teach fundamental physics concepts. Helping students understand energy transformations in different systems. Renewable Energy Technology: Developers create more efficient solar panels, wind turbines, and other renewable energy technologies that harness natural energy sources while minimizing energy waste. Here are practical examples demonstrating the Law of Conservation of Energy in everyday and scientific contexts: Roller Coasters: A roller coaster converts potential energy into kinetic energy as it descends from the highest point of the track, then back into potential energy as it climbs again. Bouncing Ball: When you drop a ball, it converts its potential energy into kinetic energy as it falls. Upon bouncing, it converts some of that kinetic energy back into potential energy. Electric Vehicles: Electric vehicles store electrical energy in batteries. This energy transforms into mechanical energy to power the wheels and kinetic energy when the vehicle is moving. Photosynthesis: In photosynthesis, plants convert solar energy into chemical energy stored in glucose, demonstrating energy transformation essential for life. Thermal Power Plants: Power plants burn fuel to produce thermal energy, which then converts to mechanical energy in turbines and finally into electrical energy through generators. According to the Law of Conservation of Energy, energy simply transforms from one form to another, maintaining constant total energy in a closed system. In black holes, energy is not destroyed; rather, it becomes trapped indefinitely, effectively removing it from the observable universe but still conserved. The law asserts that energy remains constant. It transforms between different forms, and cannot disappear or emerge from nothing in an isolated system. The law of conservation of energy states that energy can neither be created nor destroyed – it transforms from one form to another. For example, solar panels do not create energy. They harness energy from the Sun and convert light energy into electrical energy. All types of energy obey this law. As a result of energy conservation, the total energy in an isolated system is constant. If there is a loss of energy in one part of an isolated system, there must be a gain in another part. The motion of a pendulum is shown in the image below. It passes through a center point (A), reaches the extreme point (B), swings back to the center point, and finally gets to the other extreme point (C). Its kinetic energy (K.E.) is zero at the top of its swing, and its potential energy (P.E.) is maximum. In other words, when it reaches the top, all its kinetic energy is converted into potential energy. The stored potential energy is converted into kinetic energy when the pendulum returns to the center. At the center, the potential energy is zero, and the kinetic energy is maximum. Therefore, at any time, the sum of the two is constant. Since the sum of kinetic and potential energy gives mechanical energy, a swinging pendulum is an example of the conservation of mechanical energy. Conservation of Energy When a block slides down a ramp, its potential energy is converted into kinetic energy. However, due to friction, some energy is lost as heat. At any point, the sum of potential energy, kinetic energy, and thermal energy due to friction remains constant. The block and the ramp as a whole constitute an isolated system. During a collision between two bodies, the sum of kinetic energy before collision equals the sum after the collision. When a stick of dynamite explodes, the chemical energy present in the explosive is converted into kinetic energy, heat, sound, and light. The sum of all four energy forms is equal to chemical energy. In a combustion reaction, fuel burns in the presence of oxygen to produce sound and heat. Thus, all the chemical energy present in the fuel is converted into kinetic energy, heat energy, and sound energy. If we add the three energies, the sum equals the fuel’s chemical energy. The quantity of heat obtained by consuming food during the daily food intake of an animal equals the daily amount of energy released by the animal in the forms of work done, heat generated, and energy in the waste products. We assume that the animal is not gaining or losing any weight. The conservation of energy law is one of the fundamental laws of all science disciplines. In several areas of science, energy conservation is applied to derive many essential equations. Let us take the example of the first law of thermodynamics to understand this concept. Consider a system that takes in heat and does valuable work. For this system, the energy conservation equation is given by UT = Ui + Q + W Where UT: Total energy of the system Ui: Internal energy of the system Q: Heat added to or removed from the system W: Work done by or on the system Einstein’s Mass-Energy Equation Noted physicist Albert Einstein discovered in the early 20th century that mass could be converted into energy, known as mass-energy equivalence. The amount of energy associated with a specific amount of mass is given by the following famous equation in physics. E = mc2 Where, E: Energy M: Mass c: Speed of light (=3 x 108 m/s) Article was last reviewed on Friday, February 17, 2023 The law of conservation of energy is a physical law that states energy cannot be created or destroyed but may be changed from one form to another. Another way of stating this law of chemistry is to say the total energy of an isolated system remains constant or is conserved within a given frame of reference. In classical mechanics, conservation of mass and conversation of energy are considered to be two separate laws. However, in special relativity, matter may be converted into energy and vice versa, according to the famous equation E = mc2. Thus, it's more appropriate to say mass-energy is conserved. If a stick of dynamite explodes, for example, the chemical energy contained within the dynamite changes into kinetic energy, heat, and light. If all this energy is added together, it will equal the starting chemical energy value. One interesting consequence of the law of conservation of energy is that it means perpetual motion machines of the first kind are not possible. In other words, a system must have an external power supply to continuously deliver unlimited energy to its surroundings. It's also worth noting that it's not always possible to define conservation of energy because not all systems have time translation symmetry. For example, conservation of energy may not be defined for time crystals or for curved space times. By the end of this section, you will be able to: Explain the law of the conservation of energy. Describe some of the many forms of energy. Define efficiency of an energy conversion process as the fraction left as useful energy or work, rather than being transformed, for example, into thermal energy. Energy, as we have noted, is conserved, making it one of the most important physical quantities in nature. The law of conservation of energy can be stated as follows:Total energy is constant in any process. It may change in form or be transferred from one system to another, but the total remains the same.We have explored some forms of energy and some ways it can be transferred from one system to another. This exploration led to the definition of two major types of energy—mechanical energy KE+PEKE+PE and energy transferred via work done by nonconservative forces (Wnc)(Wnc). But energy takes many other forms, manifesting itself in many different ways, and we need to be able to deal with all of these before we can write an equation for the above general statement of the conservation of energy. At this point, we deal with all other forms of energy by lumping them into a single group called other energy (OEOE). Then we can state the conservation of energy in equation form asKEi+PEi+Wnc+OEi=KEf+PEf+OEf.KEi+PEi+Wnc+OEi=KEf+PEf+OEf. 7.65 All types of energy and work can be included in this very general statement of conservation of energy. Kinetic energy is KEKE, work done by a conservative force is represented by PEPE, work done by nonconservative forces is WncWnc, and all other energies are included as OEOE. This equation applies to all previous examples; in those situations OEOE was constant, and so it subtracted out and was not directly considered. The fact that energy is conserved and has many forms makes it very important. You will find that energy is discussed in many contexts, because it is involved in all processes. It will also become apparent that many situations are best understood in terms of energy and that problems are often most easily conceptualized and solved by considering energy. When does OEOE play a role? One example occurs when a person eats. Food is oxidized with the release of carbon dioxide, water, and energy. Some of this chemical energy is converted to kinetic energy when the person moves, to potential energy when the person changes altitude, and to thermal energy (another form of OEOE). What are some other forms of energy? You can probably name a number of forms of energy not yet discussed. Many of these will be covered in later chapters, but let us detail a few here. Electrical energy is a common form that is converted to many other forms and does work in a wide range of practical situations. Fuels, such as gasoline and food, carry chemical energy that can be transferred to a system through oxidation. Chemical fuel can also produce electrical energy, such as in batteries. Batteries can in turn produce light, which is a very pure form of energy. Most energy sources on Earth are in fact stored energy from the energy we receive from the Sun. We sometimes refer to this as radiant energy, or electromagnetic radiation, which includes visible light, infrared, and ultraviolet radiation. Nuclear energy comes from processes that convert measurable amounts of mass into energy. Nuclear energy is transformed into the energy of sunlight, into electrical energy in power plants, and into the energy of the heat transfer and blast in weapons. Atoms and molecules inside all objects are in random motion. This internal mechanical energy from the random motions is called thermal energy, because it is related to the temperature of the object. These and all other forms of energy can be converted into one another and can do work. Table 7.1 gives the amount of energy stored, used, or released from various objects and in various phenomena. The range of energies and the variety of types and situations is impressive. You will find the following problem-solving strategies useful whenever you deal with energy. The strategies help in organizing and reinforcing energy concepts. In fact, they are used in the examples presented in this chapter. The familiar general problem-solving strategies presented earlier—involving identifying physical principles, knowns, and unknowns, checking units, and so on—continue to be relevant here. Step 1. Determine the system of interest and identify what information is given and what quantity is to be calculated. A sketch will help. Step 2. Examine all the forces involved and determine whether you know or are given the potential energy from the work done by the forces. Then use step 3 or step 4. Step 3. If you know the potential energies for the forces that enter into the problem, then forces are all conservative, and you can apply conservation of mechanical energy simply in terms of potential and kinetic energy. The equation expressing conservation of energy is KEi+PEi=KEf+PEf.KEi+PEi=KEf+PEf. Step 4. If you know the potential energy for only some of the forces, possibly because some of them are nonconservative and do not have a potential energy, or if there are other energies that are not easily treated in terms of force and work, then the conservation of energy law in its most general form must be used. KEi+PEi+Wnc+OEi=KEf+PEf+OEf.KEi+PEi+Wnc+OEi=KEf+PEf+OEf. In most problems, one or more of the terms is zero, simplifying its solution. Do not calculate WcWc, the work done by conservative forces; it is already incorporated in the PEPE terms. Step 5. You have already identified the types of work and energy involved (in step 2). Before solving for the unknown, eliminate terms wherever possible to simplify the algebra. For example, choose h=0h=0 at either the initial or final point, so that PEgPEg is zero there. Then solve for the unknown in the customary manner. Step 6. Check the answer to see if it is reasonable. Once you have solved a problem, reexamine the forms of work and energy to see if you have set up the conservation of energy equation correctly. For example, work done against friction should be negative, potential energy at the bottom of a hill should be less than that at the top, and so on. Also check to see that the numerical value obtained is reasonable. For example, the final speed of a skateboarder who coasts down a 3-m-high ramp could reasonably be 20 km/h, but not 80 km/h. The transformation of energy from one form into others is happening all the time. The chemical energy in food is converted into thermal energy through metabolism; light energy is converted into chemical energy through photosynthesis. In a larger example, the chemical energy contained in coal is converted into thermal energy as it burns to turn water into steam in a boiler. This thermal energy in the steam in turn is converted to mechanical energy as it spins a turbine, which is connected to a generator to produce electrical energy. (In all of these examples, not all of the initial energy is converted into the forms mentioned. This important point is discussed later in this section.) Another example of energy conversion occurs in a solar cell. Sunlight impinging on a solar cell (see Figure 7.19) produces electricity, which in turn can be used to run an electric motor. Energy is converted from the primary source of solar energy into electrical energy and then into mechanical energy. Figure 7.19 Solar energy is converted into electrical energy by solar cells, which is used to run a motor in this solar-power aircraft. (credit: NASA) Object/phenomenon Energy in joules Big Bang 10 68 10 68 Energy released in a supernova 10 44 10 44 Fusion of all the hydrogen in Earth's oceans 10 34 10 34 Annual world energy use 4 × 10 20 4 × 10 20 Large fusion bomb (9 megaton) 3 . 8 × 10 16 3 . 8 × 10 16 1 kg hydrogen (fusion to helium) 6 . 4 × 10 14 6 . 4 × 10 14 1 kg uranium (nuclear fission) 8 . 0 × 10 13 8 . 0 × 10 13 Hiroshima-size fission bomb (10 kiloton) 4 . 2 × 10 13 4 . 2 × 10 13 90,000-metric ton aircraft carrier at 30 knots 1 . 1 × 10 10 1 . 1 × 10 10 1 barrel crude oil 5 . 9 × 10 9 5 . 9 × 10 9 1 ton TNT 4 . 2 × 10 9 4 . 2 × 10 9 1 gallon of gasoline 1 . 2 × 10 8 1 . 2 × 10 8 Daily home electricity use (developed countries) 7 × 10 7 7 × 10 7 Daily adult food intake (recommended) 1 . 2 × 10 7 1 . 2 × 10 7 1000-kg car at 90 km/h 3 . 1 × 10 5 3 . 1 × 10 5 1 g fat (9.3 kcal) 3 . 9 × 10 4 3 . 9 × 10 4 ATP hydrolysis reaction 3 . 2 × 10 4 3 . 2 × 10 4 1 g carbohydrate (4.1 kcal) 1 . 7 × 10 4 1 . 7 × 10 4 1 g protein (4.1 kcal) 1 . 7 × 10 4 1 . 7 × 10 4 Tennis ball at 100 km/h 22 22 Mosquito (10–2 g at 0.5 m/s)(10–2 g at 0.5 m/s) 1 . 3 × 10 − 6 1 . 3 × 10 − 6 Single electron in a TV tube beam 4 . 0 × 10 − 15 4 . 0 × 10 − 15 Energy to break one DNA strand 10 − 19 10 − 19 Table 7.1 Energy of Various Objects and Phenomena Even though energy is conserved in an energy conversion process, the output of useful energy or work will be less than the energy input. The efficiency EffEff of an energy conversion process is defined as Efficiency (Eff) = useful energy or work output total energy input = W out E in . Efficiency (Eff) = useful energy or work output total energy input = W out E in . 7.68 Table 7.2 lists some efficiencies of mechanical devices and human activities. In a coal-fired power plant, for example, about 40% of the chemical energy in the coal becomes useful electrical energy. The other 60% transforms into other (perhaps less useful) energy forms, such as thermal energy, which is then released to the environment through combustion gases and cooling towers. Activity/device Efficiency (%) Cycling and climbing 20 Swimming, surface 2 Swimming, submerged 4 Shoveling 3 Weightlifting 9 Steam engine 17 Gasoline engine 30 Diesel engine 35 Nuclear power plant 35 Coal power plant 42 Electric motor 98 Compact fluorescent light 20 Gas heater (residential) 90 Solar cell 10 Table 7.2 Efficiency of the Human Body and Mechanical Devices A realistic mass and spring laboratory. Hang masses from springs and adjust the spring stiffness and damping. You can even slow time. Transport the lab to different planets. A chart shows the kinetic, potential, and thermal energies for each spring. The laws of conservation of mass and conservation of energy are similar in that both state that the total amount of mass or energy in a closed system remains constant over time. However, the conservation of mass applies specifically to mass, while the conservation of energy applies to energy in its various forms (kinetic, potential, etc.).