

CHAPTER 1

Work and Energy

In this chapter, we are going to talk about how engineers define work and energy. It frequently takes force to get work done. Let's start with thinking about the relationship between force and energy. As we learned earlier, Force is measured in newtons, and one newton is equal to the force necessary to accelerate one kilogram at a rate of 1m/s^2 .

When you lean on a wall, you are exerting a force on the wall, but you aren't doing any work. On the other hand, if you push a car for a mile, you are clearly doing work. Work, to an engineer, is the force you apply to something, as well as the distance that it moves, in the direction of the applied force. We measure work in *joules*. A joule is one newton of force over one meter.



For example, if you push a car uphill with a force of 10 newtons for 12 meters, you have done 120 joules of work.

Formula for Work

$$W = F \cdot d$$

where W is the work in joules, F is the *force* in newtons, and d is the distance in meters.

If the force is not in the same direction as the distance, we can use the cosine of the angle between the force and the distance:

$$W = F \cdot d \cdot \cos(\theta)$$

where θ is the angle between the force and the distance.

The work-energy theorem (or work-energy principle) states that the work done on an object is equal to the **change in its energy**. In other words, if you do work on an object or

give it movement, you change its energy. Most commonly, this is used to relate the work done on an object to its kinetic energy or potential. This is derived from Newton's second law of motion, covered in the previous chapter.

$$W = \Delta E = \Delta KE = \Delta PE (\text{with units of Joules (J) or Newton-meters (Nm)})$$

Work is how energy is transferred from one thing to another. When you push the car, you also burn sugars (energy of the body) in your blood. That energy is then transferred to the car after it has been pushed uphill.

Thus, we measure the energy something consumes or generates in units of work: joules, kilowatt-hours, horsepower-hours, foot-pounds, BTUs (British Thermal Unit), and calories.

Let's go over a few different forms that energy can take.

1.1 Forms of Energy

In this section we are going to learn about several different types of energy:

- Heat
- Electricity
- Chemical Energy
- Kinetic Energy
- Gravitational Potential Energy

1.1.1 Heat

When you heat something, you are transferring energy to it. The BTU is a common unit for heat. One BTU is the amount of heat required to raise the temperature of one pound of water by one degree. One BTU is about 1,055 joules. In fact, when you buy and sell natural gas as fuel, it is priced by the BTU.

1.1.2 Electricity

Electricity is the movement of electrons. When you push electrons through a space that resists their passage (like a light bulb), energy is transferred from the power source (like

a battery) into the source of the resistance.

Let's say your lightbulb consumes 60 watts of electricity, and you leave it on for 24 hours. We would say that you have consumed 1.44 kilowatt hours, or 3,600,000 joules.

1.1.3 Chemical Energy

As mentioned early, some chemical reactions consume energy and some produce energy. This means energy can be stored in the structure of a molecule. When a plant uses photosynthesis to rearrange water and carbon dioxide into a sugar molecule, it converts the energy in the sunlight (solar energy) into chemical energy. Remember that photosynthesis is a process that releases energy. Therefore, the sugar molecule has more chemical energy than the carbon dioxide and water molecules that were used in its creation.

In our diet, we measure this energy in *kilocalories*. A calorie is the energy necessary to raise one gram of water one degree Celsius, and is about 4.19 joules. This is a very small unit. An apple has about 100,000 calories (100 kilocalories), so people working with food started measuring everything in kilocalories.

Here is where things get tricky: People who work with food got tired of saying "kilocalories", so they just started using "Calorie" to mean 1,000 calories. This has created a great deal of confusion over the years. So if the C is capitalized, "Calorie" probably means kilocalorie.

1.1.4 Kinetic Energy

A mass in motion has energy. For example, if you are in a moving car and you slam on the breaks, the energy from the motion of the car will be converted into heat in the breaks and under the tires.

How much energy does the car have?

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

Formula for Kinetic Energy

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

where E is the energy in joules, m is the mass in kilograms, and v is the speed in meters per second.

1.1.5 Gravitational Potential Energy

When you lift something heavy onto a shelf, you are giving it *potential energy*. The amount of energy that you transferred to it is proportional to its weight and the height that you lifted it.

$$E = mgh$$

a rate of 9.8m/s^2 .

Formula for Gravitational Potential Energy

The formula for gravitational potential energy is

$$E = (9.8)mh$$

$$E = mgh$$

where E is the energy in joules, m is the mass of the object you lifted, g is acceleration due to gravity, and h is the height that you lifted it.

On earth, then, gravitational potential energy is given by

$$E = (9.8)mh$$

since objects accelerate at 9.8m/s^2 .

There are other kinds of potential energy. For example, when you draw a bow in order to fire an arrow, you have given that bow potential energy. When you release it, the potential energy is transferred to the arrow, which expresses it as kinetic energy.

1.2 Conservation of Energy

The first law of thermodynamics says “Energy is neither created nor destroyed.”

Energy can change forms. Your cells consume chemical energy to give gravitational potential energy to a car you push up a hill. However, the total amount of energy in a closed system stays constant.

Exercise 1 The Energy of Falling*Working Space*

A 5 kg cannonball falls off the top of a 3 meter ladder. As it falls, its gravitational potential energy is converted into kinetic energy. How fast is the cannonball traveling just before it hits the floor?

*Answer on Page 7***1.3 Efficiency**

Although energy is always conserved as it moves through different forms, scientists aren't always that good at controlling it.

In terms of an equation, efficiency is the ratio of the useful energy output to the total energy input. It is usually expressed as a percentage.

Formula for Efficiency

$$\text{Efficiency} = \frac{\text{Useful Energy Output}}{\text{Total Energy Input}} \times 100\%$$

where the useful energy output is the energy that is actually used to do work or complete a task, and the total energy input is the total energy consumed by the system.

A machine is considered 100% efficient only if all the input work is converted into useful output work, with no energy lost to heat, friction, or sound.

For example, when a car engine consumes the chemical energy in gasoline, only about 20% of the energy consumed is used to turn the wheels. Most of the energy is actually lost as heat. If you run a car for a while, the engine gets very hot, as does the exhaust coming from the tailpipe.

A human is about 25% efficient. Most of the loss is in the heat produced during the chemical reactions that turns food into motion.

In general, if you are trying to increase efficiency in any system, the solution is usually easy to identify by the heat that is produced. Reduce the heat, increase the efficiency.

Light bulbs are an interesting case. To get the light of a 60 watt incandescent bulb, you can use an 8 watt LED or a 16 watt fluorescent light. This is why we say that the LED light is much more efficient. If you run both, the incandescent bulb will consume 1.44 kilowatt-hours; the LED will consume only 0.192 kilowatt-hours.

In addition to light, the incandescent bulb is producing a lot of heat. If it is inside your house, what happens to the heat? It warms your house.

In the winter, when you want light and heat, the incandescent bulb is 100% efficient!

Of course, this also means the reverse is true. In the summer, if you are running the air conditioner to cool down your house, the incandescent bulb is worse than just “inefficient at making light” — it is actually counteracting the air conditioner!

This is a draft chapter from the Kontinua Project. Please see our website (<https://kontinua.org/>) for more details.

Answers to Exercises

Answer to Exercise 1 (on page 5)

At the top of the ladder, the cannonball has $(9.8)(5)(3) = 147$ joules of potential energy.

At the bottom, the kinetic energy $\frac{1}{2}(5)v^2$ must be equal to 147 joules. So $v^2 = \frac{294}{5}$. This means it is going about 7.7 meters per second.

(You may be wondering about air resistance. Yes, a tiny amount of energy is lost to air resistance, but for a dense object moving at these relatively slow speeds, this energy is negligible.)



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