7.5: Forms of Energy

What Do You Think: Energy on the Mountain

We have been describing gravity solely in terms of acceleration or the force of attraction that causes that acceleration. This is correct, but it is an incomplete view of gravity. Sometimes, working with the force of gravity or its acceleration is not convenient. We might only want to understand the general characteristics of a system involving gravity, and be not at all concerned with the details of those characteristics. In such cases it is much easier to work with energy instead of forces and accelerations.

Energy is a word we use in everyday life, and like many terms in these modules, it has a more specific meaning in the context of science. The idea of energy arises in many situations. For example, there are different energy bands of light, there are chemical, gravitational and nuclear energy. Despite the various forms of energy, kinetic, potential, nuclear, chemical and so on, it is always a single number that we can calculate in a given situation. And no matter what type of energy we are dealing with, it can always be characterized by some number of the SI unit joules (J).

In this section, we will look at the concept of energy in some detail. Ideas related to energy will bolster our understanding of how and what changes can occur in the Universe and the objects it contains. The two kinds of energy that we will focus on here will be gravitational potential energy and kinetic energy. We will describe potential energy first.

7.5.1: Potential Energy

Chemical, gravitational, and nuclear energy are all forms of potential energy. For instance, chemical energy is energy that can be stored and released in chemical bonds by changing the configuration of electrons in atoms and molecules. The gravitational energy stored in a proto-star is released as the size of that star slowly decreases. The nuclear energy stored in the configuration of protons and neutrons in hydrogen and helium nuclei can be released when hydrogen is converted to helium, as is happening in the core of the Sun right now. These nuclear reactions are analogous to chemical reactions, but the amount of energy involved in the rearrangement of nuclei is much, much larger than that involved in rearranging the electrons in atoms.

Potential energy always involves the physical arrangement of a system. Let us take an example from gravity to illustrate this point. First, imagine a pinecone hanging in the top of a tall pine tree. Next imagine that same pinecone sitting on the ground beneath the tree (See Figure 7.8). The pinecone has more gravitational potential energy when it is high in the tree than when it is on the ground.

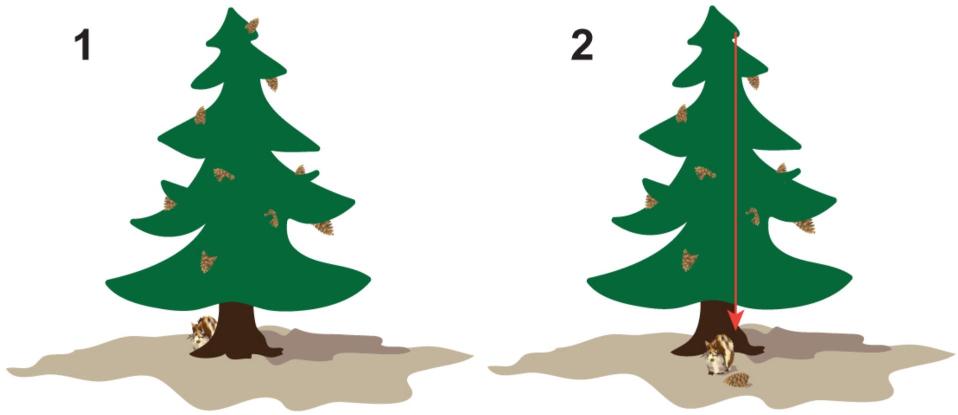

Figure 7.8: A pinecone has more gravitational potential energy when it is at the top of a pine tree than when it sits on the ground below the tree. Credit: NASA/SSU/Aurore Simonnet

There is a simple mathematical expression that describes the gravitational potential energy (*PE*) of an object when the gravitational acceleration can be assumed to be constant, which is certainly the case on Earth's surface:

$$PE = mgh$$

Breaking this expression down, we see that the potential energy is the product of the weight of an object (*mg*) and its height (*h*). From this formula, we see how the units of energy relate to the units of force and distance (or alternatively mass, acceleration, and distance): 1 J = 1 N m or 1 kg $(m/s)^2$.

Some care must be taken here by what height we mean. Is it the height above the ground? The height above sea level? Some other height entirely? It turns out that any of these will do, because potential energy is a *relative* measure of energy. We can only usefully talk about the difference in potential energy between two configurations of a system, not the absolute potential energy of either of them. An activity will help illustrate what this means.

✔ Potential Energy Differences

Assume that a pine tree is 50 meters high and that a pinecone hangs from the topmost point (an unusual place for a pinecone, but it simplifies our example). We will further assume that the pine tree is growing on a hill at a point 1000 meters above sea level. How does the gravitational potential energy of the pinecone change when it falls to the ground? We will assume that the pinecone has a mass equal to 70 grams.

1. First calculate the gravitational potential energy of the pinecone at the top of the tree:

- Given: *m* = (70 ~~g~~) / (1000 ~~g~~ / kg) = 0.07 kg ; *g* = 9.8 m/s^2 ; *h* = 50 m + 1000 m = 1050 m
- Find: *PE*
- Concept: From the expression for gravitational PE we have *PE* = *mgh*
- Solution: *PE* = (0.07 kg) (9.8 m/s^2) (1050 m) = 720.3 J

2. Now calculate the gravitational potential energy the pinecone has at the bottom of the tree:

- Given: *m* = (70 ~~g~~) / (1000 ~~g~~ / kg) = 0.07 kg ; *g* = 9.8 m/s^2 ; *h* = 1000 m
- Find: *PE*
- Concept: *PE* = *mgh*
- Solution: *PE* = (0.07 kg) (9.8 m/s^2) (1000 m) = 686 J

So, the potential energy the cone has when it is at the top of the tree is 720.3 J and the potential energy the cone has when it sits on the ground below the tree is 686 J. The difference is

$$\Delta PE = 720.3\ J - 686\ K = 34.3\ J$$

We have added the Greek symbol Δ (delta) to indicate that this is a change in the potential energy of the pinecone when it falls to the ground from the top of the tree.

You might notice that the only thing that changes between these two expressions is the height of the pinecone with respect to the tree. We could just leave off the elevation of the tree and use the amount by which the pinecone's elevation changes:

$$\Delta PE = (0.07\,kg)(9.8\,m/s^2)(50\,m) = 34.3\,J$$

This confirms what we have said: potential energy only depends on the configuration of a system, and changes in that configuration cause changes in the potential energy.

Questions

In the previous worked example we could imagine that when the pinecone dropped out of the tree it rolled down the hill, causing it to loose an additional 50 meters of elevation before coming to rest. If that were the case, what would be the total difference in its PE? Do we have to worry about things like the slope of the hill or how bumpy the ground is, or whether there are bushes on the ground that the cone has to break through? No! None of that matters. The only relevant information is the mass of the pinecone and how far it fell in total. In this case, it will lose an additional 34.3 J, and so its total change in PE will be 68.6 J. Half of this amount is from falling out of the tree, and half is from rolling down the hill.

7.5.2: Kinetic Energy

We will return to potential energy shortly, but first we want to explore another kind of energy: kinetic energy. The word kinetic refers to motion, and kinetic energy is the energy that objects have by virtue of the fact that they move. You will not be surprised to find that kinetic energy (*KE*) is also described by a simple mathematical expression:

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

Here, the mass of the particle is *m* and its speed is *v*. So you can see immediately that speed makes a big difference in KE. If a particle *doubles* its speed, its energy increases *four-fold*.

UNDERSTANDING KINETIC ENERGY

In this activity you will examine how the mass and speed of an object affect its kinetic energy.

Calculating Kinetic Energy

Worked Examples:

1. What is the kinetic energy of a 1000 kg car traveling at 100 km/hr?

- Given: To answer the question we must first convert the speed of the car to m/s.
  v = (100 ~~km~~ / ~~hr~~) (1000 m / 1 ~~km~~) / (3600 s / ~~hr~~) = 27.78 m/s
- Find: kinetic energy *KE*
- Concept: Now we can use the equation for kinetic energy: $KE = ½\, mv^2$
- Solution: KE = ½ (1000 kg) (27.78 m/s)^2 = 385,802 J = 3.858e5 J

2. Compare this to its energy at 50 km/hr.

At 50 km per hour (kph), the car has half the speed. This factor of ½ in the velocity will be squared when we calculate the energy, so the kinetic energy at that speed will be ¼ of what it was before:

$$(1/2)^2(3.858e5\ J) = (1/4)(3.858e5\ J) = 9.645e4\ J = 96,450\ J \tag{7.5.1}$$

This is why it is considerably safer to drive more slowly.

Questions

Just as for potential energy, there is no absolute amount of kinetic energy for a given object. Speed (and velocity) depends on the reference system used to measure it. So, for example, a bird flying 10 m/s will have a different amount of kinetic energy according to someone sitting on a bench watching it than it will as measured by a person riding a bike at 5 m/s. Does the direction of the bike's motion make a difference? Yes, because the relative speed between the bird and the cyclist are different if, say, the two move in the same direction or opposite directions -- or in some intermediate direction. So whenever we talk about energy, either potential or kinetic, we must keep in mind that both of them depend on the reference system we use to measure the speed and position. Observers in different reference systems can get different values for the kinetic and potential energy of particles. The most convenient reference system to use for a given situation will usually be obvious from the conditions of the problem.

7.5.3: Other Forms of Energy

Aside from kinetic and potential energy, there is also energy in radiation, like light. This is something like kinetic energy: light certainly does move. However, light does not have a mass, so we cannot find its kinetic energy using the expression above.

Scientists have found that the energy of a particle of light is given by the expression below.

$$E = hf,$$

Here h is called Planck's constant. It is a fundamental constant of nature, like the speed of light, c, and the gravitational constant, G. The other symbol, f, is the frequency of the light.

If you read the chapter on special relativity, you will learn that mass and energy are equivalent: the amount of energy in a given amount of mass is given as $E = mc^2$. This is a sort of potential energy.

So as promised, energy can take on many forms, though they all basically break down into either potential energy or kinetic energy. In the next section we will see more examples that show why energy is such an important and powerful concept.