Energy – Potential Energy*

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Abstract

This module explains potential energy in a format that is accessible to blind sudents.

1 Table of Contents

- Preface (p. 1)
    - General (p. 1)
    - Prerequisites (p. 2)
    - Supplemental material (p. 2)
- General background information (p. 2)
    - Graphic examples of potential energy (p. 2)
    - Potential energy (p. 3)
        - Gravitational potential energy (p. 4)
        - Elastic potential energy (p. 5)
    - Summary (p. 7)
- Sample calculations (p. 7)
- Do the calculations (p. 8)
- Resources (p. 8)
- Miscellaneous (p. 8)

2 Preface

2.1 General

This module is part of a collection (see http://cnx.org/content/col11294/latest/ [1]) of modules designed to make physics concepts accessible to blind students. The collection is intended to supplement but not to replace the textbook in an introductory course in high school or college physics.

This module explains potential energy in a format that is accessible to blind sudents.

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[1]http://cnx.org/content/col11294/latest/

2.2 Prerequisites

In addition to an Internet connection and a browser, you will need the following tools (as a minimum) to work through the exercises in these modules:

- A graph board for plotting graphs and vector diagrams (http://www.youtube.com/watch?v=c8plj9UsJbg [2]).
- A protractor for measuring angles (http://www.youtube.com/watch?v=v-F06HgiUpw [3]).
- An audio screen reader that is compatible with your operating system, such as the NonVisual Desktop Access program (NVDA), which is freely available at http://www.nvda-project.org/ [4] .
- A refreshable Braille display capable of providing a line by line tactile output of information displayed on the computer monitor (http://www.userite.com/ecampus/lesson1/tools.php [5]).
- A device to create Braille labels. Will be used to label graphs constructed on the graph board.

The minimum prerequisites for understanding the material in these modules include:

- A good understanding of algebra.
- An understanding of the use of a graph board for plotting graphs and vector diagrams (http://www.youtube.com/watch? [6]).
- An understanding of the use of a protractor for measuring angles (http://www.youtube.com/watch?v=v-F06HgiUpw [7]).
- A basic understanding of the use of sine, cosine, and tangent from trigonometry (http://www.clarku.edu/~djoyce/trig/ [8]).
- An introductory understanding of JavaScript programming (http://www.dickbaldwin.com/tocjscript1.htm [9] and http://www.w3schools.com/js/default.asp [10]).
- An understanding of all of the material covered in the earlier modules in this collection.

2.3 Supplemental material

I recommend that you also study the other lessons in my extensive collection of online programming tutorials. You will find a consolidated index at www.DickBaldwin.com [11] .

3 General background information

I will begin this explanation with a couple of graphic examples.

3.1 Graphic examples of potential energy

Gravitational potential energy

If you find a flat rock with a mass of 10 kg on the ground at a location on the surface of the earth where the ground is flat for miles around, that rock has little or no potential energy.

A change in potential energy

If you pick that rock up and balance it on a limb of a tree that is 2 meters off the ground, you have done at least two things:

[2] http://www.youtube.com/watch?v=c8plj9UsJbg
[3] http://www.youtube.com/watch?v=v-F06HgiUpw
[4] http://www.nvda-project.org/
[5] http://www.userite.com/ecampus/lesson1/tools.php
[6] http://www.youtube.com/watch?v=c8plj9UsJbg
[7] http://www.youtube.com/watch?v=v-F06HgiUpw
[8] http://www.clarku.edu/~djoyce/trig/
[9] http://www.dickbaldwin.com/tocjscript1.htm
[10] http://www.w3schools.com/js/default.asp
[11] http://www.dickbaldwin.com/toc.htm

- You have done work on the rock by exerting a force on the rock that displaced it upward by 2 meters. With some simplifying assumptions, we can calculate that you have done 196.2 joules of work on the rock.
- You have caused the rock to have gravitational potential energy that it did not have in its earlier position on the ground.

An accident waiting to happen

Perhaps the change in potential energy can best be illustrated by stating that the rock now has the potential to crack someone's skull open if they happen to be standing under the limb when the rock falls towards the ground with an acceleration of 9.8 m/s^2.

When the rock was laying on the surface of the earth, it did not have that potential. You created that potential by imparting potential energy into the rock when you listed it from the ground and balanced it on the limb.

Elastic potential energy

Consider a common rubber band. Because of its small mass, a rubber band can never be expected to acquire much in the way of gravitational potential energy. However, it can acquire a considerable amount of elastic potential energy.

While I don't recommend that you try the experiment with the rock described earlier, this is an experiment that you can try with no permanent damage to your person.

Thread your arm through the rubber band

Find a strong rubber band and thread your left arm through the rubber band up to the wrist. Make certain that the rubber band fits loosely on your arm. At that point, the rubber band has little or no potential energy.

Change the potential energy

Now grasp the rubber band between the thumb and forefinger of your right hand and stretch it to the point where it is almost ready to break.

At that point, you have expended your energy in stretching the rubber band, and the rubber band has acquired elastic potential energy.

How much elastic potential energy?

How much elastic potential energy did the rubber band acquire? You can get a qualitative estimate of the amount of potential energy by releasing the rubber band and letting it strike your bare wrist.

When the rubber band contacts your skin, it will impart energy into the nerve ending in your skin as its potential energy goes back to zero. If it hurts a lot, there was a lot of elastic potential energy stored in the stretched rubber band. If it doesn't hurt very much, there probably wasn't much potential energy stored in the rubber band, or you have very tough skin with few nerve endings.

3.2 Potential energy

There are several ways that an object can acquire and store energy, which we will refer to as *potential energy* . Two of the most common ways are:

- Raising the object to a new height above the surface of the earth (gravitational potential energy)
- Deforming the object within its elastic limit (elastic potential energy)

Increasing the potential energy of the rock

For example, elevating the rock by 2 meters above the ground as described earlier imparted energy into the rock. (Work was done on the rock in order to increase its height above the ground.)

Storing the potential energy

Balancing the rock on the limb caused that energy to be (temporarily) stored in the rock as gravitational potential energy. The rock stores that energy for so long as it is held at that elevated position.

Releasing the potential energy

Tipping the rock off the limb so that it would fall back to the ground caused that potential energy to be released and caused the potential energy of the rock to go back to zero.

Potential energy and the rubber band

Similarly, stretching and then releasing the rubber band as described above first stored, and then released elastic potential energy in the rubber band.

Work is required to increase the potential energy of an object

In both cases, it was necessary for you to expend energy in order to increase the amount of energy stored in the rock and the rubber band.

3.2.1 Gravitational potential energy

Gravitational potential energy is the energy stored in an object as the result of the gravitational attraction between the earth and the object. In practical terms, the energy is stored as the result of the objects height above the surface of the earth.

Every object that has a position above the surface of the earth has stored gravitational potential energy. Some common examples are

- Books on a bookshelf
- An air conditioning unit in a window on the third story of an apartment building
- You, when you climb a tree and sit on a limb or walk up the stairs to your classroom.

Because all objects are attracted to a point in the center of the earth, all objects that don't rest on the surface of the earth have potential energy.

All objects have stored gravitational potential energy

Even those objects that do rest on the surface of the earth have potential energy, because they have a strong tendency to make their way to the center of the earth. In most cases, however, that desire cannot be fulfilled so we usually consider the surface of the earth to be the reference point for gravitational potential energy.

The deep

In the final analysis, however, only those objects that rest at the bottom of the deepest point in the ocean cannot be forced to give up stored gravitational potential energy. In theory, every other object could be transported to and dropped to that point on the ocean bed, thereby giving up stored potential energy in the process.

The height and the mass are critical

The magnitude of the potential energy possessed by the rock balanced on the tree limb in the earlier example depends on two things: the height of the rock above the ground and the mass of the rock.

Gravitational potential energy is proportional to mass

The gravitational potential energy of an object is proportional to the mass of the object. Objects with more mass are capable of having more potential energy than objects with less mass. Therefore, if the rubber band discussed in the earlier example were to be placed on the same limb as the rock, the rock would have more gravitational potential energy than the rubber band due to its greater mass.

Gravitational potential energy is proportional to height

Gravitational potential energy is also proportional to the distance of the object from the center of the earth. Thus, a 10 kg rock falling from 50 meters onto your head would do more damage than the same 10 kg rock falling onto your head from 2 meters. In both cases, the potential energy of the rock would be converted to kinetic energy, (which is a topic for a future module), and that kinetic energy would be converted to pain when the rock strikes your head.

The higher the starting point for the rock,

- the faster it would be going right before it strikes your head,
- the more kinetic energy it would possess at that point in time, and
- the more damage it would do to your head.

Gravitational potential energy is proportional to the product of mass, height, and gravity

Thus, the gravitational potential energy of an object that is elevated above the surface of the earth is equal to the product of the mass of the object, the height of the object, and the acceleration of gravity. Expressed as an equation, we can write:

PEg = mass*kg * gravity*m/s^2 * height*m

where

- PEg represents gravitational potential energy
- mass, gravity, and height represent their namesakes
- kg, m, and s represent kilogram, meter, and second

Units of gravitational potential energy

As you can see from above, the units of gravitational potential energy are

kg*m^2/s^2 = kg*(m/s^2)*(m) = N*m = joule

What is the zero height reference?

Because the determination of gravitational potential energy requires knowledge of the height of the object, you must determine the height of the object above a *zero-height* reference level. Therefore, to determine the gravitational potential energy of an object, you must first decide what level you are going to consider to be zero height.

The ultimate reference

The ultimate zero-height reference is the point in the center of the earth to which all objects are attracted. Using that point, however, would lead to a lot of arithmetic accuracy problems. The radius of the earth is something like 6378100 meters, and that depends on where on the earth you are standing – death valley, Mount Everest, or somewhere in between.

I will leave it as an exercise for the student to determine why the use of the center of the earth as the zero-height reference might lead to arithmetic accuracy problems when doing calculations involving gravitational potential energy.

Doubling the height doubles the gravitational potential energy

The gravitational potential energy of an object is directly proportional to its height above the zero position. Therefore, doubling or tripling the height of the object above the zero position will have a corresponding doubling or tripling effect on the gravitational potential energy.

3.2.2 Elastic potential energy

Elastic potential energy is the energy stored in an object as a result of deforming the object within its elastic limit, such as stretching a rubber band, stretching a coil spring in a fisherman's scale, or compressing a coil spring in the suspension of an automobile.

The elastic limit

Many materials are elastic up to a point, some more than others. This means that they can recover from a deformation up to a point.

However, most materials have an elastic limit. The elastic limit is the point beyond which the material cannot recover from a deformation.

A rubber band

For example, if you stretch a rubber band by an inch or two, it will usually recover when the load is removed. However, if you stretch it too far, it will break. In that case, the rubber band has clearly been deformed beyond its elastic limit.

A steel beam

A steel beam that supports a bridge can normally flex by a small amount when loaded by traffic on the bridge and return to its original shape once the load is removed. However, there is a point beyond which it cannot recover if flexed too far.

A coil spring

A coil spring in an old-fashioned fisherman's scale can stretch up to a certain limit when loaded with a fish, and then return to its original length when the fish is removed. However, if it is stretched beyond its elastic limit, it won't return to its original length when the load is removed. (The enclosure on a fisherman's scale is usually designed to prevent the spring from being stretched beyond its elastic limit.)

Many objects store elastic potential energy

Elastic potential energy can be stored in steel beams, rubber bands, golf balls, springs, automobile tires, etc. The amount of elastic potential energy stored in such a device is related to the amount by which the object is deformed (usually stretched or compressed). The more the object is deformed, up to a point, the more elastic potential energy is stored in the object.

Springs are a special case

Springs are a special case of an object that can store elastic potential energy either through stretching or compression. Some springs are probably manufactured with one or the other in mind while other springs may be manufactured to serve both purposes.

For example, the spring in a fisherman's scale is probably manufactured with only stretching in mind. The process of weighing a fish on a fisherman's scale is to hang the fish on a hook on the bottom end of the spring and measure how far the spring stretches.

On the other hand, I believe, but am not certain, that the coil springs in the suspension of a car serve their purpose by both stretching an compressing.

A force is required

A force is required to compress or stretch a spring. The more the spring is compressed or stretched (depending on its purpose), the more force will be required to compress or stretch it further.

The spring constant

For certain springs, the amount of force required to compress or stretch the spring (up to a limit) is directly proportional to the amount of stretch or compression. This can be expressed in equation form as

Fs = k * x

where

- Fs is the force applied to the spring
- k is the constant of proportionality
- x is the amount of stretch or compression of the spring

Hooke's law

The constant of proportionality in the above equation is known as the **spring constant** . Springs that behave this way are said to follow Hooke's law, named after the 17th century British physicist Robert Hooke.

The equilibrium state

If the spring is not compressed or stretched, it is in its equilibrium state, and there is no potential energy stored in it. The equilibrium state is the state that the spring naturally assumes when no forces are acting on it. This state could be called the zero-potential energy state.

(This is the state of the rubber band that hung loosely around your wrist in the experiment at the beginning of this module.)

Potential energy versus stretch or compression

There is an equation for springs that relates the amount of elastic potential energy to the amount of stretch (or compression) and the spring constant. The equation is

PEs = 0.5 * k * x^2

where

- PEs represents the elastic potential energy stored in the spring
- k is the spring constant for the material from which the spring is made
- x is the amount of compression or stretch relative to the equilibrium state.

3.3 Summary

Gravitational potential energy can be stored in an object by moving it further away from the center of the earth. As a practical matter, this usually means moving it to a higher position relative to the ground, the floor, or a tabletop.

Elastic potential energy can be stored in an object by deforming it within its elastic limit. Usually, but not always, this involves stretching or compressing the object, but it could also mean twisting it or deforming it in some other way. If the deformation doesn't exceed the elastic limit of the object, it will return to its original shape when the load is removed.

Some materials, such as the spring material in a fisherman's scale, can sustain considerable deformation before reaching the elastic limit. Other materials, such as toasted bread, not only reach their elastic limit, but also reach their structural limit and break at the slightest amount of deformation.

Other materials, such as fresh bread and modeling clay have a low elastic limit but a relatively high structural limit. In other words, they doesn't return to their original shape when deformed, but they also don't easily break when deformed.

4 Sample calculations

The rock and the tree

You pick a flat rock with a 10kg mass off the ground and balance it on a tree limb 2 meters above the ground.

What was the gravitational potential energy of the rock before your arrival and what change in gravitational potential energy did you impart to the rock by your actions?

Answer:

Assuming that the rock was flat and the ground was flat and there was essentially no chance the the rock could roll downhill, the gravitational potential energy of the rock before you picked it up was zero.

Using the Google calculator to do the arithmetic and handle the units, after you balanced the rock on the tree limb, the potential energy was:

(10 kg) * (9.8 (m / (s^2))) * (2 m) = 196 joules

Therefore, the change in gravitational potential energy was 196 joules.

A crate and a ramp

You push a 100 kg mass up a 5 meter-long ramp and onto a platform at the upper end of the ramp. The ramp makes an angle of 36.9 degrees relative to the ground on which it is setting.

What change in gravitational potential energy did you impart to the crate?

Answer:

First compute the height of the platform at the upper end of the ramp.

height = 5 * sin(36.9 degrees) = 3m

Now compute the change in gravitational potential energy.

(100 kg) * (9.8 (m / (s^2))) * (3 m) = 2940 joules

All that matters insofar as the change in gravitational potential energy is concerned is that the crate was lifted 3 meters higher than its initial position. How that lift was accomplished doesn't matter. It could be accomplished with a ramp, a pulley, or with brute strength and the change in gravitational potential energy would be the same.

More on the crate and the ramp

How much work was done on the crate in pushing it to the top of the ramp?

Answer:

The first task is to compute the force parallel to the ramp that is required to push the crate up the ramp, ignoring the extra push required to get it moving at the bottom of the ramp. That parallel force is equal to the component of the crate's weight that is pushing down parallel to the ramp.

A little trigonometry will reveal that the component of the crate's weight that is parallel to the ramp is equal to the product of the total weight of the crate and the sine of the ramp angle relative to the horizontal ground. That gives us a requirement for a force pushing up the ramp and parallel to the ramp of

(100 kg) * 9.8 (m / (s^2)) * sin(36.9 degrees) = 588 newtons

The angle between the line of action of the force and the displacement direction of the crate was 0 degrees. Therefore, the work done on the crate was:

(588 newtons) * 5 m * cos(0) = 2940 joules

Note that the work done on the crate to move it to its new position was equal to the change in gravitational potential energy for the crate. As you may have guessed, that is not a coincidence. You will learn more about that relationship in a future module.

5 Do the calculations

I encourage you to repeat the calculations that I have presented in this lesson to confirm that you get the same results. Experiment with the scenarios, making changes, and observing the results of your changes. Make certain that you can explain why your changes behave as they do.

6 Resources

I will publish a module containing consolidated links to resources on my Connexions web page and will update and add to the list as additional modules in this collection are published.

7 Miscellaneous

This section contains a variety of miscellaneous information.

NOTE: **Housekeeping material**

- Module name: Energy – Potential Energy for Blind Students
- File: Phy1180.htm
- Keywords:
  - physics
  - accessible
  - accessibility
  - blind
  - graph board
  - protractor
  - screen reader
  - refreshable Braille display
  - JavaScript
  - trigonometry
  - potential energy
  - work
  - gravitational potential energy
  - elastic potential energy

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