Energy – Kinetic and Mechanical Energy[*]

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Abstract

This module explains kinetic and mechanical energy in a format that is accessible to blind students.

1 Table of Contents

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 kinetic and mechanical energy in a format that is accessible to blind students.

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[†]http://creativecommons.org/licenses/by/3.0/
[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

In an earlier module, you learned about two forms of potential energy:

- gravitational potential energy
- elastic potential energy

In this module, you will learn about kinetic energy and mechanical energy.

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[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

3.1 Kinetic energy

Review regarding gravitational potential energy

Recall that gravitational potential energy is energy possessed by an object due to its distance from the center of the earth. Gravitational potential energy is driven by the attraction between the earth and all objects on the earth.

Review regarding elastic potential energy

Elastic potential energy is energy possessed by objects that have been deformed within their elastic limits. Elastic potential energy is driven by a desire of those deformed objects to return to their non-deformed state of equilibrium.

Kinetic energy

Kinetic energy is energy possessed by an object because of its motion. Kinetic energy is driven by the tendency of a moving object to continue moving at the same velocity. When an object is in motion, something earlier did work on the object to cause it to attain its velocity and force will be required to cause it to change its velocity.

There's that little brother again

When your little brother throws a ball and scores a solid hit on your back (not a glancing blow), the velocity of the ball goes to zero upon contact and the kinetic energy possessed by the baseball is released into your body. This can sometimes cause pain, particularly if the ball possesses a lot of kinetic energy.

Forms of kinetic energy

Kinetic energy comes in a variety of forms, including:

- rotational, which is due to rotational motion such as a wheel on a bicycle
- translational, which is due to the movement of an object from one location to another location

I will concentrate on translational kinetic energy in this module and will deal with other forms of kinetic energy in future modules.

Two factors control the amount of kinetic energy

The amount of translational kinetic energy possessed by a moving object depends on two factors:

1. The mass of the object.
2. The velocity of the object.

How did the object attain its current velocity?

Note that it doesn't matter how the object attained its current velocity. The object may have attained its current velocity by accelerating very slowly over a period of years. The object may have fallen off a tall bookshelf and attained its current velocity fairly quickly as a result of the acceleration of gravity. Or, the object may have been shot out of a cannon due to an explosion of gun powder and acquired its current velocity very quickly.

With regard to the kinetic energy currently possessed by the object, the only things that are important are:

1. What is the mass of the object?
2. What is the current velocity of the object?

Calculating kinetic energy

We know that an object can have motion (and hence kinetic energy) at the current time only if work was done on the object earlier to put it in motion. We also know that the kinetic energy will be equal to the work that was performed on the object to put it in motion with the possible loss of kinetic energy due to friction or other factors over time.

Knowing those things, and assuming that the object gained its current velocity as a result of constant acceleration, we can derive an equation that represents the kinetic energy possessed by the object.

The definition of work – review

Recall the definition of work:

work = force * displacement * cos(theta)

where

- theta is the angle between the direction of displacement and the line of action of the force.

In this case, we might as well assume that theta is 0 degrees.

The equation for work

Therefore, W = f*d

where

- W represents work, and ultimately kinetic energy
- f represents force
- d represents distance or displacement

Acceleration is caused by force

We also know that a given force applied to an object will produce a given acceleration, as in

f = m*a

where

- f represents force
- m represents mass
- a represents acceleration

Distance traveled by an object under constant acceleration

In an earlier module, you learned that when an object is subjected to a constant acceleration, the distance traveled by the object in a given time is represented by

d = 0.5*a*t^2

where

- d represents the distance traveled
- a represents the constant acceleration
- t represents time

Substitution

Therefore, by substitution we can write

W = f*d = 0.5*f*a*t*t, or

W = 0.5*m*a*a*t*t

We're almost there

Recognizing that a = v/t where v represents velocity and t represents time, we can write

W = 0.5*m*(v/t)*(v/t)*t*t

Canceling terms in the numerator and denominator, we can write

W = 0.5*m*v*v = 0.5*m*v^2

And we're there

Since the kinetic energy possessed by the object equals the work that was done on the object to produce the current velocity (assuming no energy loss in the interval), we can write

KE = 0.5*m*v^2

where

- KE represents the kinetic energy possessed by the object
- m represents the mass of the object
- v represents the velocity of the object

Once again, even though I assumed constant acceleration to derive this equation, the equation is true regardless of the nature of the acceleration that caused the object to possess its current velocity.

KE varies as the square of the velocity

This is an extremely important equation, because it shows that the kinetic energy possessed by an object increases as the square of the velocity of the object. For example, if you are struck by a falling book with a velocity of 2 m/s, it will do four times as much work in damaging your body as a book with a velocity of only 1 m/s.

If the driver of a car increases the speed of the car from 55 mph to 70 mph, this represents about a 27-percent increase in speed but it also represents about a 62-percent increase in kinetic energy.

Miscellaneous facts about kinetic energy

Like work, kinetic energy is a scalar quantity. It has magnitude but not direction.

Also like work and potential energy, the standard unit of kinetic energy is the joule. However, there are many other units that are used to express energy including:

- 1 foot-pound = 1.36 joules
- 1 British thermal unit (Btu) = 1055.1 joules
- 1 kilowatt-hour = 3600000 joules
- 1 calorie = 4.18 joules
- 1 electron volt = $1.6*10^{\wedge}(-19)$ joules
- 1 hartree = $4.4*10^{\wedge}(-18)$ joules
- 1 ton of TNT = $4.18 *10^{\wedge}9$ joules

Some sample calculations involving kinetic energy are presented later (p. 8) .

3.2 Mechanical energy

We know what it means to do work on an object. When a force is applied to an object causing a displacement of the object (such as lifting a small child and placing that child into a feeding chair), work has been done on the object.

Force is a two-way street

A force doesn't exist in isolation. From Newton's third law, we know that for each force that is applied to one object, an equal and opposite force is applied to the other object. When you lift the child and place the child into a feeding chair, you supply the force necessary to overcome the force of gravity and lift the child. (You also do the work necessary to increase the child's gravitational potential energy.)

Work is also a two-way street

In all cases where a force is applied to an object (work is done on the object), some other object must apply the force and do the work. That force may be applied by a person, a motor, a beast of burden, rushing water, wind, etc.

An exchange of energy

In all such cases, the object doing the work possesses either potential energy or kinetic energy or both that is exchanged with the object upon which the work is performed. (When you lift the child and place the child into a feeding chair, you are expending potential energy that you possess in order to increase the potential energy possessed by the child.)

The type of energy expended

For example, the energy being expended may be in the form of

- chemical energy such as the energy stored in food, fuel, or TNT
- atomic energy such as is used in a nuclear power plant
- radiant energy such as energy received from the sun
- gravitational potential energy and/or kinetic energy as in the case of water rushing downhill through a turbine,

- elastic potential energy such as the energy stored in the spring that closes the gate to my back yard after someone opens that gate and twists the spring

Work causes objects to gain energy

Whenever work is done on an object, that object gains energy (as in the case of lifting a child into a feeding chair, thereby increasing the child's gravitational potential energy).

Mechanical energy

According to The Physics Classroom (see http://www.physicsclassroom.com/class/energy/u5l1d.cfm [12]), the energy acquired by the objects upon which work is done is known as **mechanical energy** .

Mechanical energy is the energy that is possessed by an object due to its motion or due to its position (where position includes the deformation, stretching, compressing, etc., involved in elastic potential energy). Mechanical energy can be either *kinetic energy* resulting from motion or *potential energy* resulting from the position of the object.

A speeding car has kinetic energy. An airplane in flight has both kinetic energy and gravitational potential energy. A stretched or compressed or twisted spring has elastic potential energy. (The spring on my gate doesn't obviously stretch or compress when the gate is opened. Instead, it twists.)

The ability to do work

Mechanical energy is often defined as the ability to do work because an object that has mechanical energy can do work. For example, the book on the top bookshelf has the ability to do work on your head if it falls on your head.

When a falling book strikes your head

When at rest on the bookshelf, the book has mechanical energy in the form of gravitational potential energy. On the way down, some of that potential energy is converted to kinetic energy.

When the book strikes your head and causes your head, the bone in your head, or possibly both, to be displaced, it gives up some of its kinetic energy. The kinetic energy given up by the book is absorbed by your head.

At that point, the book still has mechanical energy in the form of potential energy, and possibly some kinetic energy as well. The remaining mechanical energy could do work on your toe if the book happens to land on your toe.

In summary...

The mechanical energy possessed by an object makes it possible for the object to apply a force to some other object to cause the other object to be displaced, thus doing work on the other object.

A moving hammer

For example, a moving hammer can cause a nail to be displaced and driven into a piece of wood. In the case of a hammer, simply laying the hammer on the head of the nail, which means applying the hammer's potential energy to the head of the nail, probably won't displace the nail. However, giving the hammer a good swing, thereby imparting kinetic energy into the hammer, gives the hammer the capability to displace the nail.

Potential energy being dissipated

If you swing a hammer repeatedly for the purpose of driving nails, after awhile you will probably begin to feel tired. This is because each time you swing the hammer and impart mechanical energy into the hammer, that energy is being expended by your body. After awhile, your available potential energy in the form of chemical energy will have been depleted (or at least reduced) and you will feel tired.

The suction- cup dart gun

When I was a child, a commonly available toy was a gun that was designed to shoot projectiles at a target. The projectiles (darts) were sticks with rubber suction cups on one end. (Note that darts also come in another form that has a sharp but sturdy pin on one end and a construction that is very aerodynamic. Those darts are meant to be thrown at a target instead of being shot from a gun.)

The suction-cup dart

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[12]http://www.physicsclassroom.com/class/energy/u5l1d.cfm

For the suction-cup dart, the target was very smooth. If the dart struck the target straight on with very little angle, the suction cup would adhere to the target by squeezing air out from the suction cup and creating a weak vacuum.

Cocking the gun

To prepare the gun for shooting the dart, the stick would be inserted into the barrel of the gun and pushed against a spring contained inside the gun until some sort of catching mechanism would click into place. That mechanism would hold the spring in a compressed position until the child pulled the trigger.

With the spring compressed, the gun possessed mechanical energy due to the elastic potential energy of the spring.

Shooting the gun

When the trigger was pulled, the catch would release, the spring would expand, and the dart would shoot out of the gun at relatively high speed.

Be careful what you aim at

I still recall getting in trouble with my mother for lying on my bed and shooting darts at the ceiling, which made little round circles on the ceiling that she had to clean off. (I forgot to mention that you normally lick the suction cup before loading it into the gun so that it will make a good seal when it strikes the target.)

An exchange of mechanical energy

When the dart is loaded into the gun and the spring is compressed, the gun possesses mechanical energy. When the trigger is pulled, that mechanical energy does work on the dart causing the dart to be displaced very rapidly shooting out of the barrel of the gun. The elastic potential energy in the spring is exchanged for kinetic energy in the dart.

Another energy exchange

When the dart strikes the target, the kinetic energy in the dart is exchanged for elastic potential energy in the rubber suction cup on the front of the dart. When the striking angle is nearly perpendicular to the target, the air is forced out of the suction-cup causing the dart to adhere to the smooth surface.

Mechanical energy possessed by the dart

At that point in time, the dart has gravitational potential energy due to its height above the floor and the suction cup has elastic potential energy due to having been deformed within its elastic limit.

The slightest air leak will cause the suction cup to return to its original shape, thereby causing the dart to pop off the target. Then the gravitational potential energy possessed by the dart will cause it to fall to the floor.

3.3 Total mechanical energy

The total amount of mechanical energy possessed by an object is the sum of the potential and kinetic energy possessed by the object. Therefore,

TME = PE + KE

where

- TME represents the total mechanical energy
- PE represents the total potential energy
- KE represents the kinetic energy

Because the potential energy can be of two forms,

TME = PEs + PEg + KE

where

- TME represents the total mechanical energy
- PEs represents the potential energy due to deformation such as stretching, compressing, twisting, etc.

- PEg represents the potential energy due to gravity
- KE represents the kinetic energy

Energy is a scalar quantity

As mentioned earlier, energy is a scalar and not a vector quantity. Therefore, the total mechanical energy is simply the sum of the three types of energy possessed by the object. There are no angles or directions to contend with when computing the sum.

Conversion of energy between types

Over the course of time, a moving object can convert the types of energy between the different forms. A good example is the pendulum on a clock, or a child sitting motionless in a swing that is in motion.

When the pendulum reaches its highest point...

There is an instant in time where a swinging pendulum is at its highest point and it is not moving. At that instant, it has no kinetic energy but it has maximum gravitational potential energy.

When the pendulum reaches its lowest point...

As the pendulum goes through the lowest point in its swing, it has the greatest speed and therefore the greatest amount of kinetic energy. If you define the zero height reference as the height of the pendulum at that point, then it has no potential energy at that point in time.

Swapping kinetic energy for potential energy

Therefore, the total mechanical energy of the pendulum is swapped back and forth between kinetic energy and potential energy in a very smooth way.

If the pendulum were swinging in a friction-free environment, it would continue that process forever. The total amount of mechanical energy would stay the same but at any instant in time would be divided between potential and kinetic energy.

Of course, there is no such thing as a friction-free environment and a small amount of energy is dissipated by friction each time the pendulum swings through a cycle. Over time, therefore, the total mechanical energy in the pendulum would be depleted and the pendulum would stop swinging.

Pendulum clocks have springs

That is why pendulum clocks have springs or weights that store potential energy and impart a small amount of energy into the pendulum mechanism during each swing.

Where does the potential energy come from

That raises another issue. What happens to the clock when the spring or weights expend all of their stored energy. The answer is that eventually the pendulum will stop swinging and the clock will stop running unless a human imparts more energy into the spring or weight system that keeps the clock running.

Twenty-four hours of controlled energy transfers

I can still remember my grandfather winding the spring on his pendulum clock as the last thing he did before going to bed each night. He was converting potential energy derived from food into elastic potential energy in the clock's spring.

During the next 24 hours, that elastic potential energy would be converted to a combination of gravitational potential energy and kinetic energy in the pendulum, which would move the hands on the clock to indicate the correct time.

The next night, my grandfather would start the process all over again by imparting energy into the clock's spring.

4 Sample calculations

I will present and explain sample calculations involving both kinetic energy and mechanical energy in this section.

4.1 Kinetic energy

A roller coaster car

What is the kinetic energy possessed by a 1378 pound roller coaster car that is moving with a speed of 60 ft/sec?

Answer:

Enter the following expression into the Google search box:

0.5*1378lb * (60ft/s)^2

The resulting kinetic energy is 1.045 * 10^5 joules.

Similarly, you could enter the following into the Google search box:

0.5*625kg * (60ft/s)^2

and you would get the same answer of 1.045 * 10^5 joules.

As you can see, it doesn't matter whether you use English units or SI units for mass and velocity, as long as you do the calculation correctly. The answer is the same, because the kinetic energy of the object doesn't change just because you express those quantities in different units.

More on the roller coaster car

What would be the kinetic energy of another car with the same mass but with three times the speed?

Answer:

We don't even need to evaluate the equation to answer this question. We know that the kinetic energy varies as the square of the speed, so if we triple the speed, we will increase the kinetic energy by a factor of 3*3=9. Therefore,

KE = 9*1.045 * 10^5 joules = 9.405 * 10^5 joules

Dead Fred the daredevil

Dead Fred, the daredevil possessed a kinetic energy of 18000 joules just prior to hitting a solid brick wall on his motorcycle. If his mass was 176 pounds, what was his speed?

Answer:

KE = 0.5*m*v^2, or

v^2 = KE/(0.5*m), or

v = sqrt(KE/(0.5*m)), or

v = sqrt(18000joules/(0.5*176pound))

Enter the right-hand expression above into the Google search box and you should get a velocity of

v = 21.24 m/s

4.2 Mechanical energy

A dart gun

A dart with a mass of 0.1 kg leaves the muzzle of a dart gun with a velocity of 10 m/s. The child is holding the dart gun at a position that is 1 m above the ground. At that instant,

1. What is the potential energy of the dart?
2. What is the kinetic energy of the dart?
3. What is the total mechanical energy of the dart?
4. Assuming no losses of energy due to friction or other causes, what is the change in the total mechanical energy of the gun at the instant the dart exits the gun?

Answers:

1. Assuming that the dart was not deformed as it was forced out of the barrel of the gun, the potential energy of the dart is given by

mass*gravity*height

Enter the following into the Google search box:

(0.1 kg) * (9.8 (m / (s^2))) * (1 m)

The result should be:

Potential energy = 0.98 joules

2. The kinetic energy of the dart is given by

0.5*m*v^2

Enter the following into the Google search box:

0.5*0.1kg*(10m/s)^2

The result should be:

kinetic energy = 5 joules

3. The total mechanical energy of the dart is the simple sum of the potential energy and the kinetic energy, which is:

Total mechanical energy = 5.98 joules

4. When the dart exits the gun, the gravitational potential energy of the gun is reduced because the total mass of the gun and the dart is reduced by the mass of the dart.

In addition, the elastic potential energy stored in the spring is imparted into the dart in the form of kinetic energy.

Therefore, the loss in mechanical energy of the gun is equal to the total mechanical energy of the dart immediately upon exit from the gun barrel. Therefore, the total mechanical energy of the gun is reduced by 5.98 joules when the dart exits the gun.

A crate on a ski run

A crate containing soft drinks with a mass of 5 kg is accidentally released at the top of a ski run and slides down the ski run to the valley below. The height of the point where the crate is released is 100 m above the valley floor. The crate goes through numerous dips and over many small hills on the way down but never stops.

Assuming there is no friction, no air resistance, no deformation, and no loss of energy in any form during the trip, what is the magnitude of the crate's velocity when it reaches the valley floor?

Answer:

As presented, this is a simple case of the conversion of gravitational potential energy into kinetic energy. The fact that the crate slowed down and sped up several times during the trip while negotiating little dips and hills doesn't matter. All that really matters is the balance of energy between the starting point and point where the crate reached the valley floor. With no energy loss during the trip, the total mechanical energy at the end of the trip must equal the total mechanical energy at the beginning of the trip.

At the top of the hill, the crate's gravitational potential energy was equal to

m*g*h = 5kg*(9.8m/s^2)*100m = 4900 joules

Therefore, at the bottom of the hill, with no remaining potential energy, the crate's kinetic energy must be equal to

0.5*m*v^2 = 4900 joules

Rearranging terms gives us

v^2 = (4900 joules)/(0.5*m), or

v = sqrt((4900 joules)/(0.5*m)), or

v = sqrt((4900 joules)/(0.5*5kg))

Entering this expression into the Google calculator gives us the crate's velocity when it reached the valley floor as

v = 44.3 m/s

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 − Kinetic and Mechanical Energy for Blind Students
- File: Phy1190.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
  - kinetic energy
  - mechanical energy
  - total mechanical energy

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