# ***Chapter 10: Introduction to Energy***

## Types of Energy

The purpose of this chapter is to introduce you to the concept of energy and to teach you how to use this concept to predict or describe the motion of an object in a given situation. In this section, however, we will do something very special that will not be done again in this course; we will use a concept (namely energy) without knowing what it really is. Most people have an intuitive understanding of energy, meaning that if we say something has a lot of energy, or something uses a lot of energy, almost everyone gets the gist of what was said. In Physics, energy has a very specific and precise definition, which often does, but occasionally does not, match the "common" or "vulgar" definition used in everyday life. This definition, unfortunately, requires a few concepts which we have not yet encountered and thus would be meaningless to us at this time. Since energy is an important part of Physics we will learn a little about it and how to use it without knowing exactly what it is, but rather by using that "intuitive and vulgar" definition.

As was mentioned, the concept of energy is very, very, very important in the study of Physics (some say that the study of Physics is the study of energy). Halliday and Resnick, in their third edition of Fundamentals of Physics, describe energy (and accurately so, I believe) to be the one concept that links all the disparate elements of Physics together into a whole. If the student were to read the list of topics covered in a standard Physics class in one year and think about it a while, they might ask a question like, "Why are all these topics lumped together? Why do we study electricity, sound, heat and motion in the same class? What do these topics have in common, since they all seem so different?" The answer to this question is that they all deal with energy. Energy is the common link that brings them under the same umbrella of study.

Because energy is so important, I have chosen to introduce it in this chapter and then revisit it later in another chapter in more detail. The student should focus in this chapter on how to use the basic concepts of energy instead of what energy really is (which will be explained later). This basic understanding will allow the student to use these concepts from this point on in every chapter and allow the student more time during the course to become acquainted with energy.

The vulgar definition mentioned previously deserves to be put into words before we go any further.

> Energy is a quantity that is related to and used to find information about an objects movement, placement or heat content.

We should also add;

> Energy describes the behavior (or potential behavior) of an object, not the object itself. In other words, objects possess energy, it does not describe a property of the object.

This is not a true, Physics type definition, but it will suffice for the moment. There are three main types of energy we need to be concerned about; energy of an objects motion, position and heat.

Kinetic energy is energy an object possesses due to its motion, thus all moving objects have some potential energy. The motion can be linear or rotational, and there is a kinetic energy associated with each of these motions. We will focus only on the energy of linear motion.

The formula for kinetic energy (abbreviated by the variable T) is:

$$T=(½)mv^2$$

Notice that in here there are no vector marks. In fact, the velocity is a vector and you see that here it is squared, which is something we don't yet know how to do. It turns out that energy is a scalar, not a vector, making it easy to work with. Let us do one simple example of calculating the kinetic energy of an object.

EX BQ.) How much kinetic energy does a 50 kg ball traveling at 30 m/sec have?

From this we see that the units of energy are $kg.m^2/s^2$ which is given a special name, a Joule.

$$1\ J = 1\ kg.m^2/s^2$$

The unit is named after James Joule, a pioneer in the concept of energy. There are three other units of energy that you should be familiar with, the foot-pound and the electron volt. The foot pound is the old, English unit used to measure energy and the conversion is:

1 J = 0.738 ft.lbs

Another metric unit sometimes used is called an electron volt. An electron volt is a very small unit of energy used in circumstances that would make use of Joules (which are large) impractical. One such circumstance (and the most common one) is when you are discussing subatomic particles like protons or electrons. In these cases the mass is so small that using Joules would leave you with a large, negative exponent. The conversion is:

$1 \text{ eV} = 1.6\text{x}10^{-19} \text{ J}$

Another unit of energy to mention is an erg. An erg is like a mini-Joule. Instead of being in the MKS system, an erg is measured in the cgs system. Thus:

$1 \text{ erg} = 1 \text{ g.cm}^2/\text{s}^2 = 10^{-7} \text{ Joules}$

Finally, the last unit we want to mention is a calorie, which is an English unit. One calorie (cal.) is the energy required to raise one gram of water one degree Celsius. Often you see the unit of enemy Calorie (Cal.), which is one thousand calories (confusing, huh?). To convert between the English and metric requires us to know:

1 cal = 4.184 J.

A few other notes should be made concerning kinetic energy before we move on. The first is that the student should notice that the velocity in the kinetic energy equation is squared while the mass is not. This means that velocity is "more important" than mass in determining kinetic energy. For example, imagine two balls, one twice as massive as the other. If the smaller ball were moving twice as fast as the larger one, they would not have the same energy. The less massive ball would have twice the energy of the more massive one. This is the reason why in football it is more painful to be hit by a small, fast player than a heavy, slow player (although both hurt!).

The second note to be made is that since kinetic energy is dependent on velocity, and since velocity is relative to your frame of reference, kinetic energy is a relative quantity. Although this is a very interesting note, and carries many implications, because our frame of reference is understood to be the earth, we will generally not notice its importance.

Potential energy is the energy associated with an objects position and is a little trickier to understand. In this section when we say "potential energy" we are talking about gravitational potential energy (there are other types) <u>near the surface of the earth</u>. Potential energy is not exactly the energy of position, but in actuality is the energy associated with a <u>change</u> of position.

This distinction is very important. It is incorrect to say that an object sitting on a shelf has potential energy. The only correct way to discuss it is to say that when the object changes shelves, it has gained or lost potential energy. Many books try to make this clearer by using the surface of the earth as a zero level and saying that the potential energy of an object is the energy it would gain or lose if it went down to the surface of the earth. Although sometimes helpful, it is better to remember that you can only discuss changes in potential energy, not potential energy itself.

Potential energy has a sign associated with it (unlike kinetic energy which is always positive {why?}).

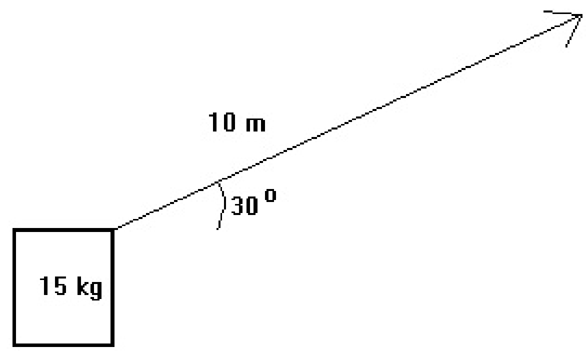
> Potential energy changes are negative if the object moves down (in the direction of gravity) and positive if the object moves up (against gravity).
>
> The formula for potential energy (abbreviated with a $\Delta U$) is:
>
> $\Delta U = -mgh$

Where h is the vertical height change of the object. Note that without a height change, $\Delta U = 0$. This gives us a very informative example of how to realized exactly how much energy is in one Joule. If we moved one small apple (about one Newton) up in the air one meter, we would have increased its potential energy by about one Joule. Remember this analogy and think about it as you do energy problems. One Joule is raising one apple one meter in the air.

EX BR.) A 15 kg book is dropped from a window, 10 m to the ground. What is its change in potential energy? Express in all units of energy.

The h in our potential energy equation was defined as the vertical height change. By vertical, we mean only the height change in the "y-direction", against or with gravity. In other words, we don't care what path the object took, we only care about the difference in height above the ground between the starting and ending points. The example below demonstrates this principle.

EX BS.) The same book is raised up 10 m at a $30^0$ angle. What is it change in potential energy?




There is another type of energy that we need to introduce; heat energy. Although technically all forms of energy are either kinetic or potential (heat is actually a combination of the two, which is difficult to understand at its most basic level), it is often convenient to label a special case as its own category. In this section we will define heat energy as the energy that is either given off or absorbed when a material changes temperature or undergoes a phase change.

You may remember the formula for calculating the heat required for a rise in temperature from Chemistry. It is:

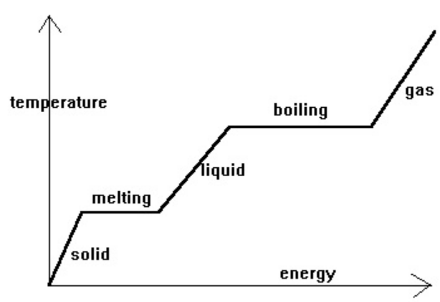
$$H=mc\Delta T$$

Where m is the mass of the sample, c is the specific heat of the material and ΔT is the temperature change. Notice that this form of energy is another delta or change. We will not be talking about "absolute" heat, only the changes in heat energy that occur when the temperature is changed. In this way, heat is like potential energy.

The specific heat © of a material is a quantity that measures how much energy it takes to raise the temperature of a certain amount of a material. The units for specific heat (in the mks system) are J/kg.$^0$C. Unfortunately, for historical reasons, specific heats are often measured in J/g$^0$C, so the student should be aware of possible unit traps in these sorts of problems. The specific heat is obviously material dependent, different materials have different specific heats, but less obviously it is pressure and temperature dependent. Technically, the specific heat of an object changes as the temperature changes. If we were to take that into account in our problems, the solution would be much more complicated (and require calculus). Fortunately, for solids and liquids, the temperature dependence (and pressure dependence) is small and thus we can treat it as a constant. In all our problems (even those occasional ones that involve gases) we will use this approximation. It is also important to note that different phases have different specific heats. In other words, the specific heat of water (liquid) is different than the specific heat of ice (solid) which is also different than the specific heat of steam (gas). An interesting (yet relatively easy) question for the student to consider is why we use degrees Celsius in specific heat instead of Kelvins.

EX BT.) How much energy does it take to raise the temperature of 100 g of water from $20^\circ$ to $70^\circ$ C (specific heat of water: 4190 J/kg$^0$C) Give an example of this amount of heat by comparing it to lifting apples.

Besides the fact that the specific heat changes after a material has undergone a phase change, there is another factor to keep in mind. Phase changes require extra energy. In other words, when water goes from liquid to gas, there is an extra burst of energy needed (quite a bit, actually) just to affect the phase change. This energy goes to rearranging the structure of the material and does not cause the temperature to rise. The student may remember a graph that is often discussed in chemistry classes, that looks like this:



This graph shows that when energy is added to a sample, its temperature rises until it reaches a phase change. At that point, energy is going into the material, but its temperature is not changing. This is the extra energy required simply to affect the phase change. There is one main assumption here, which is not often mentioned. The sample must be being heated evenly throughout the entire sample. In reality, this is very hard to accomplish.

This extra energy needed for a phase change is given by the equation:

$$H=mh_f$$

or

$$H=mh_v$$

Where $h_f$ and $h_v$ are the heats of fusion and vaporization, respectively. The heat of fusion is used when the phase change is from solid to liquid (<u>$-h_f$ is used from liquid to solid</u>) and the heat of vaporization is used from liquid to gas (<u>$-h_v$ is used from gas to liquid</u>). These constants, like specific heat, are material dependent. The example below illustrates how to use these.

EX BU.) How much energy is required to melt a block of ice (75 g) that is originally at -15° C and bring it up to 75$^0$ C (specific heat of ice = 2220 J/kg$^0$C, heat of fusion = 333 J/g)?

There is one last form of energy to be discussed, and that is energy lost or dissipated. Energy dissipated is energy that appears to be lost to a system (more on the reason the word "appears" is required in this definition later) due to friction, sound, light, or other extraneous causes. There is no formula for this energy, instead this is a "fiddle factor" type of thing. In other words, if some form of energy is too hard to account for quantitatively, we assign it to this category. Our abbreviation is $\Delta E_d$.

Before we move on to actually using these concepts in problems, we should mention that many other books explain energy using many other subcategories (like light, sound, nuclear, electric, etc.). Although helpful in explaining energy, there are really only two main categories, potential and kinetic, and all the others are different manifestations of these two (of course, each different manifestation has a different mathematical formula).

It behooves us to spend a little time acquainting the student with some of these different forms, simply so they can use them in qualitative explanations. For now, our mathematical discussion only requires the four above categories.

## Other Energy Categories

Chemical Energy: Locked up inside each chemical compound (notice compound, not atom) is a certain amount of potential energy. If the bonds in the compound are changed in any way, the amount of energy changes. Thus by rearranging the bonds (i.e. removing one element and replacing it with another, as in a chemical reaction) energy will either come out of the reaction or be required for the reaction to take place. In other words, anytime there is a change of bonds, some energy is either released or absorbed. All chemical reactions involve a change of bonds.

Electromagnetic Energy: This energy takes many forms, but the one to focus on at this time is the energy locked up as potential energy in the bonds that hold the electrons in orbit around the nucleus. Once again, if these bonds are changed (i.e. an electron is removed, added or moved to a higher orbital) the total energy changes and some is either required or released.

Nuclear Energy: This is the energy stored in the bonds that hold the protons and neutrons together in the nucleus. Once again, a change in bonds will release or require energy.

Gravitational Energy: Although already discussed, a note should be made that although our formula only works for objects near the surface of the earth, the concept of gravitational potential energy works at any distance between any two objects with mass.

Sound Energy: Whenever a sound is made, there is kinetic energy carried in the sound wave.

Light Energy: Actually a form of potential electromagnetic energy carried in a wave (or particles, don't ask).

Heat: We have already discussed heat energy, but we should remind the students that whenever the temperature of an object changes, there is a change of heat energy.

Mechanical (Potential): Mechanical or mechanical potential energy is a form of energy that is often locked up or stored in a device in some mechanical manner. Good examples of this are compressed or stretched springs, the energy of a squashed rubber ball or a piece of metal snapping back into place after being bent.

## The Conservation of Energy

The conservation of energy is the one law in physics that truly unites all its disparate parts into one complete whole. Later it will be amended to include the conservation of mass and energy (the work of ol' Albert) to become the one law in the universe that appears to have no exceptions (yet found). It is also a very misunderstood law, judging from the number of patent applications that reach the U. S. patent office each year for machines that violate this principle. In fact, this is one of the first things that the patent office checks for in eliminating extraneous and fanciful patent applications.

This law has many forms and each book has its own wording, but it can be summarized as:

> The total energy of a closed system must remain the same. The energy in the system can change forms but can never be created or destroyed.

This simple statement truly represents the beauty of Physics. It is concise and straightforward and carries hidden beneath its surface the power and majesty to explain much of the physical world. Also hidden behind its simplicity lies complexity. To truly understand the meaning and ramifications of the conservation of energy would take more than one lifetime.

Before we do some qualitative examples, we must first issue a warning and a definition. Notice the words "closed system". A system is a group of objects that is being considered as one thing. A closed system means that nothing can enter or leave the system. Very often this fact is overlooked. For example, if our system was a car, then we must also include the road, the exhaust, and the air in our system to consider it closed, otherwise things would be affecting the car and leaving the system.

At this point, we should take some time and learn to use the conservation of energy on a conceptual level. We do this by remembering that the total energy must remain the same, thus any loss in one area must be made up by a gain in the other and any gain must be accounted for by a loss. In other words, we can make predictions about the outcome of situations by examining what energy is present at the beginning of a scenario and then looking at what changes. The total must remain the same, thus any increase must be accompanied by a decrease. In each of the situations below, explain what losses or gains occur as the situation progresses. Below are some notes to keep in mind which might help in explaining these cases.

Reminders Regarding Energy Changes

1.) If there is any height change, there is a change of potential energy.

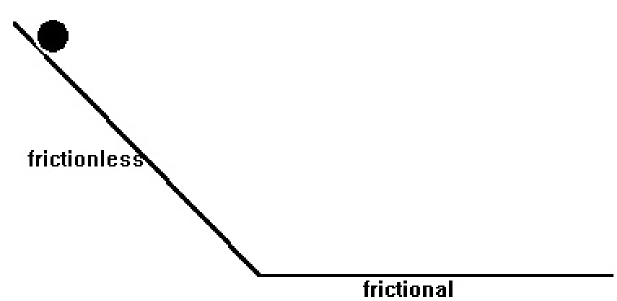
2.) If the object changes speed, there is a change of kinetic energy.

3.) If fuel is consumed, there is a loss of chemical potential energy.

4.) If friction is present, there is energy lost to heat and the surroundings.

5.) In explosions, there is a gain of sound, light and potential energy (bending objects, etc) and usually a loss of either chemical, kinetic or potential.

EX BV.) Describe the motion of the ball on the hill below according to the conservation of energy.



EX BW.) Explain, using the conservation of energy, what is occurring when a car rolls down a hill (with the motor off), hits a lamp post and drives away (only consider friction while the car is driving).

After doing the above example, it is interesting to ask what other potential energy exists in the car.

EX BX.) Explain, using the conservation of energy, what occurs when a car traveling down a highway hits its brakes and comes to a stop.

This result shows how wasteful braking is. It takes all your kinetic energy and simply discards it as heat. Wouldn’t it be better to take your kinetic energy and store it in a location where you could retrieve it later when you wanted to drive again. This is exactly the principle behind flywheels and regenerative braking in electric cars.

Perhaps an astute student has noticed a pattern here about the end result of all energy changes. It is worth thinking about.

EX BY.) Explain, using the conservation of energy, why a planet has different speeds in its elliptical orbit around the sun.

EX BZ.) Explain what occurs in terms of the conservation of energy when a rocket takes off from the earth and flies off to the deep reaches of outer space.

EX CA.) Explain, using the conservation of energy, what happens when a helium balloon is released and flies away.

EX CB1.) Explain the energy changes that occur when a nail is pounded into a piece of wood.

EX CB.) When a sky diver jumps out of a plane, they pick up speed until they reach "terminal velocity" and then continue at a constant speed. Explain this motion in terms of energy.

## The Mathematics of the Conservation of Energy

From all the above examples, you should have seen how quickly and easily information about an objects future motion can be predicted using the conservation of energy. If we were able to quantify energy and keep track of exactly how much was in each category, we should be able to make numerical predictions also. That is the true strength of this amazing law. By picking a point in the object motion and calling it "the before", we can choose another position and call it "the after" to find out exact information about the motion at that point. The method used is extremely direct, but before we begin we should discuss how and when it is best to use the conservation of energy.

Many of these problems you will encounter will seem to be the same type of problems that you encountered in our investigation of motion. Sometimes it is easier to use our equations of motion and sometimes it is easier to use energy conservation. Below are a few guidelines.

### Suggestions of When to Use the Conservation of Energy

1.) Time will not usually enter into an energy problem, there will just be a before and an after.
2.) If acceleration is not constant, energy is the easiest method to use.
3.) If motion is not following an easily defined path, it will often be too complicated to solve the problem using the motion equations. Instead, use energy considerations.
4.) If forces are specified, using the motion equations is usually the easiest way to solve the problem.

The last suggestion does not apply yet, since we have not learned about forces, but keep it in mind for later.

To solve problems with the conservation of energy, we use the following mathematical form:

Total Energy Before = Total Energy After

Kinetic Energy Before = Kinetic Energy After + Any Other Changes

$$T_i = T_f + \Delta U + \Delta H + \Delta E_d$$

where

$T_i$ = Initial Kinetic Energy

and

$T_f$ = Final Kinetic Energy

In the above formula, we use the following sign conventions:

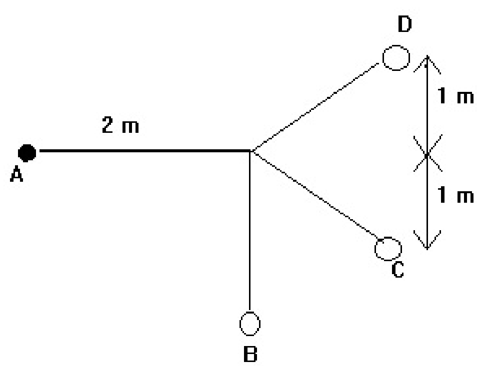
$\Delta U$ = + if object rises
- if object falls

H = + if temperature rises
- if temperature falls

$\Delta E_d$ = + if energy is lost

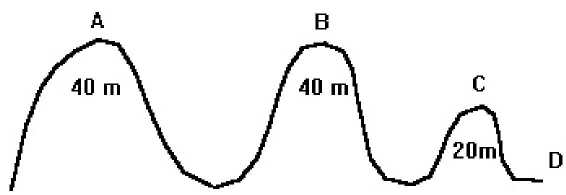
The easiest way to learn how this formula is applied is by example.

EX CC.) A 1 kg mass is placed on the end of a light rod and released as shown from point A. What is its speed at point B? What is its speed at point C?




EX CD.) A 1500 kg car traveling at 25 m/sec slows to a stop without skidding. If the brakes are made of aluminum (3 kg, c = 0.9 J/g°C), how much does the temperature of the brakes rise in order to stop the car? What factors might affect this answer in real life?

EX CE.) A frictionless roller coaster starts at point A with an initial velocity of 2 m/sec. What will be its final speed at points B, C and D?




EX CF.) Suppose the coaster reached point B with a speed of 1.25 m/sec. How much energy was lost to heat? (mass = 1000 kg)
If the coaster loses the same amount of energy going to point C, what would be its final speed?

Occasionally springs are used to store energy (this type of energy, called mechanical potential, is actually electromagnetic energy since it is a storing of energy by stretching the bonds that hold the material together) in the manner illustrated in the example below. When this energy is stored it has a value of:

$$\Delta u_{sp}=(½)k\Delta x^2$$

Where k is something called the spring constant (usually a given, it is different for each spring) and $\Delta x$ is the distance the spring is either compressed or stretched. Notice how once again, the vector is squared and the end result is a scalar (energy).

Some notes about this situation are in order. First, this equation only works for "ideal springs" which exert the same force whether they are compressed or stretched. For example, if you push an ideal spring in one centimeter and it pushes back with 10 N, then the same spring will pull with 10 N if it is stretched by one centimeter. It will work for most springs provided the $\Delta x$ is small compared to the spring. Secondly, notice the units for a spring constant: $kg/sec^2$. Many books give these constants in units of N/m (which is of course the same) but the latter is a little more illustrative of exactly what the constant measures. We will discuss spring constants in more detail when we discuss forces.

One other concept necessary in the discussion of energy is efficiency. The efficiency of a system is a measure of how much energy (as a percentage) is lost to friction. Thus, the efficiency of a system can be written in a number of ways, two of which are

Eff = What comes out/what went in

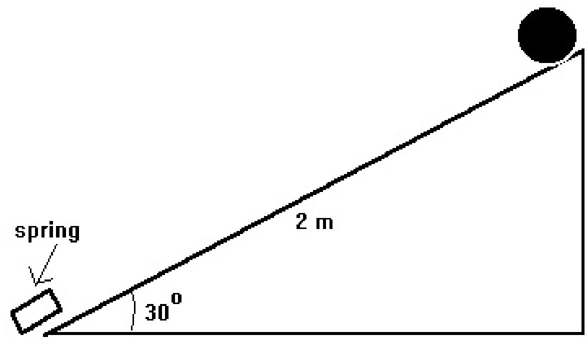
Eff = (total energy-$\Delta E_d$)/total energy

A more general method of describing efficiency is that efficiency is a measure of the useful energy increases compared to the energy decreases in the overall system.

Eff = (useful energy increases)/energy decreases

EX CG.) A ball rolls down a frictionless incline and compresses a spring at the bottom. The spring then shoots the ball back up, but some energy is lost in the transfer. If the ball is 2 kg, the spring has a k=1200 $kg/sec^2$ and is 75% efficient in its energy transfer,

a.) how much is the spring compressed?
b.) how fast is the ball going when it leaves the spring?
c.) how high does it rise?




An interesting, albeit slightly complicated, note can be made regarding part c in the problem above. Part c can be most easily done if we recognize two things: that any point can be our initial point and that the variable h in our ΔU equation is a linear variable (its exponent is one). Since we can call our initial point the very beginning and since the only loss of energy occurs in the spring, the ball will return to 75% of its initial height (because it will have only 75% of its initial energy). This works only because h is a linear variable, thus whatever changes occur (percentwise) to the energy will also occur to the height. If the height were squared, this would not work (the answer would be the square root of 75% times the original velocity).

## The Second Law of Thermodynamics

It has been stated that energy can neither be created nor destroyed but can change forms. In real life we always encounter friction, thus there is always some energy "lost" to heat. In fact, there is a law which explains this in detail. Before we discuss it, however, we need to talk about different kinds of heat energy.

Heat energy can be classified as either useful or useless heat. Useful heat energy is heat that can be turned into another type of energy. For example, a car turns the heat energy of the exploding fuel into kinetic energy of motion. Useless heat energy is energy that cannot be turned into any other form. Once energy is changed into useless heat, it remains there forever. Useless heat is the grave of energy (the actual explanation of why energy is useless is fairly complex but can be simplified into saying that heat can only be used if there is a difference in heat between two objects, useless heat is when both objects are heated, thus they cannot exchange heat).

The second law of thermodynamics says:

Every time an energy change takes place, some energy is converted to useless heat.

Thus we "lose" energy whenever an energy change occurs. This energy can never be used again. The wording above is not actually the wording of the law itself, but rather a paraphrase. Many physicists state this law as "There is not such thing as a free lunch", meaning that every time a change takes place, you have to pay with useless heat. You can never have a 100% efficient conversion of energy from one for to another. This is why perpetual motion machines are impossible to construct (although many people still try - the patent office is flooded with these every year - the second law is another law the office uses to sort out frivolous patent applications). The second law also deals with entropy, which you probably learned about in chemistry class. Entropy is a measure of the disorder of a system, in a way it is a measure of the useless heat. The second law says that the entropy of a system must always increase. If we consider the universe as a system, we can see that eventually we will run out of useful energy and we will be simply a hot ball of gas where nothing can be done. This cheery prospect is often termed "heat death". Have a nice day.

## Power and Energy

Related to the concept of energy is the concept of power. Power is the rate at which energy is used. Mathematically:

Power = Energy/time.

Thus we see that the units of power are Joules per second, which has a special name of a Watt.

1 Watt = 1 W = 1 J/sec

Named after James Watt, who was also a pioneer in the field of energy research. Thus devices which are labeled in Watts (most commonly electrical devices) are labeled to tell you how much energy they use per time. With this concept, we can do many more problems with energy.

EX CH.) If you lift a 400 kg box 2 m in the air in 3 sec, what power did you use?

EX CI.) What average power is required to lift a 2000 kg small airplane to an altitude of 2000 ft and a cruising speed of 100 mph in two minutes?

Assignment #10A

1.) If your hands have a mass of 1.5 kg each, how much energy is given off in a hand clap (speed = 0.75 m/sec just before impact)?

2.) Suppose a 30 kg cart is moving at 4 m/sec on the track below. Will it stop before the edge or will it fall off ? (E5*)


3.) If a 1500 kg car accelerated from 5 m/sec to 20 m/sec, how much energy was released by the fuel if the car motor is 60% efficient?

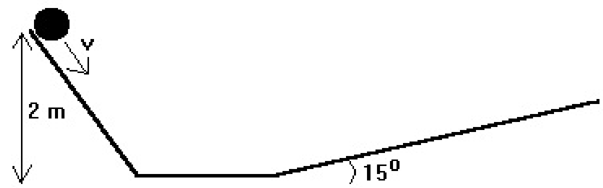
4.) Which has more kinetic energy, a 1500 kg car at 20 m/sec or a 2000 kg truck at 7.5 m/sec? How much energy does each one have?

5.) During a baseball game, the center fielder throws a ball at 32 m/s to the first baseman, who catches it at the same level. The ball has slowed to 28 m/s during its travels. How much energy was lost to friction?

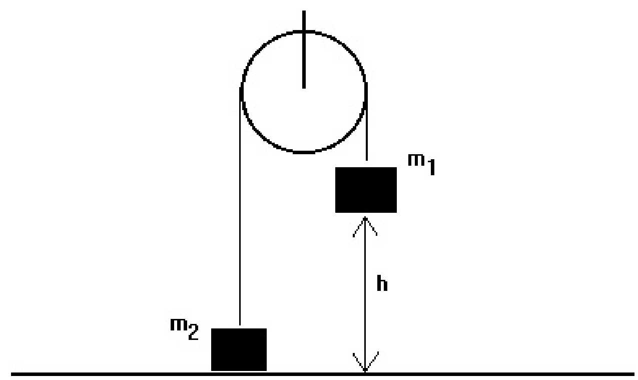
6.) If a 0.5 kg ball is dropped from a 20 story window (70 m) and is traveling at 33 m/sec the instant before it hits the ground, how much energy was lost to friction?

7.) Suppose a car accelerates from $v_1$ to $v_2$. What is the percent increase in its kinetic energy?

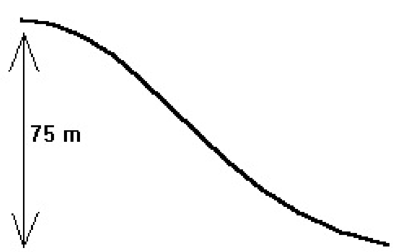
8.) If a ball is pushed from the top of the ramp below at an initial speed of 11.2 m/s, how long must the second, less angled ramp be in order to bring the ball to a stop? (E12)




9.) Using energy considerations, determine the speed of block 1 after it has fallen a distance h. (No friction, block 1 is more massive than block 2)(E8)



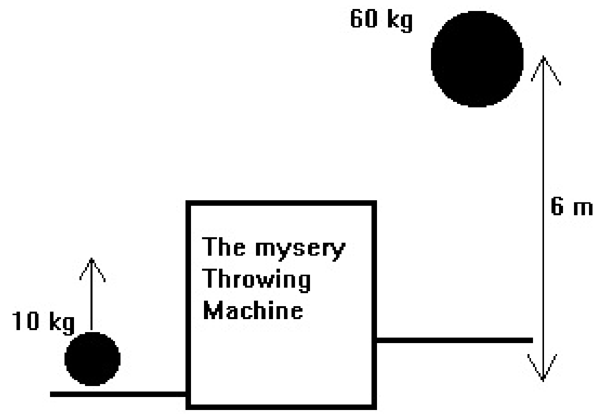

10.) A 2000 kg roller coaster rolls down the hill below and then applies the brakes and comes to a stop. How much energy was lost to heat in stopping the coaster (assume it began at the top of the hill with v=0)? If you used this energy to heat up the house, how high could you raise the temperature? Mass of air in house = 561 kg, specific heat = 700 J/g°C. (E11)



11.) Decipher: "Rapidity of nuptualization can be bemoaned over an extended period of terrestrial rotation." (DNCTHWG)

# Assignment #10B

1.) A 60 kg weight drops from 6 m onto the machine below. The machine transfers the energy from the falling ball to a 10 kg ball that it shoots back up in the air. Neglecting air resistance, how fast will the 10 kg weight be traveling when it leaves the device and how high will it rise? (Imagine this to be a perfect energy transfer.)(E10)




2.) A ball is dropped from 10 m onto the concrete. It bounces and leaves the ground with only 70% of its original speed. If the ball is 0.25 kg, how much energy is lost to heat and sound and how high will it rise after the first bounce.?

3.) On the set up below, a 4 kg ball is connected to a flywheel by string so that it can slide(not roll) down the plane. The flywheel has a radius of 7 cm. When the ball is released, it slides down the plane and when it reaches the bottom, the string comes off the flywheel, leaving it spinning at some angular velocity. The ball reaches the bottom at 1.2 m/s.

a.) What is the amount of energy given to the spinning wheel by the block?

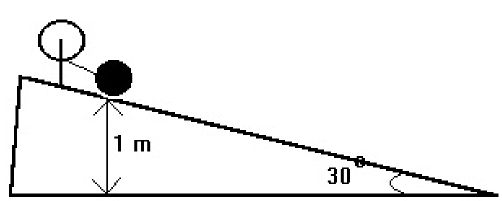
b.) What was the acceleration of the block down the plane?

c.) What was the angular acceleration of the flywheel?

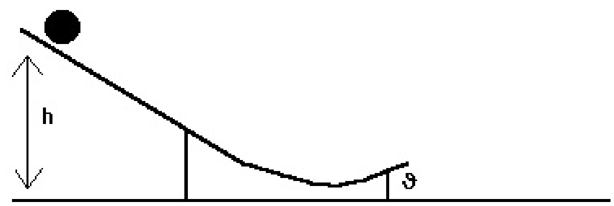
d.) What was the flywheels angular velocity at the end of the run?

e.) What is the mass of the cylinder?

(E6)



4.) A ball is released on the ramp below, whose end is angled up, causing the ball to project outward and upward. Derive an equation that gives the horizontal range of the projectile in terms of the givens. Assume the ball lands at the same height from which it is launched and assume the height of the take-off ramp is negligible. (P16)




5.) A 60 kg cannon ball is fired at a 70° angle from a point 150 m from the base of a 150 m cliff. The firing speed is 75 m/sec. Determine the velocity of the ball when it hits the ground on top of the cliff. You must use energy considerations to solve this problem, do not use projectile motion equations.

6.) A ball of clay drops from 6 m onto the ground and takes 0.04 sec to come to a stop. What power was exerted as the clay stopped if it had a mass of 300 g?

7.) If a 60 W light bulb is placed in a sealed container of 400 ml of water, how high will the temperature of the water rise in 40 sec (assuming that all the light is absorbed by the water as heat).

8.) After releasing the accelerator on your car, you notice that the car slows about 5 mph every 3 sec. If your car has a mass of 900 kg and was initially traveling at 55 mph, what is the power loss due to friction that your car is experiencing during the first 3 seconds? During the second 3 seconds?

9.) An electric motor uses 350 W as it lifts a 100 kg box three meters straight up in 10 sec. What was the efficiency of the motor?

10.) Decipher: "Those who purchase items on the open market must take heed of the possibility of being deceived." (DNCTHWG)

## Activity #9 - Catch the Ball

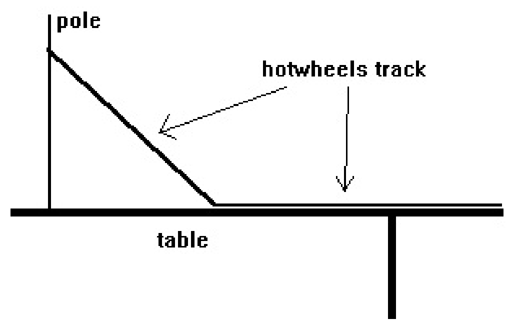
In this activity, you will use the concepts you have learned in projectile motion to attempt to position a target so that you hit it in one try.

**Warning: It is very tempting to cheat in this exercise. Do not release the ball until your instructor tells you to do so.**

Procedure:

1.) Get a ramp, steel ball and Hot Wheels track from the instructor.

2.) Position the apparatus as shown below.




3.) Use a piece of tape to mark a point about one inch from the top of the ramp. Throughout the lab you will always release the ball from this point.

4.) Measure the height of the table above the ground and then use your knowledge of projectile motion and energy to determine the exact location of the balls contact with the ground.

5.) When you are sure, your instructor will position a target (a small egg) at the location you specify.

6.) Release the ball and see if it hits the target. If it does not you must repeat the procedure with a new ramp until you hit the target.

## Activity #10 - Energy Loss

In this lab you will attempt to find a relationship between the number of bounces a ball undergoes and the amount of energy loss during the bounce.

Materials: Meter stick, "super" ball.

Procedure:

1.) Holding the meter stick vertical, drop the ball from the one meter mark.

2.) Notice and record how high the ball returns on the second, third, fourth, fifth and sixth bounce. Because of the quickness of the ball and the occasional unpredictability of bounces, it may take a few tries before you get an acceptable set of measurements.

3.) Repeat the above step four more times.

| Bounce Number | Height Before Bounce | Height After Bounce | Energy After Bounce | Energy Loss During Bounce | Percent of Loss During Bounce |
|---|---|---|---|---|---|
| 1 | | | | | |
| 2 | | | | | |
| 3 | | | | | |
| 4 | | | | | |
| 5 | | | | | |

4.) Measure the mass of the ball and determine the energy of the ball before release. Fill in the remainder of the chart (using the energy loss divided by the original energy before the bounce as the percent loss).

5.) Graph Energy Loss During Bounce versus bounce number and use the graphical technique to attempt to determine a mathematical relationship between the two.

6.) Graph Percent Energy Loss versus bounce number and attempt to determine a relationship between the two.

Hints on Conclusions: Was this a very precise lab? Did your relationships work out as expected? Do they make sense? Which relationship is better? How can you make that determination? Attempt to extrapolate using the mathematical formulae you determined. Does this method of evaluation give you any clue as to which relation is better?

General Notes: The actual relationship between bounce number and energy loss is no easy thing to determine, thus this lab is simply a crude approximation and a crude attempt to better understand energy and the results should not be taken too seriously.

## Lab #7 - Power

In this lab, you will determine power (or energy loss) in a system and attempt to determine what (if any) factors affect it. You will do so by setting up a system involving springs and a cart and timing the amount of time required before the system comes to rest. After doing so, you will determine the energy in the system before the initial time and calculate the power of the loss of energy. You will then repeat the experiment by varying one of two conditions: the initial release point or the mass of the cart. Once you have accumulated your data, you will graph energy loss versus the variable and determine if a relationship exists.

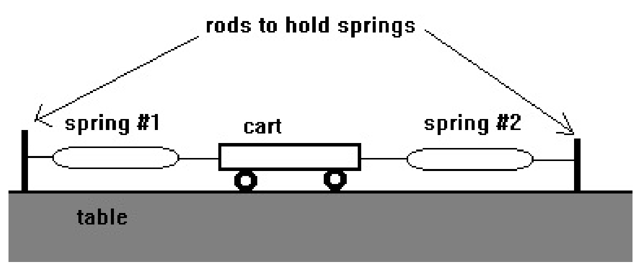
### Procedure:

1.) To begin, you must determine the spring constant of your set up. To do so, take a spring and attach it to a weight. Allow the weight to hang freely and measure how much the springs stretched. The formula below (where m is mass of weight and $\Delta x$ is distance stretched) will give you the spring constant for the spring.

$$k = mg/\Delta x$$

You must do this for each individual spring and you should also measure the unstretched length of the spring.

2.) Set up the apparatus as shown below.




Measure the stretched lengths of the springs and calculate the energy stored in the system. This will be your "final energy" after the system has come to rest.

3.) Pull the cart about 10 cm from the center position and measure the stretched lengths of the springs. Use this information to calculate the energy stored (initial energy). Release the cart and begin timing with the stop watch.

4.) When the cart come to rest, stop the clock and record the information.

5.) Repeat this three more times, finally arriving at an average for the time.

6.) Use your formulas to determine the initial energy stored in the spring at the beginning of the trial and then use that information to determine the power loss.

7.) Repeat this procedure, starting the cart at 7 cm, 4 cm, and 2 cm, from the center.

8.) From this information, graph power versus amplitude (distance the cart was pulled from center) and determine if a relationship exists. Only conclude that a relation exists if the pattern is obvious.

Spring Constant #1:____________________ Length of Stretch:______

Spring Constant #2:____________________ Length of Stretch:______

Final Energy of System:______________________

| Trial | 10 cm Time | 7 cm Time | 4 cm Time | 2 cm Time |
|---|---|---|---|---|
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| Average | | | | |

| Trial | Time | Initial Energy | Power Loss |
|---|---|---|---|
| 10 cm | | | |
| 7 cm | | | |
| 4 cm | | | |
| 2 cm | | | |

9.) Repeat the above procedure, this time varying the mass of the cart. Begin with no extra masses on the cart and then add 50 g increments until you have reached an extra 300 g (use 10 cm as amplitude for each trial). When you are finished, do not forget to measure the mass of the cart.

10.) Graph power loss versus <u>total mass</u> (cart + extra masses) and determine if a relationship exists.

| Trial | Cart | Cart + 50g | Cart + 100g | Cart + 150g | Cart + 200g | Cart + 250g | Cart + 300g |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| Aver. | | | | | | | |

| Trial | Total Mass | Average Time | Initial Energy | Power Loss |
|---|---|---|---|---|
| cart | | | | |
| cart + 50 g | | | | |
| cart + 100 g | | | | |
| cart + 150 g | | | | |
| cart + 200 g | | | | |
| cart + 250 g | | | | |
| cart + 300 g | | | | |

Hints on Analysis and Conclusions: Were the results as you expected? Can you see a physical reason for any of the relations?

# Conservation of Energy Lab

Purpose: To see how gravitational energy can change to kinetic energy and to evaluate the amount of energy lost to friction in a given situation.

Procedure:

1.) Set up a marble roller coaster track on the table, so that the ball goes down one large hill and then rides across a straight, level section of track for at least one meter. Measure the mass of the marble and record it below and record the height of the hill as measured from the table. Record the length of the straight section of track.

2.) Set a photogate to measure the velocity of the marble as it reaches the bottom of the hill.

3.) Release the marble and find its velocity at the bottom of the hill.

4.) Release the marble from the same spot again and find its velocity at the end of the one meter section. (Steps 3 and 4 can be done simultaneously if two photogates are available).

5.) Record both velocities in the chart below.

6.) Repeat the experiment two more times for different heights of the hill.

Data: (to be recorded in class)

Mass of marble:_______________ (in kg)

| Trial | Height of Hill | Length of Straight Section | Vel at Bottom of Hill | Vel at End of Track |
|---|---|---|---|---|
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |

Questions

1.) Find the potential energy of the marble at the top of the hill, and the kinetic of the marble at the bottom and at the end of the track.

| Trial | Potential at Top | Kinetic at Bottom | Kinetic at End |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |

2.) Should all these values be the same? Why or why not?

3.) Find a percent error between the kinetic at the bottom and the potential at the top for each trial.

| Trial | % error |
|---|---|
| 1 | |
| 2 | |
| 3 | |

4.) Find a percent error between the kinetic at end and the potential at the top for each trial.

| Trial | % error |
|---|---|
| 1 | |
| 2 | |
| 3 | |

5.) Where there any patterns in the two charts?

6.) Can you explain any patterns or differences in the two charts above?

7.) Find the energy lost going down the hill and the energy lost going across the straight track for each trial.

| Trail | Energy Lost Going Down Hill | Energy Lost on Straight Section |
|---|---|---|
| | | |
| | | |
| | | |

8.) Did you notice any patterns?

9.) Find the energy lost per unit length of the straight section of track.

| Trail | Energy lost/Length |
|---|---|
| | |
| | |
| | |

10.) Did you notice any patterns?