Introduction to the Concept of Energy

Changes in the Properties of Objects

In your middle school science classes, you probably heard the word “energy” many times. That makes sense: The concept of energy is one of the most important in all of science. Now that you are in high school, it’s time to give this important concept a closer look.

The most important thing to understand about the concept of energy is that it was invented by people. Specifically, it was invented so that people could make reliable predictions about things that happen in the physical world, the world of objects. By “objects” we mean not just lead pellets, bouncy rubber balls, robots or dropper poppers, but also the water in a glass or the air in a room. Often, we want to think about groups (sets) of objects. We will call a set of one or more objects a system of objects, or (to save ink) simply a system. What objects we choose to be in a system (i.e., how we define the system) is entirely up to us.

Objects and systems of objects have properties. Examples we have already encountered in earlier investigations include speed, configuration and temperature. Perhaps the most important thing about the world, something we learn when we are very little, is that properties change. The warm milk in a bottle gets cold. The other thing we learn is that properties don’t just change for no reason. They change as a result of something we will call a process.

Every process has a beginning (a start) and an end. These are two instants in time. Just like we get to define the system (choose which objects are in the system), we get to define the process (choose when the process starts and ends). For example, suppose you pick up a ball, hold it at shoulder height, let the ball go and watch it bounce and roll to a stop. We could define the system to be just the ball, or include both the ball, the Earth and maybe the air as well. Similarly, there are many different processes we could define. For example, we could define a process that starts the instant we let go of a ball and ends the instant the ball reaches the floor, or we could start the instant the ball hits the floor and end when the ball comes to rest.

Question 1: In the previous investigation, you made some observations. Pick an observation and complete the following sentence: “In [name the experiment] we observed a change in the [name the property] of a [name the object or system of objects] resulting from a process that started the instant [define the start of the process] and ended the instant [define the end of the process].”
Sometimes, there are properties that change during a process but are actually the same at the end of the process as they were at the start of the process.

Question 2: Think again about the observations you made in the previous investigation. What was a property that was the same at the start and the end of a process, even though it changed during the process? Answer by completing the following sentence: “In [name the experiment] we observed a process that started the instant [define the start of the process] and ended the instant [define the end of the process]. During this process the [name the property] of the [name the object] changed, but was the same at the start and end of the process.”

When a property is the same at the start and the end of a process, we say there has been no net change in that property. If the property is different at the end of a process from what it was at the start of the process, we say there has been a net change in the property.

Question 3: Think again about the observations you made in the previous investigation. Identify an object, a process and two properties, one for which there was a net change, and one for which there was no net change. Then complete the following sentence: “In [name the experiment] we observed a process that started the instant [something happened] and ended when [something else happened]. There was a net change in the [name one property] of the [name the object], but no net change in its [name the other property].”

Question 4: In the previous investigation, you performed a series of experiments. For each experiment, complete one row of the table on the following page. Note that there are many acceptable choices for the start and end of each process.
<table>
<thead>
<tr>
<th>Exp. no.</th>
<th>The object is the ...</th>
<th>The process starts the instant ...</th>
<th>The process ends the instant ...</th>
<th>For this process there was a net change in ...</th>
<th>For this process, there was no net change in ...</th>
</tr>
</thead>
<tbody>
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</tbody>
</table>
Introducing the Concept of Energy

Let’s quickly review what we have learned about changes in the properties of objects and systems. We will do that using as an example a system you might be very familiar with. Be sure to check in with your teacher after every question.

Question 1: Obtain a toy pull-back car from your teacher. Complete the table below. The first cell is filled in as an example. Note you may need to clarify when the process starts and ends. Leave the last column blank for now.

<table>
<thead>
<tr>
<th>Process</th>
<th>Was there a net change in speed? Explain.</th>
<th>Was there a net change in temperature? Explain</th>
<th>Was there a net change in configuration? Explain</th>
<th>[See Question 5]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Give the car a shove so that it coasts along a level surface. The process begins the instant you touch the car and ends the instant you release the car.</td>
<td>Yes. The car starts at rest, and ends in motion.</td>
<td></td>
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<tr>
<td>Pull the car back (winding up the spring inside). The process begins the instant you touch the car and ends the instant you stop moving the car backwards.</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Pick up car, carry it outside and leave it in the sun. The process begins the instant you place the car in the sun and ends an hour later.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Let go of the car after it has been pulled back. The process begins the instant you release the car and ends while the car is moving.</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Pull the car back, let it go and let it crash into a book. The process begins the instant you touch the car and ends after the car has come to a stop.</td>
<td></td>
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</tbody>
</table>

Forms of Energy
As children we figured out that changes in properties are interrelated. For example, a child quickly learns that the maximum speed of a pull-back car depends on how far she pulls it back, that is, how much she changed the configuration of the car, in particular, the shape of the spring inside the car.

The concept of energy allows us to think about these relationships quantitatively. For example, when you wind the spring of the toy car by pulling it back, we say you are increasing the “configuration energy” of the spring by a certain amount, say, 6 energy units. When you let the car go, the spring returns to its original configuration. This results in a decrease in configuration energy of 6 units and a simultaneous increase in the car’s “speed energy”. But because of friction and air drag, the car’s “temperature energy” also increases, let’s say by 2 energy units. If we know those two quantities, and there are no other physical changes, we can predict that the increase in speed energy will be 4 units, 2 units less than the 6-unit decrease in configuration energy. No wonder some people refer to energy as the “common currency” of physical change!

Question 2: Suppose it were possible to eliminate all friction and air drag from the process just described, and that the car rolls across an infinite horizontal surface.

a) By how much would the speed energy increase? Explain your reasoning.

b) Would the car ever come to a stop? Explain your reasoning.

In our example, we mentioned three forms of energy, “speed energy”, “configuration energy” and “temperature energy”. For historical reasons, these are usually called by other, more impressive names: kinetic energy, potential energy and thermal energy.

How do we know if a process changes one or more forms of energy? We can start with some basic rules (pay careful attention to the word “net”):

Without a net change in speed, there can be no net change in kinetic energy.

Question 3: Write similar rules for changes in potential and thermal energy.

Notice how each of these rules is phrased like the rule:

Without living in California, you cannot live in San Francisco.

That is because living in California is a necessary condition for living in San Francisco. You can’t live in San Francisco without living in California. In contrast, living in California is not a sufficient condition for living in San Francisco. You can live in California without living in San Francisco.

Question 4: Is a change in configuration a sufficient condition or a necessary condition for a change in potential energy? Explain.

Question 5: Go back to the table under Question 1 and write the following heading for the last
column: “Possible net energy changes” For each row, fill in this column by writing the words “kinetic energy”, “potential energy” and/or “thermal energy”.

Energy Changes and System Definitions
Whether or not there are changes in energy (especially potential energy) often depends on how you think a process, as in the following example:

Question 6: Consider a process that starts the instant you let go of a rubber ball and ends after the ball comes to a stop.

a) Did the process cause a net change in the configuration of the Earth, by which we mean the huge iron ball deep beneath our feet. (A simple “yes”, or “not as far as we can tell” is ok here).

b) Did the process cause a net change in the potential energy of the Earth? Look back at the rules we just developed. Explain your answer.

c) Did the process cause a net change in the configuration of the ball? (A simple “yes”, or “not as far as we can tell” is ok here).

d) Did the process cause a net change in the potential energy of the ball? Be careful! Don’t rely on something you memorized in middle school. Look back at the rules we just developed. Explain your answer.

e) Here’s a hard but really important question: Can you think of something that did change its configuration? Explain.
There is a word that might have helped you answer the last part of the previous question: that word is “system”. Recall that a system is a set of one or more objects.

Question 7: A student holds two golf balls, A and B, one in each hand. To begin, A and B are touching.

a) Let’s say the system contains just ball A. The student moves A and B apart. Has the configuration of the system changed? Explain your response.

b) Now let’s define the system to include both A and B. Again, the student moves A and B apart. Has the configuration of the system changed? Explain your response.

So we can say that a change in the configuration of a system requires either: 1) a change in the configuration of an object in the system (like the spring in a toy car); or 2) a change in the distance separating the objects in a system (like a ball and the Earth).

To figure out whether there has been a net change in system configuration, just imagine two “snapshots” of the system, one taken at the start of the process, the other at the end of the process. There can be no change in configuration unless the two snapshots look different.

Question 8: A student holds two golf balls, A and B, one in each hand. To begin, A and B are touching.

a) Let’s define the system to include both A and B. The student moves A and B apart. Has there been a net change in the configuration of the system?

b) Again, let’s define the system to include both A and B. This time, the student moves A and B apart and then back together again, exactly as they were. Has there been a net change in the configuration of the system? Explain your response.

To save ink, we will represent the change in the amount of system kinetic, potential and thermal energies by writing $\Delta KE$, $\Delta PE$ and $\Delta TE$, respectively. The symbol “$\Delta$” means “change in”. If you are in a hurry, you can just type DKE, DPE and DTE, but never forget to say “change in” or “delta”.

If a process brings about a net increase in kinetic energy, we can write or say “delta KE is positive” and write “$\Delta KE > 0$”. If a process brings about a net decrease in kinetic energy, we can say “delta KE is negative” and write “$\Delta KE < 0$”. If the kinetic energy is the same before and after a process, we can say “delta KE is zero” and write: “$\Delta KE = 0$”. Similarly for $\Delta PE$ and $\Delta TE$.

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1 Really, a system is a set of one or more systems, with the simplest possible system being something we call a particle. A particle is an object whose configuration cannot change.
We will develop ways of figuring out whether energy changes are positive or negative. The important thing for now is knowing whether or not net changes in kinetic, potential or thermal energies are even possible. Keeping that in mind, answer the following question.

Question 9: Complete the following table, based on the previous investigations. For experiments with two rows, come up with two different system definitions.

<table>
<thead>
<tr>
<th>Exp. no.</th>
<th>name(s) of object(s) in the system</th>
<th>start of process</th>
<th>end of process</th>
<th>possible net energy changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dropping bags of lead pellets</td>
<td>bag of lead pellets</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>bag of lead pellets and the Earth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Dropper popper and bouncy ball</td>
<td>dropper popper</td>
<td>Just before the dropper popper is turned into a hat shape</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>dropper popper and Earth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Happy and sad balls</td>
<td>“Happy” ball and Earth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Robots!</td>
<td>the robot</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Question 10:

If you have time, continue on the table from question 9 here according to the various prompts above. If the row is entirely blank you should pick an experiment, a system and the start and finish of the process.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Description</th>
<th>Time Event 1</th>
<th>Time Event 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 lead bag</td>
<td>Lead bag</td>
<td>The moment you let go of the bag</td>
<td>When you caught the bag before it hit the floor</td>
</tr>
<tr>
<td>1 lead bag</td>
<td>Lead bag and the earth</td>
<td>The moment you let go of the bag</td>
<td>When you caught the bag before it hit the floor</td>
</tr>
<tr>
<td>3 Reusable hot pack</td>
<td>hot pack</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Ammonium nitrate and water demo</td>
<td>water and ammonium nitrate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Robot</td>
<td>Robot (in the case when you let it drive up the ramp)</td>
<td>The moment you press the blue button</td>
<td>6 seconds later</td>
</tr>
<tr>
<td>6 Robot</td>
<td>Robot and earth (in the case when you let it drive up the ramp)</td>
<td>The moment you press the blue button</td>
<td>6 seconds later</td>
</tr>
</tbody>
</table>
The Law of Conservation of Energy

*Isolated Systems*

During many processes, the system interacts with the surroundings. For example, if the system is a teapot and you put the teapot on a hot stove, the system (the teapot) is interacting with the surroundings (which includes the stove). We must take that interaction into account to understand the process that is taking place.

During other processes, there might be interactions between the system and the surroundings, but those interactions are negligible. By “negligible” we mean we can understand everything we want to understand about the process without taking those interactions into account.

For example, the process of pulling back and letting go of a pull-back car is not affected in a detectable way by the position of the Moon in the sky. Interactions between the Moon and the car are way too small to measure or even to detect. The interactions are there, but they are negligible.

When all interactions with the surroundings are negligible, we say the system is isolated. For the process we are observing, that poor little system might as well be alone in an otherwise empty Universe.

**Question 1:** Think about the following process: You let go of a pull-back car, it rolls across a table, and finally stops. Which of the following systems, if any, are isolated? If the system is not isolated, identify the interactions between the system and the surroundings that we must take into account to understand the process.

a) just the car

b) the car and the table

c) the car, the table and the Earth (Note: By “the Earth” we mean the huge iron ball that is most of our planet - not the air, water, dirt and living things that coat the outside of the planet.)

d) the car, the table, the air in contact with the car, and the Earth.
The Law of Conservation of Energy
Consider a system comprising a ball and the Earth. If you drop the ball, the speed of the ball will increase. The ball is part of the system, so system kinetic energy is increasing. What about system potential energy? As the ball falls the configuration of the ball-Earth system changes. That means system potential energy might be changing as well. But is it? To decide, we state a key principle underlying the entire energy concept:

The total energy of an isolated system cannot change.

This is called the law of conservation of energy. The change in the total energy of a system is the sum of the changes of each form of energy. So the law of conservation of energy implies that, for an isolated system,

\[ \Delta KE + \Delta PE + \Delta TE = 0. \]

Question 2: Suppose a system is isolated.

a) If a process brings about no net change in either thermal energy or kinetic energy, what can you say about the change in potential energy?

b) If a process brings about no net change in thermal energy, what can you say about the changes in kinetic and potential energies? Explain.

We can use the law of conservation of energy to answer the question of what happens to the potential energy of the ball-Earth system as the ball falls. To begin with, let's neglect air resistance. Then we know two things:

1) for all practical purposes, the ball-Earth system is isolated; and
2) the temperature of the system is not changing (so \( \Delta TE = 0 \)).

That means we can use the law of conservation of energy to write:

\[ \Delta KE + \Delta PE + \Delta TE = 0 \]

\[ \Delta KE + \Delta PE + 0 = 0 \]

or:

\[ \Delta PE = - \Delta KE. \]

We know the speed of the ball is increasing, so we know the change in the kinetic energy of the system, \( \Delta KE \), is positive. This means that the change in the potential energy of the system (\( \Delta PE \)) must be negative and must be equal in magnitude to the change in kinetic energy.
Question 3: Which one or more the following is equal in magnitude to 5?
   a) - 5
   b) - (-5)
   c) -|-5|
   d) |-5|

Question 4: You toss a ball straight up, releasing the ball at the height of your shoulder, and waiting for the ball to fall to the floor. Consider the process beginning the moment you release the ball and ending the instant the ball passes shoulder height on the way down.
   a) What is the net change in potential energy of the ball-Earth system? Explain.

   b) On the previous page you figured out that the potential energy of the system must decrease as the ball falls. What can you conclude about the change in system potential energy as the ball rises? Explain.

Question 5: You throw a ball upwards into the air. At the instant you released the ball, it was moving at a certain speed. At the instant the ball has fallen back to the height where you released it, the ball will also have a certain speed. How do those two speeds compare? Explain using the law of conservation of energy. Again, we are ignoring air drag.
So What About Air Resistance/Air Drag?
As a ball falls, there is an interaction between the ball and the air. Unless that interaction has negligible effects, the ball-Earth system (which does not include the air) is not really isolated. And if a system is not isolated, we can't apply the law of conservation of energy for isolated systems! We can solve this problem by redefining our system.

Question 6: Consider a rigid ball that was at rest and now is falling. Suppose air drag is not negligible.

   a. Which of the following systems can we reasonably consider to be isolated:
      i) the ball alone
      ii) the ball and the Earth
      iii) the ball, the Earth and the air comes into contact with the ball

   Explain.

   b. For that isolated system, consider possible changes in system kinetic, potential and thermal energies. Are those changes positive, negative, or negligible? Explain.
Question 7: Take two coffee filters. Hold one in each hand. Squish one filter into a wad and leave the other cup-shaped.

a) Let go of both filters from shoulder height. Which filter takes less time to reach the level of your knees, the wadded-up filter or the cup-shaped one? Can we neglect air drag?

b) Consider two systems, each comprising a coffee filter, the Earth and the air that comes into contact with the filter. In one system, the filter is wadded up while in the other system, the filter is cup-shaped. Consider a process that begins when you let go of the coffee filter from shoulder height and ends when the filter has reached the level of your knees. For that process, is the change in kinetic energy the same for the two systems? If not, which system will have the greater kinetic energy change? Explain.

c) Consider the changes in potential energy. Are they the same for the two systems? If not, which system will have the greater change in potential energy? Explain.

d) Is the change in thermal energy the same for the two systems? If not, which system will have the greater thermal energy change? Explain using the law of conservation of energy.
More About Force, Distance and Work

Obtain a ring stand, a short rod, a clamp, a spring scale, a PASCO plunger cart with a small pulley attached and a string threaded through the pulley. Clamp the short rod to the top of the ring stand. Hang the spring scale from the rod, hook end down. Make sure the scale reads 0.0 N, adjusting the white knob, if necessary.

Question 1: Holding the cart so it does not fall, pass the hook at the bottom of the scale through both end-loops of the string. Gently let go of the cart so it hangs freely from the looped string. If necessary get some books to raise the height of the ring stand.
   a) What does the spring scale read?

   b) Remove one end of the string from the hook of the spring scale and attach that end of the string to the horizontal rod, using the loop at the end of the string. Without looking at the spring scale, predict the force reading. Explain your reasoning.

   c) Test the prediction you made in part Question 1b. Was your prediction confirmed? If not, what was the flaw in your reasoning?

Question 2: Go back to the arrangement with both ends of the string looped through the hook of the spring scale. Watch the spring scale reading as you lift the scale upward.
   a) Aside from a bit of jiggling, does the spring sensor read pretty-nearly the same all the way up, as long as you lift at constant speed?

   b) What is a reasonable estimate of the force on the string by the spring scale while lifting the cart at constant speed?

   c) Assume you lift the cart the same distance it moved vertically in the previous investigation, about 0.60 m. During this process, how much work did the hook of the spring scale do on the system comprising the cart, pulley, Earth and string? Show your calculation, based upon the relationship of work to force and the distance travelled by the point of force application.
d) Based on your answer to Question 2c what was the resulting change in system potential energy? What assumptions did you need to make to do that calculation?

Question 3: Again, remove one end of the string from the hook of the spring scale and attach it to the horizontal rod. Notice that it is possible to lift the cart by raising the spring scale, but don’t do it, yet.

   a) If you were to use this method to lift the cart and its pulley a distance of 0.60 m, what would be the resulting change in the potential energy of the system comprising the cart, pulley, Earth and string? How do you know?

   b) Based on your answer to Question 3a, how much work would the spring scale do on the system if you were to lift the cart and pulley using this method? Be sure to state any assumptions you needed to make in order to answer.

   c) Holding the spring scale, lift the object upward. What was the average spring scale reading while you were lifting at constant speed?

   d) Compare the force magnitude you recorded in Question 3c to the force magnitude you recorded in Question 2b. How was it possible to do the same amount of work with roughly half the force?
Question 4: Evaluate critically the following statement:

The observations we made in this investigation provide independent support for the main conclusion of our experiments with the robot and the cart: The magnitude of work done by an object on a system is equal to the force on the system by the object, multiplied by the distance travelled by the point of force application: \(|W| = F*d.|W| = F*d.

In this investigation, as well as the previous one, we moved a particular object upward a fixed vertical distance. Whenever we did, we were making identical (or at least equivalent) changes to the configuration of the object-Earth system.

Question 5: This meant we were causing equal changes in which system energy?

While we were moving the object upward, we measured the force \((F)\) on the object and the distance \((d)\) traveled by the point of application of that force. As far as we could tell, the product \(F*d\) did not depend on how we went about moving the object upward, as long as the vertical distance was the same, and regardless of the steepness (and length) of the ramp or the type of pulley system we used.

We have come to understand these observations a very simple way: When you move an object upward a certain distance, the potential energy of the object-Earth system changes by a certain amount, regardless of how the object is moved. If changes in kinetic and thermal energies are negligible, the change in potential energy will be equal to the energy transferred to the system by work. The product \(F*d\) does not depend upon how the moving is done because \(F*d\) is equal to the magnitude of the energy transferred by work. That is,

\(|W| = F*d|W| = F*d\)

Question 6: Why don’t we write this relationship as \(W = F*d\)? Hint: Can either \(F\) (the magnitude of the force) or \(d\) (the distance travelled by the point of force application) ever be negative?
In principle, the equation $|W| = F \cdot d$ gives us a way of quantifying any change or transfer of energy using a common unit, a unit we called the joule (J). One joule, we learned, is the energy transferred when a force of exactly one newton (1 N) acts over a distance of exactly one meter (1 m).

Question 7: The following questions may seem silly, and their answers obvious, but they are important nonetheless:

a) You accelerate a skateboard from rest by exerting a force of 12 N on the skateboard, over a distance of 2.0 m. If any net changes in configuration and temperature, as well as any energy transfers by heat, are negligible, what is the resulting change in the skateboard’s kinetic energy?

b) You lower a book, exerting an average force of 2.2 N over a distance of 0.050 m. If any net changes in speed and temperature, and any energy transfers by heat, are negligible, what is the resulting change in the potential energy of the book-Earth system?

c) You warm your hands by rubbing them together, exerting an average force of 25 N on each hand over a total distance of 2.0 m. If any net changes in speed and configuration, and any energy transfers of energy by heat, are negligible, what is the resulting change in the thermal energy of each hand?
Mass, Weight and Gravitational Potential Energy

The energy changes we have been thinking about and measuring depend on a very important property of any system, a property we have yet to mention, until now.

Question 1: Suppose increasing the temperature of a cup of coffee from 20° C to 50° C increased the thermal energy of the coffee by $6.0 \times 10^4$ J (60,000 J or 60 kJ).
   a) What would be the increase in the thermal energy of a system of ten cups of coffee, each identical to the first, also heated from 20° C to 50° C?

   b) What would be the change in temperature of the ten-cup system?

   c) If the change in temperature were due to energy transfer by heat, what would be the value of Q for one cup of coffee? Did you have to make any assumptions?

   d) What would be the value of Q for ten cups of coffee?

Question 2: Suppose speeding up a particular truck from rest to 10 m/s (about 24 mph), increases the truck’s kinetic energy by $1 \times 10^6$ J (1,000,000 J or 1 MJ).
   a) Your friend has a second, identical truck. By how much would increasing the speed of both trucks from 0 to 10 m/s increase the kinetic energy of the two-truck system? Explain your reasoning.

   b) Suppose the second truck was taken apart, melted, etc. and loaded into the back of the first truck, and the speed of the loaded truck increased from 0 to 10 m/s. Would your answer be different? Explain.

   c) What is the change in speed of the two-truck system? Careful!
In answering these questions, you were thinking in terms of a property familiar to you from the time you first shook a baby bottle to figure out if there was any milk left in it: a property called mass. The mass of an object is a measure of the amount of matter in the object. Mass is usually measured in units called kilograms (kg). One kilogram is very nearly the mass of one liter of water, the amount of water in a cube 0.100 m on each side.

Question 3: Suppose, in one of our previous investigations, you had attached a second cart to the cart you were moving upward. Suppose further that friction and air drag remained negligible and that the two carts were identical in every way.
   a) If moving just one cart upward by 0.60 m increased the potential energy of the cart-Earth system by 3.0 J, what would be the change in the potential energy of the double-cart-Earth system when the double cart was moved upward the same distance?
   b) How much energy was transferred to the double-cart-Earth system by work?
   c) We have learned that $|W| = F \cdot d$. In going from a single-cart to the double-cart, are you increasing $F$, $d$ or both?
   d) What does this suggest about the relationship between the mass of an object (m) and the force exerted on that object by the Earth (F)? Explain your reasoning.

Question 4: Suppose the force on object B by the Earth is twice the force on object A, measured at the same location. How does the mass of B compare to the mass of A? How do you know?

There is a name for the magnitude of the force on an object by the Earth: it is called the weight of the object. We will often just use the word weight.

Question 5:
   a) What are the units of mass?
   b) What are the units of weight?

Question 6: Take a side in the following (friendly) dispute between two students:

   Student 1: “Weight is just another name for mass.”
   Student 2: “Weight is proportional to mass, but they are not the same thing.”
We can describe the relationship between weight and mass using a simple algebraic expression:

\[ F = m \times g \]

where \( F \) is the weight of the object (the magnitude of the force on the object by the Earth), \( m \) is the mass of the object and \( g \) is a proportionality constant we call little \( g \). While the value of \( g \) varies depending upon your location, the mass of the object does not.

Question 7:

a) Use the equation \( F = m \times g \) to find an equation for \( g \) in terms of \( F \) and \( m \).

b) If we measure force in newtons (N) and mass in kg, what will be the units of \( g \)?

c) Using an electronic balance, determine the weight of a 0.100-kg object, in newtons. Use this result to estimate the value of \( g \). Write your result here, including units:

The relationship \( F = m \times g \) tells us that if two objects have the same mass, the Earth will exert the same amount of force on them. It also tells us that if the Earth exerts the same amount of force on two objects, they must have the same mass. Note: At the surface of the Earth, near sea level:

\[ g \approx 9.81 \text{ N/kg} \]

Question 8: Go to the community site page for this course and follow the link called Shortcut to Python template. Edit the template, changing it to a program that calculates weight, given mass in kg and given a value for \( g \) in N/kg. Save your program and use it to calculate the weight of a 32.5-kg child near the Bay School, where the value of little \( g \) is very nearly 9.81 N/kg. Copy the output of your program here:

Question 9: Make a copy of the program you wrote in Question 8 and edit the copy, changing it to a program that calculates mass in kg, given a weight in N and given a value for \( g \) in N/kg. Save your trinket and use it to calculate the mass of a child whose weight near the Bay School is 386 N. Copy the output of your program here:
We have learned that when you lift or lower an object, there is a change in the potential energy of the object-Earth system ($\Delta PE > 0$). If there are no changes in speed or temperature, that change is equal to the amount of work done by you. That is,

$$\Delta PE = W$$

If you lift an object, the force on the object-Earth system by your hand is in the same direction as the motion. Accordingly, when you lift an object, $W$ is positive. When you lower an object, the force by your hand is still upward, but now the motion is downward, so the $W$ is negative.

One way to predict the sign of $\Delta PE$ is to write:

$$\Delta PE = m \cdot g \cdot \Delta h$$

In this equation, $\Delta h$ is the change in the altitude of the object. If $h_i$ is the altitude of the object at the beginning of the process and $h_f$ is its altitude at the end, then:

$$\Delta h = h_f - h_i.$$

Question 10: Make a copy of one of your Python programs, and edit the copy to create a program that calculates the change in potential energy of an Earth-object system, given the mass of the object (m) in kg, a value for g in N/kg, and the object’s initial and final altitudes ($h_i$ and $h_f$) in m.

a) Use your program to calculate the change in the potential energy of a system comprising the Earth and a 2572-kg object when that object falls from an altitude of 612 m to an altitude of 111 m. Assume $g = 9.81$ N/kg.

b) Assuming neither the shape nor the temperature of the object changes, what is the accompanying change in the object’s kinetic energy? Explain your reasoning, using only the facts given and the law of conservation of energy.

c) Answer Questions 10a and 10b for a second object having twice the mass as the first object, and falling the same distance. Make the same assumptions as you did in Question 10b.

d) How do you think the final speeds of the two objects in Question 10c would compare, assuming they both start at rest? Explain your reasoning.
The Quantitative CEE

Let’s take a moment to review what we have learned so far. One way to do this is to make a list of all the quantities we have encountered, as well as their units. We will also include some equations we have learned, equations that relate some of these quantities to one another:

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Abbr.</th>
<th>Units</th>
<th>Abbr.</th>
<th>Relationships</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>$T$</td>
<td>degrees celsius or kelvin</td>
<td>°C or K</td>
<td></td>
</tr>
<tr>
<td>Mass</td>
<td>$m$</td>
<td>kilograms</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Force magnitude</td>
<td>$F$</td>
<td>newtons</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Distance</td>
<td>$d$</td>
<td>meters</td>
<td>m</td>
<td></td>
</tr>
<tr>
<td>Altitude</td>
<td>$h$</td>
<td>meters</td>
<td>m</td>
<td></td>
</tr>
<tr>
<td>Clock reading</td>
<td>$t$</td>
<td>seconds</td>
<td>s</td>
<td></td>
</tr>
<tr>
<td>Change in altitude</td>
<td>$\Delta h$</td>
<td>meters</td>
<td>m</td>
<td>$\Delta h = h_f - h_i$</td>
</tr>
<tr>
<td>Time interval</td>
<td>$\Delta t$</td>
<td>seconds</td>
<td>s</td>
<td>$\Delta t = t_f - t_i$</td>
</tr>
<tr>
<td>Speed</td>
<td>$v$</td>
<td>meters per second</td>
<td>m/s</td>
<td></td>
</tr>
<tr>
<td>Magnitude of gravitational force</td>
<td>$F_{grav}$</td>
<td>newtons</td>
<td>N</td>
<td>$F_{grav} = mg$</td>
</tr>
<tr>
<td>Energy transferred by work</td>
<td>$W$</td>
<td>joules</td>
<td>J</td>
<td>$</td>
</tr>
<tr>
<td>Change in gravitational potential energy</td>
<td>$\Delta PE_{grav}$</td>
<td>joules</td>
<td>J</td>
<td>$\Delta PE_{grav} = mg\Delta h$</td>
</tr>
<tr>
<td>Change in elastic potential energy</td>
<td>$\Delta PE_{elas}$</td>
<td>joules</td>
<td>J</td>
<td></td>
</tr>
<tr>
<td>Change in kinetic energy</td>
<td>$\Delta KE$</td>
<td>joules</td>
<td>J</td>
<td></td>
</tr>
<tr>
<td>Change in thermal energy</td>
<td>$\Delta TE$</td>
<td>joules</td>
<td>J</td>
<td></td>
</tr>
<tr>
<td>Energy transferred by heat</td>
<td>$Q$</td>
<td>joules</td>
<td>J</td>
<td></td>
</tr>
</tbody>
</table>
Notice several of the “relationship” boxes are blank. There are two reasons for this. First, we are treating some quantities as primary. These include the first six quantities in the table. The second reason is that we haven’t finished our study of physics!

We now want to introduce three additional relationships. When you take your next course in physics, you will learn why they hold true. For now, you will just have to take our word for it.

First, the relationship between the mass of an object, its speed, and its kinetic energy:

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

where $m$ is the mass in kg, and $v$ is the speed in m/s. You may be wondering why this equation is so complicated. One the one hand, it’s not surprising that the kinetic energy is proportional to the object’s mass ($m$): two identical cars moving at the same speed should have twice the kinetic energy as either car alone. But why the factor of $\frac{1}{2}$ and why is the speed squared ($v^2$)? We’ll have to wait until we study momentum to get a real answer to those very important questions.

Now that we have an equation for kinetic energy, we can write an equation for the change in kinetic energy, as follows:

$$\Delta KE = KE_f - KE_i = \frac{1}{2} \cdot mv_f^2 - \frac{1}{2} \cdot mv_i^2$$

where $v_i$ is the initial speed, and $v_f$ is the final speed (both in m/s).

Question 1:

a) A 12.5-kg object, initially at rest, is accelerated to a speed of 2.25 m/s. What is the change in the object’s kinetic energy (in J)?

b) Suppose the same object is accelerated from rest to a final speed of 4.88 m/s. What is the change in the object’s kinetic energy (in J)?

c) What is the final speed of the same object if its kinetic energy is changed from an initial value of 0.00 J to a final value of 182 J?
The other relationship we will just tell you about is the relationship between the mass of an object, its change in temperature, and its change in thermal energy:

\[ \Delta TE = mc\Delta T \]

Here, \( m \) is the mass in kg, \( \Delta T \) is the change in the object’s temperature, in either °C or K, and \( c \) is what we will call the **specific thermal energy capacity**.\(^2\) The units of \( c \) are J/kg °C. Different substances, like water and lead, have very different specific thermal energy capacities.

**Question 2:**

a) The specific thermal energy capacity of lead is about 129 J/kg °C. What is the change in the thermal energy of 2.20 kg of lead when its temperature increases by 0.155 °C?

b) In a very early investigation, you dropped a bag of lead pellets about 1 m, with a resulting temperature change of about 0.1 °C. How does that change compare to a prediction based upon the equations we have now for \( \Delta PE_{grav} \) and \( \Delta TE \)? To answer, follow these steps:

1) Set up a qualitative CEE table for a process that begins the instant you let go of the bag and ends the instant the bag comes to rest on the floor. Assume the bag-Earth system is isolated.
2) Find the relationship between \( \Delta TE \) and \( \Delta PE_{grav} \) for the bag-Earth system.
3) Replace \( \Delta TE \) and \( \Delta PE_{grav} \), using equations we have for those two quantities.
4) Solve for \( \Delta T \), using \( c = 129 \) J/kg °C and \( g = 9.81 \) N/kg.
5) Compare your result to 0.10 °C.

**Question 3:** Below each term of the CEE, below, write an equation that relates the energy change (\( \Delta KE, \Delta PE \) and \( \Delta TE \)) to a change in a system property (\( v, \Delta h \) and \( \Delta T \)). Also enter our equation for |\( W \)|. Notice we don’t have an equation for \( Q \) (except, of course, the CEE itself).

<table>
<thead>
<tr>
<th>( \Delta KE )</th>
<th>+</th>
<th>( \Delta PE )</th>
<th>+</th>
<th>( \Delta TE )</th>
<th>=</th>
<th>( Q )</th>
<th>+</th>
<th>( W )</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>+</td>
<td>=</td>
<td>( Q )</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Notice that the change in kinetic energy depends upon the change in speed, the change in potential energy depends upon the change in shape, and the change in thermal energy depends upon the change in temperature. Notice also that each energy change is proportional to mass. For that reason, we say that energy is an **extensive** quantity. This is in contrast to quantities like speed, altitude and temperature, which we call **intensive** quantities. Intensive quantities do not depend upon mass.

Question 4: Two cars, initially at rest, speed up to 55 mph (~25 m/s). System A comprises both cars, while System B comprises only one car.

a) Is the change in speed the same for systems A and B?

b) Is the change in kinetic energy the same for systems A and B?

Finally, here is the relationship between the distance a spring is stretched (or compressed) and the spring’s change in **elastic potential energy**:

\[ \Delta PE_{\text{elastic}} = \frac{1}{2} kd^2 \]

Here, \( d \) is the distance the spring is stretched (or compressed) in m, and \( k \) is a constant characteristic of the spring. You can think of \( k \) as a measure of the stiffness of the spring. The change in elastic potential energy will be positive if energy is transferred to the spring and negative if energy is transferred from the spring. The units of \( k \) are N/m.

Question 5:

a) A spring with \( k = 25.0 \text{ N/m} \) is stretched 0.010 m. What is the resulting change in the spring’s elastic potential energy?

b) The same spring is stretched an additional 0.010 m. What change in the spring’s elastic potential energy results from this additional stretching?
Question 6:

A 0.500-kg plunger cart has a spring with \( k = 352 \text{ N/m} \). The plunger is pushed in, compressing the spring a distance of 3.50 cm. If friction transforms half of the potential energy in the spring to thermal energy, how fast will the cart be moving along a track immediately after the plunger has extended fully?

If you were able to answer the previous question, you have a pretty good understanding of the concept of energy. Spread the word!