

## SPH3U: The Flow of Energy

Energy is a mysterious quantity that allows us to do some wonderful things. If we can keep track of energy, we can make predictions about our world that we couldn't easily do with forces.

Recorder: \_\_\_\_\_  
Manager: \_\_\_\_\_  
Speaker: \_\_\_\_\_  
0 1 2 3 4 5

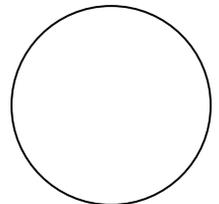
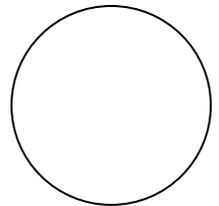
### A: The Flow of Energy

When objects interact, energy can flow or transfer between them. Often when energy is transferred it becomes stored in different ways. For example, it may be stored in the motion of an object and we label it *kinetic energy*. Or it may be stored in the vertical position of an object and we label it *gravitational energy*.

1. **Reason.** For the first part of this investigation your group will need one pullback car. We choose our system to be the car. Draw the car backwards across the table (don't release it). During this process (the drawing back process), do you think energy is flowing into or out of the system? Explain.

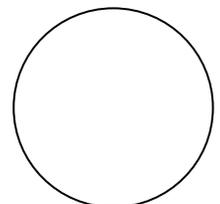
A *system* is a set of objects whose properties we choose to keep track of. An *energy flow diagram* is an illustration of the energy that flows into or out of the system. Consider all the objects that are interacting. Inside the circle we list all of the objects that are in the system and the rest we list on the outside. We draw a line between each object representing each interaction. If we know which direction energy flows between the objects, add an arrow to the line.

2. **Represent.** Complete an energy flow diagram for the system of the car while it is being pulled back at a steady speed.
3. **Explain.** Albert says, "I know I used energy to pull back the car, but I think that energy is just used up by my arm - I learned in biology that my cells burn the energy. It hasn't flowed anywhere, it's just used up." How can you demonstrate to Albert that he is wrong? Explain.
4. **Represent.** Draw an energy flow diagram for the car after you release it, while the car is speeding up. Is energy flowing into or out of the system of the car during this process? What do you think is happening to the energy of the system?



Energy is never created or destroyed - it just flows into or out of a system, or changes how it is stored within a system. This idea is called the *conservation of energy*.

5. **Represent.** After you release the car, it soon begins to slow down. Draw an energy flow diagram for the system of the car while it is slowing down. What do you think is happening to the energy of the system?

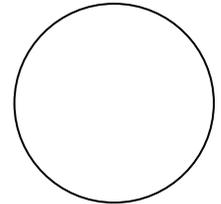
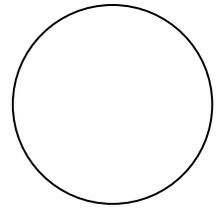


Energy often leaves a system due to friction. This causes parts of the system and the environment to become warm, indicating the presence of *thermal energy*. In time, almost all the thermal energy will leave the system, so to a good approximation we will assume that our system objects don't have the ability to store thermal energy.

## B: Energy Transfers

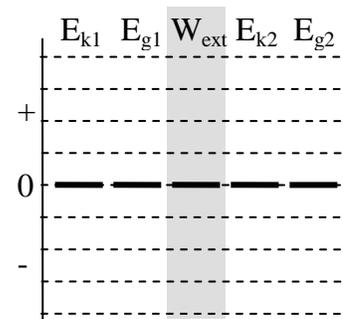
You need a marble for this next investigation.

- 1. Represent and Explain.** Create an incline using a binder or notebook. Roll the marble up the incline and catch it when it comes to rest at the top. Draw an energy flow diagram for the system of the marble after it has left your hand as it is going up the incline. Explain what the diagram tells us about the flow of energy.
- 2. Represent and Explain.** Draw an energy flow diagram for the system of the marble plus the earth while the marble is traveling up the incline, after it has left your hand. Do you think the system (marble+earth) is gaining or losing energy? Explain.

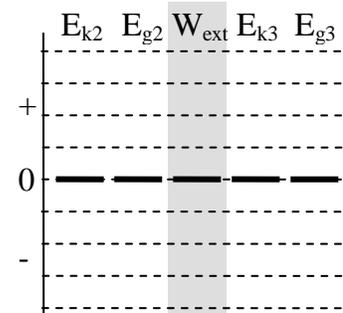


An *energy bar chart* uses a bar graph to show the amount of energy stored in each mechanism (gravitational, kinetic, elastic, etc.) at two different moments in time. Unless you know exact values, the height of the bars is not important as long as the comparisons are clear. The middle bar in the chart,  $W_{ext}$ , represents the energy flow into or out of the system.

- 3. Reason and Predict.** We will consider two events: (1) when the marble leaves your hand and (2) when it reaches the top of its trip up the incline. At those two moments in time we want to compare the energies in the system. Complete the bar chart for the energies of the system of marble+earth at moments 1 and 2. Explain your rationale.

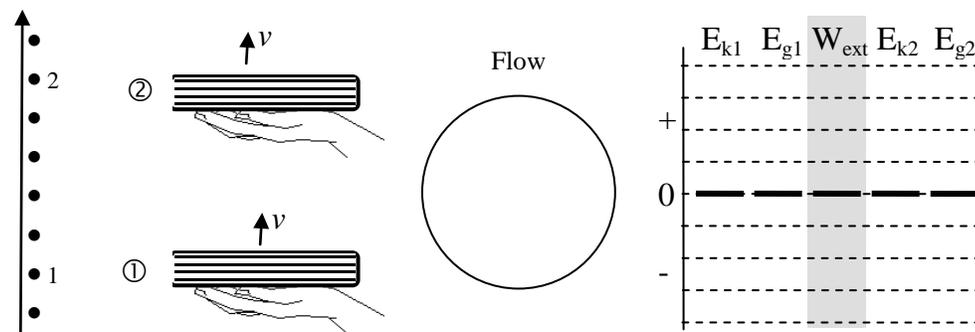


- 4. Predict.** Now we roll the marble up the incline and let it roll back down to its original position. Our third event will be when the marble returns to its original position. How much kinetic energy will it have at this moment? How does this quantity compare to the energies at moments 1 and 2? Draw this in the second bar chart.



- 5. Test.** Test your prediction using the track and motion sensor set up in your classroom. Do your observations confirm your predictions? Explain.

- 6. Represent and Explain.** Emmy lifts a book upwards at a constant speed. We note two events while the book is moving upwards. Complete an energy flow diagram and bar chart for the system of the book + earth. Explain what is happening to the energy.



## SPH3U: Doing Work!

How do we transfer energy into or out of a system? Let's find out!

Recorder: \_\_\_\_\_

Manager: \_\_\_\_\_

Speaker: \_\_\_\_\_

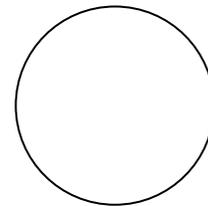
0 1 2 3 4 5

### A: The Energetic Cart

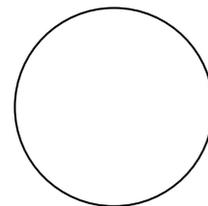
You need a dynamics cart for this part of the investigation. You may assume that the force of friction acting on the cart is small enough to neglect.

1. **Describe and Represent.** We want the cart to gain some kinetic energy. Describe how you can do this. Draw a force diagram and an energy flow diagram for the system of the cart during this process (while it gains kinetic energy.)
2. **Describe and Represent.** The cart is initially moving quickly and we want it to lose kinetic energy. Describe how you can do this. Draw a force diagram and an energy flow diagram for the system of the cart during this process.
3. **Demonstrate.** Use the cart and show these two situations to your teacher. Move on while you wait.

FD



FD



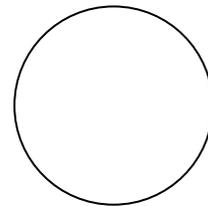
Energy can be transferred into or out of a system by an external force. When this happens we say that the force does *mechanical work* (or often just *work*) on the system. When energy flows out of the system due to the force, the system loses energy and we say that the force does *negative work*. When energy flows into the system, the system gains energy and we say the force does *positive work*. Energy is a scalar quantity and positive or negative work does not indicate any kind of direction, it only indicates a gain or loss.

### B: Measuring Work

You need a wood block for this part of your investigation.

1. **Observe and Represent.** Place the wood block in the path of the cart. Give the cart a push, release it, and let it collide with the block. Draw a force diagram and an energy flow diagram for the system of the cart during the stopping process. Explain why the cart slows down.
2. **Observe and Reason.** Try this a second time with the cart moving slower than before. Try again with it moving a bit faster than before. What do you observe is different about the stopping process in each case? What could you measure about the stopping process to help keep track of this difference?
3. **Reason.** What quantities do you think will help determine the amount of work on the system during the stopping process? Explain. (Hint: there are two!)
4. **Predict.** There are other forces acting on the cart – a normal force and the force of gravity. During the stopping process, do you think these forces doing work on the system? Explain.

FD

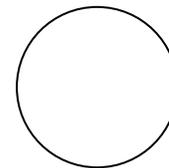
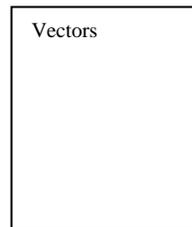


The work done by a force on a system ( $W$ ) depends on three quantities: the size of the force ( $F$ ), the displacement of the system ( $\Delta d$ ) and the angle between the force vector and the displacement vector ( $\theta$ ). These are related by the expression,  $W = F\Delta d \cos\theta$ . The units of work may be expressed as N·m, but these are actually equivalent to the unit joules (J) for energy.

### B: Working the Angles

1. **Reason and Calculate.** A cart with a mass of 0.70 kg is initially at rest. Then it is pushed horizontally by a hand with a force of 10 N.

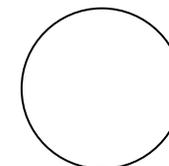
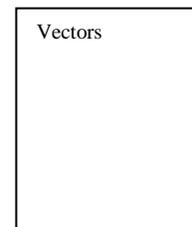
- Draw vector arrows for the force due to the hand and the displacement of the cart. Draw an energy flow diagram for the system of the cart.
- What is the angle between the two vectors? (We always compare angles by imagining drawing the vectors tail-to-tail.)
- After it moves a distance of 0.40 m, how much work (in joules) has been done by the force?



- Interpret the sign of the value for the work that you calculated. How much kinetic energy do you think the cart has now?

2. **Reason and Calculate.** The same cart is rolling along different a table and experiences a force of friction of 12 N. It rolls 0.35 m before stopping.

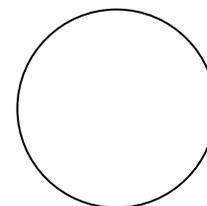
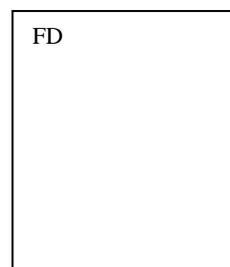
- Draw vector arrows for the force of friction and the displacement of the cart. Draw an energy flow diagram for the system of the cart.
- What is the angle between the two vectors? What is the work done by the friction force while bringing the block to rest?



- Interpret the sign of the value for the work that you calculated. How much kinetic energy do you think the cart originally had?

3. **Reason and Calculate.** Now you push on the cart for 0.50 m while it travels across the rough table. The friction force is still 12 N and you push horizontally with a force of 15 N.

- Draw energy flow and force diagrams for the system of the cart.
- Calculate the work done by each force acting on the system.



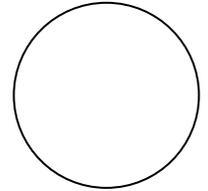
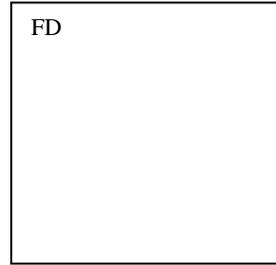
- What is the total work done on the system? How much kinetic energy did the system gain during this process?

The *net work* is the sum of all the work being done on the system. When the net work is positive, the system *gains* kinetic energy. When the net work is negative, the system *loses* kinetic energy. This idea is called the *kinetic energy - net work theorem* and is represented by the expression:  $W_{net} = E_{k2} - E_{k1} = \Delta E_k$ . Note that this is the same as finding the work done on the system by the net force vector:  $W_{net} = |F_{net}|\Delta d \cos\theta$ .

**A: The Toy Car**

You are playing with a little kid, pushing a toy car across the floor with a constant speed and making “vroom, vroom” sounds. If you stopped pushing, the car would quickly stop.

- 1. Represent.** Draw an energy flow diagram and a force diagram for the system of the car.
- 2. Reason.** Which forces do you think cause energy to flow in or out of the system? Explain.



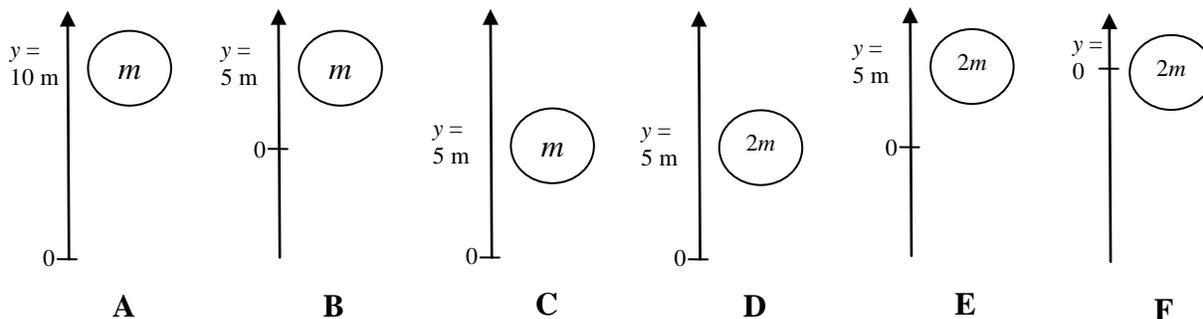
- 3. Reason.** Use the new expression for work ( $W = |F||\Delta d|\cos\theta$ ) to help complete the chart for each force acting on the car.
- 4. Reason.** In total, is energy flowing in or out of the system? Explain how you know.

Force	$\theta$	Sign of work? (+ or -)	Flow of energy? (in or out)
$F_a$			
$F_f$			
$F_n$			
$F_g$			

- 5. Reason.** Do forces acting perpendicular to the motion of a system transfer energy in or out of that system? Explain.
- 6. Reason.** Did the sign of the work depend on our choice or a sign convention? (Did we make such a choice?) Explain.
- You continue to push on the car, but it is now slowing down.
  - (a) Reason.** Is this situation accurately described by the FD and energy flow diagram above? Would you need to make any changes? Explain.
  - (b) Reason.** Is the car gaining or losing kinetic energy? Use the *kinetic energy-net work theorem* to determine the sign of the net work.
  - (c) Reason.** How does the amount of energy transferred by each force compare in this situation?
- 8. Calculate.** The size of your push is 3.1 N. The force of friction is 3.4 N. The car was initially had 1.7 J of kinetic energy. How far does it travel before stopping?

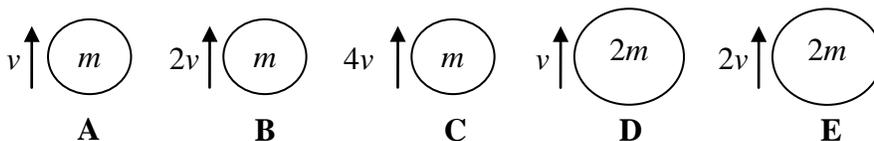
**A: Comparing Gravitational Energies**

1. **Reason.** Six objects and their vertical positions relative to an origin are shown. Rank the gravitational energies of each object relative to its vertical origin. Explain your ranking.

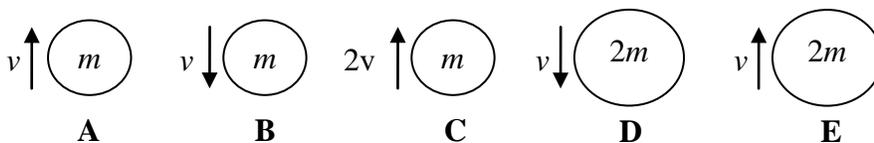


**B: Comparing Kinetic Energies**

1. **Reason.** The velocity and mass of five objects is shown to the right. Rank the amount of kinetic energy each object has. Explain your ranking.



2. **Reason.** The velocity and mass of five objects is shown to the right. (Note the directions!) Rank the amount of kinetic energy each object has. Explain your ranking.



**C: Calculating Energies**

1. **Reason.** A friend proudly shows you the results of his calculation. Explain what errors he made and correct his solution.

$$m = 250\text{ g} \quad E_{g1} = mgy_1 = (250\text{ g})(9.8\text{ N/kg})(3.4\text{ m}) = 8330\text{ J}$$

$$v_1 = 5.0\text{ km/h}$$

$$y_1 = 3.4\text{ m} \quad E_{k1} = \frac{1}{2}mv^2 = (0.5)(250\text{ g})(5.0\text{ km/h})^2 = 3125\text{ J}$$

2. **Reason.** Two identical test cars are driving down a test track and hit their brakes at the same position. One car is travelling at twice the speed as the other. Compare the kinetic energies of the two cars. Use the idea of work to explain how much further the faster car travels while braking.

## SPH3U: Measuring Energy

Recorder: \_\_\_\_\_  
 Manager: \_\_\_\_\_  
 Speaker: \_\_\_\_\_  
 0 1 2 3 4 5

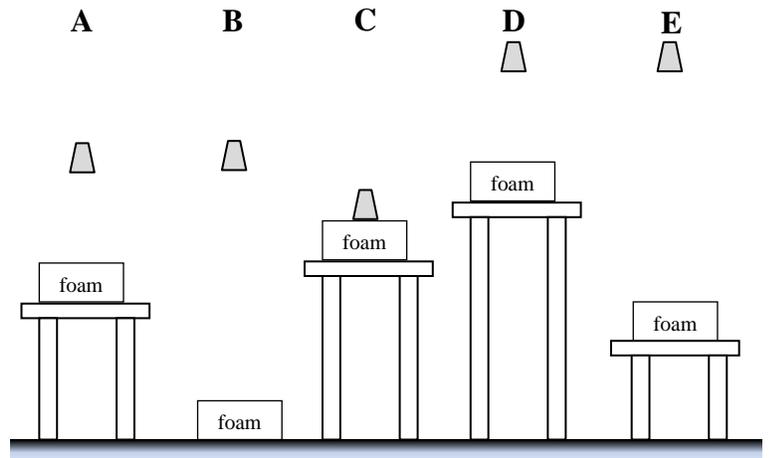
The idea of work provides us with a handy way to measure the amount of energy transferred during some process. Now we need to figure out how to use work to find out how much energy transforms into kinetic or gravitational energy.

### A: Making Dents

Imagine you lift up a heavy weight and place a foam block underneath. You let go of the weight and it falls on top of the block. A dent is left in the piece of foam.

- Reason.** What happened to the energy you used while lifting the block?
- Reason.** What could you change about this situation to change the size of the dent in the same foam block?

- Reason.** A foam block is placed on different tables with different heights above the floor. The weight is released from different positions above the floor. Rank the size of the dent created in each foam block and explain your ranking.

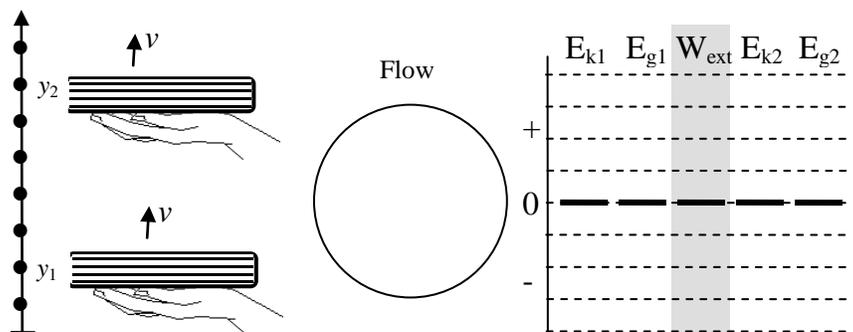


- Summarize.** Why do we believe that energy is transferred by lifting things?

When we lift an object, energy is transferred due to the gravitational interaction between the object and Earth. We say that the energy is stored in the earth's *gravitational field*. The energy is not stored in the object itself – we notice no difference in the properties of the object. When we include the earth in our system, we always include its gravitational field.

### B: Work and Gravitational Energy

- Represent.** Let's go back to an earlier example. Emmy holds a book of mass  $m$  in her hand and raises the book vertically at **constant** speed. Complete the diagrams and charts for the book-earth system.
- Describe.** During the process of lifting the book, describe the changes in energy that occur.



3. **Explain and Calculate.** The amount of energy stored as gravitational energy is equal to the amount of work done by the force of the hand on the book. Explain how to find the **size** of this upwards force. Carefully show how to create an expression for the work using the symbols  $m$ ,  $g$  and  $y_1$  and  $y_2$ .

The *gravitational energy* ( $E_g$ ) of an object of mass,  $m$ , located at a vertical position,  $y$ , above the vertical origin is given by the expression,  $E_g = mgy$ . The vertical origin is a vertical position that we choose to help us compare gravitational energies. The gravitational energy of an object at the vertical origin is set to equal to zero. So we always say that an object has a certain amount of  $E_g$  *relative* to the vertical origin.

Note that the units for work and gravitational energy are N·m. By definition, 1 N·m = 1 J, or one *joule* of energy. In fundamental units, 1 J = 1 kg·m<sup>2</sup>/s<sup>2</sup>. Remember: in order to get an answer in *joules*, you must use units of kg, m, and s in your calculations! Always use a positive value for  $g$  in your calculations and choose upwards as positive – this is our *energy-position* sign convention.

## B: Work and Kinetic Energy

Another example that we looked at earlier was our cart which was at rest and then speed up as we pushed on it with our hand.

1. **Explain.** We are going to create an expression to help us find the kinetic energy of our cart after we push on it. For each step you see in this process, identify each new equation used and explain how we get from one step to the next.

Steps	Description
1) $E_{k2} - E_{k1} = W_{net}$	
2) $E_{k2} = W_{net}$	
3) $E_{k2} =  F_{net}   \Delta d  \cos \theta$	
4) $E_{k2} =  ma   \Delta d $	
5) $E_{k2} =  ma  (v_2^2 - v_1^2) / 2a$	
6) $E_{k2} =  ma  v_2^2 / 2a$	
7) $E_{k2} =  m  v_2^2 / 2$	
8) $E_{k2} = \frac{1}{2} m v_2^2$	

The *kinetic energy* of an object is the energy stored in an object's motion. The amount of kinetic energy can be found from the expression  $E_k = \frac{1}{2} m v^2$ . Where  $v$  is the instantaneous velocity of the object at the moment in time you are interested in. The value of the kinetic energy **does not** depend on the object's direction of motion – energy is a scalar quantity. Remember, to get a result in joules, make sure you use units of kg and m/s in this equation.

## SPH3U: Changes in Gravitational Energy

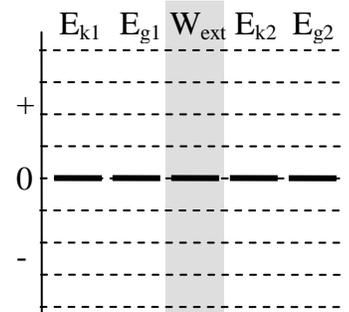
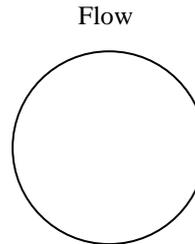
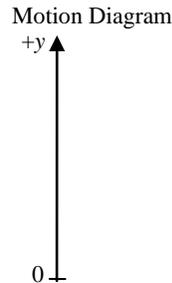
When objects move vertically energy is transferred in or out of the earth's gravitational field. Let's follow this transfer and learn how to predict the motion of the system.

Recorder: \_\_\_\_\_  
 Manager: \_\_\_\_\_  
 Speaker: \_\_\_\_\_  
 0 1 2 3 4 5

### A: The Ball Drop and Kinetic Energy

You will drop a basketball through a displacement of your choice (between 0.5 and 1.2 m) and examine the energy changes.

- Represent.** Draw a diagram of a ball falling and indicate two moments in time 1 and 2 at the start and end of its trip down (just *before* it hits!) Label the two vertical positions  $y_1$  and  $y_2$ . Complete the energy-flow diagram and bar chart for the **earth-ball** system.



Our bar charts are helpful tool for thinking about changes in energy. They are also helpful for construction an equation that relates the energy of a system at two moments in time. The total energy of a system at one moment plus any changes equals the total energy of a system at another moment:  $E_{T1} + W_{ext} = E_{T2}$ . This is called a *work-energy equation* for the system. The bar chart helps us to decide which energies to include in each total. If a particular energy is zero, we don't bother including it.

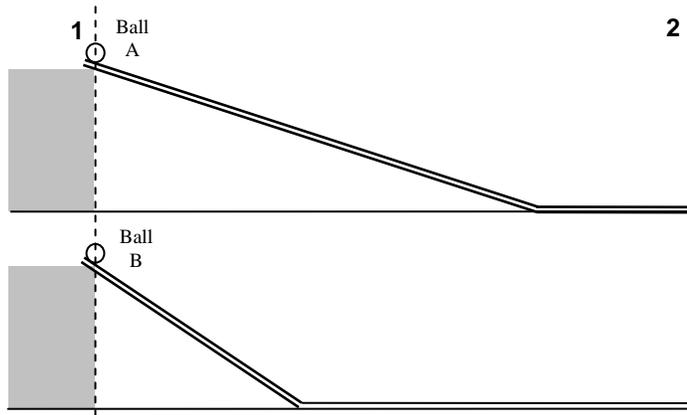
- Represent.** Construct a work-energy equation for the earth-ball system.
- Calculate.** Use the expression for kinetic energy and the expression for gravitational energy and substitute these into your equation from the previous question. Be sure to use the labels "1" and "2" where needed.
- Calculate.** Use your new equation and an important measurement to find the speed of the ball just before it reaches the ground.
- Test.** Use the motion detector set up by your teacher to measure the speed of the ball just before it hits the ground. Do the results agree with your prediction?

Gravitational and kinetic energy are two examples of *mechanical energy*. When the total mechanical energy of a system remains the same we say that the mechanical energy is *conserved*. Mechanical energy will be conserved as long as there are no external forces acting on the system and no frictional forces producing thermal energy.

- Reason.** Keeping in mind the experimental errors, was mechanical energy conserved during the drop of the ball? Explain.

## B: The Ramp Race

Your teacher has two tracks set up at the front of the class. One track has a steep incline and the other a more gradual incline. Both start at the same height and end at the same height. Friction is very small and can be neglected.



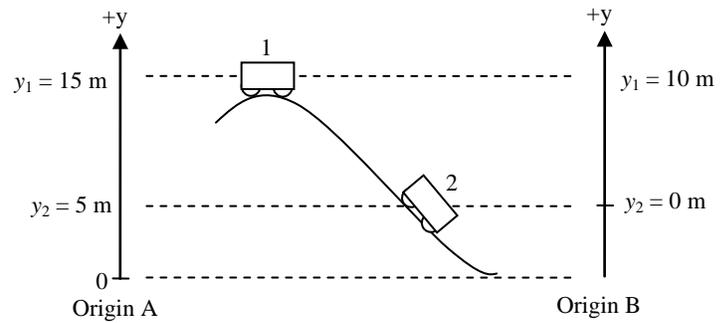
1. **Reason.** What energy changes take place as the ball travels down the incline?
2. **Reason and Predict.** Two horizontal positions, 1 and 2, are indicated in the diagram. The two balls are released at the same time. Which ball do you think will reach position 2 first? Justify your prediction with energy arguments.
3. **Reason and Predict.** How will the speeds of the two balls compare when they reach position 2? Justify your prediction.
4. **Observe.** Record your observations of the motion of the balls when they are released at position 1 at the same time.
5. **Observe.** Record your observations of the speeds of the balls when they reach position 2.
6. **Reason.** Albert says, “I don’t understand why ball B wins the race. They both end up traveling roughly the same distance and ball A even accelerates for more time! It should be faster!” Based on your observations and understanding of energy, help Albert understand.
7. **Reason.** According to your observations, how do the kinetic energies of the two balls compare at position 2? Where did this energy come from?
8. **Reason.** The distance the balls travel along each incline is slightly different, but there is an important similarity. Compare the horizontal displacement of each ball along its incline (you may need to make measurements). Compare the vertical displacement of each ball along its incline. Illustrate this with vectors on the diagram above. Which displacement is the important one when determining the change in gravitational potential energy?

The amount of energy stored in, or returned from gravity **does not depend on the path** taken by the object. It only depends on the object’s change in vertical position (displacement). The property is called *path independence* – any path between the same vertical positions will give the same results. This is a result of the fact that gravity does no work on an object during the horizontal parts of the object’s motion.

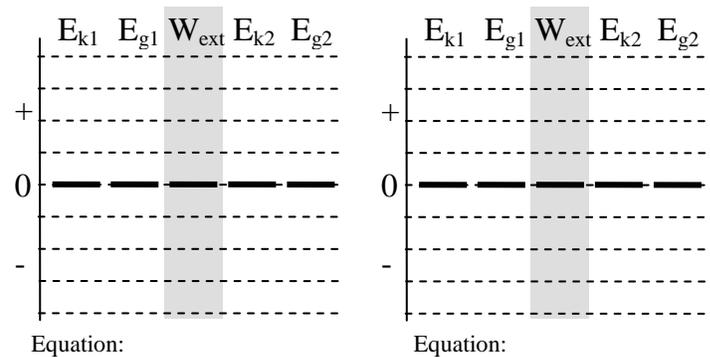
**A: Comparing Vertical Origins**

The value for the gravitational energy depends on the choice of the vertical origin. If two people choose a different vertical origin, will their calculations predict different things? Let's see!

A cart rolls down a curving track. It starts from rest at the top. We will examine two moments in time: (1) at the top of the track and (2) part way down. The system is the cart+earth.



- Represent.** Draw an energy bar chart for the two moments in time for each origin.
- Represent.** Construct a work-energy equation for the system based on each origin.



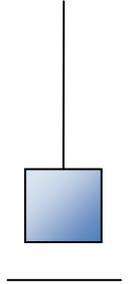
- Calculate.** Complete the chart below. Calculate the gravitational energies of the system according to each origin. Use these energies to determine how much kinetic energy and speed the cart has a moment 2.

	$E_{g1}$	$E_{g2}$	$E_{k2}$	$v_2$
Origin A				
Origin B				

- Explain.** Use both the calculations and the bar charts to explain why the choice of vertical origin did not affect the results of the calculation.

Only *changes* in gravitational potential energy have a physical meaning. The exact value of the gravitational potential energy at one position **does not** have a physical meaning. That is why we can set any vertical position as the origin. The vertical displacement of the object does not depend on the choice of origin and therefore the *change* in gravitational potential energy does not depend on it either.

1. **Reason.** A block is attached to a rope so you can raise or lower it vertically. An energy bar chart illustrates the energies at two moments in time while it is being raised or lowered.
- (a) Use the bar chart to explain what is happening to the block. Be sure to mention the speed and direction of the motion and the work the rope does.
- (b) Write the work-energy equation for each process.



Explain:	Explain:	Explain:
Work-Energy Equation:	Work-Energy Equation:	Work-Energy Equation:

2. **Represent and Calculate.** You throw a 200 g ball upwards. It leaves your hand with a speed of 10 m/s. We choose a vertical origin at the vertical position where the ball is released from your hand. We examine three moments in time: (1) it leaves your hand, (2) it is half way up, and (3) it is at its highest point.
- (a) Draw a motion diagram and label these moments.
- (b) For each moment in time, complete an energy bar chart for the earth-ball system.

<p>Motion Diagram</p>			
	$E_{k1} =$	$E_{k2} =$	$E_{k3} =$
	$E_{g1} =$	$E_{g2} =$	$E_{g3} =$
	$E_{T1} =$	$E_{T2} =$	$E_{T3} =$

(c) Calculate the energies at each moment and find the total energy of the system. Show your calculations below.

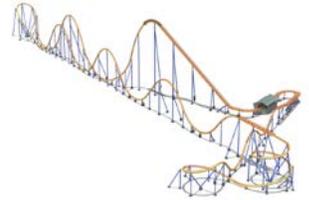
(d) Challenge: how does  $\Delta t_{12}$  compare with  $\Delta t_{23}$ ?

# SPH3U: The Conservation of Energy

Recorder: \_\_\_\_\_  
 Manager: \_\_\_\_\_  
 Speaker: \_\_\_\_\_  
 0 1 2 3 4 5

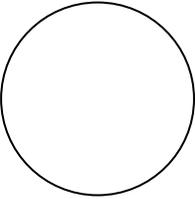
## A: The Behemoth

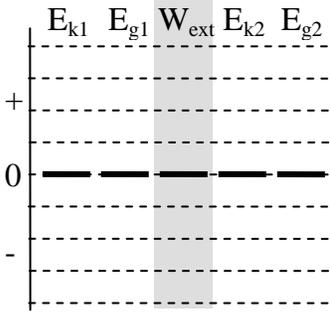
A recent rollercoaster at Canada's Wonderland is called "The Behemoth" due to its 70.1 m tall starting hill. Assume the train is essentially at rest when it reaches the top of the first hill. We will compare the energy at two moments in time: 1 = at the top of the first hill and 2 = at ground level after the first hill.



- Represent.** Draw an energy bar chart and flow diagram for the earth-train system. Write down a work-energy equation that relates the energies of the system at moment 1 with moment 2.

Flow





Work-Energy Equation

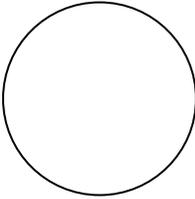
- Calculate.** Use the energy equation to find the speed of the rollercoaster at moment 2 in km/h.

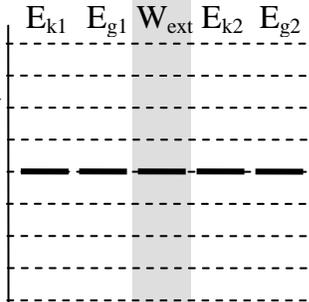
- Reason.** The official statistics from the ride's website give the speed after the first drop as 125 km/h. What do you suppose accounts for the difference with our calculation? What happened to the energy?
- Reason.** Imagine we had an infrared thermometer (a device which we can point at things and get a temperature reading). Where could we point the thermometer in order to detect the heat energy lost during the trip down the hill?

When a force of friction does work on a system, energy can be transformed into heat, or *thermal energy* ( $E_{th}$ ). This is another form of energy which we must account for in our understanding of energy. Thermal energy is not considered a form of mechanical energy since it is difficult to transform thermal energy into other forms of energy. We assume that our system objects have no means of storing or using thermal energy, so it is always lost to the environment and leaves the system. This is represented by the negative work that the force of friction does, so  $E_{th} = -W_{friction}$ .

- Represent.** Draw a new energy storage bar graph and an energy flow diagram for the **earth-train** system that takes into account the effects of friction. Write down a new work-energy equation.

Flow



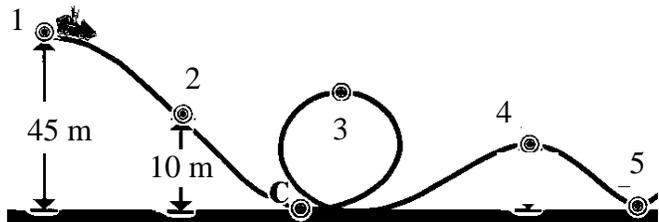


Work-Energy Equation

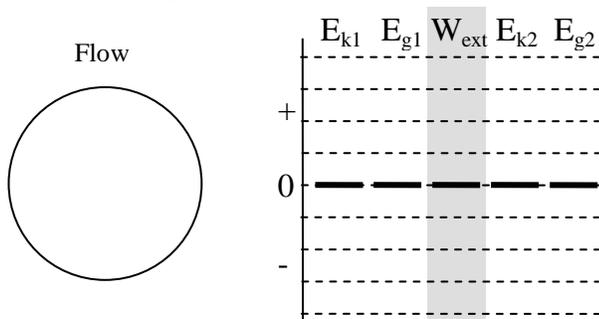
6. **Calculate.** Use the train mass,  $m_t = 2.7 \times 10^3 \text{ kg}$  to determine the amount of thermal energy at moment 2.

### B: The York Mills Flyer

Rumour has it that a rollercoaster is going to be built in our school's courtyard. Plans leaked to the media show a likely design. The train starts from rest at moment 1. For all our calculations, we will assume that the force of friction is negligible.

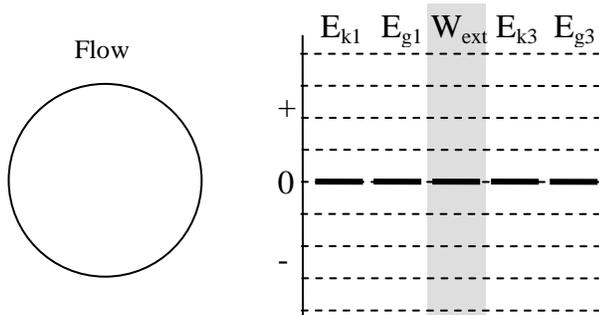


1. **Solve.** Moment 2 occurs partway down the first hill. Complete the diagram and chart. Determine the rollercoaster's speed at moment 2.



Equation

2. **Solve.** Moment 3 is the top of the loop-de-loop and is located 17 m above the ground. Complete the diagram and chart. Determine the rollercoaster's speed at moment 3.



Equation

The loop-de-loop involves some very complicated physics, the details of which are much beyond high school physics. Yet using energy techniques, we did not have to consider those complications at all! When the mechanical energy of a system is conserved, we can relate the total mechanical energy at one moment in time to that at any other moment *without having to consider the intermediate motion – no matter how complex.* Wow!

## SPH3U: Power

Winning a race is all about transferring as much energy as possible in the least amount of time. The winner is often the most *powerful* individual.

Recorder: \_\_\_\_\_

Manager: \_\_\_\_\_

Speaker: \_\_\_\_\_

0 1 2 3 4 5

*Power* is defined as the ratio of the amount of work done,  $W$ , to the time interval,  $\Delta t$ , that it takes to do the work, giving:  $P = W/\Delta t$ . The fundamental units for power are joules/seconds where 1 joule/second equals one watt (W).

### A: The Stair Master

Let's figure out your leg power while travelling up a flight of stairs.

1. **Reason.** Describe the energy changes that take place while you go up the stairs *at a constant speed*.
2. **Reason.** Explain what you would measure in order to determine the work you do while travelling up a set of stairs. Quickly sketch a diagram of this showing all the important quantities.
3. **Reason.** To calculate your power, you will need one other piece of information. Explain.

Sketch

**\*\* check with your teacher before gathering any equipment \*\***

4. **Observe.** Gather the equipment you will need for your measurements. Travel up a flight of stairs at a quick pace (but don't run, we don't want you to fall!) Record your measurements on your diagram.
5. **Calculate.** Compute your leg power in watts (W) and horsepower (hp) where  $1 \text{ hp} = 746 \text{ W}$ . Show your work. How does this compare to your favourite car? (2011 Honda Civic DX = 140 hp)

**B: Back to the Behemoth!**

1. **Solve.** The trains on the Behemoth are raised from a starting position 10 m above ground at the loading platform to a height of 70.1 m at the top of the first hill in a time of 60 s. The train (including passengers) has a mass of 2700 kg and is lifted at a *steady speed* by a motor. Ignoring frictional losses, how powerful should the motor be to accomplish this task? Complete the energy diagram and bar chart below for the earth-train system. In the work-energy equation, include a term,  $W_m$ , for the work done by the motor.

