PHY 111L Activity 6

Work-Energy Theorem: Conservation of Energy

Name: ________________________________ ID #:_____________________________

Section: _______________________________ Date: ____________________________

Lab Partners: ____ TA initials: ________

Objectives

1. Introduce the Work-Energy Theorem
2. Investigate the general case when energy is lost and experimentally determine the frictional forces
3. Investigate the special case when energy is conserved (no frictional forces) and compare (lab report)

Materials & Resources

1. Computer with DataStudio and 2 photo gates
2. Dynamics track with cart and friction pad
3. Mass set, pulley, string, and a bubble-level

Introduction

Particular physical motion can also be described by the work-energy theorem, which states that the work done equals the difference between the final and initial energy. Then,

$$(KE_f+PE_f) - (KE_i+PE_i) = W$$

where the *KE* and *PE* represent kinetic and potential energies, and the *f* and *i* subscripts refer to the final and initial locations. In the right hand side of the equation, *W* is the work done by frictional or other external forces. The kinetic and potential energies are expressed as ½ *(mass)* × *(velocity)*^{2} and *(mass)*×*(gravitational acceleration)*×*(height)*, respectively. The work is *(force)*×*(distance)* and is done here by the frictional force. It is important to know that energy and work have the same unit, joules (J).

For this lab, we use the following system: the hanging mass, *m*, creates the potential energy due to gravity and is connected to a cart with a string and pulley. Since the cart and the hanging mass are connected, the total mass of the object is $M+m$. Hence, the kinetic and potential energies for this system are $\frac{1}{2}(M+m)v^2$ and *mgh*, respectively. Let us use the work-energy theorem. For convenience, set the initial velocity to zero. Then, $KE_i = 0$ because $v_i = 0$. The difference between initial and final potential energies is *mgh* as given above. Then,

$$\tfrac{1}{2}(M+m)v_f^2 - mgh = W.$$

To obtain the final velocity, v_f, experimentally, we assume that the acceleration of motion is constant. Then the average velocity becomes $v_{average} = \frac{1}{2}(v_f + v_i)$. Another expression for the average velocity is $v_{average} = h/t$.

Setting these two expressions equal to each other gives $h/t = \frac{1}{2}(v_f + v_i)$. But since $v_i = 0$, $v_f = 2h/t$.

The masses, *M* and *m*, and the height *h* of mass *m* can be easily determined using a balance and a meter stick, respectively. Since the second part of the experiment happens with no (or very little) friction between the cart and track, the work done by friction is zero. Then,

$$\tfrac{1}{2}(M+m)v_f^2 - mgh = 0$$

This is a special case of the work-energy theorem in which no energy is lost to frictional forces and so energy is conserved; it is just transferred from potential to kinetic, or vice versa, which will be investigated in part 2 below.

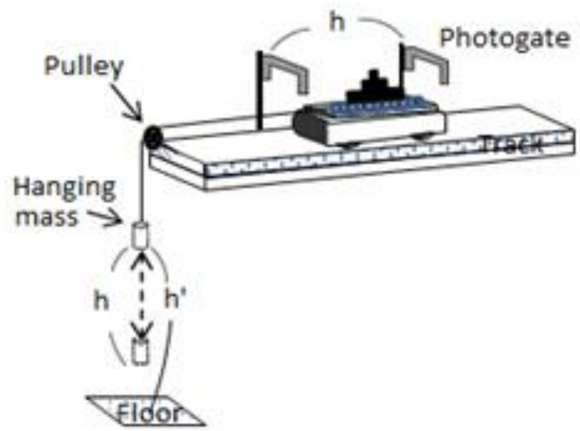
Part 1 of this lab uses the friction pad attached to the cart. The frictional force does work, *W*, on the system. Then the energy in this system is not conserved. It is interesting to note that this theorem shows that only initial and final states are needed to describe the energy of a physical system, which is consistent with Newton's laws of motion.

1. *Energy is __not__ Conserved; added frictional forces*

<u>Procedure</u>:

1) Set up the experiment as illustrated below. Set the photo gates so that $\boldsymbol{h} \approx 30$ cm; use an appropriate length of string so that $\boldsymbol{h} < \boldsymbol{h'}$ and the hanging mass $\boldsymbol{m}$ does not interact with the pulley before the cart triggers the first photo gate. Use a bubble level at the center of the track to adjust the track feet until it is level in *both* directions. Then adjust the angle of the pulley until the string attached to the cart is completely horizontal. Place the bar mass in front of the center of the cart so that the motion is <u>partially restricted</u> by the friction between the bar mass and the track as the cart is accelerated towards the pulley by the hanging mass.

2) Use a meter stick to measure the distance between the photo gates $\boldsymbol{h}$, and then use a balance to measure the mass of the hanging weight $\boldsymbol{m}$ (≈ 100g) and the <u>combined</u> mass $\boldsymbol{M}$ of the cart, bar mass, and flag. Record your results using correct significant figures, uncertainties, and units below.



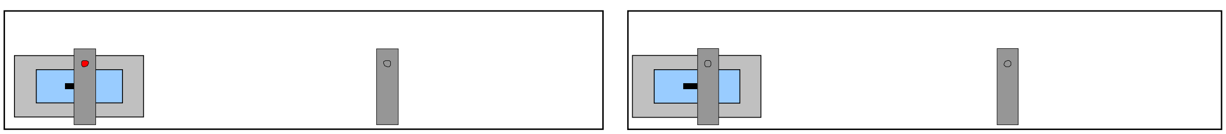
$\boldsymbol{h} \pm \Delta\boldsymbol{h}$ = ________________ (   ) ± ___________ (   )

$\boldsymbol{m} \pm \Delta\boldsymbol{m}$ = _______________ (   ) ± ___________ (   )

$\boldsymbol{M} \pm \Delta\boldsymbol{M}$ = ______________ (   ) ± ___________ (   )

3) Create an experiment in DataStudio, and then select a photo gate for digital channels 1 and 2 on the interface. Select "Digits" from the "Displays" menu and choose "Time Between Any Gates" as the data source.

4) Ensure that the initial velocity is zero, as in previous labs, by moving the cart until the red light on the photo gate comes on, then pull it back until the red light just turns off and hold the cart steady, as shown from the top below.



5) Click "Start" in DataStudio and then release the cart after a short delay. Once the cart has passed the second photo gate, stop it before it hits the pulley or the weight hits the ground. Also, be sure the weight is still when you release the cart so that it does not swing as it moves toward the floor.

6) Record the elapsed time in the table below, and then calculate the final velocity, kinetic and potential energies, as well as the work done by all external forces (friction). Record your results with correct significant figures and units in the table below.

Elapsed time: t	*Final Velocity:* $v_f = {}^{2h}/_{t}$	*Kinetic Energy:* $E_k = \frac{1}{2}(M+m)v_f^2$	*Potential Energy:* $E_p = mgh$	*Work Done (by friction):* $W_f = E_k - E_p$

7) Click on "Experiment," select "New Empty Data Table," and enter your calculated values for W_f into the "X" column of the new data table. Then select "mean" and "standard deviation" from the "Σ" drop-down at the top of the table; record these values with correct units in the space below. Do not delete or print this table until the end of part 2.

$\boldsymbol{W_f} \pm \Delta\boldsymbol{W_f}$ = ________________________ ± ___________________ (   )

Questions:

1) List all sources of friction involved in the experiment in part 1.

2) Calculate the total frictional forces $\boldsymbol{F_f}$ using $\boldsymbol{W_f} = \boldsymbol{F_f * h}$ below; record with correct significant figures and units.

$\boldsymbol{F_f}$ = ________________ (   )

3) What can you say about the kinetic and potential energies in part 1 based on the algebraic sign of $\boldsymbol{F_f}$?

2. *Energy is Conserved, negligible frictional forces (Lab Report)*

Procedure:

1) Use the exact same set up as in Part 1 above, except this time place the bar mass flat *on top* of the cart; this will *reduce*, but not completely eliminate, the friction opposing the motion of the cart without changing the combined mass $\boldsymbol{M}$. Then record your measured values for t and your calculated values for v_f, E_k, E_p, and W_o in the table below.

Elapsed time: $\boldsymbol{t}$	*Final Velocity:* $\boldsymbol{v_f = {}^{2h}/_t}$	*Kinetic Energy:* $\boldsymbol{E_k = \frac{1}{2}(M+m)v_f^2}$	*Potential Energy:* $\boldsymbol{E_p = mgh}$	*Work Done (no friction):* $\boldsymbol{W_o = E_k - E_p}$

2) Enter your calculated values for W_o into the "Y" column of the data table from step 6 in Part 1 above, record your average and standard deviation values for W_o in the space below, and then print the completed table now.

$\boldsymbol{W_o \pm \Delta W_o}$ = __________________ ± __________ (   )

Questions:

1) List all sources of friction involved in the experiment in part 2.

2) Which value is larger, $\boldsymbol{W_o}$ or $\boldsymbol{\Delta W_o}$? What does this tell you about the validity of your measurements?

3) Calculate the frictional force $\boldsymbol{F_o}$ using $\boldsymbol{W_o = F_o * h}$ and record with correct significant figures and units below.

$\boldsymbol{F_o}$ = ________________ (   )

4) What can you say about the kinetic and potential energies in part 2 based on the algebraic sign of $\boldsymbol{F_o}$?

5) What physical quantity does the difference $\boldsymbol{F_p = F_f - F_o}$ represent? Be very specific.