Work-Energy Theorem and Conservation of Energy

Your Name ____________________

Partners' Names ____________________

____

TA's signature allowing you to take the quiz or leave ____________

Obtained reasonable experimental results?	yes ☐
Answered questions?	yes ☐
Cleaned your table?	yes ☐

Introduction

Particular physical motion can also be described by the work-energy theorem, which reads <u>$(KE_f + PE_f) - (KE_i + PE_i) = W$</u>. The *KE* and *PE* represent kinetic and potential energies, and the subscript *f* and *i* are final and initial. In the right hand side of the equation, *W* is the work done by frictional or other external force. The kinetic and potential energies are expressed as ½ *(mass)* × *(velocity)*^{2} and *(mass)*×*(gravitational accel.)* × *(height)*, respectively. The work is *(force)* ×(distance) which the force here is mostly the frictional force. It is important to know that energy and work have the same unit, joules (J), whose dimension is $[L^2][M][T^{-2}]$.

The system we use is in this lab is following: The hanging mass, *m*, creates the potential energy due to gravity. Since cart and the hanging mass are connected, the total mass of the object has to be $M+m$. 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 the convenience, the initial velocity is set to be zero; namely, $KE_i = 0$. The difference of initial and final potential energies is mgh as given. Thus, the final form of the equation can be $\frac{1}{2}(M+m)v_f^2 - mgh = W$.

To obtain the final velocity, v_f, experimentally, we assume that the acceleration of motion is constant. Therefore, the average velocity is calculated by $\bar{v} = \frac{v_f + v_i}{2}$. Another expression of the average velocity is $\bar{v} = \frac{h}{t}$. These eliminate $\bar{v}$, and it becomes $\frac{h}{t} = \frac{v_f + v_i}{2}$. Using $v_i = 0$ and solving for v_f, we obtain $v_f = \frac{2h}{t}$. The masses and height are obtained by a balance and a meter stick.

The first part of the experiment is facilitated with no (or very little) friction between the cart and track. From the work-energy equation above, the work done by friction is zero, and then we have $\frac{1}{2}(M+m)v_f^2 - mgh = 0$. This is the special situation of the work-energy theorem called <u>conservation of energy</u>, which the potential energy is totally transferred into the kinetic energy. This is due to no friction; namely the work done by friction does not "deprive" the energy of the system.

The second part of the experiment uses a friction pad attached to the cart. The frictional force plays a role to reduce the energy as the work, *W*, in the equation. Then, the energy in this system is not conserved.

As for an interesting perspective, this theorem shows that only initial and final states describe the physical system, which is actually equivalent with the outcome from Newton's equation of motion.

Objectives:

- To learn the work-energy theorem
- To test the conservation law of energy
- To see how the work done by friction contributes to the energy conserved system

- **Conceptual question 1**

What are the definitions of the potential and kinetic energies? Express those in your words qualitatively. Do not just write down the formula.

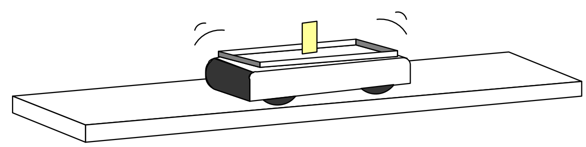
Potential energy:

Kinetic energy:

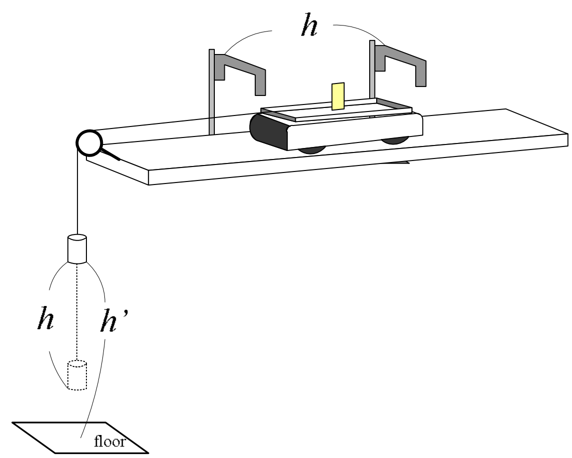
- **Conceptual question 2**

How do you interpret the conservation of energy? Can you make energy from nothing? What is the meaning of conservation in this case?

① Level the track before you start the experiment.
<u>For the dynamic cart,</u> put the cart on the precision track. If the cart stays still, the track is leveled. If the cart slides, level the track by using papers.



② Start up DataStudio. Click "Create Experiment." Select photo gate for channels 1 and 2. Display a table by double-clicking "Table." The data source must be "Time Between Any Gate, Ch2(s)." You record the "Elapsed Time."

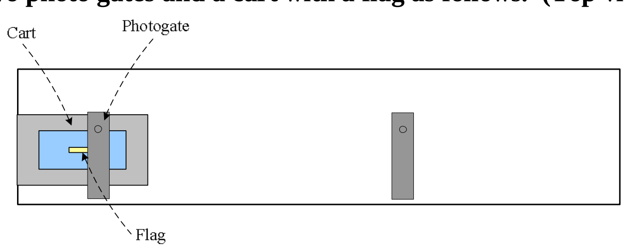


③ Measure the falling distance.
The falling distance corresponds to the distance between photo gates. Obtaining exact $h = h'$ is not necessary; however, h' MUST be larger than h (where h' is the distance from the initial height of the hanging mass to floor.)

Important Tips: 1. For the first part, make sure the hanging object is not wobbling before the release. 2. Make the glider as close to the first gate as possible. <u>**(Read the photo gate instruction below!!)**</u> 3. Use SI units, which are (m), (kg), and (s) through the experiment

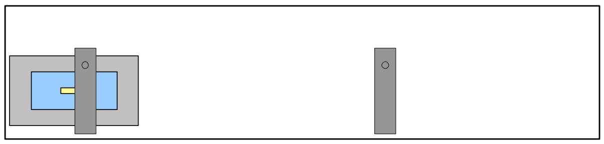
<u>This causes most significant errors in this experiment.</u> The time interval is measured by two photo gates. "<u>**No initial velocity**</u>" means that the distance between the flag and the first photo gate must be zero.

① Set up two photo gates and a cart with a flag as follows. (Top view)



② Make the cart enter the first photo gate slowly until it flashes.

③ Pull it back a little bit, then hold the cart when the light is just turned off. Ask your partner to click start, and then release the cart.



M (kg)	m (kg)	h (m)	t (s)	v_f (m/s) $\left[\frac{2h}{t}\right]$	E_k (J) $\left[\frac{1}{2}(M+m)v_f^2\right]$	E_p (J) $[mgh]$	W_f (J) $[E_k - E_p]$
cart only	0.02 kg						
cart only	0.05 kg						
cart only	0.10 kg						
cart + 1 bar	0.05 kg						
cart + 1 bar	0.10 kg						
cart + 2 bars	0.10 kg						

Questions for conservation of energy

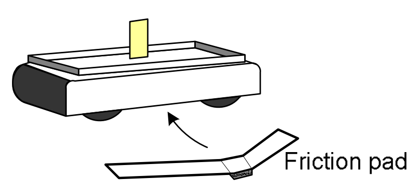
This experiment is supposed to indicate energy conservation; namely, the potential energy is completely transferred into the kinetic energy. Compare the results in E_k with E_p. Also, discuss whether or not this system conserves the energy from your results in the last column, W_f. (*If not, find the possible errors and try them again.*)

Are the kinetic energies always equal or less than the potential energies? Does this fact make sense?

2. Energy and Work Done by Friction

Note: Frictional force acts oppositely to the moving direction.

① Put the friction pad on the <u>bottom</u> of the cart as shown. Use scotch tape to attach it.



Mass of the friction pad, M_{pad}: ______________________________________ (   ) ← unit

② The Velcro makes friction between the cart and track. Make sure it contacts well to the surface.
(Imagine this is a brake of the cart.)

Stop! Answer the following conceptual question before doing the activity.

- **Conceptual question (You MUST answer and understand this question. Otherwise, you are not allowed to proceed to the experiment!! It may also hurt your grade significantly.)**

What will the motion of the cart be, faster or slower than the first part of this lab? What does friction do to the cart?

The other procedures are exactly the same as the first part.

(Note: The last column of this table must be different from that of the first part. If you obtain the same results as above, please think about why and redo the experiment.)

$M + M_{pad}$ (kg)	m (kg)	h (m)	t (s)	v_f (m/s) $\left[\frac{2h}{t}\right]$	E_k (J) $\left[\frac{1}{2}(M+m)v_f^2\right]$	E_p (J) $[mgh]$	W_f (J) $[E_k - E_p]$
cart only	0.05 kg or more						
cart only	0.10 kg or more						
cart + 1 bar	0.10 kg or more						

Questions for work and energy

How does the work done by friction depend on the change of the masses? Discuss this with your experimental results.

Find each dimension of kinetic energy (1/2 × mass × velocity^2), potential energy (mass × gravitational accel. × height), and work done by friction (coefficient of kinetic friction × normal force × distance). Do the results make sense to you?
