Course and Section_______ Names ___________________________

Date___________ ___________________________________

WORK AND ENERGY EXPERIMENT

Introduction

This lab has two goals. The first is checking the validity of the work-energy theorem. You will measure the work done by a force acting on a cart and also measure the change in kinetic energy of the cart to verify if they are equal. The second goal is to check the conservation of mechanical energy.

Equipment Two smart carts, aluminum track, clamp, string (at least 1 m), mass hanger, metal blocks, pulley with clamp, two bumpers, hook, digital scale.

Theory

<u>Work - Kinetic Energy</u>

The work- kinetic energy theorem states that the work done by a force acting on an object over a distance Δx equals the change in kinetic energy of the object:

$$W = \Delta KE$$

For a constant force in the direction of motion, $W = F \cdot \Delta x$. If the force F is not constant, then the work is calculated as $W = \int F\, dx$. This integral is mathematically equal to the area under the curve of F *vs.* x, as shown by the shaded region in the graph on the next page.
The change in kinetic energy is $\Delta KE = ½\, mv_f^2 - ½\, mv_i^2$.

<u>Conservation of Mechanical Energy</u>

The total mechanical energy E of a system is the sum of the kinetic energy KE and the potential energy PE. If only mechanical energies are considered (as for example in the case of no friction) then the total mechanical energy E is conserved

$$E_i = E_f$$

Using $E = KE+PE$, the above equation can also be written as:

$$\Delta E = \Delta(KE+PE) = \Delta KE + \Delta PE = 0 \quad \text{or} \quad \Delta KE = -\Delta PE$$

Preliminary Questions

Given two carts: one has mass *m* and the other has a mass three times *m*. You push each of them (one at a time) with the same constant force, over the same distance, starting from rest. Circle the right answer.

1. The work done on the heaviest cart is *equal* - *smaller* - *grater* than the work done on the other cart.

2. The kinetic energy of heaviest cart is *equal* - *smaller* - *grater* than the kinetic energy of the other cart.

3. The speed of the heaviest cart is *equal* - *smaller* - *grater* the the speed of the other cart.

PART 1 – Work kinetic energy: variable Force

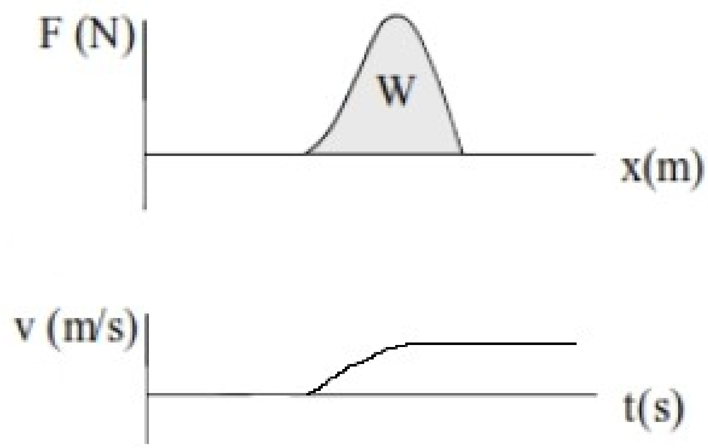

Figure 1

Procedure

Step 1. Open the data studio file "**F-x_v-t.cap**" located in the ThawSpace T: drive. Capstone will display two graphs: force *vs* position and velocity *vs* time. These two graphs are upside/down respect to the figure above.

Step 2. Pair both carts with Capstone. Choose one cart to be used as a force sensor and select it in the force vs position graph. Select the other cart for the velocity vs time graph.

Step 3. Make sure the track is firm by checking that the big clamp is holding it.

Step 4. Add one (or two) block mass on top of the cart you will be pushing. Both carts should have the rubber bumper accessory attached.

Step 5. Start the measurement by clicking the record icon in Capstone. Push the force sensor cart against the cart loaded with the block mass on it.

Note: You want to push the cart for 15-20 cm and provide a final speed high enough to minimize the effects of friction.

Step 6. Use Capstone to measure the area: carefully select the appropriate data points on the graph and click on the icon 

Step 7. Determine the maximum value of the final velocity of the cart. Click on Σ.

Step 8. Weight the cart with the added mass, and calculate the change in the kinetic energy from the value of the velocity.

Note: You only need one graph for a good run. Repeat several times your experiment until you are able to reproduce the (upside/down version of) of Figure 1. If not check with the TA.

Analysis

4. Using the data you collected, fill out the table.

Mass of the Cart (kg)	

Work (Nm)	Final Velocity (m/s)	ΔKE (J)

5. Within reasonable experimental error, is the *Work* equal to the *change in the Kinetic Energy*?

6. Calculate the percent difference between the *Work* and the *change of Kinetic Energy*

$$\%Diff = \left| \frac{W - \Delta KE}{(W + \Delta KE)/2} \right| \times 100 = \_\_\_\_\_\_\_\_$$

If you obtain a percentage difference greater than 15%, repeat your measurement and check with the instructor.

7. Which measurement would have the most experimental error involved: the work or the change in kinetic energy? And why?

8. Suppose you repeat this analysis on an inclined plane. Will the *Work* done by the applied force (your hand pushing) be equal to the *change in the Kinetic Energy*? Explain.

Print and turn in a copy containing the two plots of force vs Δx and velocity vs *t*.

PART 2 – Work kinetic energy: constant Force

For Part 2, the force applied on the cart will be due to gravity acting on the mass hanger.

9. Do you expect the experimental error to be less than in the case of Part 1? Why?

Procedure

Step 1. Close the Capstone software and reopen it with the same "**F-x_v-t.cap**" file. This time you use only one cart and set it to measure both velocity and force. Tare the force sensor.

Step 2. Replace the rubber bumper with the hook. Connect the mass hanger to the cart using the string.

Step 3. Set the cart on the track so that the hanger hits the ground before the cart reaches the end of the track. The cart should be placed so that it can travel about 15 cm with constant velocity.

Step 4. Hold the cart, start the measurement by clicking the record icon. Let the cart go.

Step 5. Determine the work and the final velocity of the cart.

Analysis

10. Using the data you collected, fill out the table.

Mass of the Cart (kg)	

Work (Nm)	Final Velocity (m/s)	ΔKE (J)

11. Repeat this experiment five times. Each time, place the cart at the same initial position.

Measurement	1	2	3	4	5
Work (Nm)					
ΔKE (J)					

12. Calculate the mean and record in the table below

Mean $\overline{W}$ =	(Nm)
Mean $\overline{\Delta KE}$ =	(J)

13. Calculate the standard deviation and the error of both the work and kinetic energy (you can use any software or online tools).

Kinetic Energy: $\sigma_T = \left(\frac{1}{N-1} \cdot \sum_{i=1}^{N} d_i^2 \right)^{1/2} =$ _____ $\quad \sigma_{average} = \frac{\sigma_T}{\sqrt{N}} =$ _____

Work: $\sigma_T = \left(\frac{1}{N-1} \cdot \sum_{i=1}^{N} d_i^2 \right)^{1/2} =$ _____ $\quad \sigma_{average} = \frac{\sigma_T}{\sqrt{N}} =$ _____

14. Record the final answer for your calculation of the mass of the cart.

$$W = \bar{W} \pm \sigma_{average} = \_\_\_\_\_\_\_\_ \pm \_\_\_\_\_\_\_\_\_$$

$$\Delta KE = \bar{KE} \pm \sigma_{average} = \_\_\_\_\_\_\_\_ \pm \_\_\_\_\_\_\_\_\_$$

15. Within reasonable experimental error, is the *Work* equal to the *change in the Kinetic Energy*?

16. In order to give a numerical meaning of the answer above, calculate the percent difference between the mean values of *Work (W)* and the *Kinetic Energy (KE)* using the equation below.

$$\%Diff = \left| \frac{W - \Delta KE}{(W + \Delta KE)/2} \right| \times 100 = \_\_\_\_\_\_\_\_\_\_$$

If you obtain a percentage difference greater than 15%, <u>repeat</u> your measurement and check with the instructor.

17. Compare your answer to question 16 with question 6 and describe the difference.

Print and turn in one of the copies containing the two plots of force vs Δx and velocity vs *t*.

PART 3 – Conservation of Energy

Procedure

In this experiment the system is: the cart + the mass hanger.

Step 1. Close the Capstone software and reopen it with the "**x-t_v-t.cap**" file. You want to measure the velocities. Add the block masses on the cart.

Step 2. Set the cart on the track so that the hanger would hit the ground before the cart reaches the end of the track. The cart should be placed so that it can travel at least 15 cm.

Step 3. Hold the cart, start the measurement by clicking the record icon. Let the cart go.

Step 4. Catch the cart at the end of the track before it collides with the pulley.

Analysis

Initial state: the cart and the mass hanger at rest, before they start to move.
Final state: the mass hanger the instant before it hits the ground, the cart at its max velocity.

18. What is the change in the kinetic energy of the cart? Write both the numerical value and the formula you used to obtain this value.

19. What is the change in the kinetic energy of the mass hanger? Write both the numerical value and the formula you used to obtain this value.

20. What is the total change in the kinetic energy ΔKE of the system?

21. What is the change in the potential energy of the cart? Write both the numerical value and the formula you used to obtain this value.

22. What is the change in the potential energy of the mass hanger? Write both the numerical value and the formula you used to obtain this value.

23. What is the total change in the potential energy ΔPE of the system?

24. Calculate the percentage difference between ΔKE and the magnitude of ΔPE.

25. From the answer above, what can you say about energy conservation of the system?

26. Which are the sources of error?