

Experiment 6 The Work-Energy Theorem

6.1 Materials to be brought to Laboratory

Laboratory report folder.
Clear plastic ruler.

6.2 List of Laboratory Equipment

Personal Computer	Science Workshop 750 Interface
Smart Pulley (ME-9387)	Force Sensor (CI-6537)
1.2 Meter Track	1 Dynamics Car (ME-9430)
Universal Clamp (ME-9376B)	Ring Stand,
Digital Balance	Set of Masses
Level	Clamp and Arm

6.3 Introduction

Consider an object that is confined to move along one direction (the X axis say). Let a constant force \vec{F} be applied to the object while the object moves a distance d . The **work** done by that force is:

$$W = |\vec{F}| |\vec{d}| \cos(\theta) \quad (5.1)$$

Where $|\vec{F}|$ is the magnitude of the force, $|\vec{d}|$ is the magnitude of the displacement, and $\cos(\theta)$ is the cosine of the angle between the direction the force points and the direction that the displacement points (see Figure 6.3-1). The work is a scalar quantity (meaning that it is described by a simple number). The work is measured in units of Newtons times meters or Joules. The work is interpreted graphically as the area under the force curve on a force vs. displacement plot.

The **Work-Energy Theorem** states that the total work done on an object (of mass m) is equal to the change in its **Kinetic Energy**.

$$W = \frac{1}{2} m V_F^2 - \frac{1}{2} m V_I^2 \quad (5.2)$$

where the final kinetic energy of the object is $\frac{1}{2} m V_F^2$ and the initial kinetic energy is $\frac{1}{2} m V_I^2$. The kinetic energy is the energy associated with the motion of the object. It is measured in units of Joules too.

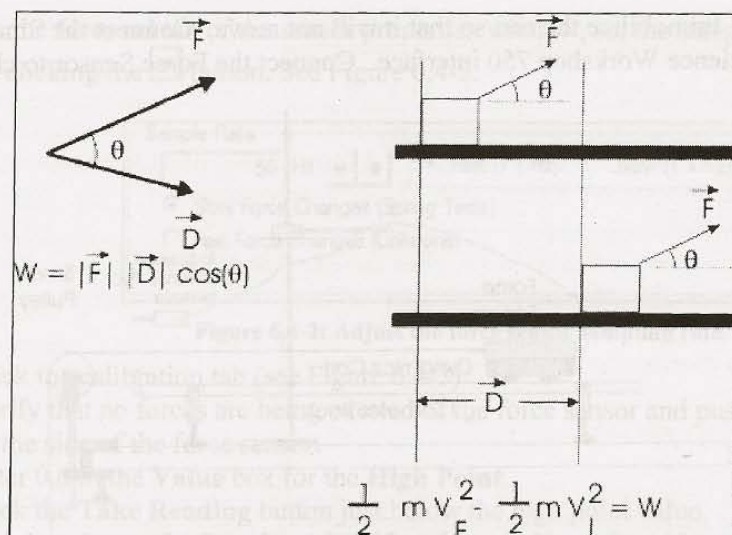


Figure 6.3-1: Definition of Work and the Work-Energy Theorem

For today's experiment, you will use a setup as shown in Figure 6.4-1. The tension of the string provides a constant force to the cart that rolls on the horizontal track. The Force Sensor will measure the force (tension, T) applied to the cart. The Smart Pulley will measure the distance (d) through which the force is applied and is also used to calculate the speed of the cart. Since the force is parallel to the displacement, $\cos(0) = 1$. Therefore, the work energy theorem as applied to today's experiment is:

$$\frac{1}{2} m v_F^2 - \frac{1}{2} m v_I^2 = Td \quad (5.3)$$

where T is the tension in the string and d is the distance the force is applied. As may be expected m is the mass of the cart, and the V 's are the initial and final velocities of the cart respectively. The cart will be released from rest so the initial kinetic energy is zero.

6.4 Experiment

6.4.1 Equipment Setup

The set up for this experiment consists of three parts: (i) Set up the 1.2 meter track and dynamics cart, (ii) use Data Studio to calibrate the Force Sensor, and (iii) set up Data Studio to record force, position and velocity information for the dynamics cart.

6.4.1.1 Set up the 1.2m track and Dynamics Cart

Your apparatus should look like Figure 6.4-1. Attach the universal clamp to the table and attach the Smart Pulley to the clamp. Level the 1.2 meter track with the level. Insure that the track is level along the length and width. Cut a length of string that is 10 cm longer than the distance from the top of the Smart Pulley to the floor. Weigh the dynamics cart with the Force Sensor attached and record the value. Weigh and record the mass of the mass hanger (the mass hanger is $\sim 50g$). Place the Dynamics Cart on the track (with the Force Sensor attached) and make sure the wheels

are in the grooves. Immobilize the cart so that it will not move. Connect the Smart Pulley to channel 1 of the Science Workshop 700 interface. Connect the Force Sensor to channel A.

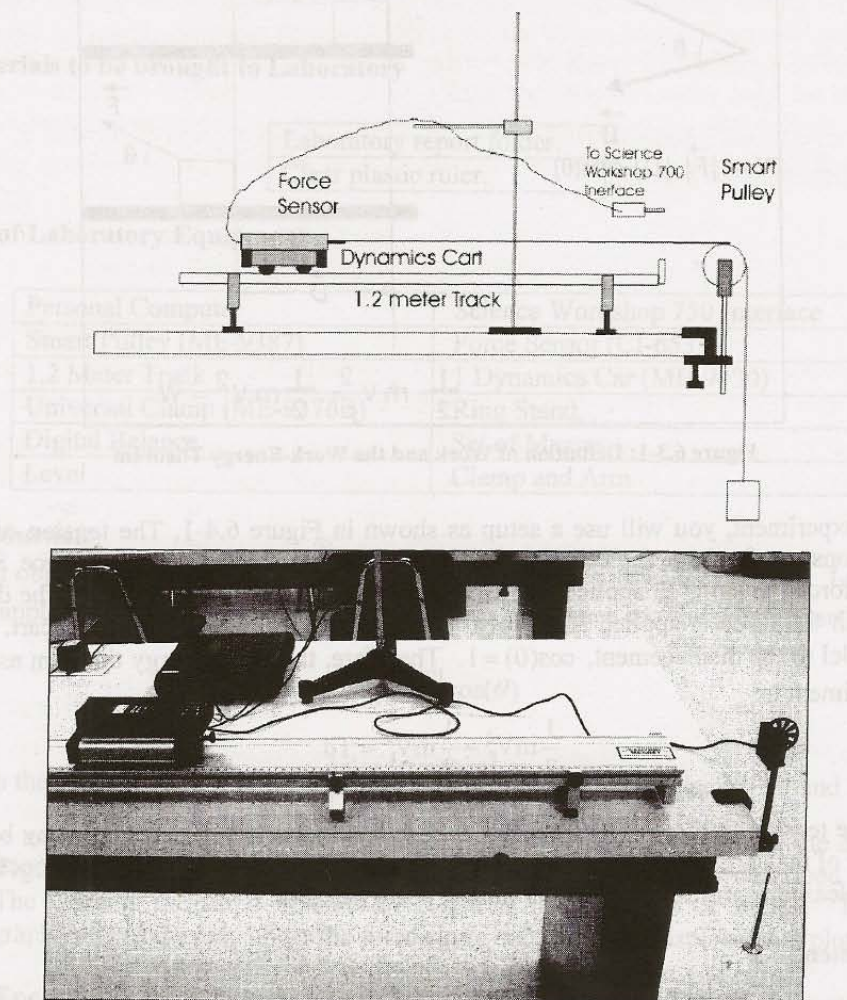



Figure 6.4-1: Work-Energy Apparatus.

6.4.1.2 Calibrate the Force Sensor

- Launch Data Studio.
- Drag & drop the **Force Sensor** icon () from the list of sensors onto channel A.
- Calibrate the force sensor (using 100g of mass):
 1. Note: The force sensor has been designed such that pulling on the force sensor gives a negative force.
 2. Double-click the force sensor icon connected to channel A. The sensor properties window appears.

- On the **General** tab of the sensor properties window, set the sampling rate to 50Hz by clicking the **+** button. See Figure 6.4-2.

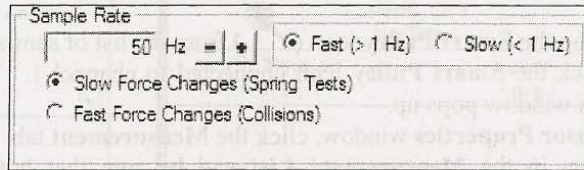


Figure 6.4-2: Adjust the force sensor sampling rate.

- Click the calibration tab (see Figure 6.4-3).
- Verify that no forces are being exerted of the force sensor and push the **Tare** button on the side of the force sensor.
- Enter 0.0 in the **Value** box for the **High Point**.
- Click the **Take Reading** button just below the high point value.
- Weigh and record approximately 100g of mass. Hang the 100g onto the hook of the force sensor by using the string you cut earlier to suspend the mass over the smart pulley.
- Calculate the weight of the 100g mass (Remember, weight = $m \cdot g$ where m is in kg).
- Type the *weight* of the 100g mass (with a negative sign) into the **Value** box for the **Low Point**.
- Click the **Take Reading** button just below the low point value.
- Change the **Sensitivity** to **Med. (10x)**.
- Click **OK** to dismiss the force sensor calibration window.
- Remove the 100g calibration mass from the force sensor.

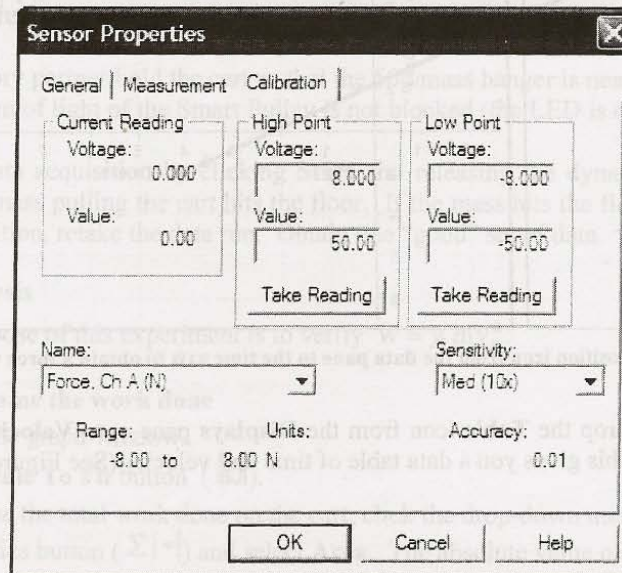



Figure 6.4-3: Force sensor calibration.


6.4.1.3 Set up Data Studio to record cart data

Set up the Smart Pulley

- Drag & drop the **Smart Pulley** icon () from the list of sensors onto channel 1.
- Double-click the **Smart Pulley** icon connected to channel 1. The Smart Pulley's **Sensor Properties** window pops up.
- On the **Sensor Properties** window, click the **Measurement** tab.
- Scroll down in the **Measurement List** and be sure that both **Position, Ch 1(m)** and **Velocity, Ch 1 (m/s)** are checked.
- Click **OK** to dismiss the sensor properties window.

Set up the graph and data table

Next you need to set up a graph of force vs. position as well as a data table of velocity for the cart.

- Drag & drop the **Graph** icon ( Graph) from the **Displays** pane onto the **Force Sensor** icon connected to channel A. This results in a graph showing force vs. time.
- Now drag the **Position, Ch 1 (m)** icon from the **Data** pane onto the x-axis of the graph (See Figure 6.4-4). When you see a dashed line around the x-axis release the mouse. You should now have a graph of force vs. position.

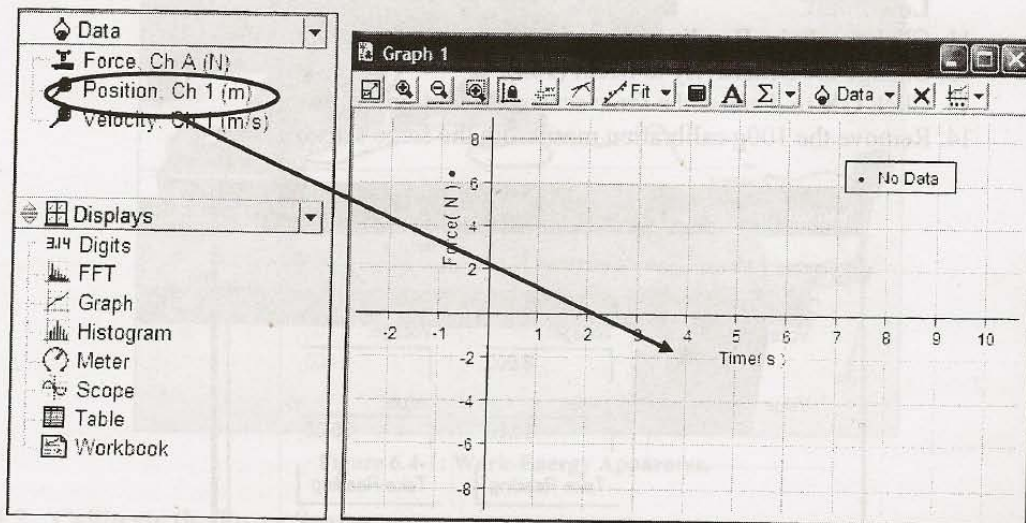


Figure 6.4-4: Drag the position icon from the data pane to the time axis to obtain a force vs. position plot.

- Finally, drag & drop the **Table** icon from the **Displays** pane onto **Velocity, Ch 1 (m/s)** in the **Data** pane. This gives you a data table of time and velocity (See Figure 6.4-5).

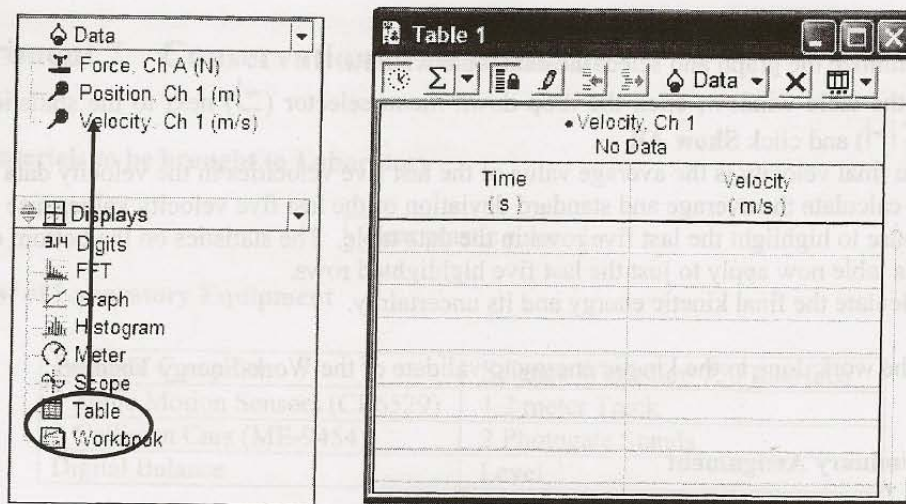


Figure 6.4-5: Drag the table icon to the velocity icon (left) to obtain a data table of velocity and time (right).

You are now ready to take data.

6.4.2 Data Acquisition

Attach the string to the dynamics cart and attach the 50g mass hanger to the free end of the string. Check that the string is over the Smart Pulley and adjust the height of the Smart Pulley until the string is level. Make sure the wheels of the cart are in the grooves of the track. Position the ring stand with an arm over the 1.2 meter track to hold the cable of the Force Sensor so that it will not drag across the table and introduce extra friction into the system.




Have your laboratory partner hold the cart so that the 50g mass hanger is near the universal clamp and so that the beam of light of the Smart Pulley is not blocked (the LED is off).

- Start the data acquisition by clicking **Start** and releasing the dynamics cart. Click **Stop** before the mass pulling the cart hits the floor. If the mass hits the floor before you stop the data acquisition, retake the data run. Obtain one “good” set of data.

6.4.3 Data Analysis

Recall that the purpose of this experiment is to verify $W = \frac{1}{2}mV_F^2$.

6.4.3.1 To determine the work done

- Maximize the graph window.
- Click the **Scale To Fit** button ().
- To determine the total work done on the cart, click the drop-down menu selector () next to the statistics button () and select **Area**. The absolute value of the area is the work done.

6.4.3.2 To determine the final kinetic energy

- Minimize the graph and select the data table window.
- In the table window, click the drop-down menu selector (∇) next to the statistics button (Σ) and click **Show All**.
- The final velocity is the average value of the last five velocities in the velocity data table. To calculate the average and standard deviation of the last five velocity values, use the mouse to highlight the last five rows in the data table. The statistics on the bottom of the data table now apply to just the last five highlighted rows.
- Calculate the final kinetic energy and its uncertainty.

Compare the work done to the kinetic energy to validate of the Work-Energy Theorem.

6.5 Preliminary Assignment

- 1) Consider an object that moves only along the positive X axis that is subjected to a constant force pointing in the positive X direction. Show the work done by this force is the area under a Force vs. Displacement plot.
- 2) A cart of mass (851.8 ± 0.1) g is configured in a setup as shown in Figure 6.4-1. The tension in the string is 0.36 N and the cart has a displacement of 40.9 cm. Determine the work done by the tension.
- 3) The cart in the previous example has a maximum velocity of (0.580 ± 0.017) m/s. Determine the kinetic energy of the cart and compare the result with the work done on the cart in Problem 2 to confirm the Work-Energy Theorem.