Physics 161

Work

Introduction

Work is defined as the force used to move an object times the distance the object is moved. In this lab, students will calculate work done by a constant and a linear force. Students will use a motion sensor to measure the distance that a cart is traveling and a force sensor to determine the force that moves the cart on the track. Students will plot the force versus distance in Capstone to determine the amount of work. In Part I, the cart will be moved by a constant force created by a dropping mass. In Part II, the cart will be moved by a stretched spring. The spring exerts a linear force on the cart.

Reference

Young and Freedman, University Physics, 12th Edition: Chapter 6, section 6.1-6.3

Theory

The work done by a constant force is defined as *the product of the magnitude of the displacement times the component of the force parallel to the displacement:*

$$W = F_{\parallel} d \tag{1}$$

or

$$W = F \cos\theta \quad d \tag{2}$$

In this lab, all the forces are either perpendicular to the motion, so that no work is done, or parallel to the motion, so the angle is zero and $\cos\theta = 1$. If the force acting on the object is not constant, then *the work done by a non-constant force in moving an object between two points is equal to the area under the $F_{\parallel} = F\cos\theta$ versus distance l curve between those two points* as shown in Figure 1.

$$W = \int_a^b F_{\parallel} dl = \int_a^b F \cos\theta \, dl \tag{3}$$

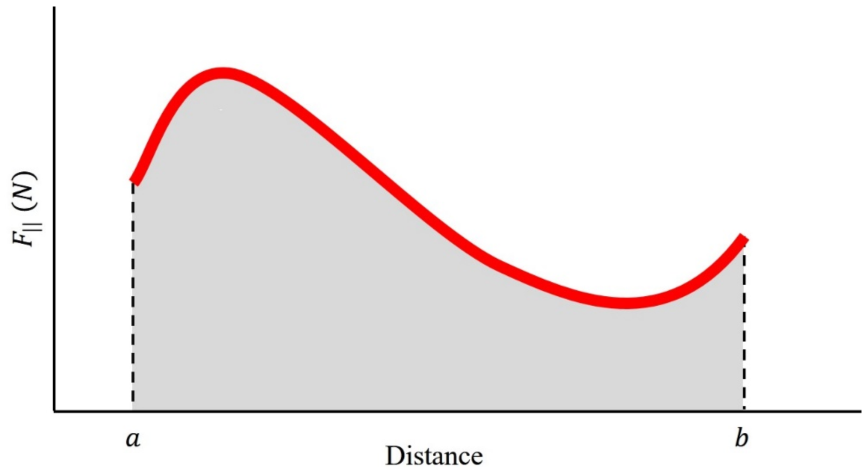

Figure 1: $F_{||}$ vs distance plot.

Numerical approximation of the area under the curve: The Trapezoid rule is one way of calculating a definite integral. The area underneath the curve can be segmented into trapezoids with equal widths Δx as shown in Figure 2, where $\Delta x = x_{i+1} - x_i$. The total area under the curve can be approximated as the sum of the areas of the trapezoids.

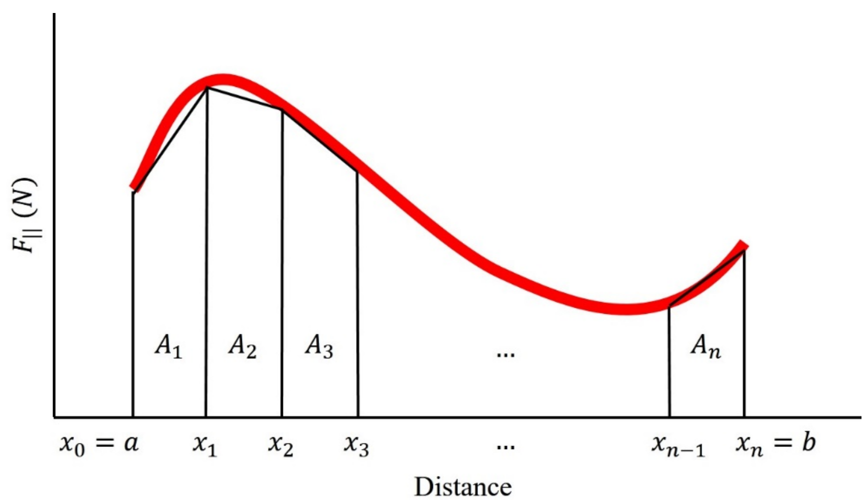

Figure 2: Trapezoid rule.

The area of the first trapezoid is:

$$A_1 = \Delta x \left(f(a) + f(x_1)\right)/2 \tag{4}$$

The area for the second trapezoid is:

$$A_2 = \Delta x\,(f(x_1) + f(x_2))/2 \tag{5}$$

And the area for the last trapezoid is:

$$A_n = \Delta x\,(f(x_{n-1}) + f(x_n))/2 \tag{6}$$

The total area is:

$$A = A_1 + A_2 + A_3 + \cdots + A_n = \sum_{i=1}^{n} A_i \tag{7}$$

Procedure

Part I: Work done by a constant force.

1. To collect data using the setup shown in Figure 3, set up the **850 Universal** interface with a motion sensor set to take data at 50 Hz. Set the switch at the top of the motion sensor to short distance ( ).

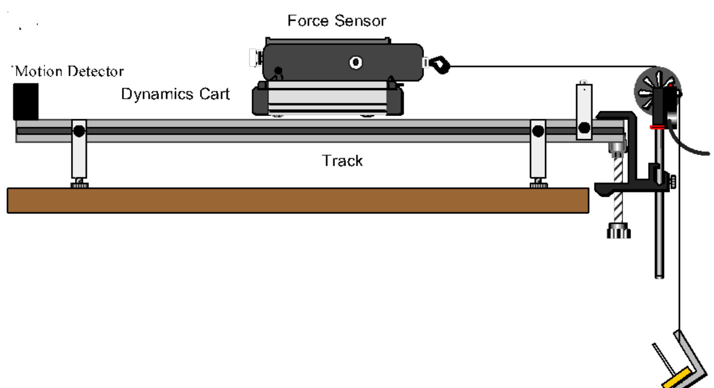

Figure 3: Setup for the experiment.

2. Connect the force sensor to the cart and set the trigger rate of the force sensor to 50 Hz as well. Place the cart 15 cm away from the motion sensor and have your lab partner hold the cart in place on the track.

3. Connect a piece of string to the force sensor and run the other end of the string over the pulley, which is attached to the other end of the track. Now place a 100 g mass on the end of the string and leave it hanging over the pulley.

4. Press the **Record** button. Hold the track firmly during the data recording. With one person holding the string slack, push the tare button on the force sensor to set force reading to zero. Release the string, and then release the cart. The cart will be moved by the hanging mass. Before the cart hits the end of the track, have your lab partner stop it. You may need to do this a couple of times to get good data.

5. Press the **Stop** button after the cart has reached the end of the track.

6. Make graphs in Capstone of the force versus position. Double click **Graph** underneath the display menu on the right hand side. Select the x axis as position and the y axis as force. Print this plot.

7. You should have a force versus position graph that looks similar to Figure 4. Use the  button to find the average force the standard deviation in the force. The average force should be calculated between the approximate position of $a \approx 0.20\ m$ to $b \approx 0.80\ m$. Please record your interval, $[a, b]$; your interval may not necessarily be $0.2\ m$ to $0.8\ m$.

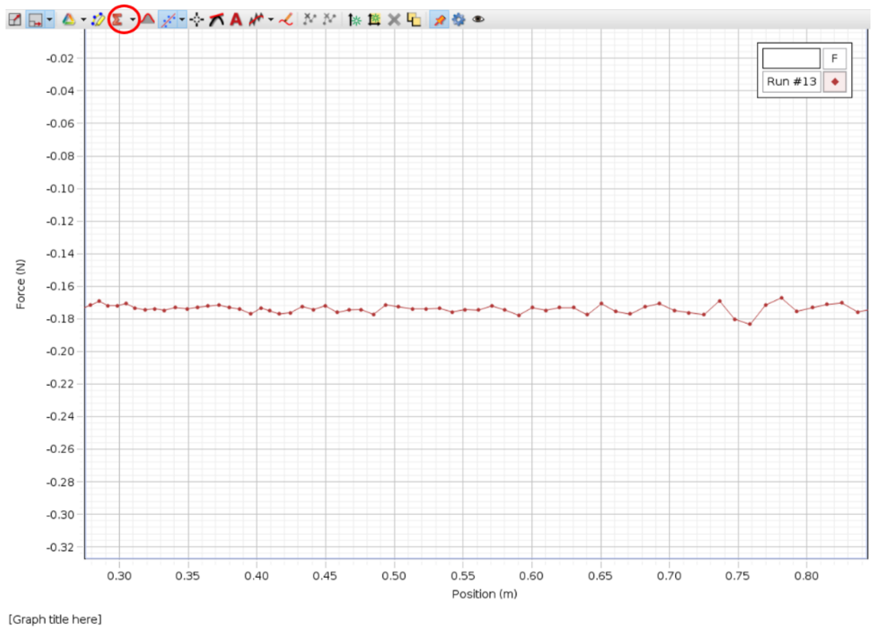

Figure 4: Force versus distance for a constant force.

8. Calculate the work using Equation (2) and the value of the average force found in Step 7. Assume $\cos\theta = 1$. Call this the theoretical work.

9. Transfer the data for Force versus position to Excel and calculate the work using Trapezoidal rule, Equation (7). Call this the experimental work.

10. Uncertainty analysis. Use the standard deviation in the force measured in Capstone(step 7) to estimate uncertainty in the work by multiplying this standard deviation by the displacement. Then use it to compare your theoretical and experimental results.

Part II: Work done by a linear force using a spring.

11. Replace the mass with a spring. Stretch the spring and connect one side of it to a 1kg weight placed on the floor as shown in Figure 5. Please remember to hold track and cart in place. Make sure that the stretched spring is completely vertical.

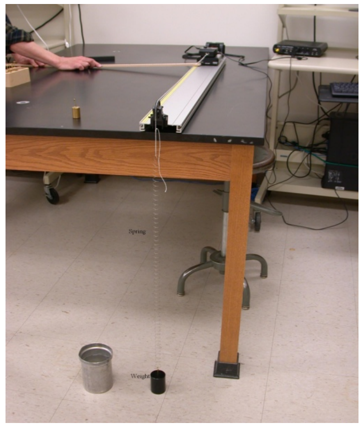

Figure 5: Work done by a spring apparatus.

12. Repeat steps 4 through 7 of the Part I procedure. Your plot should look like the plot in Figure 6.

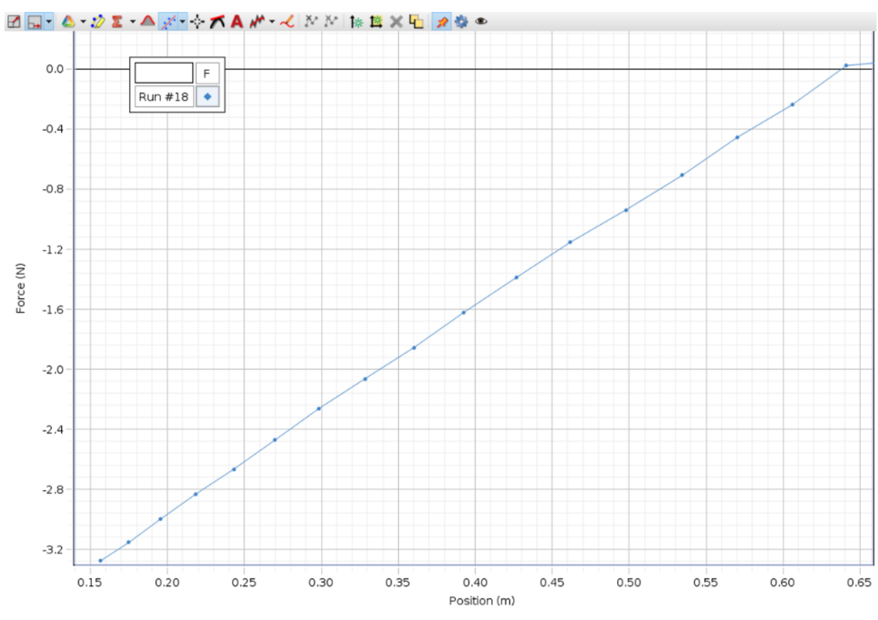

Figure 6: Force versus distance for a linear force.

13. Use the linear fit tool to find a line that fits the data. Select the most linear portion of the graph, using approximately the 0.20 m to 0.80 m portion.

14. Calculate the work using Equation (3) and the equation for the line found from Step 13. Call this work theoretical work. Remember the limit of the integral is the beginning and ending values you chose in the previous step.

15. Transfer the data for force versus position to Excel and calculate the work using Equation (7). Call this work experimental work.

16. Discuss what could account for the difference between your experimental and theoretical values.