Physics 4A

Lab 7: Work and Energy

Objective: To measure the force provided by a spring and rubber band, calculate the work done by stretching them, and find the amount of work converted to kinetic energy.

Theory:

Energy is the most important concept in science: It's the way we keep track of how everything in nature interacts. Today's experiment has two parts:

Part 1: We will measure the force required to stretch a spring (*and a rubber band*) and use the data to determine the work done to stretch the spring (*and the rubber band*),

Part 2: We will allow the spring (*and rubber band*) to interact with a cart on a track, and measure the kinetic energy that the spring (*and rubber band*) transfers to the cart.

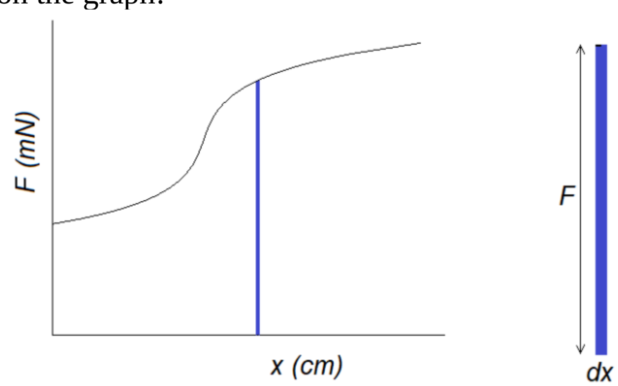
The force required to stretch a spring varies as the spring is stretched; for an *ideal* spring, this concept is expressed by *Hooke's Law.* For real springs, we expect something similar, although not necessarily the same behavior as an ideal spring.

How can we determine the work required to stretch a spring? We can stretch the spring a tiny bit at a time and we can approximate the force as constant for each small but of stretch. How small?

Isaac Newton answered this question for us when he invented *integral* calculus. The answer: *infinitesimally small*. So how will we accomplish this? We will add mass to the hanger on the spring, 5 grams at a time (for the rubber band this will be 50 grams at a time.) The spring will stretch a small amount each time, but much greater than infinitesimally small.

We will collect our data and graph the force applied to the spring versus the stretch, i.e. F vs x. We will then find the best-fit line to the data (for the rubber band we'll find the best fit *curve*!) and the corresponding equation.

The idea is that the best-fit line (or curve) will fill in the gaps between our data points. We can then imagine a tiny stretch "*dx*" and the corresponding force. We can represent these with a tall, thin rectangle on the graph:



Since *work* is the product of the force applied to the spring and the distance the spring moves, this thin rectangle represents a tiny amount of work.

If we extend this to every tiny "*dx*" across the x-axis, we can see that…

the work done to stretch the spring is represented by the area under the curve on the graph.

Newton discovered that an expression for the area under the curve can be determined from the equation for the curve itself, i.e. the "function" that is the graph. The procedure to create the expression for the area is an *integral*… and it is the inverse of the procedure for taking a *derivative* of the function.

Procedure:

Part 1: Work to Stretch a Spring

1.1. Introduction

Watch the following video that introduces the equipment and procedure for Part 1:
https://youtu.be/JMvljvPVAIs

1.2. Data

Watch the following videos to obtain data for the spring and rubber band:

Spring: https://youtu.be/LUyIvfBncxo
Rubber band: https://youtu.be/lzRiP6j03Es

Record the mass and distance stretched in Excel, then calculate the force by multiplying mass by the acceleration due to gravity. Use Excel's fill down feature so you only need to type in the equation once. All data for part 1 should be entered into the tab labelled 'Part 1'. Tabs are located on the bottom left portion of the Excel sheet.

Note: All calculations should be completed in Excel!

1.3. Graph F v. x

Create a graph of *F v. x* and find the best-fit line for the spring and rubber band. This should be linear fit for the spring. The data for the rubber band will best fit a cubic equation, i.e. a polynomial of order 3. Display the corresponding equation on the graphs.

1.4. Record the Coefficients

Record the coefficients of the force equation (i.e. the equation of the best-fit line) below the label 'Force Function', for the spring and rubber band. Use the coefficients to create the equation for the work done to stretch the spring for both the spring and rubber band. Remember that the work done is the integral of the force.

1.5. Calculated Work

Using the equation for the work (labelled Work Function), calculate the work required to stretch the spring and rubber band 4.0, 8.0, 12.0, 16.0, and 20.0 cm. The value will need to be divided by 100 to obtain an answer in mJ.

An example calculation for the spring would be "=((coeff 1)*(x^2) + (coeff 2)*(x))/100". For the cells that contain the coefficients, place a $ sign before the column number, so you can fill down the equation (therefore, you will only need to enter the equation once). An example would be "A$5", instead of "A5".

Values of work should be between 10 mJ and 120 mJ for the spring, and between 65 mJ and 900 mJ for the rubber band. If you do not get these values, send me your spreadsheet, and I'll help you find errors.

Part 2: Energy Transferred

2.1. Introduction

Watch the following video which introduces Part 2: https://youtu.be/uuazgYlH3MY

In Part 1 we calculated how much work is required to stretch the spring or rubber band five specific distances (i.e. 4.0 8.0 12.0 16.0 20.0 cm.) The work done to stretch the spring should be "stored" by the spring as *potential energy*, and the spring should then be able to transfer that energy to another object.

To test this idea, we will connect the spring (via a string that passes over a pulley) to a cart on a track, pull the cart back to stretch the spring, and then release the cart. We expect that the spring should transfer the stored energy to the cart in the form of *kinetic energy*.

The cart will pass through a photogate, which will allow us to measure the time directly. From the time we can calculate the speed of the cart and then the kinetic energy of the cart. We can then compare the kinetic energy of the cart to the energy that was stored in the spring (i.e. the work done to stretch the spring.)

We will conduct five "trials" of the procedure for Part 2, which each trial using a different value of "x".

2.2. Measure mass of cart

Change Excel tabs to the tab labelled 'Part 2'.

Watch the following video, and record the cart's mass for the spring:
https://youtu.be/GL6Jo_ddeRY

2.3. Velocity of the cart

Watch the following video to obtain data for the spring and cart: https://youtu.be/bGpm3r_7yII

For each trial, the cart is pulled back a specific distance, stretching the spring by the same distance. The cart is released and you will record the time for the cart to pass through the photogate. This measurement will be repeated 4 times for each trial. Since the mass is measured in grams and the speed of the cart is in m/s, the calculation of kinetic energy will have the unit *mJ* (milliJoules).

Note on the spring: we took a fifth measurement in Trail 5 because during the first run we were accidentally holding onto the pulley. The time of 0.1723s should be disregarded. Use the remaining data, runs 2 through 5.
Convert the velocity from cm/s to m/s for each run. Use the velocity in m/s to calculate the kinetic energy.

Calculate the average and standard deviation of the four values of kinetic energy for each trial.

2.4. Results
Summarize the results in the bottom most table in Excel. This table compares the work done to stretch a spring to the kinetic energy transferred to the cart for each of the five trials. Your values for work will come from the tab labelled 'Part 1'.

2.5. Graph K v. W
Create a graph of *K v. W*, and find the best fit line. Note that the slope of this graph is the fraction of energy that the spring was able to transfer to the cart (i.e. if *K* equals *W* for all trials, the graph would show a straight line with a slope of 1.00).

Slope values should be between a value of 0.4 and 1. If your values are not within this range, send me your spreadsheet and I'll help you find errors.

2.6. Rubber band
Repeat steps 2.3 – 2.5 for the rubber band attached to the cart. Data for the rubber band is given in the following video: https://youtu.be/AO_MJvsoX1Y.

Note on Trial 2 – we lost count of the number of runs and took five measurements instead of four. Use whichever four of the five measurements you like.

2.7. Questions
Answer the questions provided in the Excel spreadsheet, under the tab labelled "Questions". The spreadsheet will be the only item submitted through Canvas.