Experiment 3: Conservation of Mechanical Energy

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Lab Section 8 – Monday/Wednesday 11:30am

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(2) Discussion

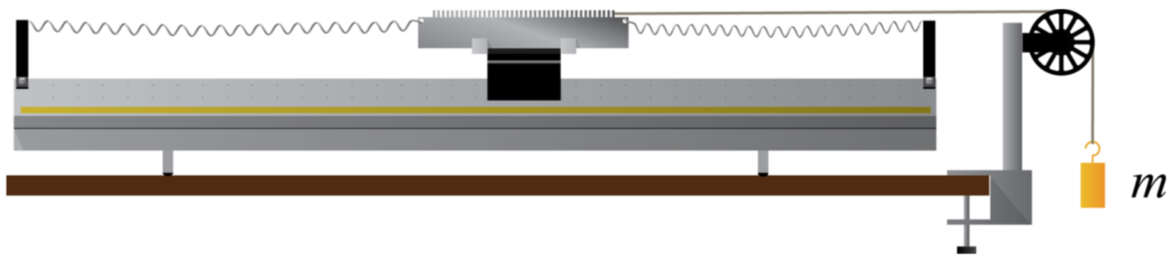

Figure 1[1]**:** This is an image of the apparatus that we used for this experiment. We hung masses of various sizes on the string to measure the effect of applied force on the displacement of the comb from equilibrium. The photogate comb is attached to a glider which sits on an air track. The glider and comb weight 232.6 g together. The comb has 61 teeth that are each 2 mm wide with 2 mm gaps in between.

Our photogate comb was lined up so that the photogates sensor would be positioned right in between the 30th and 31st tooth of the comb. More specifically, the sensor was at the right side of that gap, next to the 31st tooth. This point is the middle of the comb, and it made sense to have this as the equilibrium point for the comb. With reference to the diagram in Figure 1, our comb started with an offset to the right of the equilibrium point and then moved to the left.

Kinetic energy is dependent on velocity. Therefore, we needed to find the displacement along the comb of each tooth. We recorded the times that the photogate sensor was blocked by a tooth of the comb (sometimes referred to as a block event). We calculated the distance each tooth is away from the equilibrium point and matched these to each corresponding block event. We defined the equilibrium point, $x \equiv 0$, as the middle of the comb. Every tooth to the left of the equilibrium point has a negative position, and every tooth to the right has a positive position. Because our comb was set up so that the equilibrium point is at the start of the 31st tooth, that means that there were 30 teeth before the equilibrium point. Each tooth and each gap are 2 mm wide, so start of the leftmost tooth has an offset of -0.120 m relative to the equilibrium point. For each timestamp recorded, I incremented the value of the position by 0.004 m (this is 4 mm for each tooth and gap pairing). Since we have the position and the time for each block event, we can calculate velocity with equation 3.3 from the lab manual.

To find the kinetic energy, we plug in our values for velocity into equation 3.5 from the lab manual along with the mass of our glider and comb, which has a value of 232.6 g. This value was converted to kilograms before being used in the calculations. To calculate the values for potential energy, we use our value for the spring constant, k = 5.963 N/m and plug that into equation 3.1 along with each value of position that we calculated to find velocity.

The total mechanical energy in the system was produced by adding corresponding values for kinetic energy and potential energy together. In an ideal system, we expect this value to be constant. In our experiment, some of our energy was lost as thermal energy because of friction from the air track.

(3) Plots and Tables

The mass of our glider with the mass attached is (232.6 ± 0.35) g. The scales that we used to measure mass can only measure up to 100 g, so we counter-balanced the scale with two masses of 99.3 g and 99.2 g, each with uncertainty ± 0.2 g. The total uncertainty for the glider's mass was calculated using each counter-balancing mass' uncertainty and combining them with equation ii.22 from the lab manual.

Trials	Mass (g)	Displacement (cm)	Applied Force (N)
1	3.4	0.6 ± 0.03	0.0333 ± 0.0772
2	5.1	0.8 ± 0.03	0.0500 ± 0.543
3	19.9	3.2 ± 0.05	0.195 ± 0.0186
4	34.6	5.65 ± 0.03	0.339 ± 0.00785
5	60.4	9.92 ± 0.03	0.592 ± 0.00448
6	100.2	16.45 ± 0.05	0.982 ± 0.00363

Figure 2: This table has the values used to calculate the value of the spring constant. The spring constant was found by plotting each of these points and finding the slope of the trendline. For readability, mass is presented in units of grams, and displacement is presented in centimeters. The value of uncertainty for masses is 0.2 g. Uncertainties for applied force were calculated using equation ii.23 from the lab manual.

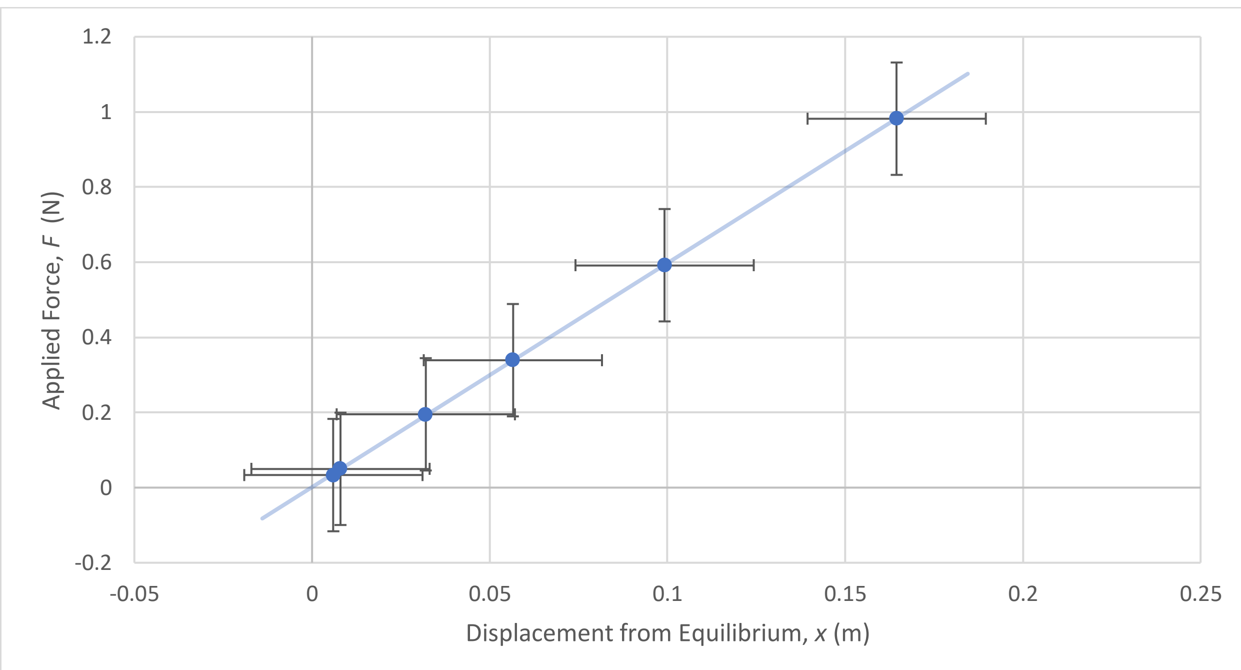

Figure 3: This plot shows how the amount of applied force on the system changes the displacement from equilibrium of the glider and comb. The relationship is linear between the displacement of the glider from equilibrium and the force applied to the system from the hanging masses. This follows the relationship of Hooke's law which states that $F = kx$ where k is the spring constant. The graph is plotted with the displacement on the x-axis and force on the y-axis so that the slope can be read off the graph and used as our spring constant, which has units of N/m. The slope of the line and value of the spring constant, k, is (5.963 ± 0.0183) N/m.

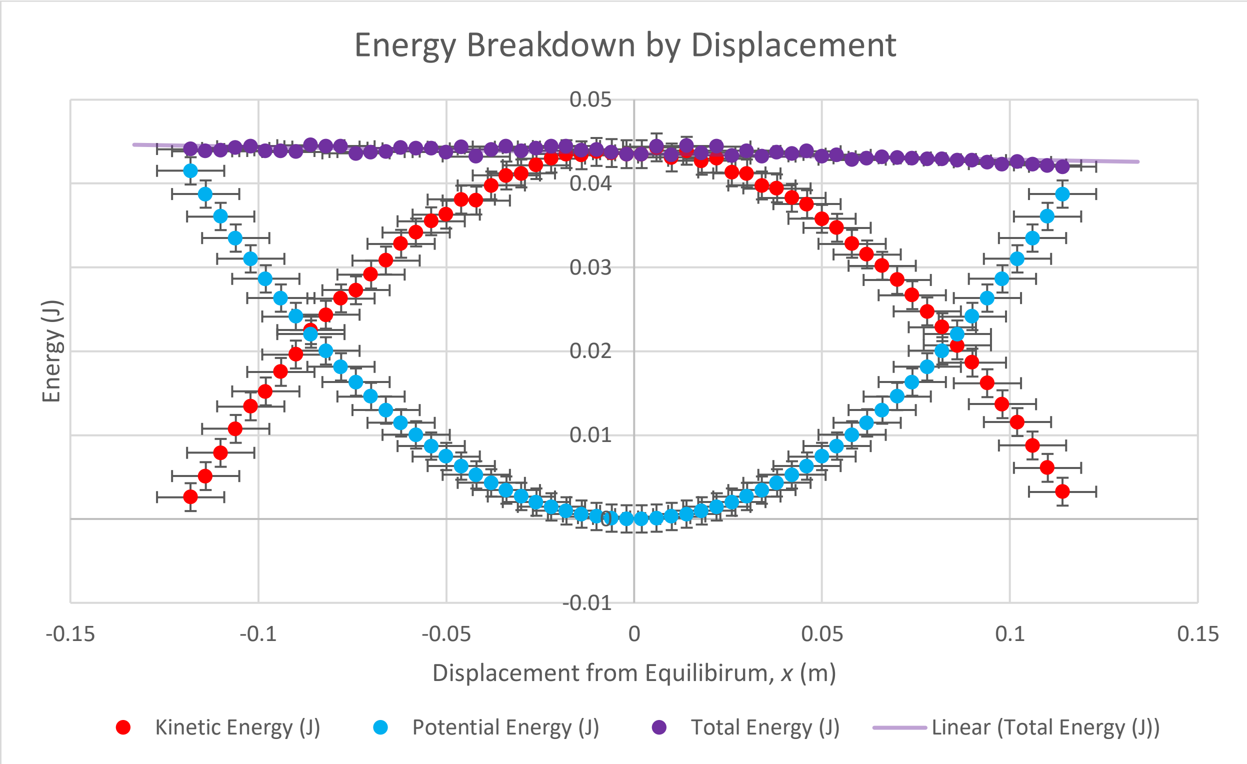

Figure 4: This plot illustrates how the energy is divided up in our glider. Each data point in all three data series represents the amount of each type of energy that the glider has at each value of displacement from the equilibrium point. The slope of the trendline is (-0.0076 ± 0.00081) J/m. As the glider moved into a positive displacement, some of the energy was lost as thermal energy because of friction between the glider and the air track.

Friction force depends on the normal force, F_N, and the coefficient of friction. The value of F_N is equal to the weight of the glider on the sled. The value of friction force is equivalent to the slope of the trendline for total energy in Figure 3.

$$F_f = \mu * F_N$$

$$(-0.0076 \pm 0.00081)\ N = \mu * ((0.2326\ \pm\ 0.0002)\ kg * 9.80\ m/s^2)$$

$$\mu = 0.0033 \pm 0.107$$

Most coefficients of friction in general are higher than our value. However, the air track is supposed to simulate a frictionless surface, so a low value makes sense in this scenario. If we look at the trend of decrease in the glider's total mechanical energy across multiple oscillation cycles (as in section 4), then we see that the force of friction is actually less than in the half cycle case that we looked at here. Thus, the coefficient of friction would also be lower if we looked at multiple cycles.

(4) Extra Credit

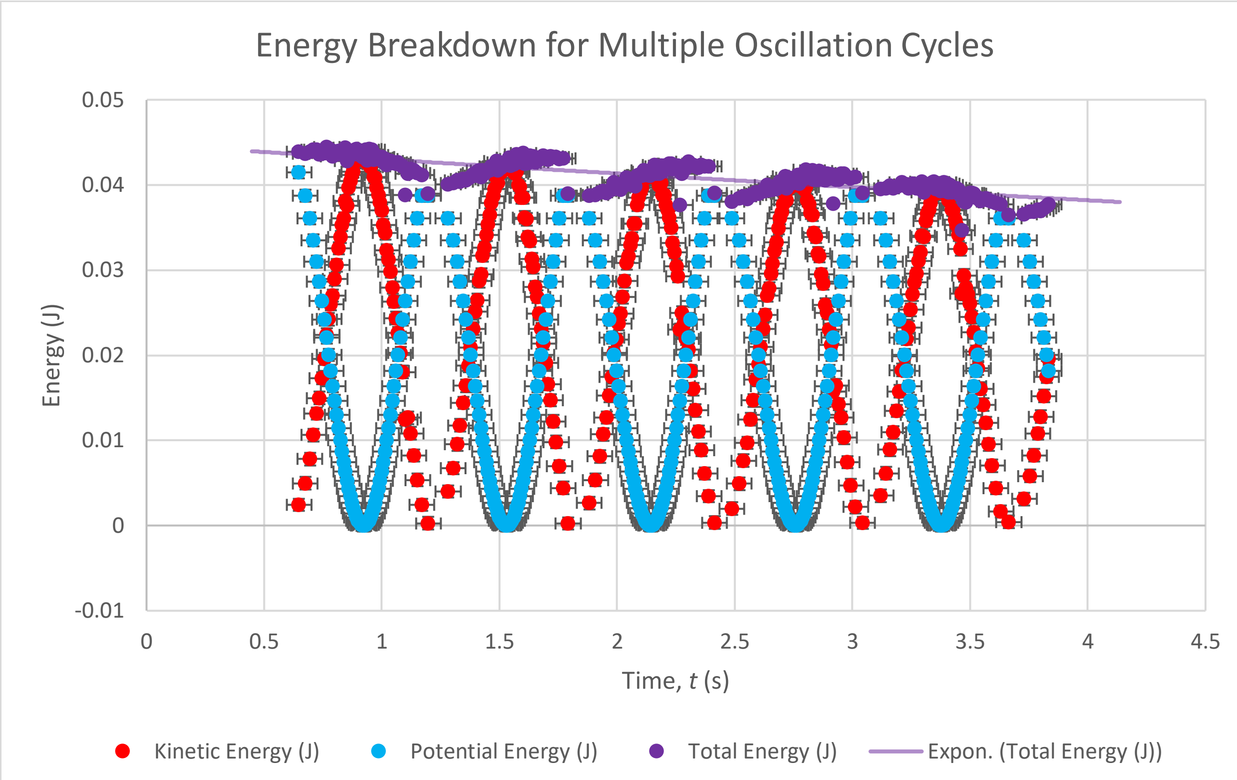

Figure 5: This plot shows the breakdown of the glider's total mechanical energy into kinetic and potential energy across multiple oscillation cycles. Each data point represents the amount of each type of energy the glider has at a particular moment in time. The total mechanical energy of the glider decreases over time because of the friction between the glider and the air track. The equation of the trendline is $E = 0.0448e^{-0.04t}$. This indicates that the energy in the system converges to a value of 0.0448 J.

To find the initial total mechanical energy, we plug in the first timestamp that we recorded into our equation.

$$E_0 = 0.0448e^{-0.04(0.64762)} = 0.04365\,J$$

Since we want to find when the amplitude of oscillation decreases by a factor of e, we use the following equation and solved for A_0.

$$E_0 = \frac{1}{2}kA_0{}^2$$

$$A_0 = \sqrt{\frac{2(0.04365)}{5.963}} = 0.121\,m$$

We want to find a value t_x, such that:

$$E(t_x) = 0.0448e^{-0.04t_x} = \frac{1}{2}k\left(\frac{A_0}{e}\right)^2$$

$$t_x = -\frac{1}{0.04}\ln\left(\frac{1}{2 * 0.0448}k\left(\frac{A_0}{e}\right)^2\right) = 108\ s$$

It will take 108 seconds for the system's amplitude of oscillation to decrease by a factor of e.

Presentation Mini-Report

Mechanical Energy Composition of an Oscillating System

K. Y. Agi[1]

Mechanical energy in a system is a combination of kinetic and potential energy. The law of conservation of energy states that energy may be transferred between states, but it cannot be created or destroyed. In this experiment, we measured the breakdown of our oscillating system's mechanical energy into kinetic and potential energy. We sought to verify this principle with a photogate comb attached to a glider on an air track that has two springs attached to it on both sides. We first determined the spring coefficient in our system by hanging masses from the glider via a pulley to see the displacement of the glider from equilibrium. These values were plotted, and the trendline's slope was used as our spring coefficient. We then we recorded the time at which each tooth of the comb blocked the photogate as the glider oscillated around its equilibrium point. With these values, we calculated the kinetic and potential energy of the system at each moment. To find the total mechanical energy of the system, we added each corresponding value pair. Our data showed that some energy was lost as thermal energy from friction. However, energy would have been completely conserved in an ideal system.

[1]Department of Engineering and Applied Sciences, University of California, Los Angeles

Word Count: 200

Bibliography

1. Campbell, W. C. et al. Physics 4AL: Mechanics Lab Manual (ver. June 27, 2018). (Univ. California Los Angeles, Los Angeles, California).