# Experiment 3:
# Conservation of Mechanical Energy

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Date of Experiment: August 21, 2017
Lab Section: Monday/Wednesday,
11:30 AM
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**WORKSHEET**

**I. Discussion**

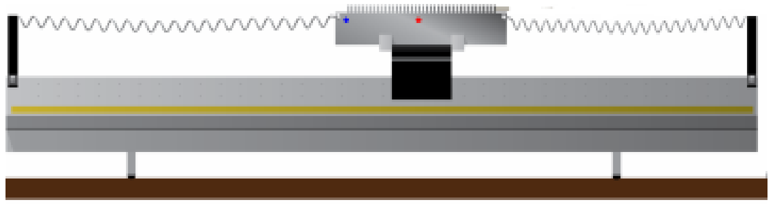

**Figure 1. Set up of Glider-Spring System**. For visual clarity, the photogate used is not shown. Figure reproduced and modified (with permission) from Fig. 3.1 by Campbell, W. C. Reference: Campbell, W. C. et al. Physics 4AL: Mechanics Lab Manual (ver. May 12, 2017). (Univ. California Los Angeles, Los Angeles, California).

With respect to the configuration in Figure 1, the system was set up so that the glider moved left during the half-oscillation run. The edge of 26th tooth (counted from the left) was chosen as the equilibrium point (approximated by the red dot on the figure). The photogate was situated relative to the relaxed spring system so that the beam was not blocked at rest, but a slight displacement to the left would cause the 26th tooth to block the sensor. A single run of the experiment involved pushing the glider back so that the sensor is right before blocking the first tooth (blue dot). The width of a tooth is 0.002 m±0.000030 m as is the space between two teeth; therefore, since the displacement from the equilibrium point covers 25 teeth and 25 gaps, the total displacement is $x =$ -0.100 m ± 0.0015 m. The initial displacement is considered negative as the glider was moved to the right when positive displacement is movement to the left.

During the run, a half-oscillation worth of timestamps were obtained, which is 51 points based on our equilibrium and starting points. Using Excel, the position $x$ at each block was calculated, where the first point is at -0.100 m, and every subsequent point is +0.004 m (tooth plus gap width) the previous position. The kinetic energy was found on Excel by creating columns for average position $x_{avg}$ in an interval, average velocity $v = \Delta x_{avg}/\Delta t$, and the average kinetic energy using $K = \frac{1}{2}\ Mv^2$, where $M$ = 0.2253 kg ± 0.00015 kg. This is equivalent to the manual's equation 3.5, $K = \frac{1}{2} M \left(\frac{x_i - x_{i+1}}{t_i - t_{i+1}}\right)^2$. Even though potential energy can be found at every $x$, since we want to compare the potential energy at the same displacement, we apply the formula $U = \frac{1}{2} k x_{avg}^2$ to get the measurement at every average position like the kinetic energy. The determination of the spring constant $k$ was found prior to the experiment by recording the displacement of the glider system due to the applied force of a hanging mass on a pulley. The resulting data, graph, and measurement of $k$ using Hooke's law—$F = kx$—are on the next page.

The energy values are plotted versus displacement in two separate series on the same graph. The sum of these energies is also plotted versus displacement.

**II. Plots and Tables**

Mass of glider with photogate comb*: 0.2253 kg ± 0.00015 kg
(*Measured relative to the sum of two measured masses. This measurement and that of the masses are added to find the total mass; thus, the uncertainty for each measurement adds up)

| Trial | Hanging Mass (±0.00005 kg) | Applied Force (±0.00049 N) | Initial Position (±0.0005 m) | Final Position (±0.0005 m) | Displacement (±0.001 m) |
|---|---|---|---|---|---|
| 1 | 0.0059 | 0.0578 | 0.434 | 0.425 | 0.009 |
| 2 | 0.0194 | 0.1901 | 0.434 | 0.401 | 0.033 |
| 3 | 0.0345 | 0.3381 | 0.434 | 0.374 | 0.060 |
| 4 | 0.0600 | 0.5880 | 0.434 | 0.335 | 0.099 |
| 5 | 0.1000 | 0.9800 | 0.434 | 0.256 | 0.178 |

**Table 1. Data Used to Determine Effective Spring Constant**. The hanging mass, initial position, and displacement on the track were measured with the scale uncertainties listed. The applied force was found using $F = mg$ (where $g = 9.8\ m/s^2$ and $\delta g = 9.8 * 0.00005$). The displacement was calculated using $x = |x_f - x_i|$ and their uncertainties were added for $\delta x$.

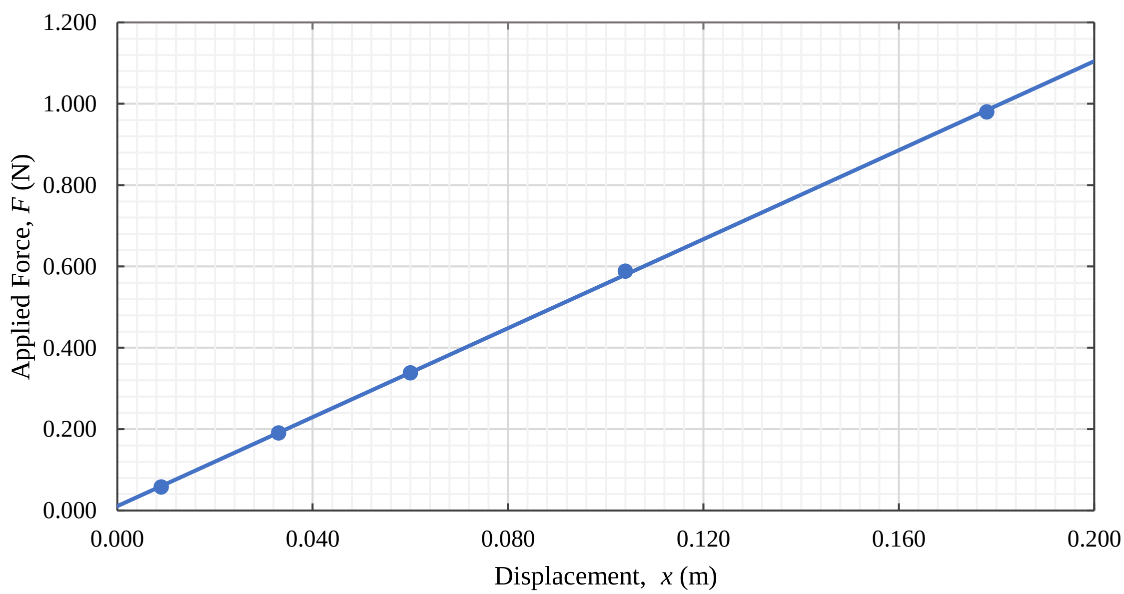


**Figure 2. Determination of Effective Spring Constant** The data points plotted represent the displacement of the glider due to the applied force provided by the hanging mass. A line was fitted to the force vs. displacement points whose equation is $F(x) = (5.50 \pm 0.15)\frac{N}{m}x$ (we ignore the intercept). Since the linear relationship between force and spring displacement is $F = kx$, the spring constant is the slope. Therefore, $k = (5.50 \pm 0.15)\ N/m$. This is later used to find the potential energy values for the experiment.

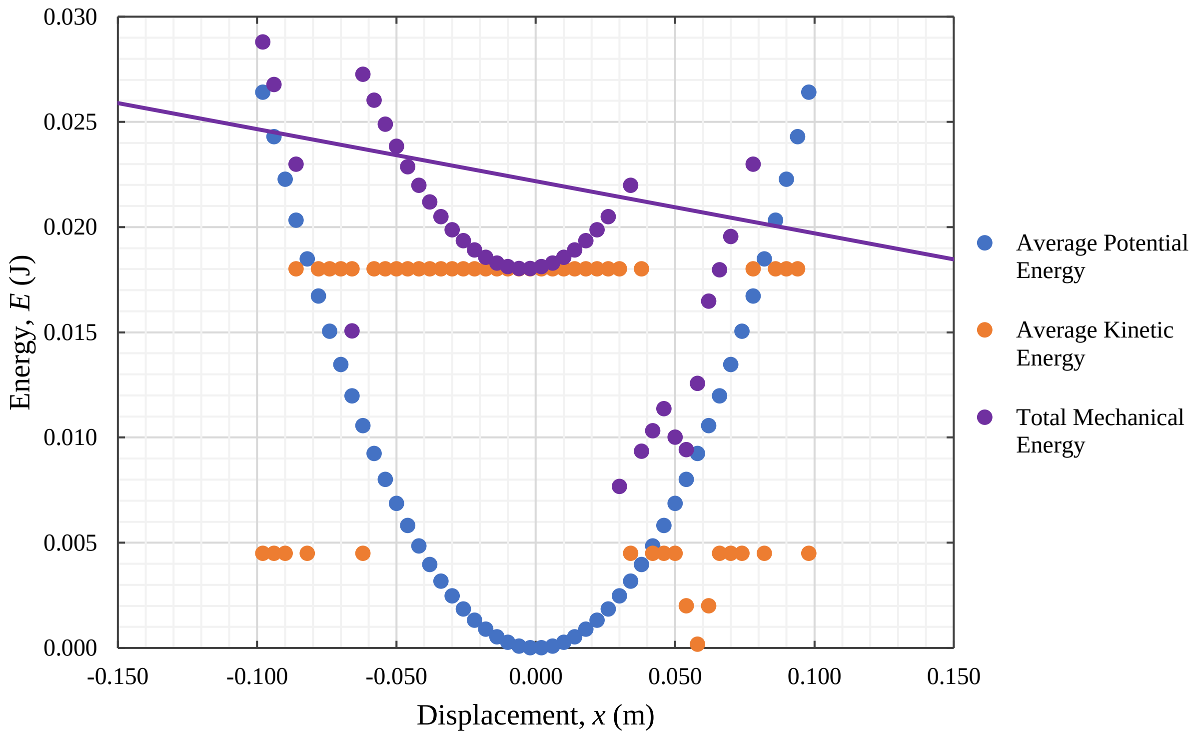


**Figure 3. Conservation of Mechanical Energy in Glider-Spring System.** The figure above tracks the potential, kinetic, and total energy of a glider spring system. The glider was pulled to before the first tooth, which is $0.100 \pm 0.0015$ m left of the 26th tooth (equilibrium point). It was released for half an oscillation, which is $0.100 \pm 0.0015$ m to the equilibrium. The potential energy (blue) and the kinetic energy (orange) were calculated using the formulas discussed earlier. These were summed to obtain the total mechanical energy at each point (purple). The purple line fitting the total energy has the equation $E(x) = (-0.028 \pm 0.020)\frac{J}{m}x + (0.0224 \pm 0.0011)J$. Unfortunately, due to lack of precision in the timestamps (only to 3 digits), the velocity was rounded to 2 digits. This led to untracked changes which consequentially failed to yield a parabolic kinetic energy curve complementing the potential energy. Thus, the total energy is not constant as per the graph. The fitted line still has a minimal slope as it is $> -1.00\frac{J}{m}$; we thus proceed to analyze our data with the line obtained.

Since $\frac{J}{m} = N$, the slope likely represents the constant friction *that converted some of the mechanical energy to thermal energy*. Since we thus assume *that the magnitude of the frictional force* $f = (0.028 \pm 0.020)N = \mu mg$, we can determine the coefficient of friction through the consequent relationship $\mu = \frac{f}{Mg}$, where M = 0.2253 kg ± 0.00015 kg and $g = 9.8\ m/s^2$. We work this out to find the value of the coefficient of friction with the uncertainty.

$$\mu = \frac{f}{Mg} = \frac{(0.028 \pm 0.020)N}{9.8\frac{m}{s^2} * (0.2253\ kg\ \pm\ 0.00015\ kg)}$$

$$\mu = \frac{0.028 \pm 0.020}{9.8 * (0.2253\ \pm\ 0.00015)} = \frac{0.028 \pm 0.020}{2.2079\ \pm\ 0.0015}$$

Now we can find $\mu_{best}$ and $\delta\mu$ using the equation ii.23 from the lab manual:

$$\mu_{best} = f_{best}(x, y) = \frac{x_{best}}{y_{best}} = \frac{0.028}{2.2079} = 0.0127$$

$$\delta\mu\ =\ \mu_{best}\sqrt{\left(\frac{\delta x}{x_{best}}\right)^2 + \left(\frac{\delta y}{y_{best}}\right)^2} = \sqrt{\left(\frac{0.020}{0.028}\right)^2 + \left(\frac{0.0015}{2.2079}\right)^2} = 0.714$$

The coefficient of friction is therefore $\mu = 0.01 \pm 0.71$. The large uncertainty is expected due to the parabolic behavior of the total energy being fitted to a line. Therefore, it would be ideal to conclude that since coefficient of friction overlaps 0, the friction is very minimal and most of the mechanical energy is conserved. However, the uncertainty makes the results inconclusive to an extent.

## III. Extra Credit

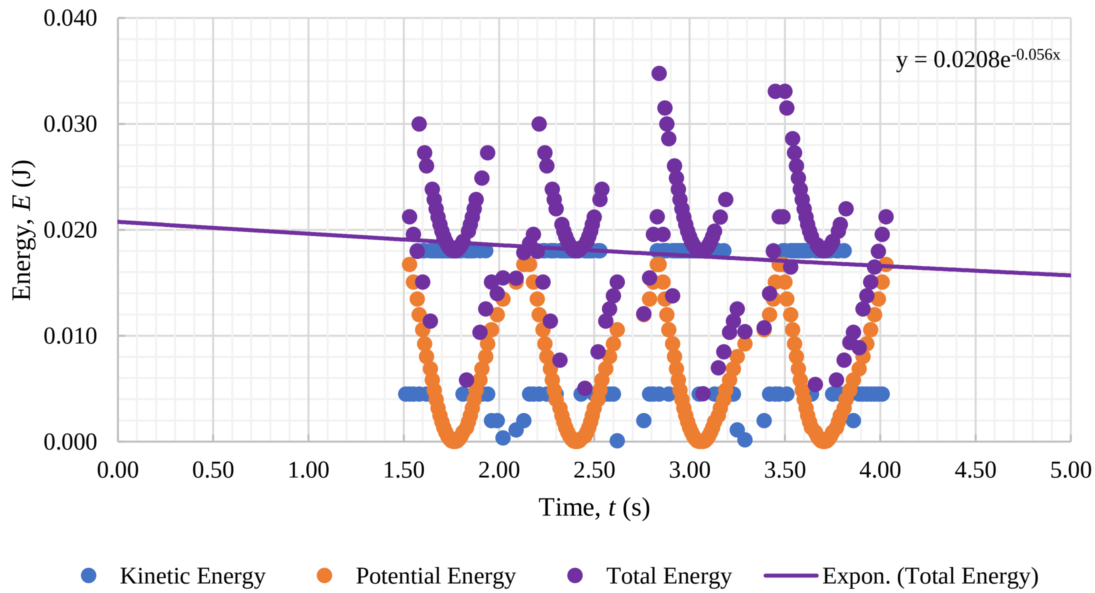


**Figure 4. Energy Dissipation Over Multiple Oscillations** Because the photogate sensor cannot distinguish direction and thus actual displacement from the equilibrium, the displacement was determined somewhat manually. Where the kinetic energy was highest—due to the precision error, this was assumed to the middle of each plateau—the displacement was set to 0. The displacement around it was adjusted accordingly. As can be seen, the total energy decreases as well, decreasing amplitude oscillation over time. This decrease is modelled by an exponential curve (purple line), whose fitted equation is $E\ =\ 0.0208e^{-0.56t}\ J$.

Estimation of time to decrease oscillation amplitude by $e$:

From the fact that $U = \frac{1}{2}kx^2$, we know that the total energy is proportional to the square of the oscillation amplitude. Therefore, we know that the energy when the original amplitude is decreased by a factor of $e$ is

$$E = \frac{1}{2}k(\frac{x}{e})^2 = \frac{E}{e^2}$$

where $E =$the initial energy based on the fitted line = 0.0208. We set this equal to the fitted equation to solve for $t$

$$\frac{0.208}{e^2} = 0.0208e^{-0.56t}$$

$$1 = e^{2-0.56t}$$

$$2 - 0.56t = 0$$

$$t = \frac{2}{0.56} \approx 4\ s$$

Therefore, it will take approximately 4 seconds to decrease the original oscillation amplitude by a factor of $e$.

Confirmation of the Conservation of Mechanical Energy in a Glider-Spring System

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Since energy can neither be created nor destroyed, the total energy of any system must be conserved—this phenomenon is observed in a glider-spring system. Atop an air track, a glider with a mounted photogate comb has a spring attached on both sides. The glider's motion is tracked when the comb blocks the photogate sensor, which records timestamps. The glider is displaced a measured distance from the 26$^{th}$ tooth of the comb, the chosen equilibrium point, and released. A half-oscillation worth of time stamps is recorded and the known block widths are used to determine the average position and velocity between each block, which are then used to find the kinetic and potential energies. The potential energy also required the determination of the effective spring constant. Unfortunately, the lack of precision in the timestamps led to an inaccurate measurement of the kinetic energy and the total mechanical energy. The total energy is still fitted to a line with a minimal negative slope, indicating the presence of friction and consequential energy dissipation. This ideally confirms the conservation of mechanical energy, but the lack of precision and accuracy in some data cause our results to be somewhat ambiguous and inconclusive.

Number of words: 198

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