Northeastern University

Report for Experiment #7

Work and Energy on an Air Track

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Abstract

This experiment utilizes the Ultrasonic Measurement System (UMS) to analyze the principles of work and energy. Two investigations will be conducted using an air track and glider equipped with a motion sensor to record the position over time. The data will be plotted and analyzed to calculate coefficients, such as velocity, which can verify physically known parameters like gravity. The two values of gravity were utilized to calculate the average gravity, which was approximately 9.5 $\frac{m}{s^2}$. This value deviates by only 2.8% from the actual value of gravity, which is 9.8 $\frac{m}{s^2}$. The work-energy theorem will also be tested to determine the relationship between work and energy. The second investigation will involve a different configuration and result in an equation dependent on two masses. The overall goal is to measure the acceleration of gravity using precision instruments. Using these values in investigation 2, we calculated the average gravity to be 10.9 $\frac{m}{s^2}$, with a percent difference of 11.2% compared to the actual value of 9.8 $\frac{m}{s^2}$. This experiment was conducted twice, with one investigation inclining the air track and using no masses, while the other kept the air track straight and hung a mass at one end to observe the change in kinetic energy and acceleration.

Introduction

In this work and energy on an air track experiment, we used the Ultrasonic Measurement System (UMS), which records an object's position relative to time, to analyze the principles of work and energy. The experiment consists of two investigations using an air track and glider with a motion sensor mounted at one end of the track. By plotting and analyzing the data, we can determine coefficients to verify parameters such as gravity and explore the experimental validity of the relation between work and energy.

To accomplish the experiment's goal, we need to understand and learn about the equipment used for data collection, including the UMS and the sonar transceiver. The UMS emits ultrasonic pulses that bounce off the object and calculate the distance traveled with the equation d = $c_s\Delta$t. For motion in the horizontal, we use the work-energy theorem, $W_{net} = \Delta KE$, and to find the velocity along the inclined plane, we use the equation v_2=2gsinθ(x−x_0).

The experiment has two investigations, where we measured the acceleration of gravity and the work-energy theorem using an air track, a computer, and a motion sensor. We conducted investigation 1 with the air track inclined and investigation 2 with the air track horizontal, and we also used a 1- ounce lead weight with a clip and paper tape to understand the work-energy theorem. To collect data, we use the UMS and the Capstone program, which measures and records the object's position and time between 10 and 50 times a second. Finally, we transfer the data to Excel, which helps determine velocity and acceleration, plot curves, and fit theoretical curves to the data points.

Investigation 1

My lab partner and I started investigation 1 by leveling our air track, setting up our PASCO Capstone computer system for data collection, and measuring our block's h value of 0.0035 ± 0.00005 m (error provided by halving the smallest increment value of our ruler). We slid the glider down the track until the reflector was about 20 cm away from the motion sensor and clicked the Record button in the Capstone window to capture our trial data. We went on to plot the position vs. time for all the data. To note the collisions of the glider with the end of the track, we observed where the direction of the glider changes abruptly on the graph and hovered our cursor over these two consecutive collisions to determine their coordinates, ((8.000 s, 1.32 m) and (10.050 s, 0.57 m)).

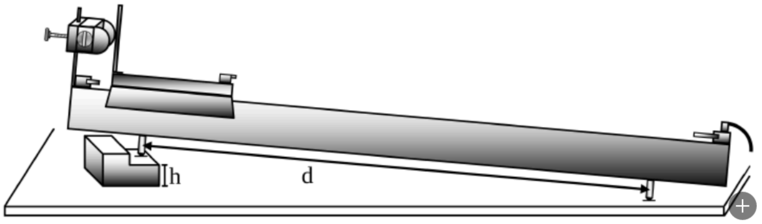


Figure 7.4 Alignment of transducer.

Figure 1.1: Visual representation of my lab partner and my lab setup [2, Figure 7.4].

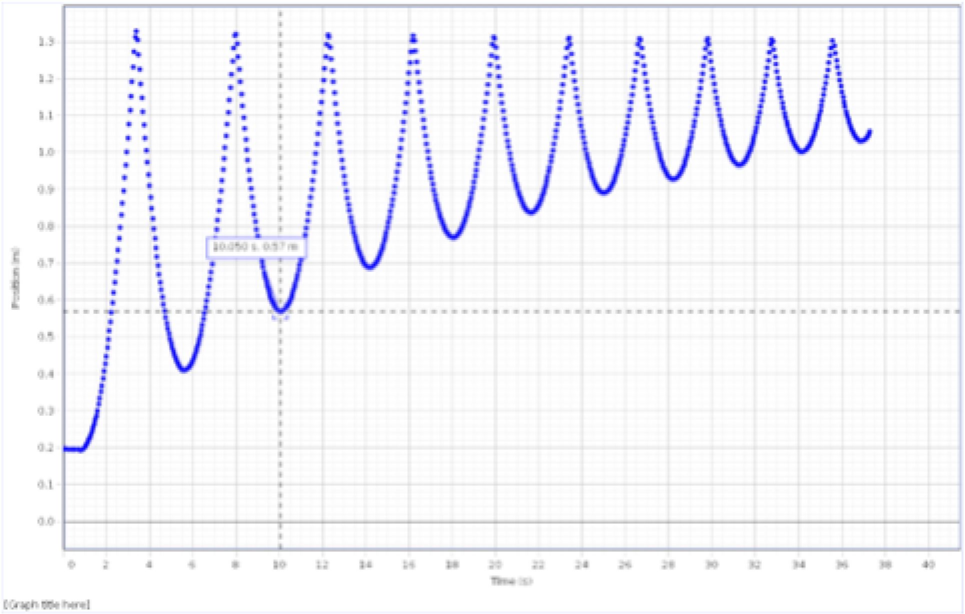


Figure 1.2: A screen capture of my lab partner and my experimental air track trial Capstone results.

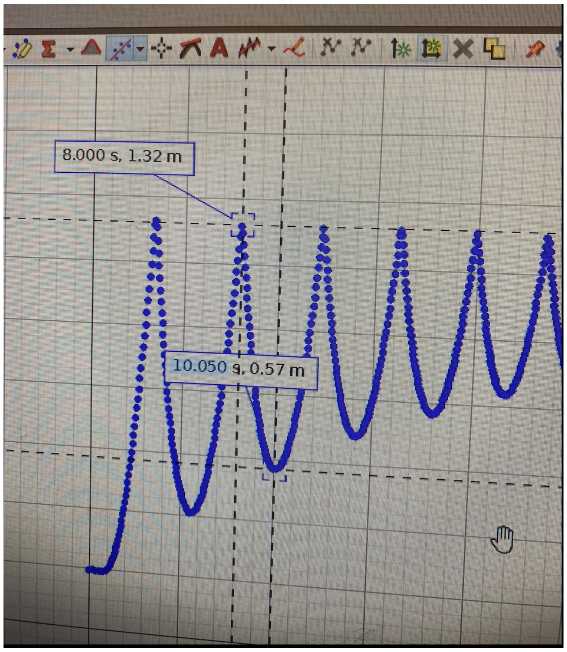


Figure 1.3: An additional screen capture of my lab partner and my experimental air track trial Capstone results with collision coordinates identified.

Next, we located these points in my data table and then copied and pasted the corresponding data between them onto a separate sheet in Excel labeling points under their respective "Time (s)" and "Position (m)" for analysis. Then, we used the Excel functions to compute our velocity (v) and velocity squared (v^2) values using the average velocity formula to find the value between points:

$$v = \frac{x_{n+1} - x_n}{\Delta t} .$$

Additionally, the error in the velocity squared value (δv^2) was determined using the following equation:

$$\delta v^2 = \sqrt{8v^2}\left(\frac{\delta x}{\Delta t}\right) .$$

Next, we calculated the average position between adjacent points using equation:

$$x_{avg} = \frac{x_{n+1} + x_n}{2} .$$

Then, we mathematically determined the error of this previously calculated value (δx_{avg}) using the the value δx = 1 mm or 0.001 m as given in our lab manual introduction [2] and the Appendix A [2] provided equation:

$$\delta x_{avg} = \frac{1}{2}\sqrt{(\delta x_1)^2 + (\delta x_2)^2} .$$

These values were all inputted and displayed in Table 1.1 with the first 9 rows representing sample data from the downward glider motion and the following 9 rows representing sample data from the upward glider motion and the visual representation of these first two columns (Figure 1.4):

Table 1.1: Sample data of calculated values from experimental trial data

Time (s)	**Position (m)**	v $(\frac{m}{s})$	v^2 $(\frac{m}{s})^2$	δv^2 $(\frac{m}{s})^2$	x_{avg} (m)	δx_{avg} (m)
1.295	8.05	-0.7	0.49	0.03959798	1.2775	0.000707106
1.26	8.1	-0.7	0.49	0.03959798	1.2425	0.000707106
1.225	8.15	-0.68	0.4624	0.03846661	1.208	0.000707106
1.191	8.2	-0.66	0.4356	0.03733524	1.1745	0.000707106
1.158	8.25	-0.66	0.4356	0.03733524	1.1415	0.000707106
1.125	8.3	-0.62	0.3844	0.0350725	1.1095	0.000707106
1.094	8.35	-0.6	0.36	0.03394113	1.079	0.000707106
1.064	8.4	-0.58	0.3364	0.03280975	1.0495	0.000707106
1.035	8.45	-0.58	0.3364	0.03280975	1.0205	0.000707106
0.569	10.1	0.02	0.0004	0.008	0.5695	0.000707106
0.57	10.15	0.02	0.0004	0.008	0.5705	0.000707106
0.571	10.2	0.06	0.0036	0.024	0.5725	0.000707106

0.574	10.25	0.06	0.0036	0.024	0.5755	0.000707106
0.577	10.3	0.08	0.0064	0.032	0.579	0.000707106
0.581	10.35	0.1	0.01	0.04	0.5835	0.000707106
0.586	10.4	0.12	0.0144	0.048	0.589	0.000707106
0.592	10.45	0.12	0.0144	0.048	0.595	0.000707106
0.598	10.5	0.16	0.0256	0.064	0.602	0.000707106

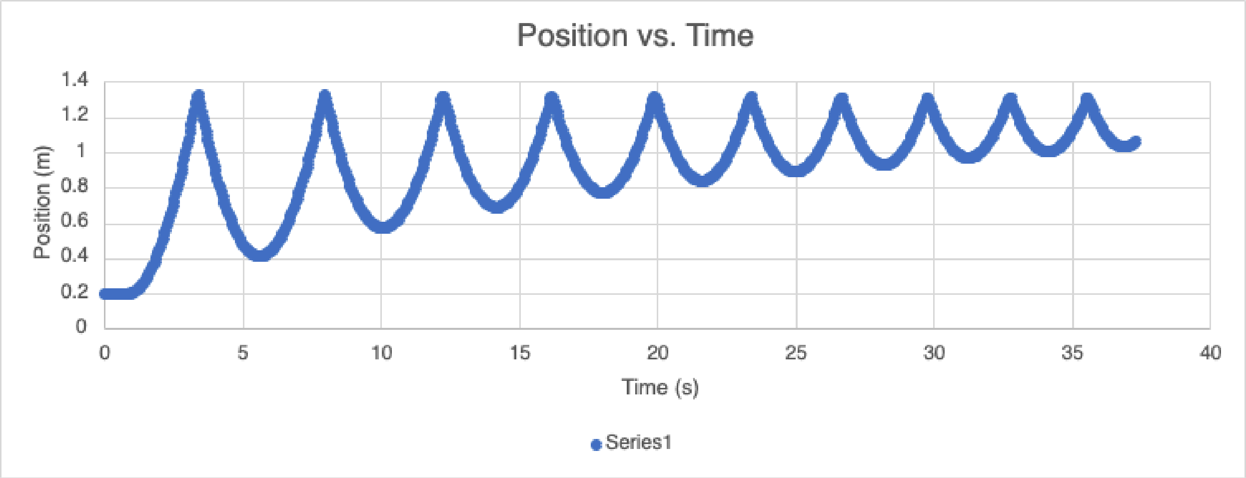


Figure 1.4: Our experimental graph displaying glider position over time of our air track-Capstone trial.

We then used these computed values to construct a plot of our velocity squared versus average position values found below (Figure 1.5).

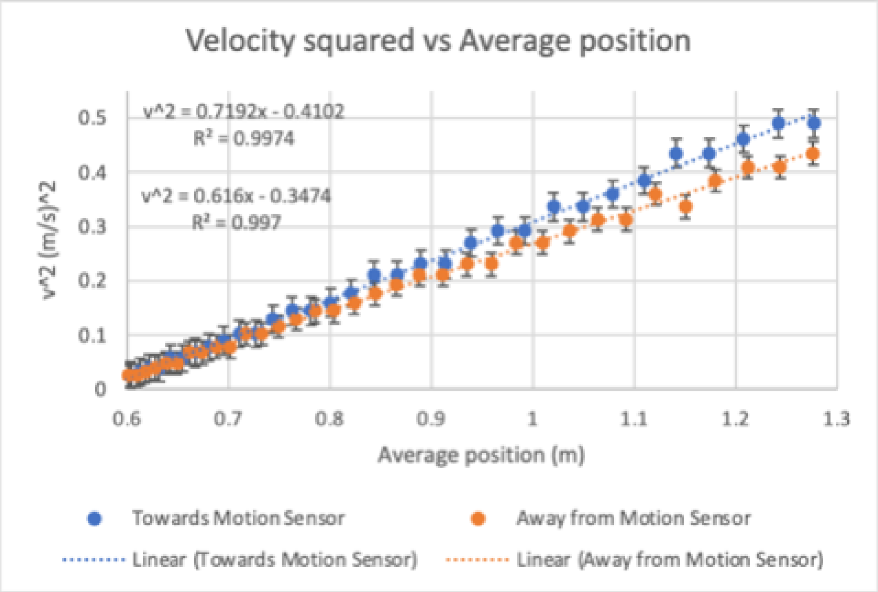


Figure 1.5: Our graph displaying velocity squared vs. average position of the positive and negative experimental glider motion.

Based on the information presented in Figure 1.5, it is evident that the slopes of the two series are slightly dissimilar. The slope in the negative direction (moving away) is recorded to be 0.719 $(\frac{m}{s})^2$, while the positive slope (moving towards) is measured at 0.616 $(\frac{m}{s})^2$. The cause of this variation in slope could be attributed to the loss of energy from friction in the system, although it is minimal, it still has an impact. Additionally, the collision between the glider and the bumper at the bottom of the track leads to a significant loss of energy, which results in the difference in slopes.

The data presented in the graph enables us to determine gravity by applying the formula that relates the slope to sin(θ). The formula for gravity is expressed as follows: $g = 2L\,(\frac{B}{h})$, where L denotes the length of the track, h represents the height of the inclined track, and B signifies the slope. The application of this formula resulted in obtaining the value of gravity for each series, which is tabulated in Table 1.2. The two values of gravity were utilized to calculate the average gravity, which was approximately 9.5 $\frac{m}{s^2}$. This value deviates by only 2.8% from the actual value of gravity, which is 9.8 $\frac{m}{s^2}$.

Table 1.2: A comparison of the found and known g values.

$g_1\ (\frac{m}{s^2})$	$g_2\ (\frac{m}{s^2})$	$g_{avg}\ (\frac{m}{s^2})$	**% difference**
10.27	8.8	9.54	2.8%

Based on the presented values, it can be concluded that the data corroborates the actual value of gravity and falls within the range of uncertainty. Therefore, the work-energy theorem has been substantiated. Nonetheless, the experiment's potential sources of error may be attributed to friction and leveling, which could have affected the results.

Investigation 2

In the second experiment, most of the equipment used in the first investigation was utilized, with the exception that a weight (measured value of 0.0285 $\pm$ 0.001 kg) was attached to the glider (measured value of 0.3804 $\pm$ 0.001 kg) using a strip of paper tape. The tape was suspended over an air pulley, with the weight positioned on one side and the side of the air track on the other. Moreover, the air track was no longer inclined in this configuration.

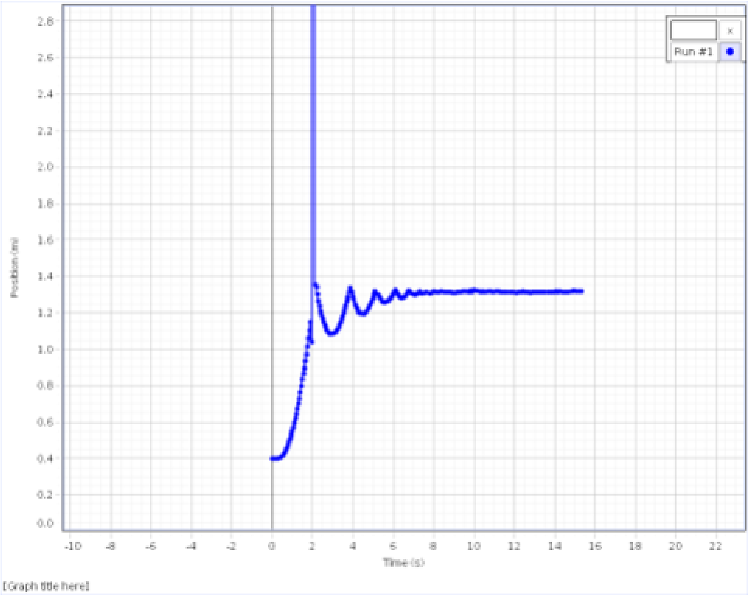


Figure 2.1: A screen capture of my lab partner and my experimental air track trial Capstone results.

Similarly to the previous investigation, the glider was propelled down the track, and its location was noted and plotted on Graph 3 (Figure 2.2). The coordinates of two successive collisions ((2.15 s, 1.35 m) and (2.95 s, 1.08 m)) and the associated data points in between were analyzed to determine the velocity (v) and velocity squared (v^2) of the glider, using the same equations as provided in the first investigation.

These values were all inputted and displayed in Table 2.1 with the first 9 rows representing sample data from the downward glider motion and the following 9 rows representing sample data from the upward glider motion and the visual representation of these first two columns (Figure 2.2):

Table 2.1: Sample data of calculated values from experimental trial data

Time (s)	**Position (m)**	v $(\frac{m}{s})$	v^2 $(\frac{m}{s})^2$	δv^2 $(\frac{m}{s})^2$	x_{avg} (m)	δx_{avg} (m)
1.34	2.2	-0.8	0.64	0.045255	1.32	0.000707
1.3	2.25	-0.6	0.36	0.033941	1.285	0.000707
1.27	2.3	-0.8	0.64	0.045255	1.25	0.000707
1.23	2.35	-0.4	0.16	0.022627	1.22	0.000707
1.21	2.4	-0.4	0.16	0.022627	1.2	0.000707
1.19	2.45	-0.4	0.16	0.022627	1.18	0.000707
1.17	2.5	-0.4	0.16	0.022627	1.16	0.000707
1.15	2.55	-0.4	0.16	0.022627	1.14	0.000707
1.13	2.6	-0.2	0.04	0.011314	1.125	0.000707

1.08	3	0.2	0.04	0.011314	1.085	0.000707
1.09	3.05	0	0	0	1.09	0.000707
1.09	3.1	0.2	0.04	0.011314	1.095	0.000707
1.1	3.15	0	0	0	1.1	0.000707
1.1	3.2	0.2	0.04	0.011314	1.105	0.000707
1.11	3.25	0.2	0.04	0.011314	1.115	0.000707
1.12	3.3	0.2	0.04	0.011314	1.125	0.000707
1.13	3.35	0.4	0.16	0.022627	1.14	0.000707
1.15	3.4	0.2	0.04	0.011314	1.155	0.000707

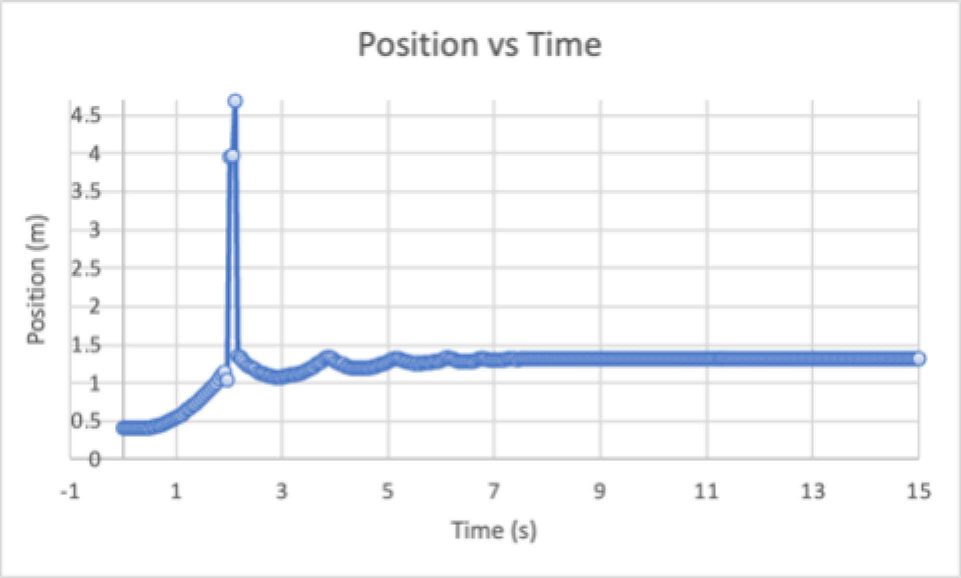


Figure 2.2: Our experimental graph displaying glider position over time of our air track-Capstone trial..

The resulting data was used to construct a graph that depicts the velocity squared of the glider as a function of its position. The graph features two series, one for the glider moving away from the sensor and another for the glider moving towards it:

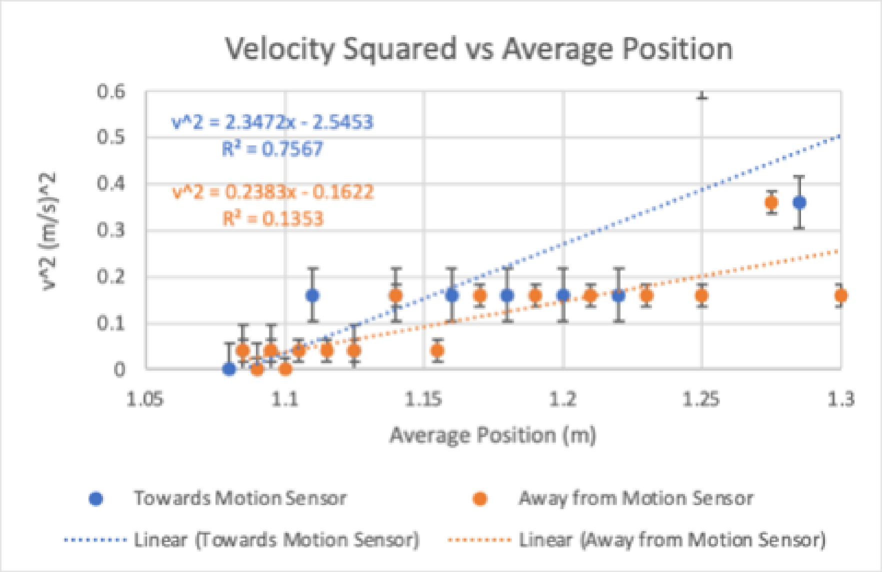


Figure 2.3: Our graph displaying velocity squared vs. average position of the positive and negative experimental glider motion.

The analysis of Figure 2.3 revealed that the slope of the glider's motion away from the sensor was 2.347 $(\frac{m}{s})^2$, whereas it was 0.238 $(\frac{m}{s})^2$ when moving towards it. The discrepancy in the slopes could once again be attributed to suboptimal leveling, negligible friction, and the loss of energy that the glider experiences upon impact with the bumper.

We determined the value of gravity by utilizing the relationship between the slope, the mass of the glider, and the weight suspended from the tape. The resulting formula is given as follows: where B represents the slope, m represents the mass of the glider, and M represents the mass of the weight. We used this formula to calculate the values of g, which are presented in Table 2.2. Using these values, we calculated the average gravity to be 10.9 $\frac{m}{s^2}$, with a percent difference of 11.2% compared to the actual value of 9.8 $\frac{m}{s^2}$.

Table 2.2: A comparison of the found and known g values.

$g_1\ (\frac{m}{s^2})$	$g_2\ (\frac{m}{s^2})$	$g_{avg}\ (\frac{m}{s^2})$	**% difference**
10.8	10.99	10.9	11.2%

The experimental value of gravity and its uncertainty encompassed the obtained data, confirming the validity of the work-energy theorem. It is worth noting that we did not use the y-intercept C to compute gravity since it cancels out. Since the initial position is 0, the y-intercept is also 0, and it cannot be employed in our calculations.

Conclusion

In conclusion, this work and energy on an air track experiment aimed to verify the work-energy theorem and determine the value of gravity, which was achieved by recording the movement of a glider along an air track using a motion sensor. In investigation 1, the track was angled to verify the work-energy theorem, while in investigation 2, the glider was attached to a vertically moving weight to verify the theorem horizontally. For both investigations, we split the data into two sets, one for the glider moving away from the sensor and one for the glider moving towards it. If the slope of these graphs was linear, the work-energy theorem would be verified, and we would obtain a reliable value for gravity. The data of the glider's velocity squared vs. average position was split for both investigations, and linear slopes on these graphs would confirm the work-energy theorem and provide an accurate value of g.

The experimental value of g was found to be 9.5 $\frac{m}{s^2}$ in investigation 1 and 10.9 $\frac{m}{s^2}$ in investigation 2, indicating that the experiment verified the work-energy theorem and provided a value for g that fit within the experimental uncertainty. And through the two investigations of this work and energy lab experiment it was found that kinetic energy was in fact conserved.Possible sources of error included the amount of air used for the air track, the loss of energy of the glider from the collision with the bumper, and the leveling of the track. To standardize future experiments, it is necessary to use a consistent amount of air and a proper apparatus for leveling the track.

Questions

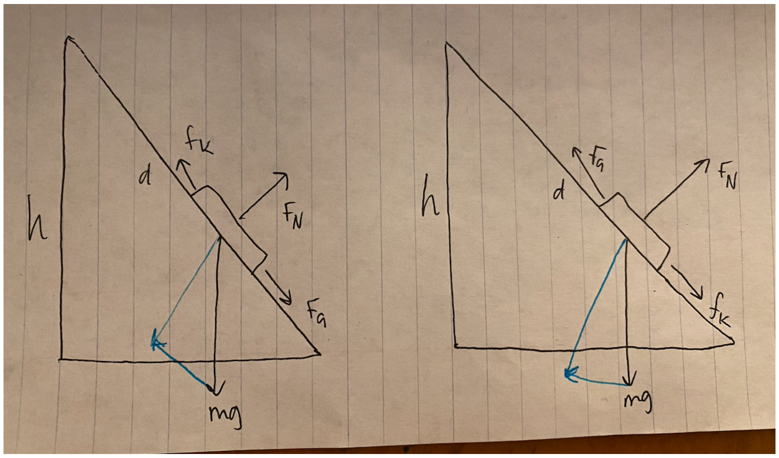
1. **As the velocity of the glider increases, does the accuracy of the motion sensor increase or decrease? (Hint: Think about how the sensor determines the glider's position.)**

   The accuracy of the motion sensor decreases in direct correlation with the increase in velocity of the glider, as it relies on reflecting sound waves to detect velocity, which becomes distorted at higher speeds.

2. **In the configuration of Investigation 1, for the upwards part of the motion, how does friction affect the total energy of the glider? How does it affect the total energy for the downwards part of the motion?**

   The opposing force of friction reduces the energy of both upward and downward motions of the glider by doing negative work on the system, thereby reducing the total energy of the glider.

3. **For the configuration of Investigation 1, draw force diagrams for all the forces on the glider including friction, for both the case of upwards and downwards motion.**



4. **For the configuration of Investigation 2, what is the acceleration of the glider if m' → ∞ to the power of apostrophe not stretchy rightwards arrow straight infinity?**

   If mass goes to infinity, the acceleration of the glider would be 9.8 $\frac{m}{s^2}$.

5. **For the configuration of Investigation 2, what is the change in potential energy from the moment of release to the moment of collision with the bumper? (Hint: Look at the change in x in the data list. Remember that only the weight is changing potential energy.) Considering the kinetic energy of the system just before it crashes into the bumper, what is the change in total energy of the system? Is the change in energy positive or negative? Explain whether your result makes sense.**

   As the glider decreases in height over time, the potential energy in the system decreases, while the work done by the negative force of friction further reduces the total energy of the system. Therefore, the change in total energy is negative as friction always takes away energy from the system.

Acknowledgments

I would like to thank my lab partner, Kelly Rosendo, for her help in executing this experiment during our lab class. I would also like to thank our Lab TA, Yin-Chun Hung, for his role in outlining the steps of the experimental process and answering any clarifying questions during our two investigations. Lastly, I would like to thank Northeastern University for providing me with the opportunity and resources to conduct this work and energy on an air track lab and write this lab analysis.

References

[1] H. Young and R. Freedman, University Physics, p 111, Pearson Education, 14th edition.

[2] Hyde, Batishchev, and Altunkaynak, Introductory Physics Laboratory, pp 411-415, Hayden-McNeil, 2017.