Work and Energy

1 Introduction

In this lab you will investigate conservation of energy and the concept of 'work' using the airtrack. You will look at the exchange between kinetic and potential energy, and the dissipation of energy by friction. In each experiment make sure you understand in what different forms the energy is stored and how it is exchanged.

2 Equipment

- airtrack with air pump,
- rubber band bumpers,
- a glider,
- pegs for gliders,
- Sonar Rangers
- computer with measurement software

3 Procedures

Read through the procedures and familiarize yourself with the equipment. This lab write-up will provide space for you to record and analyze your data.

3.1 Conservation of Energy: Spring and Kinetic

1. Carefully level the airtrack. This means that a glider can be released at any point on the track, and it will not accelerate.[1] Adjust the flow of air so that friction on the track is negligible even when masses are added to the gliders.
2. Insert the metal 'vanes' or 'flags' on the top of the glider. You should insert both so that it is balanced. Measure the total mass of the glider and flags as well as any additional masses you need below.
3. Use the rubber bumpers to launch the glider down the track. Measure the distance you stretch the rubber band, and record the resulting velocity of the glider in at least two widely separated positions and then stop the glider. Repeat several times for a given deformation of the band. Calculate the average velocity of the cart and its kinetic energy for a given extension of the band.
4. Calculate the average E_K (in Joules) and its uncertainty from the standard deviation of the mean making sure you correctly propagate the uncertainties in your measurements.

[1] If it accelerates in one direction on one side and the opposite direction on the other side of the track, then the track is bowed, and you will have to note how severely.

Extension of rubber band:________________________________

Trial	T_1	T_2	v_1	v_2	E_{K1}	E_{K2}
1						
2						
3						
4						
5						

Average $E_K \pm \Delta E_K$ _______________________

Extension of rubber band:________________________________

Trial	T_1	T_2	v_1	v_2	E_{K1}	E_{K2}
1						
2						
3						
4						
5						

Average $E_K \pm \Delta E_K$ _______________________

Extension of rubber band:________________________________

Trial	T_1	T_2	v_1	v_2	E_{K1}	E_{K2}
1						
2						
3						
4						
5						

Average $E_K \pm \Delta E_K$ _______________________

Question: Is there is much loss of energy due to friction? How can you tell?

Question: Assuming your bumper obeys Hooke's Law, calculate its elastic constant by equating the potential energy at the start ($E_p = ½ kx^2$) to the kinetic energy for each trial, and averaging the three trials. Be sure to use SI units. Remember that if the 3 trials have different uncertainties for k, you will need to correctly average them by weighting by their uncertainties,.

Spring constant k:__________________________

If you have time, you may wish to measure the spring constant directly by suspending known weights from the band and measuring the distance you stretch the band.

3.2 Conservation of Energy: Spring, Gravitational and Kinetic

1. Elevate the end of the track opposite the rubber band bumper. The angle should be steep enough so that the glider, when launched by the spring, will stop **before** reaching the opposite end. It should not be so steep that the glider scrapes the track as it moves. Measure the height of the track at the location of the spring, and at a known distance away. Use this to determine the angle of inclination:

   Angle of inclination α = ____________________________

2. Using the Sonar Rangers, measure the velocity as a function of time. Calculate the change in height between the point where the glider is launched and the point where the glider velocity is measured. Also calculate the change in the gravitational potential energy between the two positions.

   Height at rubber band: h_1

   Height where velocity measured: h_2

   Change in height: $\Delta h_{12} = h_2 - h_1 =$ __________________________

   Change in gravitational potential energy: $mg\Delta h_{12} =$ ______________________

3. Launch the glider up the track with the rubber band bumper. You will compare the total energy at the start (potential energy in the spring) to the energy where you measured the velocity (kinetic and gravitational) to that at the highest point (gravitational potential energy). Try a number of runs with different initial energies. Record your data on the next page. Can you see any affect of friction?

Input data for each event:

s = compression of Spring
L_{max}=Furthest distance **from spring** the glider reaches, measured at trailing edge.

Calculated quantities for each event:

v_1 = Speed of glider

$E_0 = ½ ks^2$ = Initial potential energy

$E_1 = mgh_{12} + 1/2\ mv_1^2$ = Total energy

$E_2 = mgh_{max} = mgL_{max}\sin\alpha$ = Potential energy at top

Trial	s	T	L_{max}	E_0	E_1	E_2
1						
2						
3						
4						
5						

Repeat the above experiment, adding mass to the glider. Load the glider in such a fashion that it does not scrape when it travels.

Trial	s	T	L_{max}	E_0	E_1	E_2
1						
2						
3						
4						
5						

Question: For comparable extensions of the spring, how do the values of L_{max} for the two different cases? Can you make a quantitative comparison?

3.3 Friction:

1. Level the airtrack. Place bumpers on both ends of the track so that the glider can bounce off each end. Set up a Sonar Ranger at each end of the track.

2. Start the glider moving at a reasonable rate of speed, so that it will bounce several times back and forth on the airtrack. Determine the velocity of the glider each time it passes the same point traveling in the same direction.. This allows you to measure the velocity of the glider after it has traveled two track lengths. Calculate the kinetic energy (E_i) for the i-th lap of the glider, and the change in kinetic energy of the glider each pass.

Trial 1:

Pass #	T_i	v_i	E_i	E_i-E_{i-1}
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Trial 2:

Pass #	T_i	v_i	E_i	E_i-E_{i-1}
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Question: Assume the frictional force is a constant, independent of *v*. Calculate the work done by the frictional force, and thus the change in kinetic energy of the glider, for every lap the glider travels, as a function of m, g, μ_k and the length of the track L.

Plot ΔE_i as a function of *v*. This will indicate if the frictional force varies with velocity

3. Plot ΔE_i as a function of $2nL$, the distance traveled between velocity measurements. For some part of the trajectory this is (one hopes) linear. From the slope of this line and your above expression determine the coefficient of kinetic friction, μ_k

$\mu_k \pm \Delta\mu_k$= ______________________________

4) Place a large “vane” in the glider to create a large frictional force and repeat the above measurements. Do you see any indications that the friction is a function of velocity.

5 Questions

Please answer the following questions on a separate sheet of paper. Use complete sentences, and diagrams when appropriate.

1. Describe the dependence of the frictional force on the velocity shown in your data. Is there any regime were it was constant? If not, can you characterize the dependence?

2. Is your calculation of μ_k consistent with the energy measurements you made in the first section of the lab? Calculate the amount of energy you would expect to lose as the cart went uphill. Is it consistent with the level of energy conservation you observed?

3. List any major systematic and random errors that affected your results. How significant were they? How could you minimize the larger ones?

4. Imagine you wanted to design an experiment to measure the coefficient of kinetic friction when the airtrack pump is turned off. Now the glider will not make multiple passes. How might you design experiments to measure the coefficients of static and kinetic friction?