Lab 6: Conservation Laws

1 Introduction

In this lab, we will study momentum and energy conservation through collisions of air track gliders. Collisions are complicated processes in general, but conservation laws allow us to understand some of their properties without needing to know the details involved in the actual collision. We will also examine the conversion of kinetic energy to potential energy as a glider travels down an incline.

2 Key Concepts

- Momentum
- Kinetic and potential energy
- Mechanical energy
- Conservation laws
- Elastic and inelastic collisions

3 Theory

When dealing with collisions, we often want to answer questions like: What will be the outgoing velocities of the colliding objects? or How much energy was lost in the collision? Trying to directly apply Newton's second law $\vec{\mathbf{F}} = m\vec{\mathbf{a}}$ is not very useful in this situation, since we don't typically know anything about the forces involved in the collision. Nevertheless, we can answer many of these types of questions using the powerful ideas of momentum and energy conservation.

The **momentum** of an object is defined to be its mass times its velocity. It is a vector quantity that points in the same direction as the velocity:

$$\vec{\mathbf{p}} = m\vec{\mathbf{v}}.$$

The **kinetic energy** of an object of mass m moving with speed v is a scalar and is given by

$$K = \frac{1}{2}mv^2.$$

There is also energy associated with an object's weight and its height above the ground called **gravitational potential energy**. Depending on the circumstances, there might be other types of potential energy present, such as elastic, chemical, or electric, but we are only interested in that due to gravity in this lab. For an object of mass m at a height h above the ground, the potential energy is

$$U = mgh.$$

The **total mechanical energy** of a system is defined to be $K + U$, the sum of the kinetic and potential energies.

In any system, to say that a quantity is *conserved* means that its value does not change over time, even though the system and other associated quantities may change. The law of **conservation of momentum** therefore says that if there is no net external force acting on a system, the total momentum of the system is constant. External forces are those exerted on any part of the system by an outside object, as opposed to internal forces, which are those that parts of the system might exert on itself. The system in our collision experiments consists of two air track gliders. Although gravity is present as an external force on the gliders, the normal force provided by the air track compensates so that there is no *net* external force on the system. In equation form, conservation of momentum is expressed as

$$\vec{\mathbf{p}}_{1,i} + \vec{\mathbf{p}}_{2,i} = \vec{\mathbf{p}}_{1,f} + \vec{\mathbf{p}}_{2,f},$$

where 1 and 2 are labels for the gliders, and i and f mean initial and final. This is a statement then that says the total momentum of the system before the collision equals the total momentum after. Since collisions on the air track happen in one dimension, we won't need the full vector form of this equation—just the scalar form. However, we will have to keep proper track of signs.

There is a similar expression for the **conservation of mechanical energy** of an isolated system. For our two gliders, it reads

$$K_i + U_i = K_f + U_f,$$

where

$$K_i = \frac{1}{2}m_1 v_{1,i}^2 + \frac{1}{2}m_2 v_{2,i}^2$$

is the total initial kinetic energy, and

$$U_i = m_1 g h_{1,i} + m_2 g h_{2,i}$$

is the total initial potential energy, etc.. This equation is exactly true only when friction and other non-conservative forces (gravity is a conservative force) are absent. Of course, some amount of friction will always be present in real experiments, so we will use this equation assuming that the contribution of all the non-conservative forces is negligible compared to the kinetic and potential energies.

Collisions are described as either elastic or inelastic, depending on which quantities are conserved in them. **Elastic collisions** are those where both kinetic energy and momentum are conserved. In **inelastic collisions**, momentum is still conserved but kinetic energy is not—some gets converted into other forms like elastic potential energy and heat. In other words, the rule to remember is that *momentum is conserved in all collisions where there are no net external forces, while kinetic energy is conserved only in elastic collisions.* In practice, we can generally view elastic collisions as those where the objects bounce off each other and inelastic collisions as those where they stick together to some extent.

Again, the power of these conservation equations comes from the fact that we need not know (and often can't know) the precise details of some complicated process like a collision. However, we can still analyze the behavior of a system, since there are quantities that remain the same regardless of the details.

4 Experiment

4.1 Equipment

- Triple beam balance
- Set of masses
- Vernier calipers
- Marble tiles (6) and aluminum squares (2)
- Air track with air supply
- Air track gliders with magnets (2)
- Photogates with stands (2)
- Computer with Logger Pro software

4.2 Procedure

The first part of the experiment will examine collisions between two gliders on a level air track. Photogates will measure the speeds of the gliders before and after the collisions. The second part will look at energy conservation of a single glider on the inclined air track.

4.2.1 Part I: Collisions

1. Decide which glider to call glider 1 and which to call glider 2. Keep track of this throughout the experiment. Use the triple beam balance to measure their masses, and record your results in the spaces below.

   Mass of glider 1 (kg): ________________ ± ________________

   Mass of glider 2 (kg): ________________ ± ________________

2. Make sure the two photogates are positioned above the track so that the top edge of the gliders will pass through and interrupt the photogate light beams. The exact separation of the photogates is not important for this part of the experiment, but there should be enough space between them for both gliders to fit comfortably.

3. Turn on the air supply, and practice a few collisions by sending the gliders toward each other (magnet sides inward) to collide near the middle of the track. **Slow collisions only!** The gliders should not actually touch or cause each other to jump up off the track during the collision.

4. Open the Lab 7 Collisions Logger Pro file. Determine which photogate corresponds to which velocity column in the program data table so that you can keep track of the correct velocities of the gliders.

5. Measure the lengths of the gliders using calipers, and enter the values in the boxes below the velocity table in Logger Pro. (The software uses this information along with the time the photogate light beams are interrupted to determine the glider velocity.)

	Initial				Final			
Trial	$\text{dir}_{1,i}$	$v_{1,i}$ (m/s)	$\text{dir}_{2,i}$	$v_{2,i}$ (m/s)	$\text{dir}_{1,f}$	$v_{1,f}$ (m/s)	$\text{dir}_{2,f}$	$v_{2,f}$ (m/s)
1								
2								
3								
4								
5								
6								
7								

Table 1: Data table for velocities before and after collisions.

6. Place glider 2 at rest near the center of the air track (between the photogates), and hold glider 1 near the end of the track. It should pass through photogate 1 when you push it toward glider 2.

7. Click the Collect button, wait a few seconds until the software is ready to take data, and then send glider 1 to collide with glider 2.

8. Click Stop after the collision and all gliders have passed through the photogates (if they are going to).

9. Record the initial and final velocities of each glider in Table 1. Taking the positive direction to be the initial direction of glider 1, record also the directions for each glider by writing either a + or - (or N/A for gliders at rest).

10. Repeat twice more with a different initial velocity for glider 1 but glider 2 still stationary initially.

11. Now do 4 collisions where both gliders are moving toward each other initially. The gliders should each pass through their respective photogates before colliding between them. Record the velocities and directions as before.

4.2.2 Part I Data

1. Calculate the momentum of each glider before and after the collision for each trial, and record in Table 2. For example, the initial momentum of glider 1 is $p_{1,i} = \text{dir}_{1,i} \cdot m_1 \cdot v_{1,i}$.

2. Calculate the *total* momentum of the system before and after the collision for each trial. The signs of the momenta are important here, so make sure you take them into account.

3. Calculate the percent difference between $p_{\text{total},i}$ and $p_{\text{total},f}$.

4. Calculate the kinetic energy of each glider before and after the collision for each trial, and record in Table 3.

5. Calculate the total kinetic energy of the system before and after the collision for each trial.

Trial	$p_{1,i}$	$p_{2,i}$	$p_{1,f}$	$p_{2,f}$	$p_{\text{total},i}$	$p_{\text{total},f}$	% difference
1							
2							
3							
4							
5							
6							
7							

Table 2: Data table for momentum analysis of collisions. All units of p are kg m/s.

6. Calculate the percent difference between $K_{\text{total},i}$ and $K_{\text{total},f}$.

Trial	$K_{1,i}$ (J)	$K_{2,i}$ (J)	$K_{1,f}$ (J)	$K_{2,f}$ (J)	$K_{\text{total},i}$ (J)	$K_{\text{total},f}$ (J)	% difference
1							
2							
3							
4							
5							
6							
7							

Table 3: Data table for energy analysis of collisions.

4.2.3 Part II: Single Glider on Incline

1. You will only use glider 1 for this part, so change the value of Glider_2_Length in Logger Pro to equal that of Glider_1_Length.

2. Measure the thickness of 4 stacked marble tiles with calipers, and record this as the height of the air track in the space below. Put the tiles under the single support leg of the air track to elevate the end by this thickness. You might need to adjust the height of the photogates to accommodate the incline.

3. Using the ruler markings on the side of the air track, move the photogates so that one is at 60 cm and the other is at 160 cm as measured from the end with the single leg.

4. Record the distance d between the photogates in the space below.
5. Calculate the incline angle of the track using trigonometry and the above measured distances. Record the angle below.

   $h =$ **height of air track (m):** ____________________

   $d =$ **distance between photogates (m):** ____________________

   $\alpha =$ **incline angle:** ___________

6. Place glider 1 at the top end of the air track and release it. Make sure it glides freely down the track and that both photogates register it as it passes through.
7. Return the glider to the top of the track, and now use Logger Pro to measure the glider's velocity at the position of each photogate as it travels down the track. The label 1 refers to the higher photogate and 2 to the lower. Record the velocities in Table 4.
8. Repeat for a total of 3 trials.
9. Perform trials 4-6 with 40 g (evenly distributed) added to the glider, and trials 7-9 with 80 g added.

Trial	m (kg)	v_1 (m/s)	v_2 (m/s)	U_1 (J)	K_1 (J)	K_2 (J)	ME_1 (J)	ME_2 (J)	% diff.
1									
2									
3									
4									
5									
6									
7									
8									
9									

Table 4: Data table for velocity and energy of the glider on the inclined track.

4.2.4 Part II Data

For each trial in Table 4, calculate and record:

1. the potential energy of the system when the glider passes through photogate 1 ($U_1 = mgh$)
2. the kinetic energies K_1 and K_2 of the glider as it passes through the photogates

3. the total mechanical energy ($ME = K + U$) of the system at the location of photogates 1 and 2

4. the percent difference between ME_1 and ME_2

Notice that by taking the potential energy at photogate 1 to be mgh, we are implicitly assuming $U_2 = 0$ at the height of photogate 2. This is not a problem, since we are always free to choose the zero reference point of potential energy without affecting the physics.

5 Analysis

5.1 Part I: Collisions

1. According to theory, momentum is conserved in all collisions. Do the results you obtained in Table 2 confirm this expectation? Explain any discrepancies by discussing what specific experimental errors or limitations could have caused them.

2. Theory says that *total energy* is always conserved in collisions, but *kinetic energy* is only conserved in elastic collisions. Was kinetic energy conserved in all the collisions of part I? If not, where could the missing energy have gone?

3. What can you say about the elasticity of the collisions in this experiment?

5.2 Part II: Single Glider on Incline

1. Draw a picture of the glider on the inclined track, including the position of the photogates. Label d, h, and α, and show how you calculated α.

2. Label the zero reference point of potential energy in your picture.

3. Find an expression for the acceleration of the glider down the incline. Are your velocity measurements for different masses in Table 4 consistent with this acceleration?

4. Was the total mechanical energy conserved in Table 4? If not, try to explain the discrepancies by focusing on the specific experimental errors or limitations that could have caused them. (There is an interaction between the magnets on the gliders and the electrically conductive air track that causes drag on the gliders, so they move slightly slower than they otherwise would. Look up the phenomenon of eddy currents if you're interested to know more. This is one limitation of the equipment, but you should try to think of others.)