[redacted] 80

1. EFFORT: Very Good

FOLLOWING DIRECTIONS:

2. COMPLETENESSS:
   a. Showed P conserved for all 4 collisions. ✓
   b. Showed calculations incl. unc. calc'n. for collision 2. ✓
      i. Used Eqn. Editor. ✓
   c. Showed KE conserved in coll. 1-3. ✓
   d. Showed KE not conserved in coll. 4 ✓
   e. Showed why ½ KE vanishes in frictionless sticking collision if P is conserved. NO ATTEMPT
   f. Explained what forms of energy lost KE took. NO
   g. Proved using numbers there was friction between gliders and track. (No calc'n req'd.) WRONG
   h. Explained effect of greater separation of photogates on conservation of P. ✓
   i. Described how to get data needed to test conservation if friction is significant. NO ATTEMP
      i. Correctly identified needed data. NO
   j. Explained why friction affects kinetic energy more than momentum. ✓

3. FORMATTING/TEXT ISSUES:
   a. Section headings. NO
      i. Appropriate mat'l i
   b. Equation format. ✓
      i. Used example of sample formal report on web site. ✓
   c. Tables/Figures have titles/numbers. ✓ NO table of equipment
      i. Sequential numbers (1,2,3,...) ✓
   d. Tables, eqns., figures integrated in text. ✓
   e. Defined variables on first use.
   f. Used past tense exclusively. NO
      i. Stated what YOU DID?
   g. No personal pronouns ✓
   h. Addressed the criticisms of your first formal report? ✓

Much better job

4. USEFULLNESS TO CUSTOMER. GOOD
   a. Could one use report to reproduce experiment and analyses?

5. CLARITY. GOOD

6. TECHNICAL ACCURACY GOOD

Experiment 9: Conservation of Momentum and Kinetic Engrgy

By

[redacted]

~~Lab Partner: Trav~~[redacted]

15 November 2016

DO NOT USE 2 WORDS FOR SAME THING.

Abstract

The experiment compared the kinetic energies and momenta of the one-dimensional motion of two gliders as examined on an air track before and after collision. This was for the purpose of testing both the law of conservation of kinetic energy and that of momentum. In the first three ~~cases of the experiment~~ collisions, momenta and kinetic energies were established before and after collision for equal masses of the ~~bodies~~ gliders, smaller mass of the target body and a larger mass for the target body with respect to the projectile glider mass. In the ~~second case~~ fourth collision, the kinetic energies and momenta were established before and after collisions for ~~the~~ gliders subjected to inelastic collision. The results obtained confirmed ~~all three hypotheses under consideration~~ within the ~~uncertainties of measurement~~. Reader does not know what these are. Were K and P conserved or not?

Objectives

The main objective of this experiment was to test the conservation of kinetic energy and the conservation of momentum.

The specific objectives of the experiment were:

- To measure the velocities of two air track gliders before and after they collide.
- To calculate the kinetic energies and momenta of the gliders before and after they collide.
- To compare the kinetic energies and momenta before and after collision.

Introduction and Theory

Momentum is only conserved when no net external force such as friction acts on the system under investigation. This is demonstrated in Equation 1 and Equation 2 below.

$$\vec{F} = m\vec{a} \tag{1}$$

$$\vec{F} = \frac{d\vec{p}}{dt} = \frac{d(m\vec{v})}{dt} = \frac{md\vec{v}}{dt} \tag{2}$$

While conducting the experiment, all net forces were minimized as much as possible. Motion was also confined to one direction in this experiment to ensure vector notation is dropped for the necessary calculations. Due to the elimination of external forces during the experiment, Equation 3 was used to demonstrate the conservation of linear momentum before and after collision.

$$P_B = m_1 v_{1B} + m_2 v_{2B} = m_1 v_{1A} + m_2 v_{2A} = P_A \qquad (3)$$

Where:

m_1 : the mass of the projectile glider.

m_2 : the mass of the target glider.

V_{1B}: the velocity of the projectile glider before collision.

V_{1A}: the velocity of the projectile glider after collision.

V_{2B}: the velocity of the target glider before collision.

V_{2A}: the velocity of the target glider after collision.

P_B: the momentum before collision.

P_A: the momentum after collision.

The kinetic energy of an object of mass m moving in a straight line is given by Equation 4 below.

$$k = \frac{1}{2} m v^2 \qquad (4)$$

The analogy with Equation 3 is shown in Equation 5 below.

$$K_B = \frac{1}{2} m_1 {v_{1B}}^2 + \frac{1}{2} m_2 {v_{2B}}^2 = \frac{1}{2} m_1 {v_{1A}}^2 + \frac{1}{2} m_2 {v_{2A}}^2 = K_A \qquad (5)$$

Equation 3 ~~is~~ was confirmed when the inequality ~~in Equation 6 below~~ ~~is~~ was met.

$$|\%Diff(P)| \leq 2\left(\frac{\sigma P_A - P_B}{P_B}\right) \times 100\% \tag{6}$$

Equation 5 ~~is~~ was confirmed when the inequality ~~in Equation~~ 7 ~~below~~ ~~is~~ was met.

$$|\%Diff(K)| \leq 2\left(\frac{\sigma K_A - K_B}{K_B}\right) \times 100\% \tag{7}$$

The uncertainty in momentum ~~is~~ was propagated through equation p=mv ~~as~~ in Equation 8 ~~below.~~

$$\sigma_P = \sqrt{\left(\frac{\sigma_m}{m}\right)^2 + \left(\frac{\sigma_v}{v}\right)^2} \times P \tag{8}$$

The uncertainty in kinetic energy ~~is~~ propagated through equation $k = \frac{1}{2}mv^2$ as Equation 9 below.

$$\sigma_K = \sqrt{\left(\frac{\sigma_m}{m}\right)^2 + \left(2\frac{\sigma_v}{v}\right)^2} \times K \tag{9}$$

The experiment investigated both elastic (kinetic energy is conserved) and inelastic (kinetic energy is not conserved) collisions. Three hypotheses were also tested ~~under consideration during the experiment as listed below~~:

redundant

1. Hypothesis 1: Equation 5 holds for elastic collisions.
2. Hypothesis 2: Equation 5 does not hold for inelastic collisions.

3. Hypothesis 3: Equation 3 holds for both elastic and inelastic collisions.

Procedure

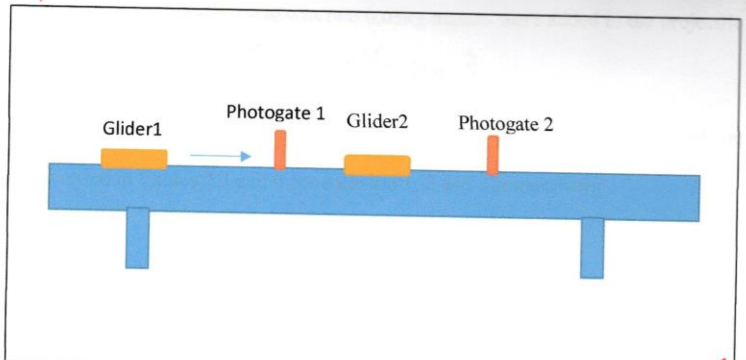

Figure1: The experiment setup: ~~In the air track, use one~~ glider 1 is projectile. ~~to collision the other glider~~ and ~~use~~ two photogates were used ~~to~~ measure and record the time ~~for~~ each glider ~~passed time~~ was in them. Glider 2 is the target

For the three near-elastic collisions:

With the target glider In the center of the track where the collision would occur, the air track was levelled ~~with the target glider positioned~~. ~~Also there are~~ the two foot support under the air track ~~which~~ was adjusted to raise one end of the track. In the front of the front glider, there was a small, metal collider with a flat metal blade in the lower hole. ~~Same with~~ In the other front glider, ~~the target glider also had~~ there was a rubber-band inserted in to the lower hole in the adjacent end. After collision, the target glider started moving because the ~~front~~ projectile glider transferred ~~few~~ its energy – and momentum to the target glider.

Two photogates were placed on the two sides of the gliders and as close as possible without having either glider flag in a photogate and the Capstone program recorded the data.

The target glider flag was placed ~~at~~ 2cm before the second photogate ~~without the flag being in the gate~~ before collision.

The ~~front~~ projectile glider was given a ~~hand~~ push by hand for a velocity between 0.7m/s and 0.9 m/s when the ~~front~~ glider passed the first photogate.

For collisions 2 and 3, ~~there was~~ two 0.05kg masses were added to the projectile for collision 2 for the and target glider re~~spectively.~~ for collision 3

The measured values of momentum and kinetic energy before and after collision were recorded in Tables 2,3 and 4 for collision 1, 2 and 3 respectively.

For the inelastic collision, after the first two steps of the procedure:

A collider with a nail was inserted into the lower hole in front of the projectile glider and a collider with wax inserted in the lower hole in the adjacent end of the target glider. (An eraser was used to smooth~~en~~ the wax before every data-taking collision)

Both gliders with the attached colliders were weighed and the masses recorded in Table 1.

The measured values of total momentum and kinetic energy before and after collision were recorded in Table ~~5~~ 6.

Data and analysis

Table 1 Glider masses -with attachment			
		w/0.100kg	±σ
Projectile, m_p (kg)	0.1998	0.2998	0.0010
Target, m_t (kg)	0.2006	0.3006	0.0010
Flag Length proj. (m)	0.1		0.0010
Flag Length Targ. (m)	0.1		0.0010
Time meas. (s)			0.0010

Table 2 collision 1: Equal masses - near elastic

	Projectile		Projectile		Target		Target		Total		Total	
Trial	1	±σ	2	±σ	1	±σ	2	±σ	1	±σ	2	±σ
Δt_B (s)	0.1221	0.0010	0.1388	0.0010								
Δt_A (s)					0.1298	0.0010	0.1525	0.0010				
v_B (m/s)	0.8193	0.0106	0.7203	0.0089								
v_A (m/s)					0.7703	0.0097	0.6556	0.0078				
p_B (kg-m/s)	0.1637	0.0023	0.1439	0.0019					0.1637	0.0023	0.1439	0.0019
p_A (kg-m/s)					0.1545	0.0021	0.1315	0.0017	0.1545	0.0021	0.1315	0.0017
K_B (J)	0.0671	0.0019	0.0518	0.0014					0.0671	0.0019	0.0518	0.0014
K_A (J)					0.0595	0.0015	0.0431	0.0011	0.0595	0.0015	0.0431	0.0011

Table 3 Collision 2: Smaller mass at rest - near elastic

	Projectile + .1000kg		Projectile		Target		Target		Total		Total	
Trial	1	±σ	2	±σ	1	±σ	2	±σ	1	±σ	2	±σ
Δt_B (s)	0.1160	0.0010	0.1227	0.0010								
Δt_A (s)	0.7777	0.0010	1.1694	0.0010	0.1243	0.0010	0.1165	0.0010				
v_B (m/s)	0.8619	0.0114	0.8147	0.0105								
v_A (m/s)	0.1286	0.0013	0.0855	0.0009	0.8045	0.0103	0.8585	0.0113				
p_B (kg-m/s)	0.2584	0.0036	0.2442	0.0034					0.2584	0.0036	0.2442	0.0034
p_A (kg-m/s)	0.0386	0.0004	0.0256	0.0003	0.1614	0.0022	0.1722	0.0024	0.1999	0.1659	0.1978	0.1741
K_B (J)	0.1114	0.0030	0.0663	0.0017					0.1114	0.0030	0.0663	0.0017
K_A (J)	0.0025	0.0001	0.0007	0.0000	0.0649	0.0017	0.0739	0.0020	0.0674	0.0650	0.0747	0.0739

need some text
explaining each
table

Table 4 Collisions 3: Larger mass at rest - near elastic

Trial	Projectile 1	±σ	Projectile 2	±σ	Target + .1000kg 1	±σ	Target 2	±σ	Total 1	±σ	Total 2	±σ
Δt_B (s)	0.1273	0.0010	0.1223	0.0010								
Δt_A (s)	0.5639	0.0010	0.4915	0.0010	0.1918	0.0010	0.1776	0.0010				
v_B (m/s)	0.7854	0.0100	0.8176	0.0106								
v_A (m/s)	-0.1773	-0.0018	-0.2035	-0.0021	0.5213	0.0059	0.5630	0.0065				
p_B (kg-m/s)	0.1569	0.0021	0.1634	0.0023					0.1569	0.0021	0.1634	0.0023
p_A (kg-m/s)	-0.0354	-0.0004	-0.0407	-0.0005	0.1567	0.0019	0.1692	0.0021	0.1213	0.1607	0.1286	0.1741
K_B (J)	0.0616	0.0016	0.0668	0.0018					0.0616	0.0016	0.0668	0.0018
K_A (J)	0.0031	0.0001	0.0041	0.0001	0.0408	0.0009	0.0318	0.0007	0.0440	0.0410	0.0359	0.0321

Table 5 Collision 4 : Larger mass at rest - inelastic

Trial	Projectile 1	±σ	Projectile 2	±σ	Target + .1000kg 1	±σ	Target 2	±σ	Total 1	±σ	Total 2	±σ
Δt_B (s)	0.1398	0.0010	0.1246	0.0010								
Δt_A (s)	0.4190	0.0010	0.3784	0.0010	0.4288	0.0010	0.3854	0.0010				
v_B (m/s)	0.7154	0.0088	0.8027	0.0103								
v_A (m/s)	0.2387	0.0025	0.2643	0.0027	0.2332	0.0024	0.2594	0.0027				
p_B (kg-m/s)	0.1429	0.0019	0.1604	0.0022					0.1429	0.0019	0.1604	0.0022
p_A (kg-m/s)	0.0477	0.0005	0.0528	0.0006	0.0701	0.0008	0.0780	0.0009	0.1178	0.0848	0.1308	0.0942
K_B (J)	0.0511	0.0013	0.0644	0.0017					0.0511	0.0013	0.0644	0.0017
K_A (J)	0.0143	0.0003	0.0175	0.0004	0.0082	0.0002	0.0101	0.0002	0.0224	0.0164	0.0276	0.0202

Table 6 Summary of conservation measurements

Collision No.	Trial	Total p_B (kg-m/s)	σP_B (kg-m/s)	Total p_A (kg-m/s)	σP_A (kg-m/s)	%$\sigma(P_A.P_B)$	P % Diff	Total K_B (J)	σKB (J)	Total K_A (J)	σKA (J)	%$\sigma(K_A-K_B)$	KE % Diff
1	1	0.1637	0.0023	0.1545	0.0021	1.8880	-5.6043	0.0671	0.0019	0.0595	0.0015	3.6268	-11.2498
1	2	0.1439	0.0019	0.1315	0.0017	1.7813	-8.6179	0.0518	0.0014	0.0431	0.0011	3.3851	-16.8262
2	1	0.2584	0.0036	0.1999	0.1659	64.2282	-22.6243	0.1114	0.0030	0.0674	0.0650	58.4002	-39.4779
2	2	0.2442	0.0034	0.1978	0.1741	71.2987	-18.9968	0.0663	0.0017	0.0747	0.0739	111.5225	12.5875
3	1	0.1569	0.0021	0.1213	0.1607	102.3887	-22.7148	0.0616	0.0016	0.0440	0.0410	66.5268	-28.6232
3	2	0.1634	0.0023	0.1286	0.1741	106.5573	-21.2896	0.0668	0.0018	0.0359	0.0321	48.0804	-46.1980
4	1	0.1429	0.0019	0.1178	0.0848	59.3315	-17.5915	0.0511	0.0013	0.0224	0.0164	34.2380	-56.1312
4	2	0.1604	0.0022	0.1308	0.0942	58.7358	-18.4542	0.0644	0.0017	0.0276	0.0202	31.4793	-57.1357

NO WAY

NO

NO

NOWAY

Table 7 Summary Table for tests of hypotheses

Collision No.	Trial	P Conserved Y/N	Hyp 3 Confirmed Y/N	K Conserved Y/N	Hyp 1 Confirmed Y/N	Hyp 2 Confirmed Y/N
1	1	Y	N	Y	N	~~Y~~ N/A
1	2	Y	N	Y	N	~~Y~~ N/A
2	1	N	Y	N	Y	~~N~~ N/A
2	2	N	Y	N	Y	~~N~~
3	1	N	Y	N	Y	~~N~~
3	2	N	Y	N	Y	~~N~~
4	1	N	Y	N	~~Y~~ N/A	N
4	2	N	Y	N	~~Y~~ N/A	N

N/A = NOT APPLICABLE

Discussion

Considering the inequalities in Equation 10 below and ~~feeding in~~ nems the smallest value of absolute momentum percent difference for collision 2 obtained in Table 6:

$$|\%Diff(P_A - P_B)| \leq 2\%unc\sigma_{(P_A-P_B)} \tag{10}$$

$$18.9968\% \leq 2 \times 71.2987\%$$

Hence the experimental data obtained supported Hypothesis 3. In the elastic collision, the change in kinetic energy as a result of the collision should be zero within experimental uncertainty.

By equation 8 can get the $\%uncP_A$ and $\%uncP_B$.

Then use equation 11 and 12 can get the $\%unc(P_A - P_B)$

$$\%unc(K_A - K_B) = \frac{\sigma_{(K_A-K_B)}}{K_B} * 100\% \tag{11}$$

$$\sigma_{(K_A-K_B)} = \sqrt{\sigma {P_A}^2 + \sigma {P_B}^2} \tag{12}$$

For example the Collision2 Trial 1,

$$\%unc(K_A - K_B) = \frac{\sigma_{(K_A-K_B)}}{K_B} * 100\% = \frac{\sqrt{0.0674^2+0.0030^2}}{0.0030} * 100\% = 58.4002\%$$

For the collision2 Trial 2,

$$\%unc(K_A - K_B) = \frac{\sigma_{(K_A-K_B)}}{K_B} * 100\% = \frac{\sqrt{0.0747^2+0.0663^2}}{0.0663} * 100\% = 111.5225\%$$

Considering the inequality in Equation 7 for all data obtained for collisions 1,2 and 3:

Collision1 Trial 1: 11.2498%>2×3.6268%

Collision1 Trial 2: 16.8262%>2×3.3851%

Collision2 Trial 1: 39.4779%<2×58.4002%

Collision2 Trial 2: 12.5875%<2×111.5225%

Collision3 Trial 1: 28.6232%<2×66.5268%

Collision3 Trial 2: 46.198%<2×48.0804%

Hence Hypothesis 1 was not supported by the experimental data obtained.

In accordance with the inequality in Equation 7, the data obtained for the experiment on collision 4 did not support Hypothesis 2 as quantified below:

Collision4 Trial 1: 56.1312%<2×32.2380%

Collision4 Trial 2: 57.1357%<2×31.4793%

The values obtained for the collision 4 indicate that momentum was not conserved after the collision. This points to the presence of friction between the air track and the gliders since the total momentum before collision should have equaled the total momentum after collision in a system free of external forces. In Table 5, for the first trial of the collision, P_A for the projectile was 0.0407 kg-m/s while that for the target glider was 0.0701kg-m/s. P_B for the projectile glider was 0.1429kg-m/s while that of the target glider was 0kg-m/s. A comparison of the two totals before and after collision gave 0.1429kg-m/s and 0.1108kg-m/s respectively which pointed to a loss of momentum after collision.

NO. COMPARE $V_{A\,projectile}$ to $V_{A\,target}$

Moving the photogates further apart in this experiment would lead to poorer conservation momentum because there would be a greater distance ~~of~~ for friction (external force) ~~effect~~ to act. As a result, the projectile glider would move over the air track with a decreasing ~~acceleration~~ velocity rather than a constant ~~acceleration~~ velocity which impacts the conservation of linear momentum. Friction has a greater deal of effect on kinetic energy than it has on momentum. This is because kinetic energy is expressed as a square of velocity hence the small change in velocity caused by friction is magnified at a time when it is negligible in terms of momentum.

Conclusion

The experimental data obtained did not confirm all the hypotheses under consideration. This was attributed to the effect friction had on the whole system and other errors inherent in the measurement system and process.