# ☐PHYS115 ☐PHYS121 ☐PHYS123
# ☐PHYS116 ☐PHYS122 ☐PHYS124
# Lab Cover Letter

Author (*You*) Trevor Swan Signature: Trevor Swan

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Lab Partner(s) Adi Mallik

Date Performed 2/28/24 Date Submitted 3/4/24

Lab (*such as #1: UNC*) #4: COL

TA: Philip Dudones

**GRADE** (*to be filled in by your TA*) See your TA for detailed feedback.
An '*x*' next to a subcategory means you need to improve this aspect of your work.

***Paper Subtotals* (points)**

( ) ***General* (6)**
_____ Sig. figs.
_____ Units
_____ Clarity of Presentation
_____ Format

( ) ***Abstract* (4)**
_____ Quantity or principle
_____ How measurement was made
_____ Numerical Results
_____ Conclusion

( ) ***Intro & Theory* (9)**
_____ Basic principle
_____ Main equations to be used
_____ Apparatus
_____ What will be plotted
_____ Fitting parameters related

( ) ***Exp. Procedures* (15)**
_____ Description
_____ Stating and justifying uncertainties
_____ Data Record
_____ Quality of Lab Work

( ) ***Analysis & Error Analysis* (20)**
_____ Discussion
_____ Equations & Calculations
_____ Presentation inc. Graphs, Tables
_____ Results Reported & Reasonable
_____ Underlined items addressed

( ) ***Discussion & Conclusions* (6)**
_____ Numerical comparison of results
_____ Logical conclusions
_____ Discussion of pos. errors
_____ Suggestions to reduce errors

( ) **Paper Total (60 points)**
**(30 points for CME or EPF)**

( ) **Notebook (10 points)**
_____ Format (*proper style, following directions*)
_____ Apparatus (*brief description of equipment, including sketches*)
_____ Data (*including computer file names and manually recorded data*)
_____ Experimental Technique (*describing your procedures; stating & justifying uncerts.*)
_____ Analysis (*results and errors*)

( ) **Worksheet(s)/Fill-in-the-Blank-Report (30 points)** *if applicable*

( ) **Adjustments** – late submissions, improper procedures, etc. – or bonus points for exceptional work.

## ( ) Total Grade

*Graded by ___________ (TA's initial)*

# COL Worksheet

**Your Name:** Trevor Sm... **Signature:** [signature]

**Lab partner(s):** Adi Mallik

**Course & Section:** 121 Section B **Station #** 112 **Date:** 3/4/24

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**Section D. Procedure**

1. What are the masses of your two carts, gratings, and mass bars?

$m_{cart1}$ = 0.4964 ± 0.0001 Kg (units)

$m_{cart2}$ = 0.4911 ± 0.0001 Kg (units)

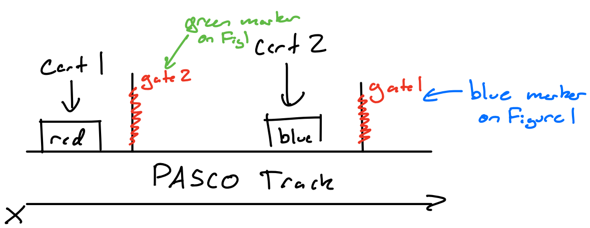
$m_{grating1}$ = 0.0124 ± 0.0001 Kg (units)

$m_{grating2}$ = 0.0124 ± 0.0001 Kg (units)

$m_{bar1}$ = 0.4980 ± 0.0001 Kg (units)

$m_{bar2}$ = 0.4952 ± 0.0001 Kg (units)

Notes
- $m_1$ is the red cart
- $m_2$ is the blue cart
- ± 0.0001 Kg derived from the digital scale's precision




2. What is the average velocity for each photogate? Remember that if the two don't agree, you will have to find their ratios and adjust the velocities of all subsequent velocity measurements.

$v_{photogate1}$ = 0.309 ± 0.008 m/s (units)

$$\delta_{v_1} = \frac{0.03086}{\sqrt{17}} = 0.0075$$

$v_{photogate2}$ = 0.273 ± 0.005 m/s (units)

$$\delta_{v_2} = \frac{0.02342}{\sqrt{19}} = 0.0054$$

**Section E Analysis**

$$\text{Ratio } (R) = \frac{v_1}{v_2} = \frac{0.309}{0.273} = 1.134 \quad \therefore \quad v_1 = 1.134 \cdot v_2 \Rightarrow \text{blue} = R \cdot \text{green}$$

blue cart (1) side

red cart (2) side

3. Record your data in the tables below. Do not forget to include the directions for the vector quantities.

$V_{red}$ Columns from Lab Notebook multiplied by R in the following tables.

- All Cart 1 columns below are $x_{blue}$ in lab notebook

**Collision 1**

| | Cart 1 before collision | Cart 1 after collision | Cart 2 before collision | Cart 2 after collision |
|---|---|---|---|---|
| Mass (kg) | 1.0068 ± 0.0001 | 1.0068 ± 0.0001 | 0.9987 ± 0.0001 | 0.9987 ± 0.0001 |
| Velocity (m/s) | 0.851 ± 0.003 | -0.12 ± 0.02 | 0 ± 0 | 0.6537 ± 0.0102 |
| Momentum (kg m/s) | 0.857 | -0.12 * | 0 | 0.6259 |
| Kinetic energy (J) | 0.365 | 0.0072 | 0 | 0.2134 |

$\varepsilon_p$ = -0.270

$$\varepsilon_p = \frac{0.6259 - 0.857}{0.857} = -0.2697$$

$\varepsilon_k$ = -0.415

$$\varepsilon_k = \frac{0.2134 - 0.365}{0.365} = -0.4153$$

* theoretical value as L3 Pro didn't record $v_2'$

$$v_2' = R * \frac{m_1 v_1 + m_2 v_2 - m_1 v_1'}{m_2}$$

Increased UNC too

E.1 in Manual Approves use of this calculation for one missing final velocity

**Collision 2**

| | Cart 1 before collision | Cart 1 after collision | Cart 2 before collision | Cart 2 after collision |
|---|---|---|---|---|
| Mass (kg) | 1.0068 ± 0.0001 | 1.0068 ± 0.0001 | 0.5035 ± 0.0001 | 0.5035 ± 0.0001 |
| Velocity (m/s) | 0.48 ± 0.05 | 0.11 ± 0.02 | 0 ± 0 | 0.654 ± 0.002 |
| Momentum (kg m/s) | 0.48 | 0.11 | 0 | 0.329 |
| Kinetic energy (J) | 0.12 | 0.0061 | 0 | 0.108 |

$\varepsilon_p =$ −0.31  $\varepsilon_p = \frac{0.329-0.48}{0.48} = -0.31$

$\varepsilon_k =$ −0.10  $\varepsilon_k = \frac{0.108-0.12}{0.12} = -0.10$

**Collision 3***

| | Cart 1 before collision | Cart 1 after collision | Cart 2 before collision | Cart 2 after collision |
|---|---|---|---|---|
| Mass (kg) | 0.5088 ± 0.0001 | 0.5088 ± 0.0001 | 0.4487 ± 0.0001 | 0.4487 ± 0.0001 |
| Velocity (m/s) | 0.40 ± 0.05 | 0.12 ± 0.01 | 0 ± 0 | 0.21 ± 0.01 |
| Momentum (kg m/s) | .20 ± 0.03 | .061 ± 0.005 | 0 ± 0 | 0.21 ± 0.01 |
| Kinetic energy (J) | .04 ± 0.01 | .0037 ± 0.0006 | 0 ± 0 | 0.022 ± 0.002 |

$\varepsilon_p =$ 0.05 ± 0.17  $\varepsilon_p = \frac{P_2' - P_1}{|P_1|} = \frac{0.21-0.20}{0.20} = 0.05$

$\varepsilon_k =$ −0.45 ± 0.15  $\varepsilon_k = \frac{K_2' - K_1}{K_1}$  $\frac{0.022-0.04}{0.04} = -0.45$

**Collision 4**

| | Cart 1 before collision | Cart 1 after collision | Cart 2 before collision | Cart 2 after collision |
|---|---|---|---|---|
| Mass (kg) | 1.0068 ± 0.0001 | 1.0068 ± 0.0001 | 0.4487 ± 0.0001 | 0.4487 ± 0.0001 |
| Velocity (m/s) | 0.8 ± 0.1 | 0.41 ± 0.01 | 0 ± 0 | 0.43 ± 0.01 |
| Momentum (kg m/s) | 0.81 | 0.41 | 0 | 0.43 |
| Kinetic energy (J) | 0.32 | 0.085 | 0 | 0.092 |

$\varepsilon_p =$ −0.47  $\varepsilon_p = \frac{0.43-0.81}{0.81} = -0.47$

$\varepsilon_k =$ −0.71  $\varepsilon_k = \frac{0.092-0.32}{0.32} = -0.71$

**Collision 5**

| | Cart 1 before collision | Cart 1 after collision | Cart 2 before collision | Cart 2 after collision |
|---|---|---|---|---|
| Mass (kg) | 0.5088 ± 0.0001 | 0.5088 ± 0.0001 | 0.4487 ± 0.0001 | 0.4487 ± 0.0001 |
| Velocity (m/s) | 0 ± 0 | −1.72 ± 0.01 | 0 ± 0 | 0.53 ± 0.01 |
| Momentum (kg m/s) | 0 | −0.875 | 0 | 0.53 |
| Kinetic energy (J) | 0 | 0.753 | 0 | 0.14 |

$\Delta p =$ −0.34 Kg.m/s

$\Delta K =$ 0.89 J

$$\begin{cases} P_1 = P_2 = 0 \\ K_1 = K_2 = 0 \end{cases} \Rightarrow \begin{array}{l} \Delta p = (P_1' + P_2') - 0 \\ \Delta K = (K_1' + K_2') - 0 \end{array}$$

$$\Delta p = -0.875 \frac{kg \cdot m}{s} + 0.53 \frac{Kg \cdot m}{s} = -0.34 \frac{Kg \cdot m}{s}$$

$$\Delta K = 0.753 J + 0.14 J = 0.89 J$$

Recall: $\begin{cases} P_1 = P_2 = 0 \\ K_1 = K_2 = 0 \end{cases} \Rightarrow \begin{array}{l} \Delta p = (p_1' + p_2') - 0 \\ \Delta K = (K_1' + K_2') - 0 \end{array}$

**Collision 6**

| | Cart 1 before collision | Cart 1 after collision | Cart 2 before collision | Cart 2 after collision |
|---|---|---|---|---|
| Mass (kg) | 1.0068 ± 0.0001 | 1.0068 ± 0.0001 | 0.4987 ± 0.0001 | 0.4987 ± 0.0001 |
| Velocity (m/s) | 0 ± 0 | −1.059 ± 0.004 | 0 ± 0 | 0.434 ± 0.007 |
| Momentum (kg m/s) | 0 | −1.066 | 0 | 0.933 |
| Kinetic energy (J) | 0 | 0.565 | 0 | 0.436 |

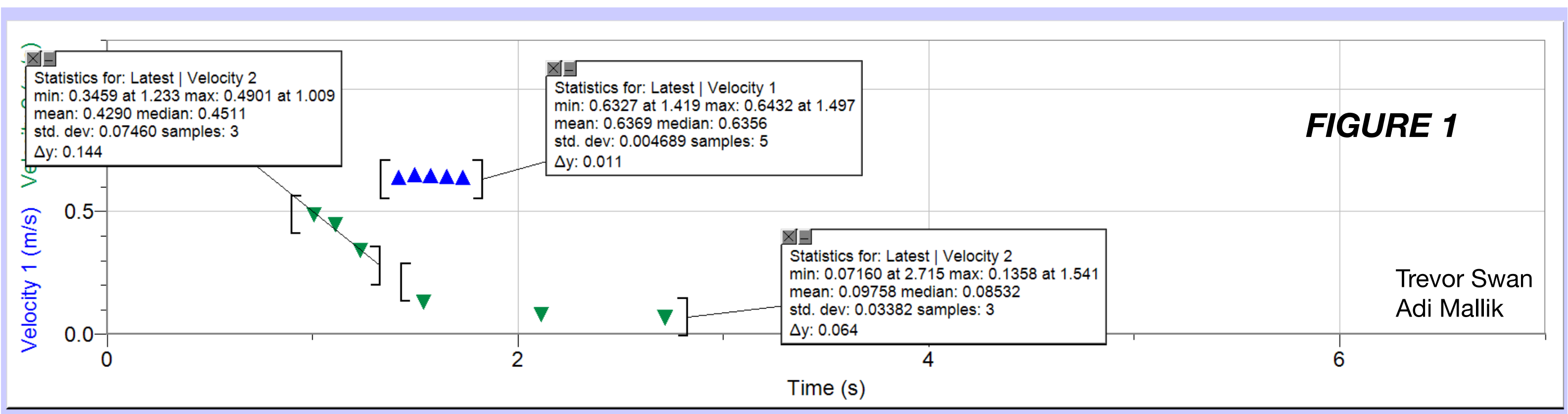
$\Delta p =$ −0.133 Kg.m/s. $\quad \Delta p = -1.066\ \frac{kg \cdot m}{s} + 0.933\ \frac{kg \cdot m}{s} = -0.133\ \frac{kg \cdot m}{s}$

$\Delta K =$ 1.001 J. $\quad \Delta K = 0.565\ J + 0.436\ J = 1.001\ J$

4*. Write out the error analysis for collision 3 to find the uncertainties in momentum and kinetic energy, and the uncertainties in $\varepsilon_p$ and $\varepsilon_k$.

Error Analysis on Next Two Pages

Collision 2 Velocity Graph with Statistics



Trevor Swan
tcs94

## COL3: Error Propagation and Analysis

### Cart 1:

**Before**

Momentum: $p = mv$

$\delta_{p_m} = \frac{\partial}{\partial m}(mv)\,\delta_m = v\,\delta_m = 0.40(0.0001) = 4\times10^{-5}$

$\delta_p = \sqrt{\delta_{p_m}^2 + \delta_{p_v}^2}$ $\quad \delta_{p_v} = \frac{\partial}{\partial v}(mv)\,\delta_v = m\,\delta_v = 0.5088(0.05) = 0.02544$

$$\boxed{\delta_p = \sqrt{(4\times10^{-5})^2 + 0.02544^2} = 0.03 \ \frac{kg\cdot m}{s}}$$

Kinetic: $K = \frac{1}{2}mv^2$

$\delta_{K_m} = \frac{\partial}{\partial m}\left(\frac{1}{2}mv^2\right)\delta_m = \frac{1}{2}v^2\delta_m = \frac{1}{2}(0.40)^2(0.0001) = 8\times10^{-6}$

$\delta_K = \sqrt{\delta_{K_m}^2 + \delta_{K_v}^2}$ $\quad \delta_{K_v} = \frac{\partial}{\partial v}\left(\frac{1}{2}mv^2\right)\delta_v = mv\,\delta_v = 0.5088(0.40)(0.05) = 0.010176$

$$\boxed{\delta_K = \sqrt{(8\times10^{-6})^2 + .010176^2} = 0.01 \ J}$$

**After**

Momentum: $p' = mv'$

$\delta_{p'_m} = \frac{\partial}{\partial m}(mv')\,\delta_m = v'\delta_m = 0.12(0.0001) = 1.2\times10^{-5}$

$\delta_{p'} = \sqrt{\delta_{p'_m}^2 + \delta_{p'_{v'}}^2}$ $\quad \delta_{p'_{v'}} = \frac{\partial}{\partial v}(mv')\,\delta_{v'} = m\,\delta_{v'} = 0.5088(0.01) = 0.005088$

$$\boxed{\delta_{p'} = \sqrt{(1.2\times10^{-5})^2 + 0.005088^2} = 0.005 \ \frac{kg\cdot m}{s}}$$

Kinetic: $K' = \frac{1}{2}mv'^2$

$\delta_{K'_m} = \frac{\partial}{\partial m}\left(\frac{1}{2}mv'^2\right)\delta_m = \frac{1}{2}v'^2\delta_m = \frac{1}{2}(0.12)^2(0.0001) = 7.2\times10^{-7}$

$\delta_{K'} = \sqrt{\delta_{K'_m}^2 + \delta_{K'_{v'}}^2}$ $\quad \delta_{K'_{v'}} = \frac{\partial}{\partial v'}\left(\frac{1}{2}mv'^2\right)\delta_v = mv'\delta_v = 0.5088(0.12)(0.01) = 6.1\times10^{-4}$

$$\boxed{\delta_{K'} = \sqrt{(7.2\times10^{-7})^2 + (6.1\times10^{-4})^2} = 6.1\times10^{-4} \simeq 0.0006 \ J}$$

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### Cart 2:

**Before**

Momentum and Kinetic Energy are 0 initially because this cart is stationary! This implies $0 \pm 0 \ \frac{kg\cdot m}{s}$ and $0 \pm 0$ J in this case!

**After**

Momentum: $p' = mv'$

$\delta_{p_m} = \frac{\partial}{\partial m}(mv')\,\delta_m = v'\delta_m = 0.21(0.0001) = 2.1\times10^{-5}$

$\delta_{p'} = \sqrt{\delta_{p'_m}^2 + \delta_{p'_{v'}}^2}$ $\quad \delta_{p_v} = \frac{\partial}{\partial v'}(mv')\,\delta_{v'} = m\,\delta_{v'} = 0.9987(0.01) = 0.009987$

$$\boxed{\delta_{p'} = \sqrt{(2.1\times10^{-5})^2 + (0.009987)^2} = 0.01 \ \frac{kg\cdot m}{s}}$$

Kinetic: $K' = \frac{1}{2}mv'^2$

$\delta_{K'_m} = \frac{\partial}{\partial m}\left(\frac{1}{2}mv'^2\right)\delta_m = \frac{1}{2}v'^2\delta_m = \frac{1}{2}(0.21)^2(0.0001) = 2.205\times10^{-6}$

$\delta_{K'} = \sqrt{\delta_{K'_m}^2 + \delta_{K'_{v'}}^2}$ $\quad \delta_{K'_{v'}} = \frac{\partial}{\partial v'}\left(\frac{1}{2}mv'^2\right)\delta_{v'} = mv'\delta_{v'} = 0.9987(0.21)(0.01) = 0.00209727$

$$\boxed{\delta_{K'} = \sqrt{(2.205\times10^{-6})^2 + 0.00209727^2} = 0.002 \ J}$$

$\underline{\varepsilon_p}$:  $\varepsilon_p = \dfrac{P_2' - P_1}{P_1}$

$\delta_{\varepsilon_{P_1}} = \dfrac{\partial}{\partial P_1}\left(\dfrac{P_2' - P_1}{P_1}\right)\delta_{P_1} = \left| -\dfrac{P_2'}{P_1^2} \right| \delta_{P_1} = \left(\dfrac{0.21}{0.20^2}\right)(0.03) = 0.16$

$\delta_{\varepsilon_p} = \sqrt{\delta_{\varepsilon_{P_2'}}^2 + \delta_{\varepsilon_{P_1}}^2}$

$\delta_{\varepsilon_{P_2}} = \dfrac{\partial}{\partial P_2'}\left(\dfrac{P_2' - P_1}{P_1}\right)\delta_{P_2'} = \dfrac{1}{P_1}\delta_{P_2'} = \left(\dfrac{1}{0.20}\right)(0.01) = 0.05$

$\delta_{\varepsilon_p} = \sqrt{0.05^2 + 0.16^2} = 0.17$

$\underline{\varepsilon_K}$:  $\varepsilon_K = \dfrac{K_2' - K_1}{K_1}$

$\delta_{\varepsilon_{K_1}} = \dfrac{\partial}{\partial K_1}\left(\dfrac{K_2' - K_1}{K_1}\right)\delta_{K_1} = \left| -\dfrac{K_2'}{K_1^2} \right| \delta_{K_1} = \left(\dfrac{0.022}{0.04^2}\right)(0.01) = 0.1375$

$\delta_{\varepsilon_K} = \sqrt{\delta_{\varepsilon_{K_2'}}^2 + \delta_{\varepsilon_{K_1}}^2}$

$\delta_{\varepsilon_{K_2}} = \dfrac{\partial}{\partial K_2'}\left(\dfrac{K_2' - K_1}{K_1}\right)\delta_{K_2'} = \left(\dfrac{1}{K_1}\right)\delta_{K_2'} = \left(\dfrac{1}{0.04}\right)(0.002) = 0.05$

$\delta_{\varepsilon_K} = \sqrt{0.1375^2 + 0.05^2} = 0.15$

5. For the elastic collisions, did your data fit the conservation of energy and momentum model? Explain.

No, My data did not fit the CofE and CofM models. The expected value for $\varepsilon$ for both momentum and kinetic energy is predicted to be 0 for elastic collisions. Due to imperfections in my equipment and our lack of consideration of friction my $\varepsilon$ values were non-zero quantities for Collisions 1 to 3. Accounting for Uncertainties, Collision 3 is relatively close to the model.

6. For the inelastic collisions, did your data fit the conservation of momentum model? Explain. What was the relative energy loss? Where did the energy go?

Collision 4 involved an inelastic collision without an explosion. This Collision did not fit the models for momentum. Our $\varepsilon$ values were non-zero quantities. For energy, our $\varepsilon_K$ value was about 0.71 J for lost energy. The energy loss here is due to friction on the track along with our ramp not being perfectly level. Bends in the PASCO track increase the amount of energy needed to push a cart so that's most likely where energy was lost. Friction also caused energy to be lost in the form of heat. Some Kinetic Energy is lost when first hitting the Target Cart with the instances ultimately resulting in a net loss of energy relative to this collision.

7. For the "explosion," did your data fit the conservation of momentum model? Explain. What was the energy gained?

For the explosions (Collisions 5 and 6), neither experiment fit the model for conservation of momentum. Both quantities $\Delta p$ were negative non-zero values, with Collision 6 tending closer to 0 than Col 5. We expected $\Delta p$ values of 0 for both Collisions, but our results <u>did not</u> align with this. The Kinetic Energies $\Delta K$ were positive in either case with $\Delta_K = 0.895$ for Col 5 and $\Delta K = 1.001$ J for Col 6. This perceived increase, or gain, in energy is most likely a result of the potential energy stored in the spring of our blue cart. This is also why, most likely, our $\Delta K$ are so similar for these two collisions.

**GRADE:**_______ (out of 30 points) **GRADED BY** ________ (TA's initials)