Physics 4A

Lab 8: Momentum

Objective: To investigate several collisions, measuring initial and final momentum and kinetic energies in each case, and observe conservation of momentum, but not necessarily conservation of kinetic energy.

Theory:

According to Newtons 3rd Law, momentum should be conserved in a collision; that is, the total momentum of both objects immediately before the collision should be equal to the total momentum of both objects immediately after the collision. This is because:

the objects apply equal, but opposite, forces to each other for the same time…

so they apply an equal, but opposite, ***impulse*** *to each other…*

so the two objects experience equal and opposite ***change in momentum***.

One object gains momentum while the other loses the same amount of momentum. The total momentum of the two objects together is the same before and after the collision.

We will test this concept with two carts on a track. We will record the time for the carts to pass through photogates and use these times to calculate the speed of the carts (just as we've done in previous labs.) We will perform four different types of collisions:

Part 1: carts will stick together after the collision, with Velcro bumpers

Part 2: carts will repel each other without physical contact, with magnets in their bumpers

Part 3: carts will collide with physical contact, but will not stick together

Part 4: carts will be initially together, but will push away from each other

Note: even though the carts never touch each other in Part 2, their interaction still qualifies as a collision because they apply equal and opposite forces to each other for the same time.

For each of these four parts we will perform 12 collisions. For each collision, we will calculate the speeds of each cart, the momentum of both carts before and after the collision, and the kinetic energy of both carts before and after the collision. We can then consider how well the momentum was conserved in our collisions, and consider the effect of the collision on the kinetic energy of the carts.

For all collisions, we will use a red cart and a blue cart. The red cart will be the cart that is initially in motion; the red cart will always collide with the stationary blue cart. (The only exception is Part 4, for which both carts are initially stationary.)

For each part, the collisions are separated into three "trials":

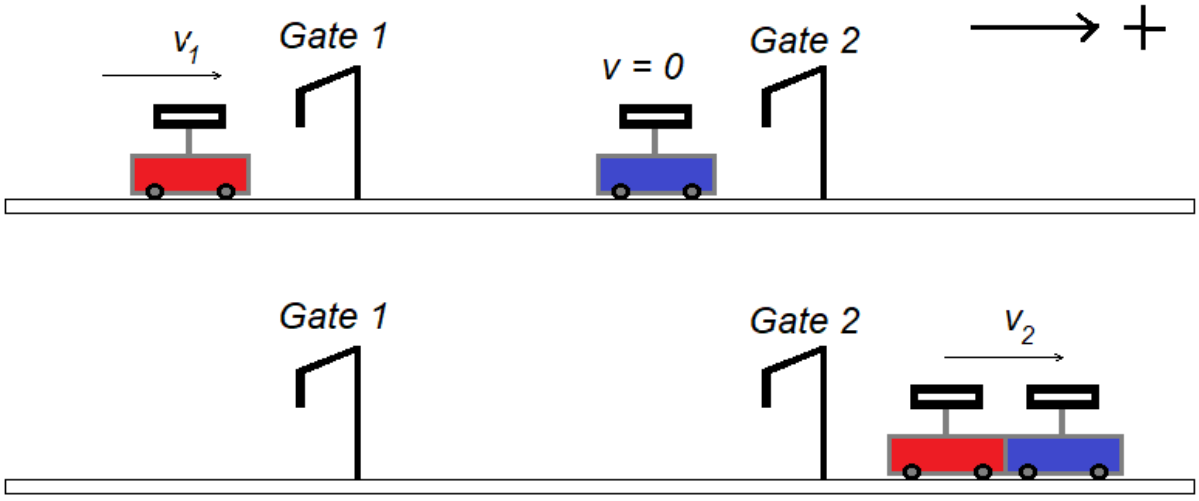
Trial 1: the carts have approximately equal masses
Trial 2: the red cart has greater mass
Trial 3: the red cart has less mass

Procedure:

Part 1: Inelastic Collisions

1.1. Introduction

In this part, the carts will "stick together" after the collision. For this reason, they will have the same speed after the collision. We will define v_1 as the speed of the red cart before the collision and v_2 as the speed of the two carts together after the collision.



Note that we will measure t_1 in ***Gate 1***, from which we will calculate v_1, and we will measure t_2 in ***Gate 2***, from which we will calculate v_2. **Note that both velocities are in the positive direction.**

1.2. Data

Watch the following videos to obtain data for the carts sticking together:

Trial 1: https://youtu.be/7UCHmI28v4M
Trial 2: https://youtu.be/l2aQg2hPiPI
Trial 3: https://youtu.be/W71srByBwKg

For each of the three trials:

- Record the mass of each cart.
- Record t_1 and t_2 for each of the four runs.

Note: All calculations should be completed in Excel!

1.3. Calculations

For each of the three runs, calculate v_1 and v_2 (remember, v = d/t, where d is the length of the tab). Remember, once the values of a trial have been calculated, all you need to do is copy/paste the cells into the next trial, and the values will update. However, with each trial, the masses of the carts will be different. Therefore, copy run 1, update the masses, then fill down.

For each of the three runs, calculate ***initial p*** and ***final p***. To calculate the momentum in kg·cm/s, you will have to convert the cart's mass to kilograms. A sample equation looks like "$=m_1*v_1/1000$". Place a $ sign in front of the letter and number of the cell containing the mass so you will be able to use Excel's fill down feature.

For each of the three runs, calculate ***initial K*** and ***final K***. To calculate the kinetic energy in mJ, you will have to convert the velocity to m/s (divide by 100), the cart's mass to kilograms (divide by 1000), then convert J to mJ (multiply by 1000). Notice how the cart's conversion and the conversion to mJ cancel out. However, the velocity still needs to be converted, then squared, which results in a value being divided by 10,000. A sample equation looks like "$=0.5*m_1*v_1\text{^}2/10000$". Place a $ sign in front of the letter and number of the cell containing the mass so you will be able to use Excel's fill down feature.

1.4. Bar Graphs

Create a bar graph of the initial and final momenta. To do this, highlight the 8 values of initial and final momentum, and insert a Column graph. Right click on the graph, and change the name of Series 1 to 'initial p'. Highlight 'Series 2', and change the name to 'final p'. Under Chart Design > Quick Layout, choose the layout that includes a title, legend, x axis and y axis labels. It looks like:  . Change the title, x axis and y axis labels to match the data.

Create a bar graph of the initial and final kinetic energies using the same technique. Label Series 1 as 'initial K', and Series 2 as 'final K'.

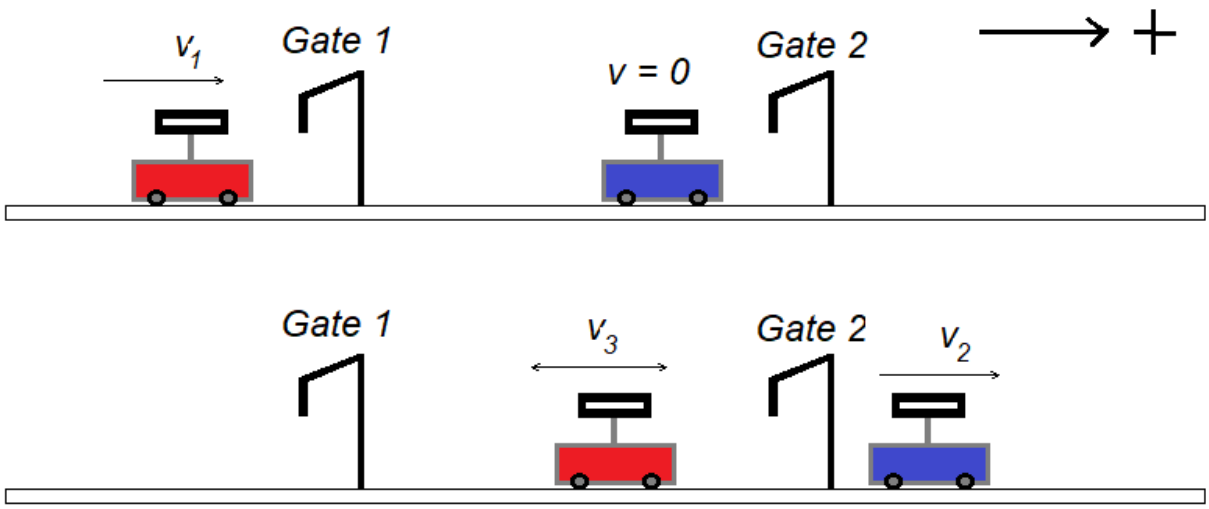
The bars of initial and final momentum should be similar, and the final kinetic energy bars should be less than the initial kinetic energy bars. If this is not what you are seeing, send me your Excel sheet so I can help you find the calculation errors.

Part 2: Elastic Collisions

2.1. Introduction

In this part, the carts will repel each other with magnets. These collisions should be "elastic"; that is, we expect that the kinetic energy of the carts before the collision should be the same as the kinetic energy of the carts after the collision.

Since the carts do not move together after the collision, we must allow for a final velocity of the red cart, which we will call v_3.



Note that:

- *The direction of the red cart is different for the three trials; it depends on the mass of the red cart.*
- *For Trial 1, the red cart will stop after the collision; there is no* v_3 .
- *For Trial 2, the red cart will move to the right, following the blue cart, after the collision.*
- *For Trial 3, the red cart will move to the left, rebounding off the blue cart.*

Note: for Trial 3, the final velocity of the red cart is in the negative direction. This will be important for the calculation of the momentum after the collision.

For Trial 2, Photogate 2 will measure both t_2 and t_3 . For Trial 3, Photogate 1 will measure both t_1 and t_3 .

The procedure for Part 2 is identical to that of Part 1, with the addition of the measurement of t_3 and the corresponding calculation of v_3.

2.2. Add Excel Sheet

On the bottom left corner of Excel, there is a tab labelled 'Part 1'. Right click on the tab, select 'Move or Copy', select '(move to end)' and click on 'Create a copy'. Once the new tab is made, right click on the tab, select 'Rename', and rename to 'Part 2'.

Right click on the 'C' column and click 'insert'. For Trial 2 and Trial 3, in the new column C, type in the label 't_3 (s)'.

Right click on the 'E' column and click 'insert'. For Trial 2 and Trial 3, in the new column F, type in the label 'v_3 (cm/s)'.

2.3. Data

Watch the following videos to obtain data for the carts colliding:

Trial 1: https://youtu.be/gOMXg51-W1I

Trial 2: https://youtu.be/iztoclcBLr4
Trial 3: https://youtu.be/q6IYlQLxvnc

For each of the three trials:

- Record the mass of each cart.
- Record t_1 t_2 and t_3 (if there is a t_3) for each of the four runs.

2.4. Calculations

Note that all values and graphs in Trial 1 should automatically update.

Trial 2 and 3 now have a t_3 and an associated v_3 which need to be included in the calculations.

For Trial 2, the initial momentum and initial kinetic energy should automatically update. The equation for the final momentum is now different, as both carts are moving, where $p_f = p_1 + p_2$. A sample equation would be "=(m_1*v_2 + m_2*v_3)/1000". The equation for the final kinetic energy is also different, where $K_f = K_1 + K_2$. A sample equation would be "=0.5*(m_1*v_2^2 + m_2*v_3^2)/10000".

For Trial 3, with the red cart moving to the left at the end, the final momentum is $p_f = -p_1 + p_2$. Therefore, the equation for the final momentum should look like =0.5*(–m_1*v_2 + m_2*v_3)/1000". The equation for the kinetic energy for Trail 3 should be the same as Trial 2.

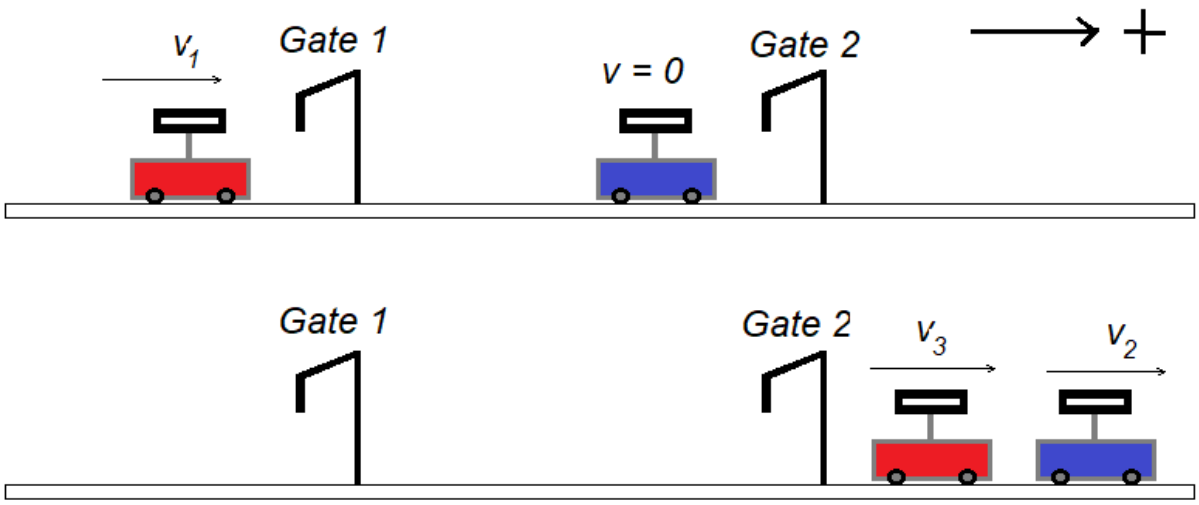
The graphs automatically update as the data is changed.

This time, the bars of initial and final momentum should be similar in height, and the bars of initial and final kinetic energies should also be similar in height. If this is not what you are seeing, send me your Excel spreadsheet so I can help find errors.

Part 3: Regular Collisions

3.1. Introduction

In this part, the red cart physically collides with the blue cart. We also see in this part the effect of small frictional forces acting on the carts in the short time between when we record the velocities of the carts (i.e. when they pass through the photogates) and when the collision occurs. As the carts stay separated after the collision, the red cart will have a final velocity v_3, just as in Part 2. However, in Part 3 we will see that the final velocity of the red cart is always to the right, following the blue cart.



Note that in Part 3 t_3 will be measured by Gate 2, and all three velocities are in the positive direction.

3.2. Add Excel Sheet

Right click on the tab titled 'Part 2', select 'Move or Copy', select '(move to end)' and click on 'Create a copy'. Once the new tab is made, right click on the tab, select 'Rename', and rename to 'Part 3'.

Input appropriate labels for Trial 1 for t_3 and v_3 (including units), and remove the labels t_3 and v_3 from Trial 3.

3.3. Data

Watch the following videos to obtain data for the carts colliding:

Trial 1: https://youtu.be/a_ciDgx3XZs
Trial 2: https://youtu.be/926sTfRgdEM
Trial 3: https://youtu.be/Htzlqb2lDLE

For each of the three trials:

- Record the mass of each cart.
- Record t_1 t_2 and t_3 (if there is a t_3) for each of the four runs.

3.4. Calculations

For Trial 1 and Trial 2, the calculations will automatically update. For Trial 3, the equations will have to be updated, and should be the same as the calculations done in step 1.3.

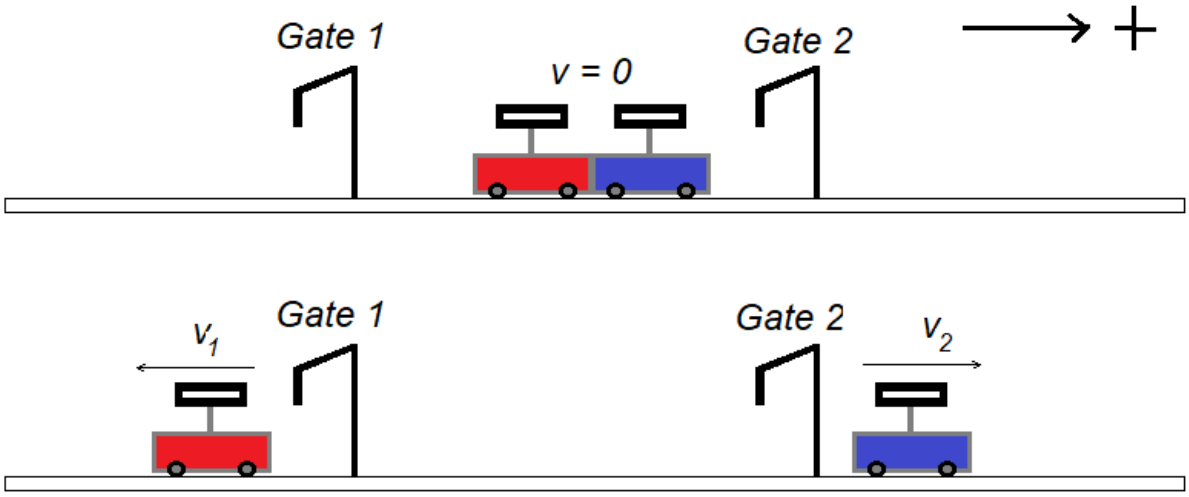
The graphs will automatically update with the new numbers.

You should see the bars of final momenta and kinetic energies be less than the bars for initial momenta and kinetic energies. If you do not see this, send me your Excel sheet, so I can help look for errors.

Part 4: Explosion Collision

4.1. Introduction

In this part, the red cart and blue cart start at rest and in contact. A spring-loaded plunger inside the blue cart is then released by pushing a button at the top of the cart. The plunger allows the blue cart to push the red cart to the left… and by Newton's 3rd Law, the red cart pushes the blue cart to the right!



Note that in this part there is no initial velocity, so we will use v_1 for the final velocity of the red cart. Also note that v_1 is in the negative direction.

The procedure for Part 4 is identical to that of the previous three parts, with one important exception: instead of calculating ***initial p*** and ***final p***, we will calculate the final momentum of each cart and compare those values. This is necessary because while the momentum before the collision is exactly zero, due to measurement uncertainties the final momentum will not be exactly zero. It is not possible to compare zero to a non-zero value.

But we do expect that the momentum of the red cart after the collision should be equal (and opposite) to the momentum of the blue cart after the collision. So comparing these is equivalent to the comparisons we made to the momentum in Parts 1, 2 and 3.

We will still calculate the combined kinetic energy of both carts after the collision, just as in the first three parts.

4.2. Add Excel Sheet

Right click on the tab labelled 'Part 1', select 'Move or Copy', select '(move to end)' and click on 'Create a copy'. Once the new tab is made, right click on the tab, select 'Rename', and rename to 'Part 4'.

Remove K_i from each of the trials. Rename 'init p' as 'p red (cm/s)'. Rename 'final p' as 'p blue (cm/s)'.

4.3. Data

Watch the following videos to obtain data for the carts undergoing in the explosion:

Trial 1: https://youtu.be/5We2FZrbNuA
Trial 2: https://youtu.be/PBkb5UNdjms
Trial 3: https://youtu.be/7IiVNuySpeg

For each of the three trials:

- Record the mass of each cart.
- Record t_1 and t_2 for each of the four runs.

4.4. Calculations

All calculations should automatically update, except the final kinetic energy. To calculate the final kinetic energy, the kinetic energies of both carts need to be added together. A sample equation would be "=0.5*(m_1*v_2^2 + m_2*v_3^2)/10000".

4.5. Questions

Answer the questions provided in the Excel spreadsheet, under the tab labelled "Questions". The spreadsheet will be the only item submitted through Canvas.