Report of laboratory experiment

Collision

Laboratory of Experimental Physics for AI

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Abstract

In this laboratory experience, we studied the laws of motion, Newton's laws, the elastic and inelastic collisions and the role of friction. To do so we used two small carts able to connect via Bluetooth to a pc with *Pasco Capstone* software to show multiple graphs with time, position, velocity, motion and acceleration under various conditions. We then exported and analysed the data acquired in this report. Our data of course are not 100% accurate since for the first experiment we do not consider the role of friction even if it has definitely taken part in our experiments.

1. The goal of the experiment

The experiment is realised by monitoring the motion of one or two carts moving on a rail (that can be inclined) under different conditions (mass, forces applied, etc.). The goal of the experiment is to verify Newton's laws of motion and the impulse-momentum theorem. Consider a cart free to move along a flat rail, in the absence of friction. If a force is acting on the cart, the cart will accelerate. If the cart is pushed and then let go it will move along the rail with a linear uniform motion. If a fixed wall is placed at the end of the rail, there will be a collision between the cart and the wall. Such collisions can be elastic, inelastic or partially elastic depending on the type of cart and type of wall under consideration. These types of collision differ by the (total or partial) conservation of the cart kinetic energy. If the rail is inclined by a certain angle instead of being flat, the force of gravity will also act on the cart. Furthermore, the presence of friction can slow down the motion of the cart. The collisions can be studied also using two carts on the same rail. Taking into account the impulse-momentum theorem we know that the variation in the momentum of the cart during the collision is equal to the force impulse from the cart to the wall. A force sensor located on the front side of the cart can measure such force and thus verify the validity of the impulse-momentum theorem.

In this lab, we focused in particular on

- The second Newton's law with different mass and with both flat and inclined planes
- The conservation of momentum and kinetic energy during a collision when one cart is moving and the other one is still, and when both carts are moving.

2. Experimental setup and methods

The instrumentation for this laboratory consists of:

- A rail (which can also serve as an inclined plane) with a wall on one end;
- A goniometer attached to the rail with error $\pm\ 0,1'$[1]
- A pulley (on the opposite end of the rail) to pull the cart against gravity using a set of weights and a wire
- Two carts (coloured red and blue) instrumented with sensors of time, position, velocity and acceleration
- A set of additional weights that can be used to increase the mass of the cart
- A computer to record the data of the carts (using the CAPSTONE software)[2]
- A phone with the app *Measure* for calibrating the angle (with an error of $\pm\ 1'$)
- A level, used to value the angle of the rail
- A scale with error $\pm\ 0,01\ g$

[1] Check Image 3
[2] https://www.pasco.com/products/software/capstone#downloads-panel

3. Results

3.1 Verify Second Newton's law

In our first exercise we try to verify the second Newton's law, which states that:

$F = ma$
F: Force [N]
m = mass [Kg]
a = acceleration [m/s^2]

To verify the second Newton's law we decided to weigh the mass on the scale and then compare it with the mass obtained from the second Newton's law m = F/a.
To reduce as much as possible any error we have also decided to run this experiment various times.

3.1.1 The first experiment

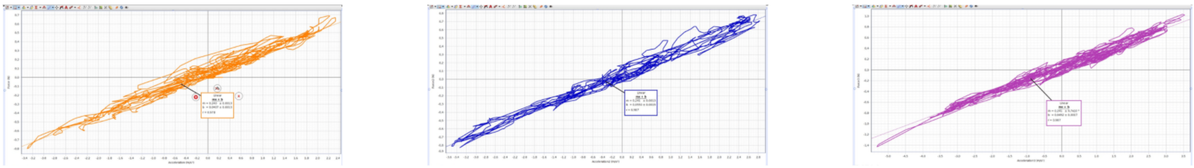
At first, we weigh the cart with the laboratory scale, the result is:
m_{cart} = (251,10 $\pm$ 0,01) g[3].

With the *Pasco Capstone,* it is possible to see in live the acceleration and the force applied to the cart. On the x-axis was displayed the acceleration in metres per second squared [m/s^2] and on the y-axis was the force in Newton [N].
When the cart starts to move, on the graph the force and its corresponding acceleration are displayed. We moved the cart back and forth for around 10 seconds, this allowed us to have a better and more precise graph.

After the graph was shown we pressed the button *select curve fits to be displayed or apply selected curve fits to active data* on top of the graph. This function on the *Pasco Capstone* displays a linear equation in the form $y = mx + q$, with *m* as the angular coefficient of the linear equation and representing the mass of the cart, in this way we were able to check if the mass obtained from the second Newton's equation was similar to the one weighed on the scale.

For this experiment, we delineated three different tests. Each of their graphs can be seen down here:

[3] For the entire part of the first and second experiment (3.1 and 3.2) we used only the blue cart and not the red one. The red car will be used in the experiment 3.3.



Graph 1, 2, 3: the first experiment of the second Newton law I[4][5]

The masses obtained from the graphs are the following:
$m_1 = (240 \pm 0{,}0013)$ g
$m_2 = (241 \pm 0{,}0013)$ g
$m_3 = (241 \pm 9{,}7\text{x}10^{-4})$ g

The average value of the three masses is:
$m_{avr} = (240{,}7 \pm 8{,}6\text{x}10^{-6})$[6] g
It can be noticed that this result is quite close to the mass of the cart weighed on the scale, there is a difference of not more than 10 g.

After a small discussion, we deduce that there might be two main reasons for this error[7]:

- The first one is that we didn't push and/or pull the cart from the hook, that is that the force measured by *Pasco Capstone* is different from the force actually used to move the cart.
- The second possible reason is that we didn't calibrate the cart properly, even if we restored it to factory calibration multiple times before running the experiment, the data still seems to be offset.

Of course, there is also human error and some non-conservative forces like the friction (of air and of the rail) that definitely have taken part in our experiments. The two possibilities reported before are just two ideas that at the beginning of our report started to come out. We don't believe that there is one specific reason for the significant error between the scaled mass and one of the graphs, definitely different types of errors have taken place and altered our result.

3.1.2 The second experiment

[4] For a better visualisation check the following link
[5] The entire data collected from our lab can be visualise at the link. It might be difficult to read and so we strongly suggest to download *Pasco Capstone*, to see how visit footnote n.2
[6] To calculate the error we followed *A Summary of Error Propagation*. Physical Sciences 2, Harvard University, Fall 2007 at the link
[7] And for the future one

In this experiment we added two metal[8] bars on top of the cart and re-run the same experiment. In this way, we could confirm the results measured on the page before.

We re-scaled the cart and its mass was:
m_{cart} = (251,10 $\pm$ 0,01) g.
We also weighted the two irons bars on the scale at the same time, and their mass was:
m_{bars} = (507,38 $\pm$ 0,01) g

The total mass of the cart and the irons bars is the sum of their weight.

$$m_{tot,1} = m_{cart} + m_{weight} = (251{,}10 \pm 0{,}01)\ \text{g} + (507{,}38 \pm 0{,}01)\ \text{g} = (758{,}48 \pm 0{,}01)\ \text{g}$$

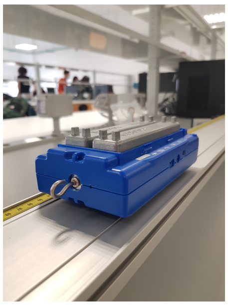
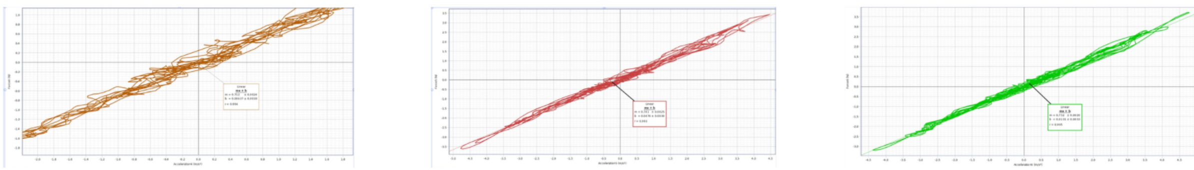


Image 1, Cart with the two metal bars on top

As we have done in the first experiment we can again use the *Pasco Capstone* program to check if the mass obtained from the linear equation is close to the one weighed on the scale. On the x-axis was displayed the acceleration in metres per second squared [m / s^2], and on the y-axis the force in Newton.

For this experiment, we made three separate tests:



Graph 4, 5, 6: second experiment of the second Newton law I[9]

m_4 = (712 $\pm$ 0,0024) g
m_5 = (741 $\pm$ 0,0025) g
m_6 = (732 $\pm$ 0,0020) g

The average of the mass obtained from the graph 4, 5, 6 is:
m_{avr} = (728,2 $\pm$ 5,5x10^{-6}) g

[8] We deduced it was metal, but of course, it might not be. A good idea would have been not only to weigh the bars on a scale but also to check their volume by measuring the change of height inside a glass of water. In this way, we could have known the density of the material, so the material, of the two bars.
[9] Check footnote n.4

Again the mass scaled and the masses weighted, are not very close to each other as we would have expected, the difference is about 30 grams, which is an offset of 4% of the weight scaled, even if it might not seems like a lot 30 grams of error in relation of just 758,48 grams in our option might have a big impact on the results.

3.1.3 The third experiment

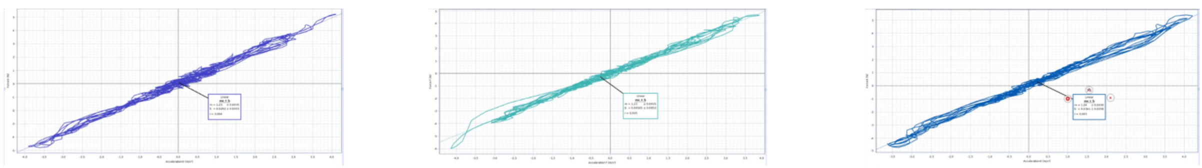
In this experiment we added two more bars on top of the cart for the last run, to check if Newton's second law was still applicable.

The two new masses are:
$m_{bars,2} = (507,65 \pm 0,01)$ g

So the total mass is now is the sum of the cart, the two metal bars used in the second experiment and the other two just scaled:

$m_{tot,2} = m_{tot,1} + m_{weigth} = (758,48 \pm 0,01)$ g + $(507,65 \pm 0,01)$ g = $(1266,1 \pm 0,01)$ g

Using the same function of *Pasco Capstone* of the last experiment we report the three new graphs of the new experiment:



Graph 7, 8, 9: third experiment of the second Newton law[10]

$m_7 = (1,23 \pm 0,0035)$ Kg
$m_8 = (1,24 \pm 0,0036)$ Kg
$m_9 = (1.23 \pm 0,0035)$ Kg

The average of the mass obtained from the graphs 7, 8, 9 is:
$m_{avr} = (1,23 \pm 4.9\text{x}10^{-3})$ Kg

3.1 Conclusion

If we compare the result we obtain:

EXPERIMENT 1							

[10] Check footnote n.4

Scaled mass	first test	second test	third test	avr experiment 1	Scaled mass	Difference of mass
251,10	240	241	241	244	251,10	7,07
EXPERIMENT 2						
Weight added						
507,38						
Total scaled mass	first test	second test	third test	avr experiment 1	Scaled mass	Difference of mass
758,48	712	741	732	737	758,48	21,32
EXPERIMENT 3						
Weight added						
507,65						
Total scaled mass	first test	second test	third test	avr experiment 1	Scaled mass	Difference of mass
1266,13	1230	1230	1240	1242	1266,13	24,09

Chart I[11]

As displaced in the last column (Difference of mass) we can see an increasing offset in our calculation. In the first experiment, we tried to give some explanation of this inconsistency. It also might be that the scale was not calibrated right. In our personal opinion, we believe we run the majority (if not all) of the experiment pushing the cart, not from the hook, and so the force registered by *Pasco Capstone* and displayed on the graph is not equivalent to the actual force displaced.

After all, we can say that for the non-inclined plane the second Newton's law holds, that is "*The change of motion [acceleration] is proportional to the motive force impressed; and is made in the direction of the right [straight] line in which that force is impressed*"[12]. Now we should test again that this law also holds for inclined planes.

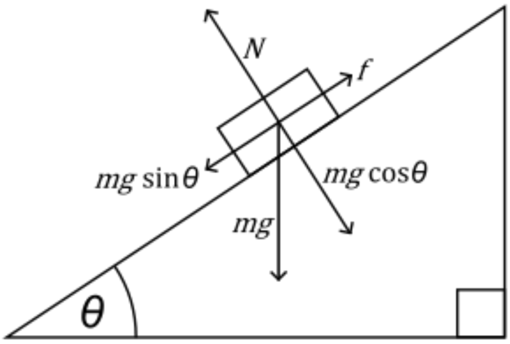
3.2 Gravity and inclined plane

After showing[13] that Newton's second law holds, we tilt the rail. Since the rail is no longer flat, a non-null force due to gravity now acts on the cart. The component of such force along the direction of the rail is given by:

[11] For checking the file visit the link
[12] Newton, *Principia* [Motte, Vol. 1, p.13]
[13] Or to be more precise: *after we have tried to show*

$$|Fg| = mg \cdot sin(\theta)$$

m: mass [Kg]
g: gravitational acceleration ≅ 9.81 [N/Kg]



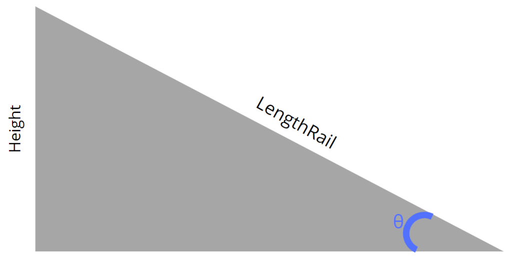
profile, View. "Vector Dynamics Reflection". *Followingphysics12.Blogspot.Com*, 2013, http://followingphysics12.blogspot.com/2013/11/vector-dynamics-reflection.html.

Our aim of this part of the experiment is to verify that the measured acceleration is compatible with the one expected based on the above formula using the measured values of rail angle and cart mass. As we can see in the image above Fg is a force parallel to the inclined rail.

Image 2: a photo of the inclined plane in the laboratory

3.2.1 First experiment - 10’

To start we decided to incline the plane of 10’ above the horizontal line. We measured the angle θ using the goniometer located on the rail. To have a more precise angle we also estimated the value of the angle using the compass on our phone and the base trigonometric function.

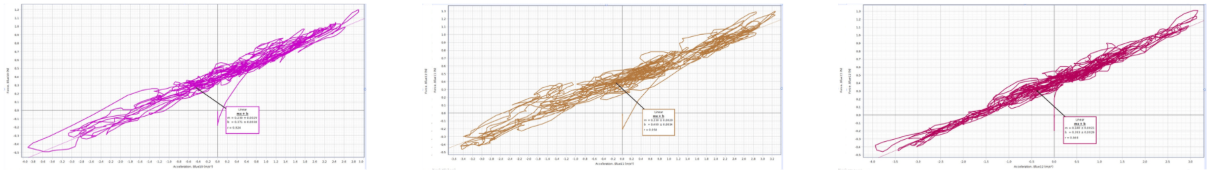


Knowing that $sin(\theta) = \frac{LengthRail}{Height}$ we can conclude that $\theta = sin^{-1}(\frac{LengthRail}{Height})$. So we decided to measure with a metre the length of the rail and the height of the rail at the end (where it is maximum) and where it is minimum (closer to the table).

First experiment				
Height Max (cm)	Height Min (cm)	Length Rail (cm)	Angle measured with goniometer	Angle measured with iPhone
26,6	5,7	122	10	10
Δheight (cm)	hyp/cat		Angle calculated	
20,9	0,1713114754		9,864079759	

Chart 2[14]

The mass of the cart scaled is:
m_{cart} = (251,10 ± 0,01) g.



Graph 10, 11, 12: First experiment of gravity and inclined plane[15]

m_{10} = (0,239 ± 0.0029) Kg
m_{11} = (0,230 ± 0.0020) Kg
m_{12} = (0,240 ± 0,0021) Kg

The average is
m_{avr} = (0,236 ± 4.1x10^{-3}) Kg

The mass measured by the graph of *Pasco Capstone* seems again to be offset of 15g, that is an error of 5.9% of the mass-weighted on the scale, it is not a significant error but we need to consider it. But again Newton's second law seems to hold, but for being sure we ran this experiment also when the plane is inclined of 5' and 15'.

[14] For checking the file visit the link (Google Sheet, page 2)
[15] Check footnote n.4

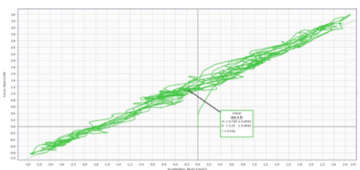
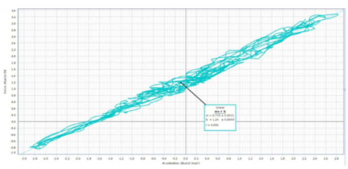
3.2.1.1 Add weight to the first experiment

Before changing the inclination of the plane we decided to do a little experiment and increase the weight of the cart by adding on top of it two metal bars.[16] Since the weight now is higher than one of the first experiments and the angle of the rail did not change we expect to have a higher force.

The mass of the cart scaled is:
m_{cart} = (251,10 $\pm$ 0,01) g.
The sum of the mass of the two metal bars is:
m_{bars} = (507,38 $\pm$ 0,01) g.

So the total mass of the cart and the two metal bars is the sum of m_{cart} and m_{bars}:
$m_{tot,1} = m_{cart} + m_{bars}$ = (758,48 $\pm$ 0,01) g

We pulled and pushed the cart back and forth multiple times and we ran the same experiment two times. The following graphs represent the values reported:

Graphs 13, 14. Second experiment of gravity and inclined plane[17]

m_{13} = (0,728 $\pm$ 0,0063) Kg.
m_{14} = (0,735 $\pm$ 0,0031) Kg.

The average of m_{13} and m_{14} is:
m_{avr} = (0,732 $\pm$ 0,0035) Kg.
While $m_{tot,1}$ is (758,48 $\pm$ 9,6x10^{-3}) g.

If we consider that some errors definitely have taken place we can conclude that the mass-weighted and the mass obtained from the two tests are close, and so that the second Newton's law again holds for inclined planes too.

[16] For a clear representation see Image 1
[17] Check footnote n.4

3.2.2 Second experiment - 5'

We decided to incline the plane of 5 degrees above the horizon. We measured the inclination with the goniometer on the rail, the iPhone app, and with the goniometric functions. The data collected about the angle are reported here:

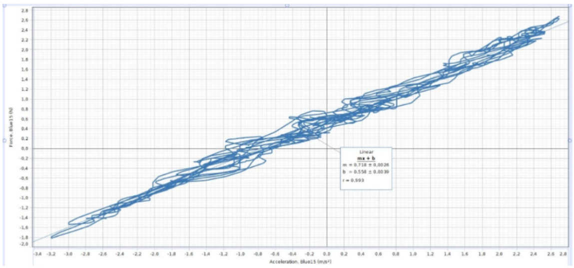
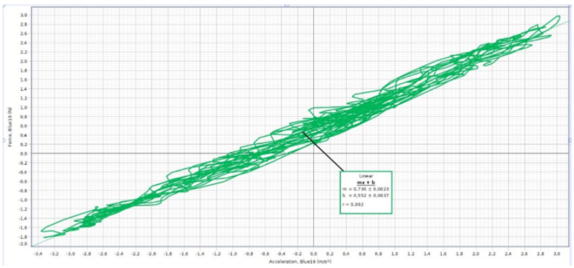
Second experiment				
Height Max (cm)	Height Min (cm)	Length Rail (cm)	Angle measured with goniometer	Angle measured with iPhone
15,8	5,2	122	5	5
Δheight (cm)	hyp/cat		Angle calculated	
10,6	0,0868852459		4,984442656	

Chart 3[18]

In this part of the experiment we decided to increase the weight of the cart to do so we added two metal bars on top of the cart.[19]

The mass of the cart scaled is:
$m_{cart} = (251{,}10 \pm 0{,}01)$ g.
The sum of the mass of the two metal bars weighted is:
$m_{bars} = (507{,}38 \pm 0{,}01)$ g.

So the total mass of the cart and the two metal bars is the same as the first experiment and it is the sum of m_{cart} and m_{bars}
$m_{tot,2} = m_{cart} + m_{bars} = (758{,}48 \pm 0{,}01)$ g

Graph 15, 16. Third experiment of gravity and inclined plane[20]

$m_{15} = (0{,}718 \pm 0{,}0026)$ Kg.
$m_{16} = (0{,}736 \pm 0{,}0023)$ Kg.

[18] For checking the file visit the link (Google Sheet, page 2)
[19] For a clear representation see Image 1
[20] Check footnote n.4

The average of m_{13} and m_{14} is:
m_{avr} = (0,737 $\pm$ 0.0035) Kg.
While $m_{tot,2}$ is (758,48 $\pm$ 0,01) g.

There is a difference between the mass-weighted and the mass measured on *Pasco Capstone* of (21,5 $\pm$ 0,01) g that is consistent with what we expected.

3.2.3 Third experiment - 15’

In the last experiment with the inclined plane we inclined the rail of 15’
As done in the first and second experiment with the inclined plane we measured the angle using the goniometer attached to the rail, the iPhone and the goniometric functions, the results are the following:

Third experiment				
Height Max (cm)	Height Min (cm)	Length Rail (cm)	Angle measured with goniometer	Angle measured with iPhone
36,4	4,8	122	15	15
Δheight (cm)	hyp/cat		Angle calculated	
31,6	0,2590163934		15,01170642	

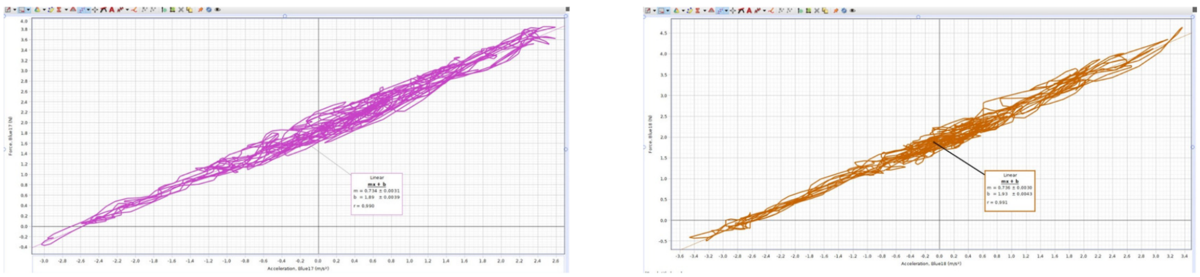
Chart 4[21]

Image 3: The goniometer on the rail

[21] For checking the file visit the link (Google Sheet, page 2)

The mass of the cart scaled is:
m_{cart} = (251,10 $\pm$ 0,01) g.
The sum of the mass of the two metal bars weighted is:
m_{bars} = (507,38 $\pm$ 0,01) g.

So the total mass of the cart and the two metal bars is the same as the last experiment and it is the sum of m_{cart} and m_{bars}
$m_{tot,3} = m_{cart} + m_{bars}$ = (758,48 $\pm$ 0,01) g



Graph 17, 18. Forth experiment of gravity and inclined plane[22]

m_{17} = (0,734 $\pm$ 0,0031) Kg.
m_{18} = (0,736 $\pm$ 0,0030) Kg.

The average of m_{13} and m_{14} is:
m_{avr} = (0,735 $\pm$ 0,0035) Kg.
While $m_{tot,3}$ is (758,48 $\pm$ 0,01) g.

The mass-weighted on the scale and the mass obtained from *Pasco Capstone* have a difference of (23,5 $\pm$ 0,01) g. Since it is not a massive difference we can conclude that the second Newton's law holds again.

3.2 An interesting conclusion

If we take a look at the graph of the inclined plane (from graph 10 to graph 18) we can see that, similar to the graph before the data represented seems to have a relationship and they can be represented as a line of the equation $y = mx + q$ [23]. We already discussed what the angular coefficient m represented, but this time we want to put our attention on the element *q* of the equation. We know that q is a constant since it does not change when x increases or decreases, but we can also notice a pattern, that is that q seems to be always (if we don't consider the error) close to $mgsin(\theta)$. If we try to represent this on a chart we have:

[22] Check footnote n.4
[23] Sometime *q* is also be called *b*, but still represent the same thing

	mass scaled	mass from graph	angle mesured θ	m*g*sin(θ) scaled	m*g*sin(θ) graph	q measure d		difference mass scaled	difference mass graph
Graph_10	0,251	0,239	10	0,4276	0,4071	0,371		0,0566	0,0361
Graph_11	0,251	0,230	10	0,4276	1,7035	0,409		0,0186	1,2945
Graph_12	0,251	0,240	10	0,4276	0,4088	0,393		0,0346	0,0158
				0,0000					
				0,0000					
Graph_13	0,758	0,728	10	1,2912	1,2401	1,21		0,0812	0,0301
Graph_14	0,758	0,735	10	1,2912	1,2521	1,26		0,0312	0,0079
Graph_15	0,758	0,718	5	0,6481	0,6139	0,558		0,0901	0,0559
Graph_16	0,758	0,736	5	0,6481	0,6293	0,552		0,0961	0,0773
				0,0000	0,0000			0,0000	0,0000
				0,0000	0,0000			0,0000	0,0000
Graph_17	0,758	0,734	15	1,9246	1,8636	1,89		0,0346	0,0264
Graph_18	0,758	0,736	15	1,9246	1,8687	1,93		0,0054	0,0613

Chart 5[24]

Except for Graph_11 where the difference mass graph is very high, we can say that the data seems accurate, that is that q seems to be close to $mgsin(\theta)$.

3.3 Collisions Between carts

In physics, a collision is an event in which two or more bodies exert forces on each other in a relatively short time.[25]

In this part of the laboratory we analysed the collision between two carts (called blue and red), the initial information are the following:

Mass of the blue cart weighed on the scale: $(271{,}72 \pm 0{,}01)$ g
Mass of the red cart weighed on the scale: $(273{,}09 \pm 0{,}01)$ g

Mass of weight 1 weighed on the scale: $(253{,}72 \pm 0{,}01)$ g
Mass of weight 2 weighed on the scale: $(254{,}07 \pm 0{,}01)$ g
Mass of weight 3 weighed on the scale: $(253{,}07 \pm 0{,}01)$ g
Mass of weight 4 weighed on the scale: $(254{,}60 \pm 0{,}01)$ g

[24] For checking the file visit the link (Google Sheet, page 4)
[25] Collision - Wikipedia. (2011). Retrieved 25 January 2022, from link.

Before running the collision between the red and the blue cart we took both carts and we connected them via Bluetooth to the pc and we restored the carts to factory calibration, in this way we verified that the calibration was correct and we avoided (maybe) some errors.

Using the conservation of momentum and kinetic energy the following equations can be obtained:

$v_f^R = (\frac{mR-mB}{mR+mB}) * v_i^R + (\frac{2mB}{mR+mB}) * v_i^B$
$v_f^B = (\frac{2mR}{mR+mB}) * v_i^R + (\frac{mB-mR}{mR+mB}) * v_i^B$
v^R is the velocity of the red cart [m/s], v^B is the velocity of the blue cart [m/s]

To check if with a collision there is conservation of momentum and kinetic energy we decided to find from the *Pasco Capstone* the initial velocity of the blue and the red cart and then calculate the final velocity of both carts and compare them with the final velocity measured by *Pasco Capstone*. For this experiment, we didn't take into account friction.

3.3.1 The first test

As the first test of the collisions between carts we analysed the collision when the blue cart is moving toward the red one and the red one is still on the rail.

We tried to imagine before the collision what would happen and this was what we planned to happen:

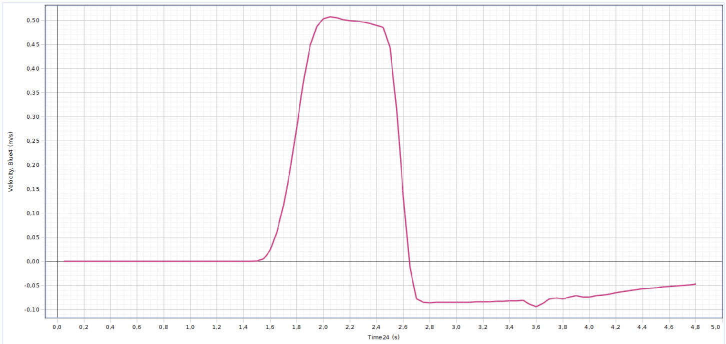
- At first the velocity of the blue cart is constant and it is moving toward the red cart that is still.
- When the collision happens, we imagined that the red cart would start moving following the same initial direction of the blue cart, but with a slower velocity than the initial blue one.
- At the end the blue cart should start going in the opposite direction of its initial, but with a slower velocity.

In this experiment the blue cart had on top the weight 1, so the total mass was:
$m_{Tblue} = m_{blue} + m_{weight1} = (271{,}72 \pm 0{,}01)$ g + $(253{,}72 \pm 0{,}01)$ g = $(525{,}44 \pm 0{,}01)$ g.

The red cart instead had weight 2 and 3 on top, so the total mass was:
$m_{Tred} = m_{red} + m_{weight2} + m_{weight3} = (273{,}09 \pm 0{,}01)$ g + $(254{,}07 \pm 0{,}01)$ g + $(253{,}07 \pm 0{,}01)$ g = $(780{,}23 \pm 0{,}02)$ g.

This is the graph of the blue cart, on the x-axis, there is the time expressed in seconds and on the y-axis, there is the velocity of the red cart in m/s.
As you can see for the first 1,4 seconds the velocity of the blue cart is constant at 0 m/s. This is because we started recording the measurements before the cart was moving, in this way

we were sure to not miss any particular change in velocity when the cart was moving. For the experiment now we can just non consider the first seconds when the blue cart is still.

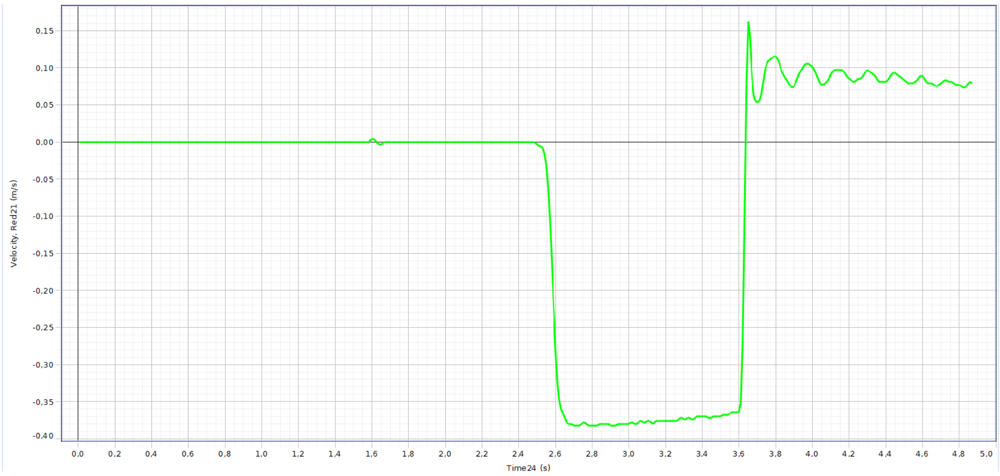


Graph 19. Blue cart[26]

The following graph has on the y-axis the velocity of the red cart in m/s and on the x-axis the time in seconds. As can be seen the, red cart remains still for a longer time than the blue one, that is because the blue cart was moving toward the red one and it required some time.

About graph 20 we need to specify 2 important things.

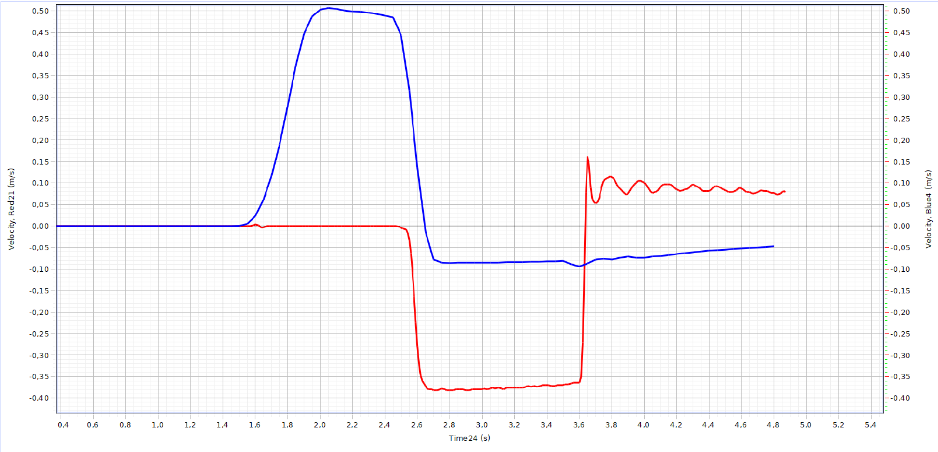
- The first one is that around 1.6s it seems to be a small variation of velocity of the red cart, this is a small error that we decided to not consider as part of our data
- From 3,7s to 4,8 s there is a portion of the graph that is not part of the collision, probably it is when the cart started bouncing against the wall. The experiment has as the main focus the collision between the blue and the red cart, so the last part of the red cart is not our main interest.



Graph 20. Red cart[27]

If we decided to combine graph 19 and graph 20 we obtain the following graph:

[26] Check footnote n.4
[27] Check footnote n.4



Graph 21. Blue and Red cart[28]

The blue cart is represented with a blue line and the red cart is represented with a red line. As can be seen, there are some similarities between the two graphs.

- For the first 1,5 seconds, both carts have a velocity constant equal to 0 m/s
- From 1,5s to 2,0s the blue cart is increasing its velocity, going from 0 m/s to 0,50 m/s. While this is happening the red cart remains still with a velocity equal to 0 m/s.
- The collision starts to happen around 2,5 seconds, we know that because from 2,5s the velocity of the blue cart starts decreasing rapidly and at the same time the red cart is chaining its velocity.
- The collision ends around 2,65s that is when the velocity of both red and blue cart remains constant at a fixed value.
- From 3,6s to the end of the graph is not in our interest since the collision already has taken place and the data is ruined with a wall collision and the force of our hands trying to stop the cart from another collision.

Using the conservation of momentum and kinetic energy the following equations can be obtained:

$$v_f^R = \left(\frac{mR-mB}{mR+mB}\right) * v_i^R + \left(\frac{2mB}{mR+mB}\right) * v_i^B$$
$$v_f^B = \left(\frac{2mR}{mR+mB}\right) * v_i^R + \left(\frac{mB-mR}{mR+mB}\right) * v_i^B$$

We are trying to determine the final velocity of both the red cart and the blue cart from the equation above and from the graph to check if the data are correct or not.

We know that:
$m_{Tb} = (525{,}44 \pm 0{,}01)$ g
$m_{Tr} = (780{,}23 \pm 0{,}02)$ g
$V_{ib} = (0{,}50 \pm 0{,}1)$ m/s
$V_{ir} = (0 \pm 0{,}1)$ m/s

From this we can calculate v_{fb} and v_{fr}, we obtain that:

[28] Check footnote n.4

v_{fb} = -0,097 m/s
v_{fr} = 0,40 m/s

The data of v_{fb} and v_{fr} can be obtained from the graph and the results are similar:
$V_{fb} = (-0,080 \pm 0,1)$ m/s
$v_{fr} = (-0,37 \pm 0,1)$ m/s

The values calculated from the conservation of momentum and kinetic energy are similar to the values obtained from the graph, so we can conclude that in this collision there is conservation of momentum and kinetic energy.

The final velocity of the red cart obtained from the graph has a negative sign, instead, the one calculated using the conservation of momentum and kinetic energy is positive. This is probably because the red cart was facing the wrong direction as so on the graph was reported negative while instead, it was positive.

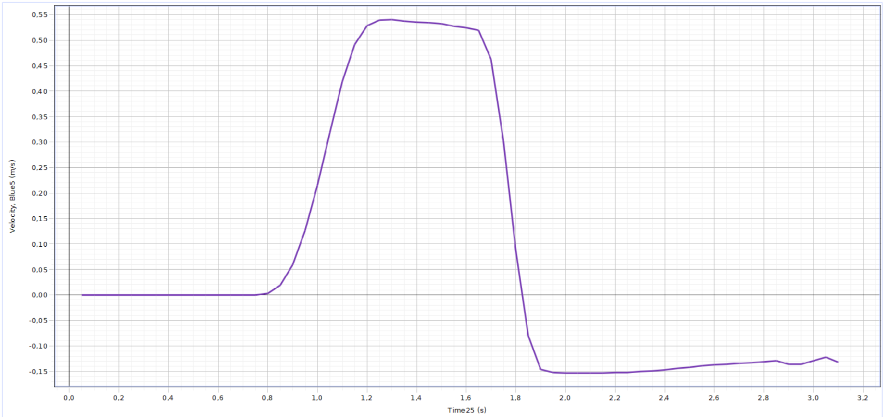
3.3.2 The second test

In this experiment the blue cart is moving while the red one remains still around the centre of the rail.

In this experiment the blue cart had on top the weight 1, so the total mass was:
$m_{Tblue} = m_{blue} + m_{weight1} = (271,72 \pm 0,01)\ g + (253,72 \pm 0,01)\ g = (525,44 \pm 0,01)\ g$

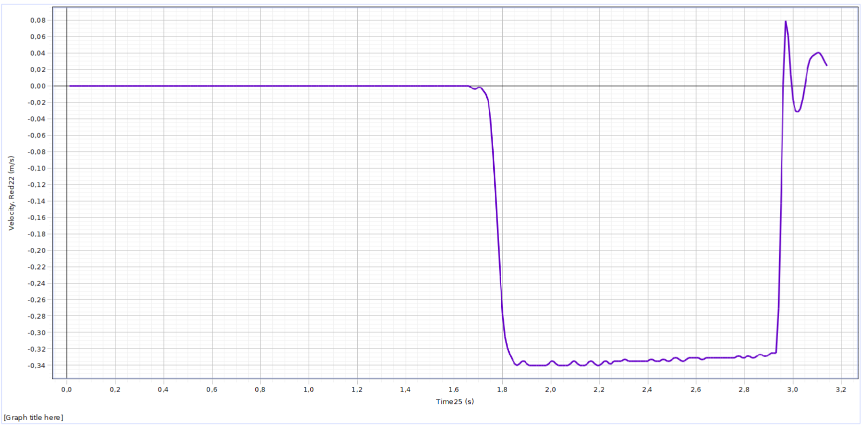
The red cart instead had weight 2, 3 and 4 on top, so the total mass was:
$m_{Tred} = m_{red} + m_{weight2} + m_{weight3} + m_{weight4} = (273,09 \pm 0,01)\ g + (254,07 \pm 0,01)\ g + (253,07 \pm 0,01)\ g + (254,6 \pm 0,01)\ g = (1034,7 \pm 0,02)\ g$

The following graph represents the velocity in m/s on the blue cart on the y-axis while on the x-axis it represents the time in seconds. For the first 0,8s the cart remains with velocity 0 m/s and then it starts to increase velocity reaching 0,54m/s in 1,0s. From the graph we can find out that the collision must have taken place from 1,6s to 1,9s, that is when the cart is decreasing its velocity reaching -0,15m/s.



Graph 22. Blue cart[29]

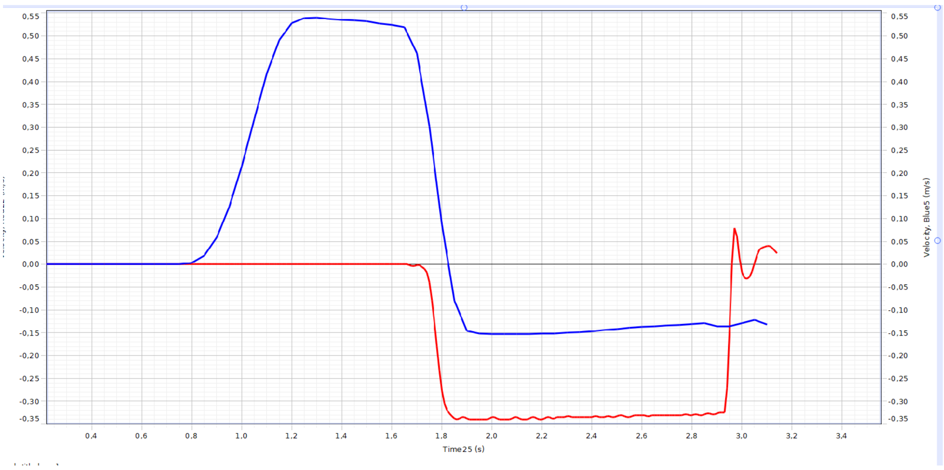
The following graph represents the velocity of the red cart in m/s on the y-axis and on the x-axis the time in seconds. Here we can see that the red cart remains still for a longer time than the blue one. The collision happens when the cart starts decreasing its velocity reaching -0,34m/s in 1,8s. After that moment the velocity of the blue cart seems to remain constant and we are not considering the velocity of the cart after 2,0s because the collision has already taken place.



Graph 23. Red cart[30]

If we decided to combine graph 22 and graph 23 we obtain the following graph:

[29] Check footnote n.4
[30] Check footnote n.4



Graph 24. Blue and Red cart[31]

It is not difficult to notice that the collision took place at 1,6s to 1,8s because both velocities of the blue and the red cart are changing rapidly.

We know that:
m_{Tb} = (525,44 $\pm$ 0,01) g
m_{Tr} = (1034,83 $\pm$ 0,02) g
V_{ib} = (0,53 $\pm$ 0,1) m/s
V_{ir} = (0 $\pm$ 0,1) m/s

From this we can calculate v_{fb} and v_{fr}, using the conservation of momentum and kinetic energy, we obtain that:
v_{fr} = 0,35 m/s
v_{fb} = -0,17 m/s

The data of v_{fb} and v_{fr} can be obtained also from the graph and the results are similar:
v_{fr} = (-0,33 $\pm$ 0,1) m/s
V_{fb} = (-0,15 $\pm$ 0,1) m/s

Again the final velocity obtained from the graph has a negative sign, while the one calculated is positive. This is because the sign of the velocity in *Pasco Capstone* is based on which side is facing the cart, but we know that the velocity should be positive because the red is moving in the same direction as the initial blue one.

3.3.3 The third test

[31] Check footnote n.4

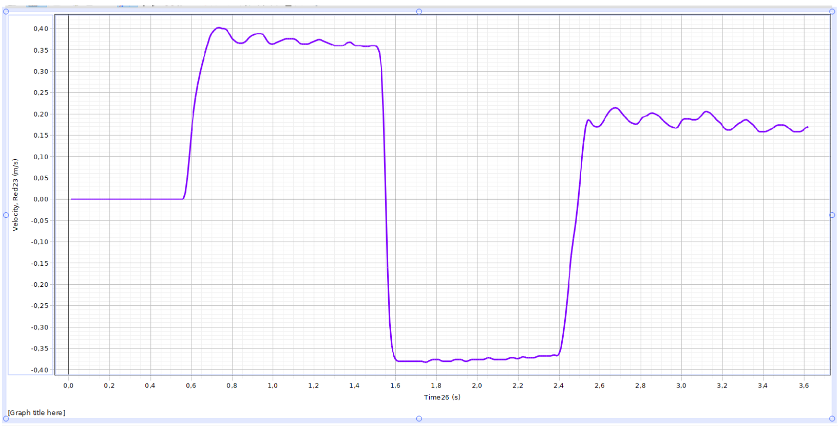
In this experiment about collision we decided to test what happens when both the red cart and the blue cart are moving before the collision. We decided to make them go against each other.

In this experiment the blue cart had on top the weight 1 and 4, so the total mass was:
$m_{Tblue} = m_{blue} + m_{weight1} + m_{weight4} = (271{,}72 \pm 0{,}01)\ g + (253{,}72 \pm 0{,}01)\ g + (254{,}60 \pm 0{,}01)\ g = (780{,}04 \pm 0{,}01)\ g$

The red cart instead had weight 2 and 3 on top, so the total mass was:
$m_{Tred} = m_{red} + m_{weight2} + m_{weight3} = (273{,}09 \pm 0{,}01)\ g + (254{,}07 \pm 0{,}01)\ g + (253{,}07 \pm 0{,}01)\ g = (780{,}23 \pm 0{,}02)\ g$

As always we tried to imagine before the experiment what would happen
- The blue cart is going towards the red one and so one velocity should be positive and one negative (we will discuss the sign later)
- At the moment of collision we imagine that both velocities should drop
- After the collision both carts should go in the opposite direction of their initial, and so both velocities should be negative.

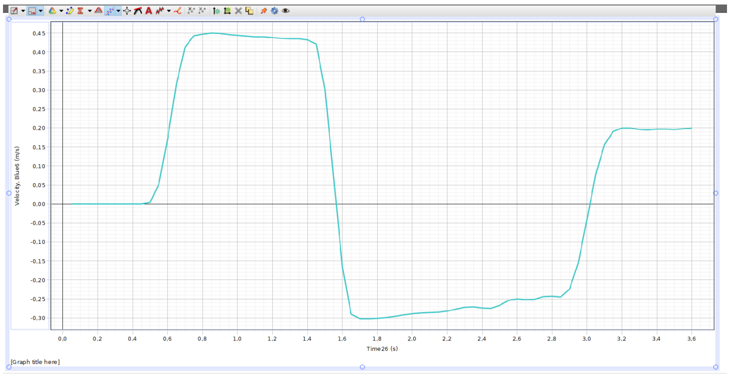
In the graph 25 on the x-axis is represented the time in seconds, on the y-axis instead the velocity in m/s. For the first 0,5s the velocity is constant and equal to 0 m/s, the cart start moving around 0,5s and it is increasing its velocity until it reaches 0,40 m/s at 0,6s, it will remain tendentially constant until the collision that happens around 1,5s because it drastically drop its velocity reaching at 1,6s -0,37m/s. After that point it remains constant.



Graph 25. Red cart[32]

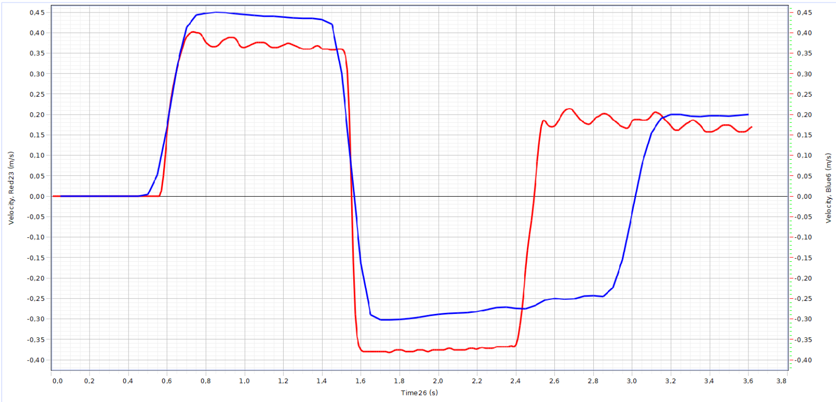
The next graph represents the velocities of the blue cart, we started recording on the *Pasco Capstone* before the cart was moving. This explains why until 0,35s the velocity is constant at 0 m/s. From 0,35s to 0,7s the cart starts moving and it is increasing its velocity. After that moment until 1,4s the velocity remains constant then it drops rapidly until in 1,6s it reaches -0,30m/s. This is the moment of the collision. After the collision took place the velocity was negative.

[32] Check footnote n.4



Graph 26. Blue cart[33]

If we combine graph 25 and graph 26 this is what we obtain:



Graph 27. Blue and Red cart[34]

We can clearly see the moment of the collision from 1,4s to 1,6s because both velocities of the carts change rapidly. After that moment both cards are going in the opposite direction of their initial one and so the velocities are negative.

Is important to know that in this experiment the carts are moving against each other, so one velocity should be positive and one negative. *Pasco Capstone* instead does not know if a velocity is positive or negative, it is calibrated on the direction of the cart, so on the graph results that both carts have positive velocity, but we know that one (before and after the collision) should be positive and the other one negative.

Again from the conservation of momentum and kinetic energy the following equations can be obtained.

$$v_f^R = \left(\frac{mR-mB}{mR+mB}\right) * v_i^R + \left(\frac{2mB}{mR+mB}\right) * v_i^B$$

$$v_f^B = \left(\frac{2mR}{mR+mB}\right) * v_i^R + \left(\frac{mB-mR}{mR+mB}\right) * v_i^B$$

[33] Check footnote n.4
[34] Check footnote n.4

We are trying to determine the final velocity of both the red cart and the blue cart from the equation above and from the graph to check if the data are correct or not.

We know that:
m_{Tr} = (780,04 $\pm$ 0,01) g
m_{Tb} = (780,23 $\pm$ 0,02) g
From the graph we can find out that
v_{ir} = (0,37 $\pm$ 0,1) m/s
v_{ib} = (0,45 $\pm$ 0,1) m/s

Using the conservation of momentum and kinetic energy we can calculate that:
v_{fb} = (0,37 $\pm$ 0,1) m/s
v_{fr} = (0,45 $\pm$ 0,1) m/s

From the graph we obtain that
v_{fb} = (-0,30 $\pm$ 0,1) m/s
v_{fr} = (-0,37 $\pm$ 0,1) m/s

As explained before, the signs are not accurate because *Pasco Capstone* is measuring the velocity as the two carts were going in the same direction. The results seem to be a little offset but not completely inaccurate.

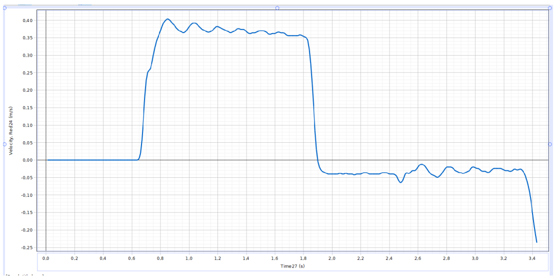
3.3.4 The fourth test

In this experiment we again tested what happens if two carts are moving before they make a collision.

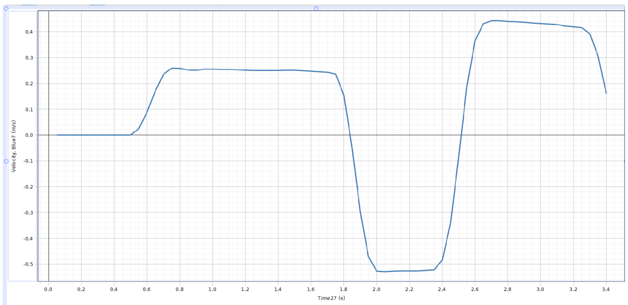
The blue cart had on top the weight 1, so the total mass was:
m_{Tblue} = m_{blue} + $m_{weight1}$ = (271,72 $\pm$ 0,01) g + (253,72 $\pm$ 0,01) g = (525,44 $\pm$ 0,01) g

The red cart instead had weight 2, 3 and 4 on top, so the total mass was:
m_{Tred} = m_{red} + $m_{weight2}$ + $m_{weight3}$ + $m_{weight4}$ = (273,09 $\pm$ 0,01) g + (254,07 $\pm$ 0,01) g + (253,07 $\pm$ 0,01) g + (254,6 $\pm$ 0,01) g = (1034,83 $\pm$ 0,02) g

The following two graphs show that around 0,4s both the red and the blue carts are moving, again this collision is made when they are going against each other but *Pasco Capstone* represented both positive, we know instead that one should be negative.

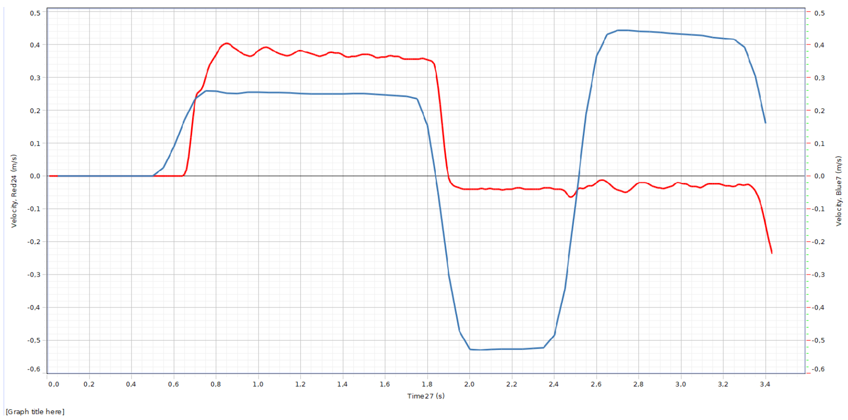


Graph 28. Red cart[35]



Graph 29. Blue cart[36]

If we decided to combine graph 22 and graph 23 we obtain the following graph:



Graph 30. Blue and Red cart[37]

Here we can clearly see that the collision happened around 1,8s seconds because both carts start decreasing. After the collision (around 2,0s) the velocity of the blue and of the red carts remains constant.

We know that:
m_{Tb} = (525,44 $\pm$ 0,01) g
m_{Tr} = (1034,83 $\pm$ 0,02) g

[35] Check footnote n.4
[36] Check footnote n.4
[37] Check footnote n.4

V_{ib} = (0,25 $\pm$ 0,1) m/s
V_{ir} = (0,37 $\pm$ 0,1) m/s

From this using the conservation of momentum and kinetic energy the following equations can be obtained:

$$v_f^R = \left(\frac{mR-mB}{mR+mB}\right) * \ v_i^R + \left(\frac{2mB}{mR+mB}\right) * \ v_i^B$$
$$v_f^B = \left(\frac{2mR}{mR+mB}\right) * \ v_i^R + \left(\frac{mB-mR}{mR+mB}\right) * v_i^B$$

we can calculate than v_{fb} and v_{fr}, we obtain that:
v_{fb} = 0,41 m/s
v_{fr} = 0,29 m/s

The data of v_{fb} and v_{fr} can be obtained from the graph and the results are not completely similar:
v_{fr} = (-0,05 $\pm$ 0,1) m/s
V_{fb} = (-0,5 $\pm$ 0,1) m/s

3.3 Conclusion

In conclusion we can say that the momentum and kinetic energy are conserved during the collision if we are not taking into account the friction. There were some problems related to the sign because *Pasco Capstone* was considering the first velocity always as positive, while it could be negative.

Collision											
FIRST TEST				Initial calculated	Final calculated		Initial graph	Final graph	Final (sign corrected)		Difference final
	m blue	525,44	**Vblue**	0,5	0,402		0,5	-0,37	-0,37		0,772
	m red	780,23	**Vred**	0	-0,098		0	-0,08	0,08		-0,178
SECOND TEST				Initial calculated	Final calculated		Initial graph	Final graph	Final (sign corrected)		Difference final
	m blue	525,44	**Vblue**	0,53	0,357		0,53	-0,33	-0,33		0,687
	m red	1034,83	**Vred**	0	-0,173		0	-0,15	0,15		-0,323

THIRD TEST				Initial calculated	Final calculated		Initial graph	Final graph	Final (sign corrected)		Difference final
	m blue	780,23	Vblue	0,37	0,370		0,37	-0,3	-0,3		0,670
	m red	780,04	Vred	0,45	0,450		0,45	-0,37	-0,37		0,820
FOURTH TEST				Initial calculated	Final calculated		Initial graph	Final graph	Final (sign corrected)		Difference final
	m blue	525,44	Vblue	0,25	0,289		0,25	-0,05	-0,05		0,339
	m red	1034,83	Vred	0,37	0,409		0,37	-0,5	-0,5		0,909

Collision Chart[38]

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4. Conclusion

Even if we had some errors in the results we really enjoyed this laboratory, and that's why the majority of our group decided to present this report. We learned many things to do and not to do and now we are more aware of the errors we might encounter in future situations. At the beginning of the laboratory we were (and still are now) amazed by the Pasco software, we had never seen it in action before the lab and was shocking seeing the graph made in real-time. We believe it is an amazing tool for the physics lab, not only because it is not complicated but also because it made our work in the lab way easier.

The majority of the conclusion were made not during the writing session of this laboratory report, but live during the lab when we discussed with the professor and with ourselves. In the end, we were able to prove that the second Newton's law holds when the plane is not inclined and even when it's inclined. Also on the collision part, we showed that the conservation of momentum and kinetic energy holds. During all these experiments we didn't pay particular attention to the role of friction, we know that it was present, but we simplified it without considering it. Of course, we know that the friction with air and the friction with the rail are present and that they do not disappear "magically", but we considered it negligible in this case.

We also want to say that some experiments of our lab are not part of this report because the data became very difficult to read, (on one of the first footnotes there is the link of our Google Drive with the .txt file exported from the Capstone software). The truth is that when we decided to work on this report we weren't sure about some cart-run, this is because we named some experiments poorly and so the following days when we analyse the data

[38] For a better visualisation check here page 4, collision

collected, we were not sure on which part was referred. That’s why some parts were omitted, even if all the data collected are still available.

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Tito Nicola Drugman
Michele Ventimiglia