Department of Physics

Conservation of Momentum

PH 111X Lab 4R

Last Edited October 5, 2023

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Abstract

Conservation of momentum is a fundamental physics law. In the propulsion of all rockets, jet engines, deflating balloons, and even in the motions of squids, octopuses, and plants seed dispersing, momentum is conserved. Conservation of momentum plays also an important role in particle physics. Strong evidence exists that energy, momentum, and angular momentum are all conserved in all particle interactions. The annihilation of an electron and positron at rest, for example, cannot produce just one photon because this will violate the conservation of linear momentum.

In this lab we will investigate the law of conservation of linear momentum by analyzing different types of collision.

Lab Objectives

- Understand conservation of momentum to elastic collisions.
- Analyze momentum graphs for elastic and inelastic collisions.
- Comparative analysis of collision and conservation of momentum in two different systems.
- Data presentation through plotting.
- Propagation of systematic and statistical errors.

Lab Materials

- Camera.
- Tracker Software [4].
- Object of known length to calibrate on (ruler, friend of known height, 8"x11" piece of paper etc.).
- Two objects of similar or widely different masses.

Links for this lab

- Tracker Software

Links for this lab

- For part I, momentum simulation,
- then for part II, International Space Station (ISS) collisions video

Introduction

This lab has **three** parts. In Part I, you will use a Physics Aviary [6] simulation to review the concept of momentum and conservation of momentum. In Part II, using Tracker, you will analyze and plot data taken from the International Space Station [3] (ISS). In, Part III you will replicate the chosen ISS video, but on earth!

Part I: Momentum Simulation

Please go to the website for the Momentum Lab [5]. In the simulation provided on Physics Aviary you will investigate how different parameters, such as mass, velocity, and the angle the collision of curling stones, influence the final velocities and direction of the curling stones in the collision process.

There you will control the mass, velocity, and angle of impact of curling stones.

Question 1 *Using the data collected from the simulation, what is the momentum of the second curling stone after the first one hits it?*

Please include a screenshot of the final simulation that you used for your calculation.

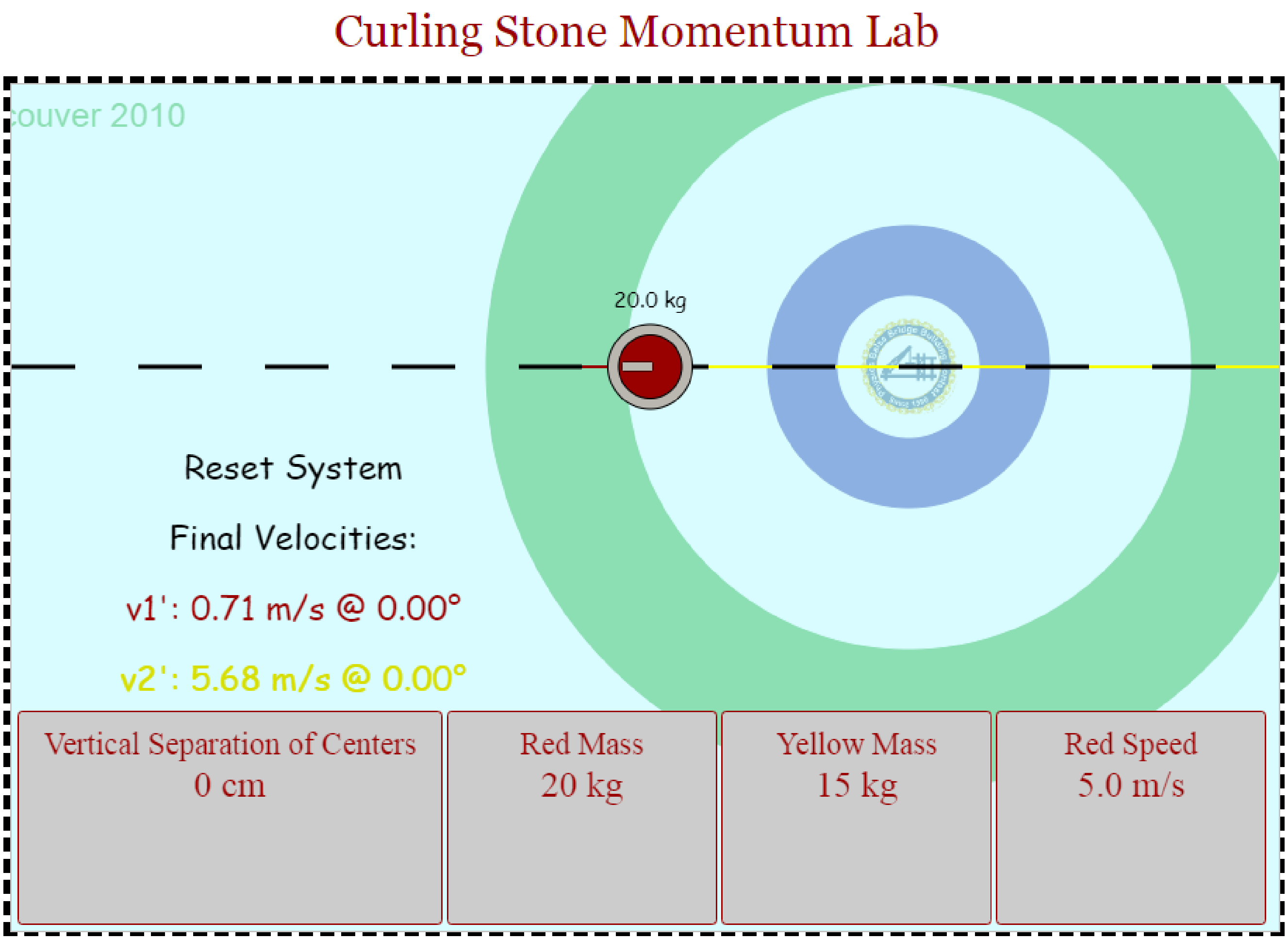

Figure 1: Example of the final view of the Curling Stone Momentum simulation. Please do not use the exact same screenshot as what is pictured here.

Part II: Momentum on the International Space Station

We recommend watching the introductory video to impulse and collisions distributed by the National Space Academy about the video made on the ISS (NSA) [3].

In this section we will ask you to open one of the provided Tracker video's from the ISS, and then try and replicate that motion[2]. You can find a summary of the video's in the appendix, and you can access them both on their website and on our course website. For those with slow internet we recommend accessing the video's directly at the National Space Academy's website as they can be downloaded individually there.

Part III: Graphical Analysis of Different Types of Collisions

- Choose a video from the table presented above to analyze. You can choose any from the list in the appendix.
- Open it in Tracker and switch to the provided velocity graph. If you open the .trk file the Tracker analysis has already been done for you.

Question 2 *Calculate the conservation of momentum from your chosen video, using the velocity calculated with tracker after and before the collision has occurred. Report the percentage of momentum conserved.*

- Try and replicate the ISS video you choose, but on earth! Analyze this collision video that you make yourself in Tracker or Logger Pro.
- Calculate the velocity before and after the collision. When calculating the velocity would you use the average velocity or the maximum velocity?
- If you do not know the mass of the colliding items you used that is fine, please estimate it's mass and then estimate the percentage change of momentum before and after collision. [1]

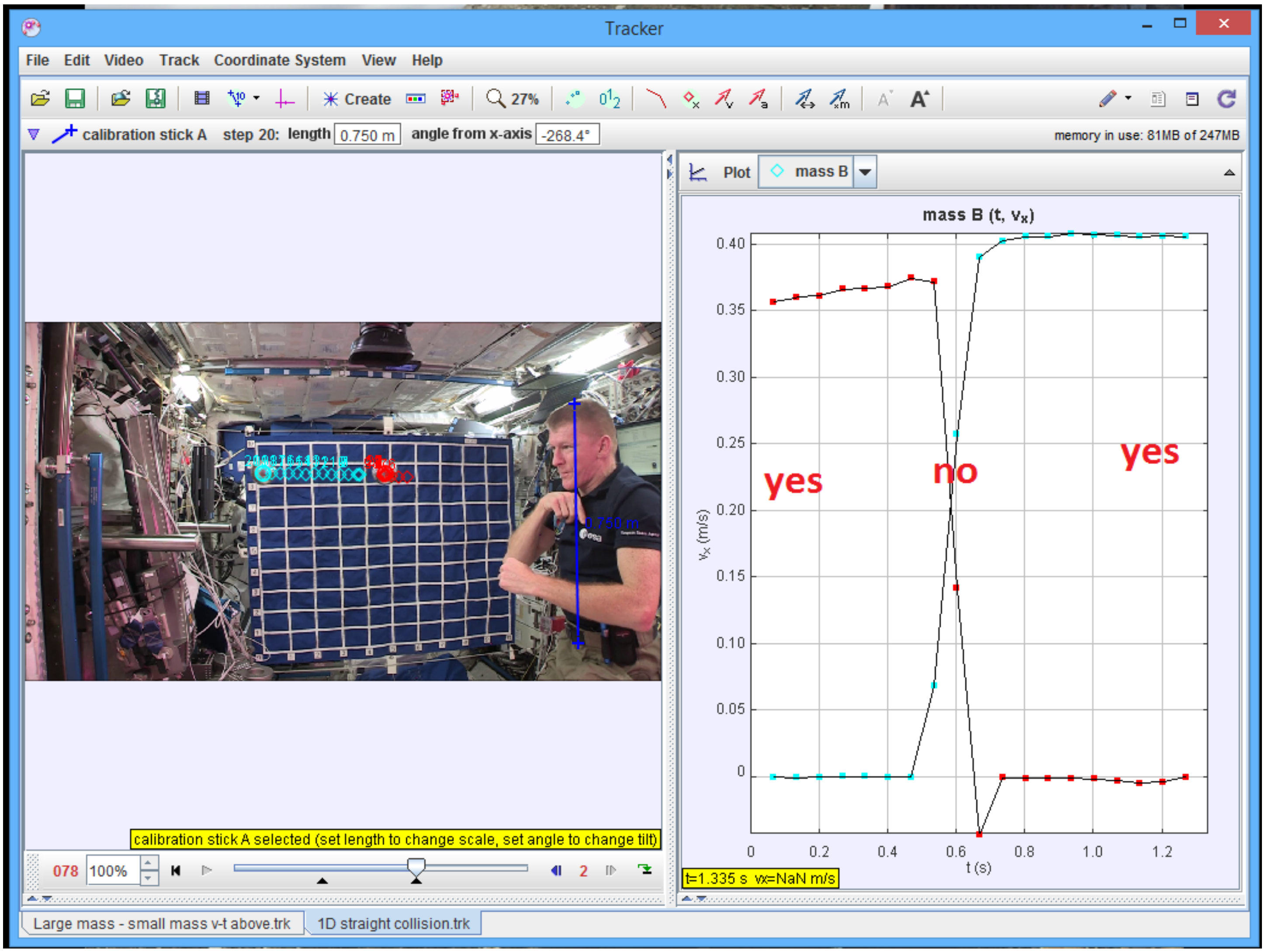

Figure 2: There are three words written on the graph of the horizontal velocity graph. The label 'yes' indicates where you should analyze the momentum, and 'no' indicates where you should not. Image taken from ISS video [3].

Question 3 *Experimental Method*

In complete sentences, communicate the steps that you took when recording and analyzing the video you created.

Pretend you are writing this so a fellow student that missed this lab could take and analyze the data using only this section. For example, you do not need to tell them to press start on your camera, or open the program, but you would want to tell them what materials you used for your collisions, and any thing that tricked you up in that process.

[1] Most tennis balls are around 57 g [1], and most cans of soup have their weight on them.

Question 4 **Graphing the data**

To compare and contrast the two collisions observed in your two videos please create one graph of both data sets from the two videos. These plots will include:

- *The momentum versus time of the ISS video and your second, created, video.*
- *Use different colors for the two momenta. See the Github for an example on how to plot two things to one graph in Python.*
- *If your two data sets use very different scales please use two different scales Python Code to do so.*
- *Include a caption that clearly describes which motion is which. (1-2 sentences)*

Question 5 **Results**

Describe the differences in motion including how much momentum (in terms of percentages, similar to what you found in question 2) was conserved in both collisions. Include numbers and include your calculations of the percent difference was conserved.

Discuss the fits you applied, and why or why not they are the appropriate fits.

Discuss where your estimates for the systematic uncertainty came from, and why those numbers seem reasonable to you. If you needed to propagate the uncertainty on the mass or velocity or time forward please include those calculations below.

Question 6 **Conclusion**

What accounts for the differences or similarities in the collisions. How do the numbers you calculated above support your position? (4-5 sentences).

Question 7 *Please include the name of which space video you chose and a link to the video you made in a drop box link or google drive link.*

Extra Credit:Worm

Please refer to the file at the end of the course website for the extra credit assignment comparing healthy worms and worms with Alzheimer's like symptoms. Please see the assignment summary for more information, but know that this is cutting edge research being done here at WPI by Dr J over in the biology department!

Appendix

Fit Line Error's

As you can see in 3 our data points do not perfectly match the fit we've applied. In fact, the amount those data points differ from the fit are an important part of understanding your data. Please just include a note about what method you chose in your caption. Your data will often fluctuate randomly. When that occurs we call this statistical error. To reduce that error one should take more data, which is what we have done by including more than one Tracker point (for example, 6 points on a line is often better than 5). However, the amount that the data fluctuates around your theory needs to be quantified. Often a physicists goal is to reduce the statistical error until it does not matter anymore.

Statistical error is not quite the same as fit error, however. For a very clear summary on the difference please see this Wikipedia article. Their series on statistical errors is extremely well written, and often has numerous professional citations and you are welcome to reference it. For example, what they call Observational Bias we call Systematic Error and that is also a very well written article.

For more Python specific information please see chapter 3, exercise 3.8, of Mark Newman's free book on computational physics that is cited in the biography [8]. There he gives an example of least squares fitting using the photoelectric effect data that won the 1905 (A. Einstein) and 1923 (R. Millikan) Nobel Prizes. His example is written in Python, but the math should be the same for any other programming language.

if you are curious how error propagation of fits is a lifelong skill for professional physicists P. H. Richter of Communications Systems and Research Section at NASA's Jet Propulsion Lab has a high order treatment of error for fitting lines at the referenced link [9].

Python

Please see the Github repository for Python examples for this lab. There you will also find the code used in Lab 3, which may also prove useful. You will also find code there on how to plot the two data sets together.

For more Python in physics we also recommend Eric

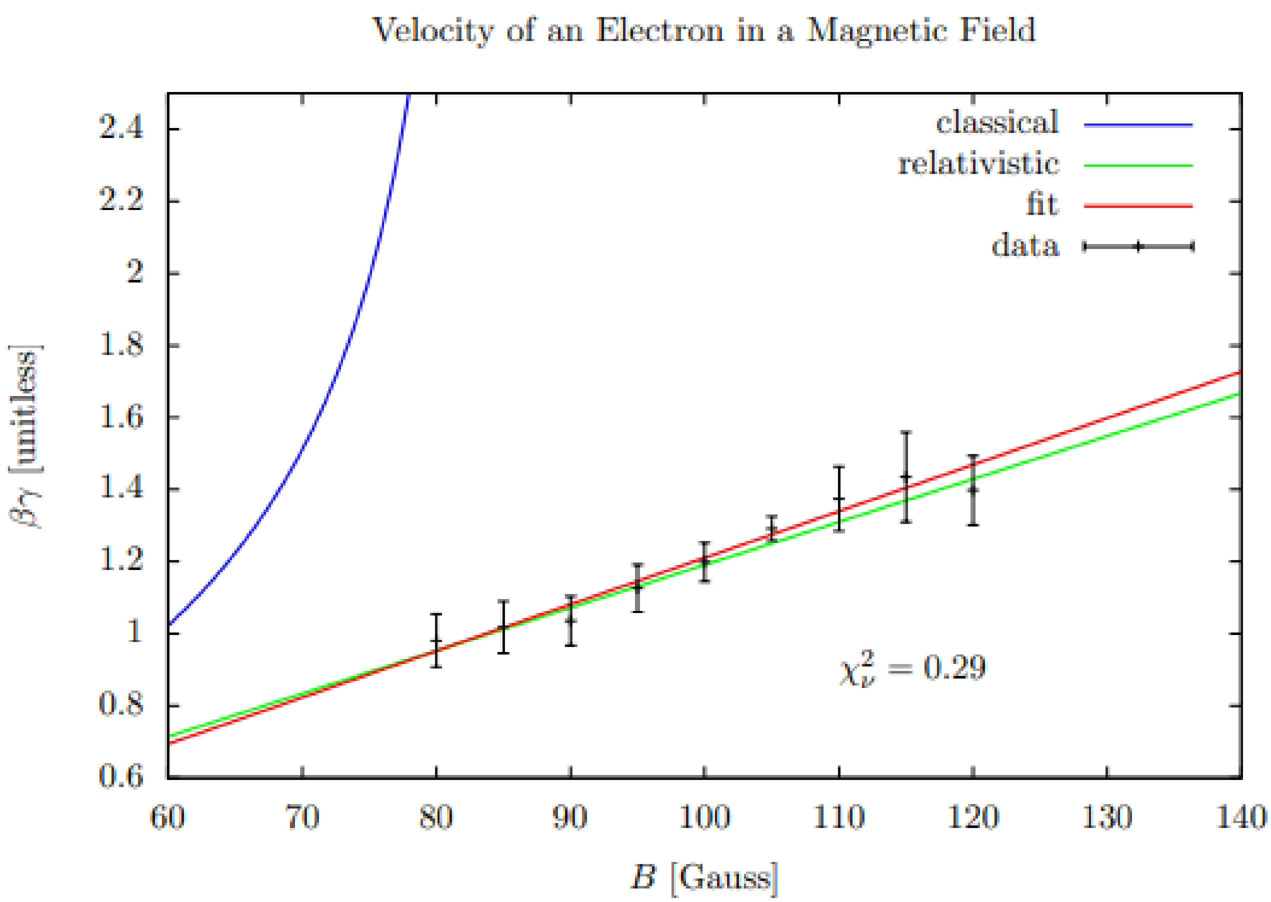

Figure 3: Example of a good figure with excellent error bars and a label. Figure from Philip Ilten of University College Dublin [7].

Ayers book which can be found here.

Propagation of Uncertainties review from Lab 1

Using the calculated measurements you just found, calculate the area of the keyboard. Again, the initial calculation is trivial, but what about the uncertainties? This time we will use a slightly different method of error propagation because we are multiplying them instead of adding them. This method is valid for both multiplication and division of measurements with uncertainties. The formula is

$$\frac{\delta A}{|A|} = \frac{\delta x}{|x|} + \frac{\delta y}{|y|}\,, \tag{1}$$

where A is the area, x is the length, y is the width, δx and δy are the uncertainties associated with these measurements, and δA is the propagated uncertainty of the area.

Exporting data from Tracker

After you have downloaded the Tracker software here and tracked your moving object you will want to export your data for your analysis software.[2]

The first way to export your data is to go 'File' to 'Export' to 'All Cells' to 'Save As...' That will save all the data you can see on your data table, which is in the bottom right corner in Fig. 4.

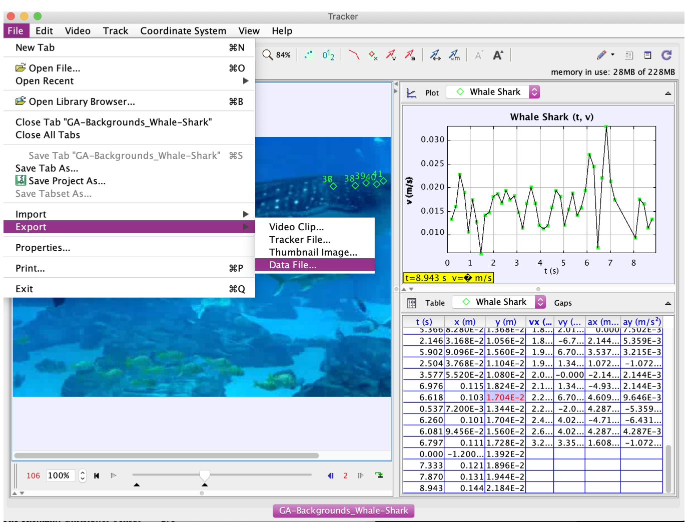

Figure 4: The first way to export your data is to go 'File' to 'Export' to 'All Cells' to 'Save As...' That will save all the data you can see on your data table, which is in the bottom right corner in this image.

Then you want to save all cell's as in Fig. 5. You will only save the data displayed on the chart, so if you wish to change what data you see click the Tables button as in Fig. 6.

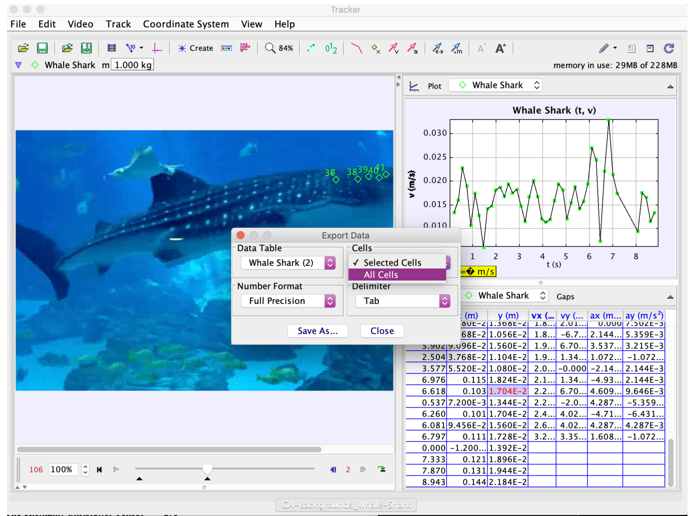

Figure 5: Choose 'All Cells' and 'Full Precision' when saving your data.

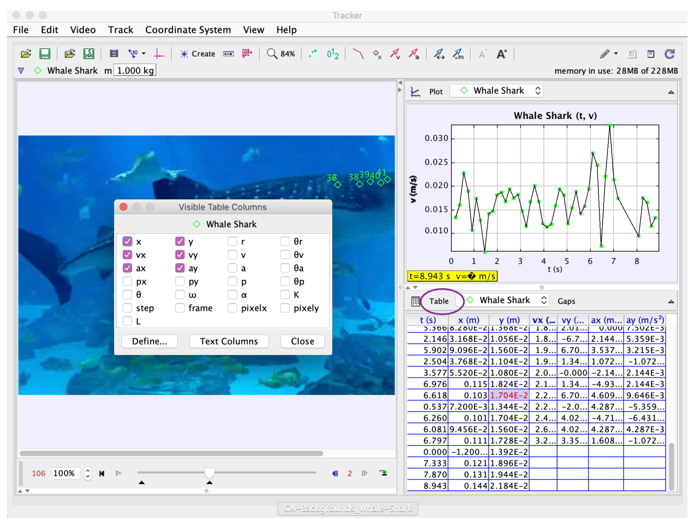

Figure 6: Clicking on the table icon allows you to choose which data you wish to see on your table, and therefore what date you wish to export.

The second way to export data is right click on your chart, choose 'Analyze' and then export from the file tab. You can see the Analysis button appear in Fig. 7, and then where to export from in Fig. 8.

[2] Please remember to use any analysis software aside from Excel or Google Sheets. Matlab, Python, C++, Stata, R are all great software's to use

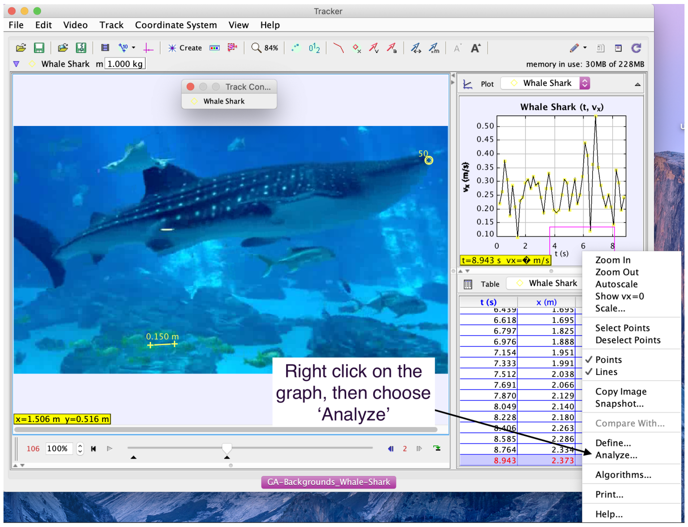

Figure 7: The analysis function can be very helpful when you want to see the Tracker plot clearer.

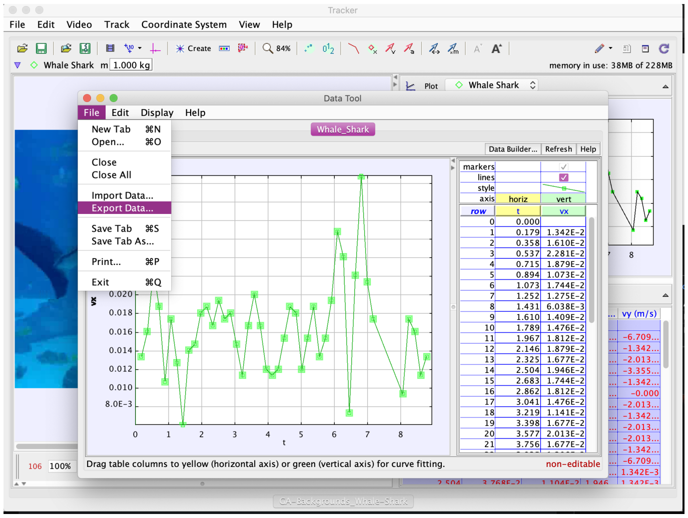

Figure 8: You can also export from the analysis function.

Collisions Video Summary		
Video File Name	Summary of Movement	Mass
V1 Two equal mass head on side view	A side on video of a moving ball colliding with a stationary ball of equal mass	1kg
V2 Two equal mass head on above - drift	An overhead video of a moving ball impacting a stationary ball of equal mass with the balls both drifting sideways after impact	1kg
V3 Oblique collision	A side on video of a moving ball colliding obliquely with a stationary ball of equal mass	1kg
V4 Inelastic large spin	A side on view of an inelastic collision between two balls of equal mass that join with velcro on collision	1kg
V5 Inelastic little spin	A side on view of an inelastic collision between two balls of equal mass that join with velcro on collision	1kg
V6 Inelastic collision top view	An overhead vie of an inelastic collision between two balls of equal mass	1kg
V7 Large mass into small mass	A side on view of a collision between a moving ball of large mass and a stationary ball of small mass	1kg and 0.05kg
V8 Large mass into small mass from above	An overhead view of a collision between a large mass ball and a stationary ball of smaller mass	1kg and 0.05kg
V9 Small mass into large mass	A side on view of a collision of a small mass ball with a stationary ball of larger mass	1kg and 0.05kg

References

[1] The Physics Factbook mass of a tennis ball, 2000.

[2] National Space Academy. A brief explanation of each teaching video, 2020.

[3] National Space Academy. Collisions, 2020. NSA Website.

[4] Douglas Brown. Tracker software help, 2020. Tracker website.

[5] fmculley@gmail.com. The physics aviary impulse lab, 2013.

[6] fmculley@gmail.com. The physics aviary momentum lab, 2013.

[7] Philip Ilten. The hitchhiker's guide to first year physics labs at ucd. 2010.

[8] Mark Newman. *Computational Physics with Python*. CreateSpace Independent Publishing Platform, 2012.

[9] P. H. Richter. Estimating errors in least-squares fitting. *TDA Progress Report*, 42(122):107–137, 1995.