

RELATIVISTIC TIME DILATION

INTRODUCTION:

This week we will study a famous experiment which conclusively disproves the classical theory of relativity by showing that moving muons -- subatomic particles with a mean lifetime of 2.2 microseconds -- have significantly longer lifetimes when they move at speeds close to the speed of light. We will watch a film demonstrating the experiment, and then we will measure the lifetime of these particles.

BEFORE LAB: *Skim* David Frisch and James Smith, [\\ourslu\classes\Koon\221L\Muons\AJPMuonPaper.pdf](https://ourslu.classes.koon/221L/Muons/AJPMuonPaper.pdf).

THE MOVIE:

This week you will be watching a film of the experiment (Frisch and Smith, above) designed to measure time dilation using muon decay. After the film, please answer questions 1-4 below in your lab notebooks, which you should turn in at the end of lab. After these preliminaries, we will start our experiment, which is described below.

PRELIMINARY QUESTIONS:

1. *DESCRIBE THE EXPERIMENT*: Briefly describe the procedure used in the experiment. Your description should answer all of the following:
 - What do the two counts (blips) recorded on the oscilloscope represent?
 - How do the researchers *know* that they are only counting muons?
 - What is the purpose of the iron, and why is less used at sea level?
2. *TIME DILATION FACTOR*: The article mentioned above states (p. 351) that the muons measured in their experiment had velocities of $v = 0.9950c$ to $0.9954c$ for the measurements on top of Mt. Washington (6300ft), but $0.9881c$ to $0.9897c$ in Cambridge, MA. So, overall, we can say that $v = 0.992c \pm 0.003c$.
 - Calculate the time-dilation factor, γ (gamma), including uncertainty, for $v = 0.992c \pm 0.003c$. (Make use of your lab text --- D. C. Baird's *Experimentation* --- if you don't already know how to calculate uncertainty.)
3. *LAB FRAME*: (Answer the following for an observer on the ground.)
 - Convert Mt. Washington's height to meters ($1\text{m} = 3.28\text{ft}$)
 - How long does it take the muons to travel this distance?
 - If the muons' mean lifetime is $2.20\ \mu\text{s}$ in their own frame, what is it in the lab frame? (Include uncertainty.)
 - How many lifetimes does it take the muons to reach sea level? (Include uncertainty)
4. *MUONS' FRAME*: (Answer the following from the muons' perspective.)
 - To the muons, how high is Mt. Washington? (Include uncertainty.) How long does it take to travel this distance?
 - What is the muons' mean lifetime in their own frame?
 - How many lifetimes does it take the muons to reach sea level? (Include uncertainty)

THE EXPERIMENT:

EXPERIMENTAL SETUP

- Each individual in this lab section will sign up to collect 20 hours of data sometime during the upcoming week. We will analyze the data from all 20-hr sessions next week. Please be prompt in showing up for your data collection session and please leave the equipment in good order for the next person.
- Set the High Voltage [HV] to about -1200V. The HV monitor will read 1/100 of this value.
- Set the threshold to about 180mV. The monitor will read this value.
- Make sure the Pulser on the big black cylinder is turned OFF.

SOFTWARE SETUP

- Choose the "muon" shortcut on the desktop to start the software.
- Select "Configure" and Choose the following values: com4, $6\ \mu\text{s}$, and 20. Click "Save & Exit".
- Click Start to begin taking data. Beware that having either monitor connected to an external meter will produce false data points. Remove any meters.

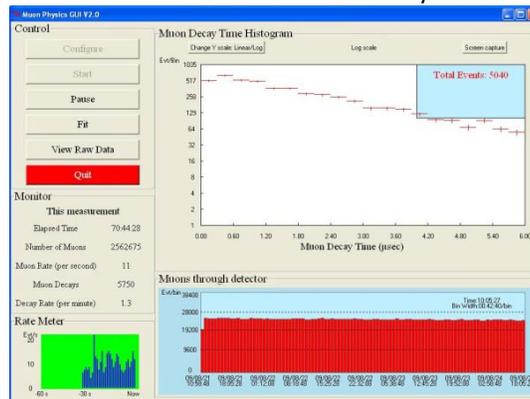
- Click the “Change Y Scale: Linear/Log” to display a logarithmic Y axis.



Left: Scintillator assembly sitting atop the oscilloscope and Experimental Control Unit.
 Right: Top of the scintillator assembly.

AS DATA STARTS TO COME IN

- Bring a partner with you (or even some random person off the street). Keep your eyes on the oscilloscope while your partner keeps an eye on the computer screen graph, warning you every time the “Total Events” number changes. Bearing in mind the time lag, do these events have any correlation to anything you see on the oscilloscope screen?
- Leave the experiment alone and come back in 20 hours to harvest your data.



Screenshot of experiment software.

STOP THE DATA COLLECTION

- Press the “Pause” button. Do NOT press “Quit”. Not yet.
- Record the following data as displayed on the computer screen:

- Elapsed Time .
- “Number of Muons” (lefthand side of screen) and “Total Events” (on graph).
- “Number of Muons” from lefthand side of screen.
- Select “Print Screen” on the computer. This copies the screen image. Open up a copy of “Paint” (Start button > All Programs > Accessories > Paint) and paste it into that file. Save it as a jpg file, e.g. 221L Koon 9-18-09.jpg, and save it. You will want to print it out later for your lab notebook.

HARVESTING THE RAW DATA

- Click the “View raw data” button.
- In the new window that opens up, type a sufficiently large number at the bottom of the screen under “Number of raw data events”. Click “Read”. Wait for the values to appear in the main part of this window.
- Verify that the data at the top and bottom of the window correspond to the times that you began and ended the data collection. If not, re-enter a larger number under “Number of raw data events” and repeat the last step.
- Use the mouse/touchpad and shift key to highlight ALL the data. Press Ctrl+C to copy it.
- Open up Notepad (Start Button > All Programs > Accessories > Notepad) and paste (Ctrl+V) the data into it. Again, verify that the top and bottom data correspond to the beginning and the end of your data collection.
- Give this file a descriptive title, e.g. “221L Koon 8-19-09.txt”, that includes the course name, your name, and the collection date. Save it to the computer’s Desktop AND to a USB flash drive of your own.
- You should click the “Quit” button to end the data collection session when you are confident that you have harvested all your data.

PRESORTING RAW DATA

You will notice that the data consists of pairs of data: the time and the muon “decay time”, in NANOseconds. You will also notice that most of the data are around 40000ns or 40microseconds, which we know to be orders of magnitude longer than a typical muon lifetime. These are not real data, and should be discarded. Here’s how to do that.

- Open up your “*.txt” data file in Excel 2007 (earlier versions do not allow for as many data points as you likely took). You will need to do this on a computer other than the one which collected the data. Notice that both the date and the decay time occupy a single column.
- Click the Data tab at the top of the Excel page and choose “Text to Columns”. This will walk you through a wizard to separate the columns.
 - Highlight the entire Column A. Select Fixed width and press Finish. This should break the two data into separate columns. Ignore the first column (time & date).
- Highlight, Copy and Paste the data in column B into column D, starting at cell D3. We are keeping column B as a backup, just in case we mess up in the data manipulation that follows.
- This is a good time to save this file as an Excel file. Save it to the class T: drive (T:koon/221L/Submissions/).
- We need to get rid of all those 40microsecond bogus data points. Select your data in column D. Sort the data by choosing the Data tab, then “Sort”. In the window that pops up, select the column, then sort it by “Values” in order of “Smallest to Largest”.
- Scroll down and delete all the data larger than 40microseconds. Compare the number of “good” data points left to the values that had been displayed on your computer screen. Comment on this in your lab notebook. Working with this smaller data set will make life much easier for all of us.

We will continue analyzing the data from you and from all your lab classmates next week in lab. The main chore will be grouping your data into “bins” as the computer has done for the lovely graph it displayed of your data.

WEEK2: ANALYSIS

- Make sure your version of Excel has the Analysis ToolPak installed. Click the Data tab, look for “Data Analysis” at the extreme right-hand side of the Ribbon. If you don’t have it installed, look for the instructions “Load the Analysis Toolpak” in Excel’s Help utility.
- Read instructions in “Present your data in a histogram” in Excel’s Help utility, and set up the data to create a histogram.

- Choose 100ns, 200ns, 300ns,..., 20,000ns as bin values.
- Plot your histogram data using a Scatter graph. Right click the vertical axis, select "Format Axis" and change it to a logarithmic display. Remove the 100ns datum from the graph. (Why do you think this bin's frequency count is too small?)
- Comment on whether the muon decay is now in fact exponential.
- Now we want to find the rate of the decay. It will go as $\exp(-t/\text{lifetime})$. Add an exponential trendline to the data and display the equation of fit on the graph. If there are regions of data that *don't* fit an exponential, remove them from the fit. Make sure the constant in the exponent has enough significant figures by right-clicking the equation, selecting "Format Trendline Label" and adjusting the number format. Calculate the lifetime from the slope. Compare this to the expected value of a muon's mean lifetime.
- Okay, but you still have no indication on this graph of what the uncertainty in this value is, what range of values it is consistent with. Time for more Data Analysis. In your histogram data, add a data to the right that consists of the logarithm of the adjacent histogram frequency. Select Data Analysis from the Data tab, and choose Regression. It will ask for your y-axis data and your x-axis data (be careful to get the right one in the right window). Enter these and choose a 95% confidence level. Enter "Okay" and the data will appear on a new spreadsheet page. The first two digits to the right of "X Variable" will be the slope and its uncertainty. Write these down in your lab notebook and calculate the lifetime AND ITS UNCERTAINTY. How do these two values compare to the accepted value?