# Muons and Special Relativity

How does the detection of muons on ground level prove Einstein's Theory of Special Relativity?

## Introduction

- A muon has similar properties to an electron. However, it is 200 times heavier.
- When created in the atmosphere, they travel at approximately 98% of the speed of light.
- Formed when energised protons in cosmic rays strike the atmosphere.
- Usually has a mean life time of about 2.2 microseconds.
- First discovered by Carl Anderson and Seth Neddermeyer at Caltech in 1936.
- Later, it was used to observe time dilation for the first time, predicted in Einstein's concept of special relativity.

## About our Project

We investigated how the detection of muons on ground level prove Einstein's Theory of Special Relativity. We then designed the following hypothesis:

"Without Special Relativity, the presence of muons observed in our experiment would lead to an improbable number of muons in the Earth's atmosphere."

We thought this would be correct because we believed the chances of observing muons on the Earth's ground would be negligible unless there were an unrealistic number of muons in existence in the Earth's atmosphere.

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## Method

- We calculated and recorded the theoretical percentage of muons that would reach the ground when excluding and including Special Relativity.
- We then conducted the experiment with a particle detector and recorded our result.
- Special Relativity would be proved in two instances:

1. If the rate of muons on ground level suggested a probable number of muons in the Earth's atmosphere according to Special Relativity.
2. If the number of muons was improbable when not considering the theory then this would be proof for Special Relativity.

- There were two stages of working that we used to calculate the values we needed.
- Firstly, we needed to find the mean life time of the muons when taking special relativity into consideration. This was done with Equation 1

$$t' = \frac{t}{\sqrt{1 - \frac{v^2}{c^2}}} \quad ①$$

- (t stands for the mean life time of a muon. t' stands for the mean life time when considering time dilation from Special Relativity.
- The fraction in the bottom half of the right hand side stands for 98% of the speed of light.)

- After doing this, we used Equation 2 to calculate the percentage of muons we expected to reach the Earth's ground level.

$$\frac{N}{N_o} = e^{-\lambda t} \quad ②$$

- (The left hand side of the equation stands for a percentage.
- '*e*' is a constant.
- Lambda (λ) stands for the reciprocal of the mean life time of the muon (which we calculated previously).
- 't' is the time taken for the muons to reach ground level.)

## Results

We calculated that without taking into account special relativity, on average, the percentage of muons predicted to be measured at ground level would be **9.7 x $10^{-8}$ %**.

When we took into account special relativity, the percentage on average of muons predicted to be measured at ground level was **0.06%**, which was significantly larger. The averages were taken from a distance of 10,000 m to 20,000 m, as this is where we believe muons are created.

By calculating the rate of muons, we worked out on average the number of muons in every square centimetre in every second at ground level . We assumed all of the muons created survived and reached the Earth's ground level for this. Without special relativity, the number of muons per centimetre squared every second would have to be **13,639,175.26**, and with special relativity, this value would be **22.05 muons**.

## Conclusions

We have proved that Special Relativity is correct in two separate ways.

If we look at the result with special relativity, we find only 22.05 muons per $cm^2$ per second .This is a much more probable result. These results show our hypothesis to be correct, as only a negligible percentage of muons would reach the Earth's ground if special relativity was not taken into account (9.7 x $10^{-8}$ %).

Furthermore, if we look at the results, we found that without Special Relativity, it shows a ridiculously high number of muons. Seeing as we found only 4 muons in 2 hours, 13,639,175.26 muons cannot be right.