Muon Lifetime Measurement

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The present experiment was interested in verifying the high penetrating power of muons, and measuring the half-life of muons using two different approaches mentioned in literature.

1. INTRODUCTION

Muons were first discovered by Carl Anderson, Seth Neddermeyer and their colleagues in 1936, when they studied the tracks left behind by comic rays in their cloud chamber. Atmospheric muons are short-lived particles but are nonetheless fast-moving and thus have high penetrating power. They can pass through a block of lead easily without being stopped.

In order to measure the half-life of muons, Coan, Liu and Ye described a method using a time-to-digital converter to record the lifetime of individual muons detected. Mühry and Ritter suggested a simpler method using a digital oscilloscope.

The present experiment was interested in verifying the high penetrating power of muons, and based on the above-mentioned methods, measuring the half-life of muons using two different approaches.

2. MUON

Atmospheric muons are actually secondary products of cosmic rays. When the primary cosmic rays enter the atmosphere, they collide with the nuclei of atmospheric gases. The collisions give rise to a handful of new particles, such as pions and kaons, unstable mesons which quickly decay into muons.

Muons are elementary particles just like electrons, but have a mass 200 times as large. Muons produced in a cosmic ray shower have enormous energy and can travel at a speed as fast as 0.99c.

3. PENETRATING POWER OF MUON

In order to test the high penetrating power of muon, an experiment was set up. Two Geiger-Müller tubes (Aware RM-60) were connected to a coincidence circuit, which is then connected to a computer, such that only when both counters record a signal at the same time will a signal be sent to the computer. A block of lead of dimension 216x102x63mm was placed between the two counters, as shown in Fig.1a, Fig.1b and Fig.1c.

Since common radiations like α, β and γ radiations cannot penetrate a lead block, so if a signal is recorded at the computer, it must mean that the particle triggering the signal must have passed through the lead. On the earth surface, the majority of charged radiations other than α, β and γ radiations comes from muons. Therefore, we can safely assume that if we record any signals, they mostly come from muons.

Fig.1a

Fig.1b

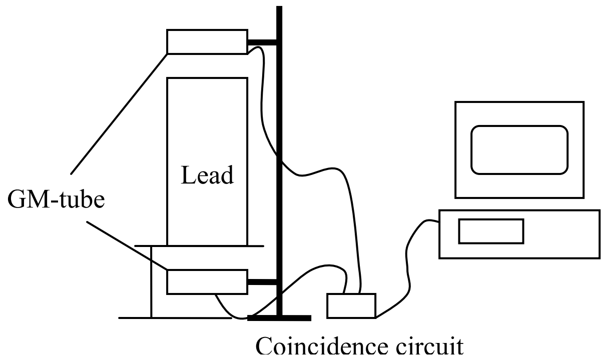

Fig.1c: Setup for testing the penetrating power of muon

The experiment was run for 3 days, using the computer to record the number of signals automatically. A second step, then, was to remove the lead block and run the experiment for another 3 days.

I recorded 57 ± 13% counts in the setup with a lead block and 118 ± 9% counts in the one without a lead block. When a lead block is placed between the counters, there is a 52% decrease in counts. However, a considerable part of this decrease in counts may be due to the filtering of common radiations. Hence, the experiment showed that the lead block cannot efficiently block muons. This confirms that muons have high penetrating power.

4. SCINTILLATOR & PHOTOMULTIPLIER TUBE

In order measure the half-life of muons, a plastic scintillator (BC-416) of diameter 150mm and height 200mm was used. The scintillator was connected with a PMT (RCA 8055). A voltage of 1800V was applied to the PMT. The whole setup was placed in an opaque black plastic cylinder, as shown in Fig.2, in order to shield light from the PMT, because light leakage can damage the tube when high voltage is applied. The structure of the scintillator and the PMT is shown in Fig.3.

When a muon enters the box and passes through the scintillator, there is a chance that it is stopped by it. The scintillator material will then release the energy absorbed by emitting a photon. If the photon released strikes on the photocathode of the PMT, electrons will be emitted and accelerated towards the dynodes which are set at gradually more positive voltage. At each dynode, a larger amount of electrons are emitted when the incident electrons hit upon it. This creates an avalanche effect, which amplifies the signal by as much as 10^8 times.

Fig.2: Scintillator and PMT in a plastic cylinder

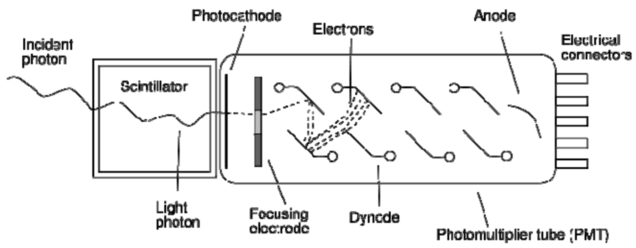

Fig.3: Structure of scintillator and PMT

5. HALF-LIFE OF MUON

Occasionally, a muon entering the scintillator is slowed down or even stopped so that it decays inside the setup. A negatively charged muon μ^-, for example, decays as follows:

$$\mu^- \rightarrow e^- + \nu + \nu$$

The electron creates a signal which is then amplified by the PMT. By measuring the time lag between the first signal generated when a muon enters the scintillator and the second signal generated when the muon decays, it is possible to obtain the lifetime of individual muons.

In the first part of the experiment, a preliminary survey of the half-life of muon is done by connecting the scintillator and the photomultiplier tube with a digital oscilloscope (Tektronix TDS210). The time lag can be measured on the oscilloscope and is defined by the distance between the peaks of two successive pulses generated from the PMT. The setup is shown in Fig.4.

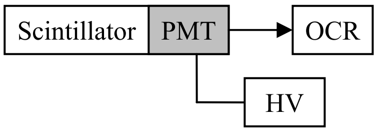

Fig.4: Setup for measuring muon lifetime

The lifetime distribution follows an exponential decay curve, therefore the half-life of muon can be obtained by using $t_{1/2} = \ln(2)/\lambda$, once the decay constant λ is determined by plotting the distribution.

A total of 157 counts were recorded in 160 minutes during the experiment. Fig. 5 shows a plot of ln(N), where N is the frequency, against lifetime.

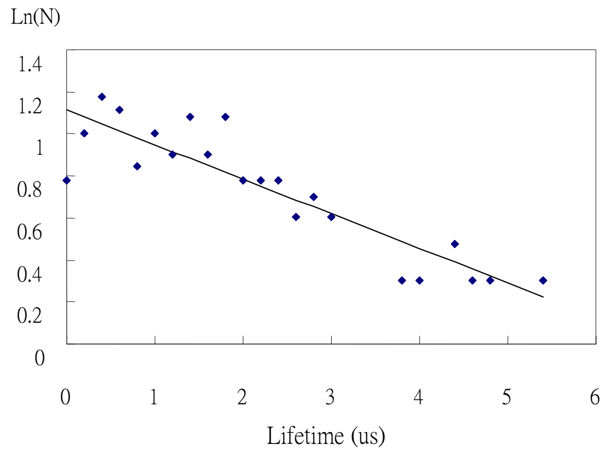

Fig.5: Ln(N)-lifetime graph of muon

From the graph, the half-life of muon is determined to be 4.22μs ± 11%. The value is almost 2 times as large as the accepted value. This may be due to the insufficient amount of data. But as a first approximation, the value is at least on the same order of magnitude.

A better and more sophisticated arrangement of the setup was done in order to obtain a more precious value for the half-life.

The output of the PMT is connected to a pre-amplifier (Canberra 2005E), which is then connected to an amplifier (Canberra 1718). The voltage gain of the amplifier was set to 2X. The amplified signal was output to a single channel analyzer (SCA) for selecting only desired signals. The Lower Level (E) threshold was set to 7.0V, and the Window (ΔE) threshold was set to 10.0V. Output of the SCA was then sent to an MSA card installed on a PC. The MSA card was able to record the time lag between a triggering signal and a second signal automatically. The setup is shown schematically in Fig.6.

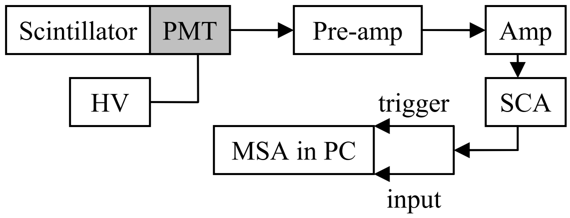

Fig.6: Modified setup for measuring muon lifetime

A total of 14187 counts were recorded in 586416 seconds during the experiment. Fig. 7 shows a plot of ln(N), where N is the frequency, against lifetime.

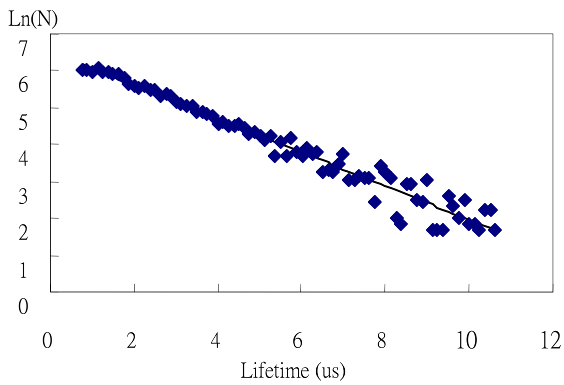

Fig.7: Ln(N)-lifetime graph of muon

From the graph, the half-life of muon is determined to be 1.52μs ± 2%. The value is 30% smaller than the accepted value of 2.2 μs. The error may be caused by a delay in the SCA.

6. CONCLUSION

Although the results in general agree with the accepted value in the order of magnitude, meaning that the experimental setup was functioning as expected, the exact values were not in accordance. This was probably due to technical concerns which were not taken care of due to time limit.

6. REFERENCES

Close, F., M. Marten & C. Sutton (2002). *The particle odyssey: a journey to the heart of the matter*, Oxford: New York.

Gould, C.R. & R.L. Ives (1975). Am. J. Phys. **43**, 918.

Leo, W.R., *Techniques for nuclear and particle physics experiments : a how-to approach*

Mühry, H. & P. Ritter, (2002). "Muons in the classroom", *The Physics Teacher* **40**, 294

Rossi, B. (1966). *Cosmic rays*, Allen & Unwin: London.