A "Physics 510" Experiment to Study Weak Interactions in Muon Decay

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This research project attempts to construct an experiment that explores weak interactions in muon decay to demonstrate concepts taught in the Physics 510 course for graduate students.

I. INTRODUCTION

We aim to build an experiment that measures muon mass using cosmic ray muons. We intend to use it to demonstrate the concepts taught in "Physics 510", a course for graduate students. We seek also to determine the validity of the theorem

$$\tau_\mu = G_F^2 m_\mu^5 / 192\pi^3 \tag{1}$$

by obtaining many measurements to derive the Fermi coupling constant G_F.

II. PROCEDURE

Measure muon mass

$$\mu^+ \rightarrow e^+ \nu_e \nu_\mu \tag{2}$$

When a muon decays, it produces a positron and 2 neutrinos. The distribution of energies of the positrons are to be measured; then, dN/dE_e is plotted over mass. We look for the endpoint of the graph, which corresponds to half the muon mass, $1/2m_\mu$, and find that $E = 53MeV$. Using

$$E = 1/2 m_\mu c^2 \tag{3}$$

we find that $m_\mu \approx 106MeV$.

Collecting data

We set up the scintillators indoors and on the roof top of the Newman Laboratory. The latter counted

- 59.7 events per hour without the copper sheet, and
- 40.3 events per hour with the copper sheet,

which contradicts our expectations. Since copper stops the muons, we are suppose to obtain a higher reading for them.

Measure energy of positron

Let the positron pass through a region of magnetic field. It will travel in a circular trajectory, whose radius we measure to derive the positron momentum using the formulae

$$\vec{F} = q\vec{v} \times \vec{B} = qvBmv^2/r = qvBmv = qBr \tag{4}$$

The positron mass is so small that, relativistically, energy and momentum are approximately equal.

$$E = \sqrt{p^2 + m^2} \approx p \tag{5}$$

Measure trajectory of positron

We build drift tubes where a wire passes through the cylinder, and fill it with a mixture of helium and methane. The positrons then ionize the gases, and electrons are released. When they are attracted to the wire, the machine gives a signal.

Since the voltage in the middle of the tube is positive, the electrons drift towards the wire. Using a drift velocity of approximately 25 .... m/ns and distance, we calculate the time of the drift.

Construction of drift tube

We wrapped a piece of aluminum mylar around a vacuumed tube (to hold it in place) and end rings. After sealing the edge, we removed the tube, then attached plastic covers to the end rings. We filled it with gas to test the amount of pressure it could withstand.

Problems and solutions in constructing the drift tube

The seam was insecure with the first few tubes; we remedied the problem by sealing it with epoxy. We applied the same substance to seal minor leaks along the tube. We eliminated the internal aluminum flap of the seal by having the edge dipped in sodium hydroxide to remove the metal. As more trial tubes were constructed, one's skill was refined to produce better tubes with a more even distribution of tension along the delicate body.

III. RESULTS

When the drift tube was filled with gas and the voltage supply turned on, the light bulb attached to the end of the tube was illuminated approximately every second on the average. This may be due to the electrons drifting towards the wire, or other elements in the tube.

IV. CONCLUSIONS

We aim to investigate the problems associated with collecting data of the muons, especially the factors that cause the readings to contradict our expectations. We also aim to develop a reasonable assembly technique for constructing the drift tube in order to conduct our experiment effectively. We will continue to develop our research to achieve the more sophisticated levels as funding, resources and other related factors permit.

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[1] T. Thomas first posed the problem in Phys. Rev. Lett. **77**, 123 (1990).

[2] R. Richards attempted to solve the problem but left work for me to do.

[3] H. Harold still could not solve the problem – but I did.