μ–Mesons in Flight
Spring 2011

We will watch the film *Time Dilation: An Experiment with μ–Mesons* that describes an experiment testing the theory of special relativity performed by David H. Frisch of MIT and James H. Smith of U. Illinois (*cf*. Frisch & Smith, 1963, American Journal of Physics, vol. **31**, p. 342).

μ–Mesons, or *muons*, are elementary particles with the charge of the electron and mass $207m_e$. They are produced in Earth's atmosphere by collisions of cosmic rays (H nuclei – protons – from the sun and explosions of giant stars that fling them to the far reaches of the galaxy where they encounter Earth) with atmospheric atomic nuclei.

Short Answers – *Answer the following questions while watching the movie:*

1. Moving clocks move slow by what factor?
2. What is this effect called?
3. What are the three steps in the procedure used by Frisch and Smith?
4. How thick a pile of iron covers the scintillator when the experiment is performed on top of Mt. Washington?
5. What is the purpose of the iron pile?
6. On the oscilloscope face, the first pulse is created by μ-mesons. What makes the *second* pulse?
7. On the oscilloscope, what does the horizontal distance between the first and second pulse on a trace measure?
8. What is the loud, clunky timer recording?
9. Prof. Frisch creates a bar graph (by hand!) during the experiment; what does the *vertical* scale indicate?
10. How many μ-mesons were measured during a one-hour run at top of Mt. Washington?
11. Were the μ-mesons *at rest* or *moving* with respect to the observers when on the experiment was performed on Mt. Washington?
12. How high is Mt. Washington?
13. What is the *range of speeds*, in terms of *c* (the speed of light) of the μ-mesons that stop in the scintillator?
14. What can the vertical axis of bar graph also represent?
15. How many μ-mesons were *predicted* to survive to sea level?
16. What is the difference in attire at Cambridge vs. the top of the mountain?
17. At sea level, how thick is the pile of iron?
18. Why is the pile of iron shorter than it was at the top of the mountain?
19. How many μ-mesons were *actually* counted at sea level?

20. By what factor do the μ-mesons run slow when moving by the observers than when the μ-mesons are at rest?

21. How high does Mt. Washington appear to be to a person riding on a fast moving μ-meson?

Examine the Motion of Muons Relativistically – *Answer the following after watching the movie:*

a. Frisch and Smith calculated the factor that μ-mesons run slow when moving by the stationary observers (see question 20 above). Noting that this factor is $\frac{1}{\gamma_\mu}$ calculate the value of γ_μ (you won't need your calculator for this calculation!)

b. Knowing that $\gamma_\mu = \frac{1}{\sqrt{1 - v^2/c^2}}$, *algebraically* solve this equation for *v*.

c. Now calculate the velocity of the traveling μ-mesons using your value of γ_μ, in units of *c* (calculate the velocity to 4 significant figures). How does this velocity compare with the range in question 13 above?

d. The equation for *time dilation* is $\Delta t = \gamma\, \Delta t_o$, where Δt_o is the *proper time* (the time measured in the same reference frame where the event occurs). Taking an average muon decay time of 2.2×10^{-6} *s* as the proper time, calculate the lifetime of a muon in *our* frame of reference.

e. The equation for length contraction is $L = \frac{L_o}{\gamma}$, where L_o is the proper length (measured where the object is at rest). Taking the proper length of the mountain as 1920 *m*, calculate the height of Mt. Washington in the *μ-meson's* frame of reference.

Discussion:

If you have a conversation about physics at your dinner table this evening and someone says, "Relativity is just a theory, it's never been proved," how would you respond? Is having an experimental result be consistent with a theory equivalent to "proving" that theory?