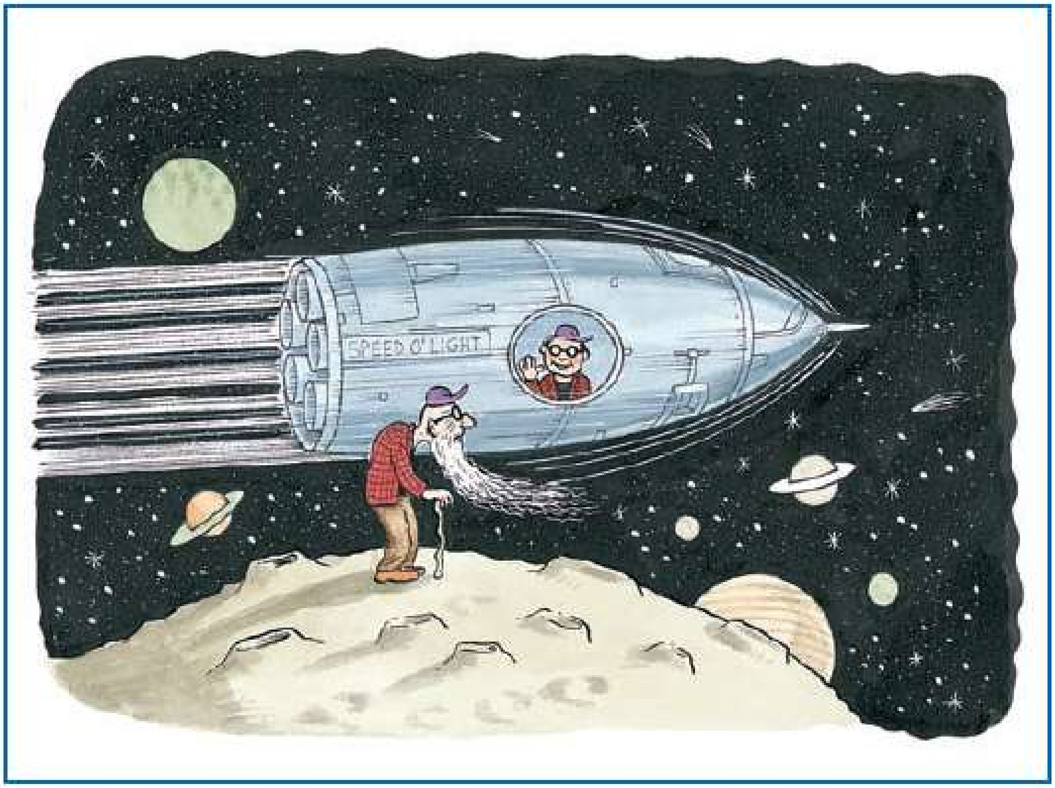
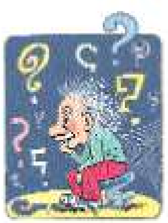
Special Relativity





What Do You Think?

Einstein's Theory of Special Relativity predicts that time goes more slowly for objects moving close to the speed of light than for you. If you could travel close to the speed of light, you would age more slowly than if you remained on Earth. This prediction doesn't fit our "common sense."

- **Does this prediction make sense to you? Explain your thinking.**
- **What do you mean by "common sense"?**

For You To Do

1. A muon is a small particle similar to an electron. Muons pour down on you all the time at a constant rate. If 500 muons arrive at a muon detector in one second, then 500 muons will arrive during the next second.

   Muons have a half-life of 2 microseconds. (A microsecond is 1 millionth of a second, or 1×10^{-6} s.) Beginning with 500 muons, after 2 microseconds there will be about 250 muons left. (That is 1 half-life.) After 4 microseconds (2 half-lives) there will be about 125 muons left. After 6 microseconds (3 half-lives) there will be about 62 muons left.

   a) How many muons would be left after 4 half-lives?

2. The half-life of muons provides you with a muon clock. Plot a graph of *the number of muons* versus *time*. Use 500 muons as the size of the sample. This graph will become your clock.

   a) If 125 muons remain, how much time has elapsed?

   b) If 31 muons remain, how much time has elapsed?

   c) If 300 muons remain, how much time has elapsed?

   d) If 400 muons remain, how much time has elapsed?

3. Measurements show that 500 muons fall on the top of Mt. Washington, altitude 2000 m. Muons travel at 99% the speed of light or $0.99 \times 3.0 \times 10^8$ m/s.

   a) Calculate the time in microseconds it would take muons to travel from the top of Mt. Washington to its base.

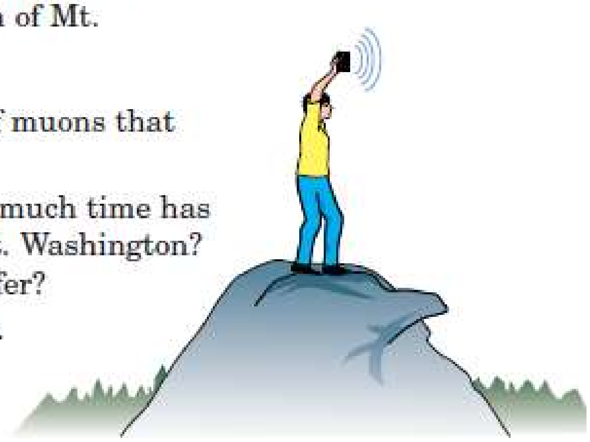
   b) Use your calculation and the muon clock graph to find how many muons should reach the bottom of Mt. Washington.

4. Experiments show that the actual number of muons that reach the base of Mt. Washington is 400.

   a) According to your muon clock graph, how much time has elapsed if 400 muons reach the base of Mt. Washington?

   b) By what factor do the times you found differ?

   c) Suggest an explanation for this difference.



Physics Words

muon: a particle in the group of elementary particles called leptons (not affected by the nuclear force).

Albert Einstein had an answer. The muon's time is different than your time because muons travel at about the speed of light. He found that the time for the muon's trip (at their speed) should be 0.8 microseconds. That is the time that the muon's radioactive clock predicts.

d) As strange as that explanation may sound, it accurately predicts what happens. Work with your group to come up with another plausible explanation.

FOR YOU TO READ

Special Relativity

Physicists of this century have had a difficult decision to make. They could accept common sense (all clocks and everyone's time is the same), but this common sense cannot explain the data from the **muon** experiment. They could accept Einstein's Theory of Special Relativity (all clocks and everyone's time is dependent on the speed of the observer), which gives accurate predictions of experiments, but seems strange. Which would you choose, and why?

The muon experiment shows that time is different for objects moving near the speed of light. You calculated that muons would take 7 microseconds to travel from the top of Mt. Washington to its base. Experiments show that the muons travel that distance in only 0.8 microseconds. Because of their speed, time for muons goes more slowly than time for you!

Time is not the only physical quantity that takes on a new meaning under Einstein's theory. The length of an object moving near the speed of light shrinks in the direction of its motion. If you could measure a meter stick moving at 99% of the speed of light, it would be shorter than one meter!

Perhaps the most surprising results of Einstein's theory are that space and time are connected and that energy and mass are equivalent. The relationship between energy and mass is shown in the famous equation $E = mc^2$. Put in simple words, increasing the mass of an object increases its energy. And, increasing the energy of an object increases its mass. This idea has been supported by the results of many laboratory experiments, and in nuclear reactions. It explains how the Sun and stars shine and how nuclear power plants and nuclear bombs are possible.

Meter stick traveling at near the speed of light, as seen from Earth

Meter stick on Earth's surface