

Problem 1

The positive muon μ^+ is an unstable particle, and it has an average lifetime of 2.20×10^{-6} s (measured in its reference frame) before decaying.

- (a) If such a particle is moving, with respect to the laboratory, with a speed of $0.900c$, what average lifetime is measured in the laboratory?
- (b) What average distance, measured in the laboratory, does the particle move before decaying?

Problem 2

A spacecraft flies away from the earth with a speed of 4.80×10^6 m/s relative to the earth and then returns at the same speed. The spacecraft carries an atomic clock that has been carefully synchronized with an identical clock that remains at rest on earth. The spacecraft returns to its starting point 365 days (1 year) later, as measured by the clock that remained on earth.

- (a) What is the difference in the elapsed times on the two clocks, measured in hours?
- (b) Which clock, the one in the spacecraft or the one on earth, shows the shorter elapsed time?

Problem 3

An unstable particle is created in the upper atmosphere from a cosmic ray and travels straight down toward the surface of the earth with a speed of $0.9954c$ relative to the earth. A scientist at rest on the earth's surface measures that the particle is created at an altitude of 45.0 km.

- (a) As measured by the scientist, how much time does it take the particle to travel the 45.0 km to the surface of the earth?
- (b) Use the length-contraction formula to calculate the distance from where the particle is created to the surface of the earth as measured in the particle's frame.
- (c) In the particle's frame, how much time does it take the particle to travel from where it is created to the surface of the earth?

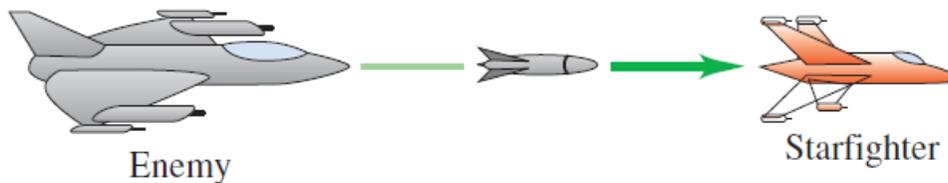
Problem 4

Two particles are created in a high-energy accelerator and move off in opposite directions. The speed of one particle, as measured in the laboratory, is $0.650c$ and the speed of each particle relative to the other is $0.950c$. What is the speed of the second particle, as measured in the laboratory?

Problem 5

An enemy spaceship is moving toward your starfighter with a speed, as measured in your frame, of $0.400c$. The enemy ship fires a missile toward you at a speed of $0.700c$ relative to the enemy ship.

- (a) What is the speed of the missile relative to you? Express your answer in terms of the speed of light.
- (b) If you measure that the enemy ship is away from you when the missile is fired, how much time, measured in your frame, will it take the missile to reach you?



Problem 6

Electromagnetic radiation from a star is observed with an earth-based telescope. The star is moving away from the earth with a speed of $0.600c$. If the radiation has a frequency of 8.64×10^{14} Hz in the rest frame of the star, what is the frequency measured by an observer on earth?

Problem 7

A proton has momentum with magnitude p_0 when its speed is $0.400c$. In terms of p_0 , what is the magnitude of the proton's momentum when its speed is doubled to $0.800c$?

Problem 8

How much work must be done on a particle with mass m to accelerate it from:

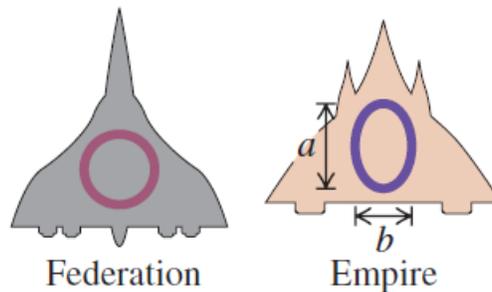
- (a) rest to a speed of $0.090c$?
 - (b) a speed of $0.900c$ to a speed of $0.990c$?
- (express the answer in terms of mc^2)

Problem 9

A cube of metal with sides of length a sits at rest in a frame with one edge parallel to the x -axis. Therefore, in S the cube has volume a^3 . Frame S' moves along the x -axis with a speed u . As measured by an observer in frame S' , what is the volume of the metal cube?

Problem 10

The starships of the Federation are marked with the symbol of the federation, a circle, while starships of the Empire are marked with the Empire's symbol, an ellipse whose major axis is 1.40 times longer than its minor axis ($a = 1.40b$ as shown in the diagram). How fast, relative to an observer, does an empire ship have to travel for its marking to be confused with the marking of a federation ship?



Problem 11

Protons in an accelerator at the Fermi National Laboratory near Chicago are accelerated to a total energy that is 400 times their rest energy. (a) What is the speed of these protons in terms of c ? (b) What is their kinetic energy in MeV?