Exercise 37.8

Review | Constants

At $x = x' = 0$ and $t = t' = 0$ a clock ticks aboard an extremely fast spaceship moving past us in the $+x$-direction with a Lorentz factor of 100 so $v \approx c$. The captain hears the clock tick again 1.00 s later.

Part A

Where and when do we measure the second tick to occur?

Enter your answers numerically separated by a comma. Express x in meters and Δt in seconds.

$x, \Delta t$ = m, s

Submit Request Answer

Exercise 37.11 - Enhanced - with Feedback

Muons are unstable subatomic particles that decay to electrons with a mean lifetime of 2.2 μs. They are produced when cosmic rays bombard the upper atmosphere about 14 km above the earth's surface, and they travel very close to the speed of light. The problem we want to address is why we see any of them at the earth's surface.

Part A

What is the greatest distance a muon could travel during its 2.2 μs lifetime?

Express your answer with the appropriate units.

μÅ ?

d = Value Units

Submit Request Answer

Part B

According to your answer in the previous part, it would seem that muons could never make it to the ground. But the 2.2 μs lifetime is measured in the frame of the muon, and muons are moving very fast. At a speed of 0.999c, what is the mean lifetime of a muon as measured by an observer at rest on the earth?

Express your answer with the appropriate units.

μÅ ?

t_{life} = Value Units

Part C

How far would the muon travel in this time?

Express your answer with the appropriate units.

$d =$ Value Units

Submit Request Answer

Part D

Can we find muons in cosmic rays?

- no
- yes

Submit Request Answer

Part E

From the point of view of the muon, it still lives for only 2.2 μs , so how does it make it to the ground? What is the thickness of the 14 km of atmosphere through which the muon must travel, as measured by the muon?

Express your answer with the appropriate units.

h = Value Units

Submit Request Answer

Part F

Is the muon able to reach the ground?

- no
- yes

Submit Request Answer

Exercise 37.17 - Enhanced - with Solution

Review | Constants

A pursuit spacecraft from the planet Tatooine is attempting to catch up with a Trade Federation cruiser. As measured by an observer on Tatooine, the cruiser is traveling away from the planet with a speed of $0.650c$. The pursuit ship is traveling at a speed of $0.840c$ relative to Tatooine, in the same direction as the cruiser.

For related problem-solving tips and strategies, you may want to view a Video Tutor Solution of Relative velocities.

Part A

What is the speed of the cruiser relative to the pursuit ship?

Express your answer in meters per second.

$|v'|$ = ______ m/s

Submit Request Answer

Part B

What is the direction of speed of the cruiser relative to the pursuit ship?

- toward the pursuit ship
- away from pursuit ship

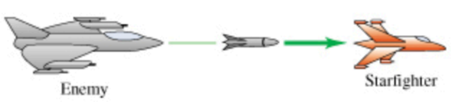
Submit Request Answer

Exercise 37.18 - Enhanced - with Feedback

Review | Constants

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. (Figure 1)

Figure



Part A

What is the speed of the missile relative to you?

Express your answer in terms of the speed of light.

u = c

Submit   Request Answer

Part B

If you measure that the enemy ship is 8.00×10^6 km away from you when the missile is fired, how much time, measured in your frame, will it take the missile to reach you?

Express your answer in seconds.

t = s

Exercise 37.20 - Enhanced - with Feedback

Two particles in a high-energy accelerator experiment are approaching each other head-on, each with a speed of $0.9380c$ as measured in the laboratory.

Review | Constants

Part A

What is the magnitude of the velocity of one particle relative to the other?

Express your answer in terms of speed of light.

ΑΣφ ?

v' = c

Submit Request Answer

Provide Feedback

Next

Review | Constants

A spaceship has length 120 m, diameter 25 m, and mass 4.0×10^3 kg as measured by its crew. As the spaceship moves parallel to its cylindrical axis and passes us, we measure its length to be 50 m.

Part A

What do we measure its diameter to be?

Express your answer with the appropriate units.

d = Value Units

Submit Request Answer

Part B

What do we measure the magnitude of its momentum to be?

Express your answer with the appropriate units.

p = Value Units

Review | Constants

A particle has a rest mass 6.64×10^{-27} kg and momentum 2.03×10^{-18} $\mathrm{kg \cdot m/s}$.

For related problem-solving tips and strategies, you may want to view a Video Tutor Solution of Energetic electrons.

Part A

What is the total energy (kinetic plus rest energy) of the particle?

Express your answer in joules.

E = J

Submit Request Answer

Part B

What is the kinetic energy of the particle?

Express your answer in joules.

K = J

Part C

What is the ratio of the kinetic energy to the rest energy of the particle?

$\frac{K}{E_0}$ =

Submit

Request Answer

Review | Constants

Two protons (each with rest mass $M = 1.67 \times 10^{-27}$ kg) are initially moving with equal speeds in opposite directions. The protons continue to exist after a collision that also produces an η^0 particle. The rest mass of the η^0 is $m = 9.75 \times 10^{-28}$ kg.

Part A

If the two protons and the η^0 are all at rest after the collision, find the initial speed of the protons, expressed as a fraction of the speed of light.

Express your answer as a multiple of the speed of light.

ΑΣφ ?

v_i = c

Submit Request Answer

Part B

What is the kinetic energy of each proton?

Express your answer in megaelectron-volts.

ΑΣφ ?

K = MeV

Part C

What is the rest energy of the η^0, expressed in MeV?

Express your answer in megaelectron-volts.

ΑΣφ ?

E_0 = MeV

Submit

Request Answer

Review | Constants

A cube of metal with sides of length a sits at rest in a frame S 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.

Part A

As measured by an observer in frame S', what is the volume of the metal cube?

Express your answer in terms of a, u, and c.

V =

Submit Request Answer

Provide Feedback

Next

Physicists and engineers from around the world have come together to build the largest accelerator in the world, the Large Hadron Collider (LHC) at the CERN Laboratory in Geneva, Switzerland. The machine accelerates protons to high kinetic energies in an underground ring 27 km in circumference.

Part A

What speed v of proton in the LHC if the proton's kinetic energy is 6.0 TeV? (Because v is very close to c, write $v = (1 - \Delta)\, c$ and give your answer in terms of Δ).

Δ =

Submit Request Answer

Part B

Find the relativistic mass, m_{rel}, of the accelerated protons in terms of their rest mass.

Express your answer as a multiple of a rest mass.

m_{rel} = $\cdot m_{\mathrm{rest}}$

Problem 37.51 - Enhanced - with Feedback

The Russian physicist P. A. Čerenkov discovered that a charged particle traveling in a solid with a speed exceeding the speed of light in that material radiates electromagnetic radiation. (This is analogous to the sonic boom produced by an aircraft moving faster than the speed of sound in air. Čerenkov shared the 1958 Nobel Prize for this discovery.)

Review | Constants

Part A

What is the minimum kinetic energy (in electron volts) that an electron must have while traveling inside a slab of crown glass (n = 1.52) in order to create this Čerenkov radiation?

Express your answer in megaelectron volts.

ΑΣφ ?

K = MeV

Submit Request Answer

Provide Feedback

Next >

Review | Constants

A nuclear bomb containing 17.0 kg of plutonium explodes. The sum of the rest masses of the products of the explosion is less than the original rest mass by one part in 10^4.

Part A

How much energy is released in the explosion?

Express your answer in joules.

W = J

Submit Request Answer

Part B

If the explosion takes place in 4.50 $\mu\mathrm{s}$, what is the average power developed by the bomb?

Express your answer in watts.

P_{av} = W

Part C

What mass of water could the released energy lift to a height of 1.00 km?

Express your answer in kilograms.

m = [ ] kg

Submit

Request Answer

A small sphere with charge Q is resting motionless on an insulated pedestal in a laboratory. In the frame of reference S of the laboratory, the *z*-axis points upward, there is a magnetic field $\vec{B} = -B\hat{j}$, and there is no electric field.

Review | Constants

Part A

What is the net force on the sphere?

Express your answer with the appropriate units.

F = Value Units

Submit Request Answer

Part B

The same sphere is viewed from a passing spacecraft moving with velocity $\vec{v} = v\hat{i}$ as seen from the laboratory. Using $\vec{B}' = \vec{B}\gamma$, where γ is the Lorenz factor, what is the magnetic field $\vec{B}'$ seen by observers in the spacecraft if their coordinate axes are aligned with those of the laboratory?

Express your answer in terms of the variables B and γ. Express your answer in terms of the unit vectors $\hat{i}$, $\hat{j}$, and $\hat{k}$. Use the 'unit vector' button to denote unit vectors in your answer.

$\vec{B}'$ =

Part C

From the perspective of the spacecraft, the sphere has a nonzero velocity and therefore feels a nonzero magnetic force. What is that magnetic force?

Express your answer in terms of the variables B, Q, v, and γ. Express your answer in terms of the unit vectors $\hat{\imath}$, $\hat{\jmath}$, and $\hat{k}$. Use the 'unit vector' button to denote unit vectors in your answer.

ΑΣφ ?

$\vec{F}\,'$ =

Submit Request Answer

Part D

The net electromagnetic force on the sphere is necessarily the same when viewed from the laboratory frame and from the spaceship frame. This can be true only if there is a nonzero electric field $\vec{E}\,'$ in the spaceship frame. Determine $\vec{E}\,'$.

Express your answer in terms of the variables B, v, and γ. Express your answer in terms of the unit vectors $\hat{\imath}$, $\hat{\jmath}$, and $\hat{k}$. Use the 'unit vector' button to denote unit vectors in your answer.

ΑΣφ ?

$\vec{E}\,'$

Part E

Generalize your conclusion: If the electromagnetic field is $(\vec{E}, \vec{B}) = (0, \vec{B})$ in inertial frame S, then in another frame S' moving at velocity $\vec{v}$ relative to S, what is the component of the electric field $\vec{E}'_{\perp}$ perpendicular to $\vec{v}$?

- $\vec{E}'_{\perp} = 0$
- $\vec{E}'_{\perp} = \gamma\vec{v} \times \vec{B}$
- $\vec{E}'_{\perp} = \gamma\vec{v}\vec{B}$
- $\vec{E}'_{\perp} = -\gamma\vec{B}$

Submit Request Answer

Two events are observed in a frame of reference S to occur at the same space point, the second occurring 1.70 s after the first. In a frame S' moving relative to S, the second event is observed to occur 2.00 s after the first.

Review | Constants

Part A

What is the difference between the positions of the two events as measured in S'?

Express your answer with the appropriate units.

x' = Value Units

Submit Request Answer

Provide Feedback

Next

Einstein and Lorentz, avid tennis players, play a fast-paced game on a court where they stand 20.0 m from each other. They play without a net. The tennis ball has mass 0.0580 kg. Ignore gravity and assume that the ball travels parallel to the ground as it travels between the two players. Unless otherwise specified, all measurements are made by the two men.

Part A

Lorentz serves the ball at 81.0 $\mathrm{m/s}$. What is the ball's kinetic energy?

Express your answer with the appropriate units.

K = Value Units

Submit Request Answer

Part B

Einstein slams a return at $1.82 \times 10^{8}\ \mathrm{m/s}$. What is the ball's kinetic energy?

Express your answer with the appropriate units.

K = Value Units

Part C

During Einstein's return of the ball in part A, a white rabbit runs beside the court in the direction from Einstein to Lorentz. The rabbit has a speed of $2.25 \times 10^8 \ \mathrm{m/s}$ relative to the two men. What is the speed of the rabbit relative to the ball?

Express your answer with the appropriate units.

μÅ ?

v = Value Units

Submit Request Answer

Part D

What does the rabbit measure as the distance from Einstein to Lorentz?

Express your answer with the appropriate units.

μÅ ?

l = Value Units

Part E

How much time does it take for the rabbit to run 20.0 m , according to the players?

Express your answer with the appropriate units.

t = Value Units

Submit Request Answer

Part F

The white rabbit uses his pocket watch to measure the time (as he sees it) for the distance from Einstein to Lorentz to pass by under him. What time does he measure?

Express your answer with the appropriate units.

t_0 = Value Units

Problem 37.64

Review | Constants

The French physicist Armand Fizeau was the first to measure the speed of light accurately. He also found experimentally that the speed, relative to the lab frame, of light traveling in a tank of water that is itself moving at a speed V relative to the lab frame is

$$v = \frac{c}{n} + kV$$

where n = 1.333 is the index of refraction of water. Fizeau called k the dragging coefficient and obtained an experimental value of k = 0.44.

Part A

What value of k do you calculate from relativistic transformations?

k =

Submit Request Answer

Provide Feedback

Next

Review | Constants

In high-energy physics, new particles can be created by collisions of fast-moving projectile particles with stationary particles. Some of the kinetic energy of the incident particle is used to create the mass of the new particle. A proton-proton collision can result in the creation of a negative kaon (K^-) and a positive kaon (K^+) :

$p + p \rightarrow p + p + \mathrm{K}^- + \mathrm{K}^+$

Part A

Calculate the minimum kinetic energy of the incident proton that will allow this reaction to occur if the second (target) proton is initially at rest. The rest energy of each kaon is 493.7 MeV, and the rest energy of each proton is 938.3 MeV. (*Hint:* It is useful here to work in the frame in which the total momentum is zero. Note that here the Lorentz transformation must be used to relate the velocities in the laboratory frame to those in the zero-total-momentum frame.)

Express your answer in megaelectron volts.

ΑΣφ ?

K = MeV

Submit Request Answer

Part B

How does this calculated minimum kinetic energy compare with the total rest mass energy of the created kaons?

ΑΣφ ?

$\frac{K}{2m_{\mathrm{K}}c^2}$ =

Part C

Suppose that instead the two protons are both in motion with velocities of equal magnitude and opposite direction. Find the minimum combined kinetic energy of the two protons that will allow the reaction to occur.

Express your answer in megaelectron volts.

K = MeV

Submit Request Answer

Part D

How does this calculated minimum kinetic energy compare with the total rest mass energy of the created kaons? (This example shows that when colliding beams of particles are used instead of a stationary target, the energy requirements for producing new particles are reduced substantially.)

$\frac{K}{2m_{K}c^2}$ =

Review | Constants

Part A

Consider the Galilean transformation along the x-direction: $x' = x - vt$ and $t' = t$. In frame S the wave equation for electromagnetic waves in a vacuum is

$$\frac{\partial^2 E(x,t)}{\partial x^2} - \frac{1}{c^2}\frac{\partial^2 E(x,t)}{\partial t^2} = 0$$

where E represents the electric field in the wave. Using the Galilean transformation find the wave equation in frame S'.
This has a different form than the wave equation in S. Hence the Galilean transformation *violates* the first relativity postulate that all physical laws have the same form in all inertial reference frames. (*Hint:* Express the derivatives $\partial/\partial x$ and $\partial/\partial t$ in terms of $\partial/\partial x'$ and $\partial/\partial t'$ by use of the chain rule.)

- $\frac{\partial^2 E(x',t')}{\partial x'^2} - \frac{1}{c^2}\frac{\partial^2 E(x',t')}{\partial t'^2} = 0$
- $\left(1 - \frac{v^2}{c^2}\right)\frac{\partial^2 E(x',t')}{\partial x'^2} + \frac{2v}{c^2}\frac{\partial^2 E(x',t')}{\partial x'\partial t'} - \frac{1}{c^2}\frac{\partial^2 E(x',t')}{\partial t'^2} = 0$
- $\frac{\partial^2 E(x',t')}{\partial x'^2} + \frac{2v}{c^2}\frac{\partial^2 E(x',t')}{\partial x'\partial t'} - \frac{1}{c^2}\frac{\partial^2 E(x',t')}{\partial t'^2} = 0$
- $\left(1 - \frac{v^2}{c^2}\right)\frac{\partial^2 E(x',t')}{\partial x'^2} - \frac{1}{c^2}\frac{\partial^2 E(x',t')}{\partial t'^2} = 0$

Submit   Request Answer

Part B

Repeat the analysis of part A, but use the Lorentz coordinate transformations, and find the wave equation in frame S'.

- $\left(1-\frac{v^2}{c^2}\right)\frac{\partial^2 E(x',t')}{\partial x'^2}-\frac{1}{c^2}\frac{\partial^2 E(x',t')}{\partial t'^2}=0$
- $\frac{\partial^2 E(x',t')}{\partial x'^2}+\frac{2v}{c^2}\frac{\partial^2 E(x',t')}{\partial x'\partial t'}-\frac{1}{c^2}\frac{\partial^2 E(x',t')}{\partial t'^2}=0$
- $\left(1-\frac{v^2}{c^2}\right)\frac{\partial^2 E(x',t')}{\partial x'^2}+\frac{2v}{c^2}\frac{\partial^2 E(x',t')}{\partial x'\partial t'}-\frac{1}{c^2}\frac{\partial^2 E(x',t')}{\partial t'^2}=0$
- $\frac{\partial^2 E(x',t')}{\partial x'^2}-\frac{1}{c^2}\frac{\partial^2 E(x',t')}{\partial t'^2}=0$

Submit

Request Answer