Question 10 (2 marks) 53% av 1.2

The length of a spaceship is measured to be exactly one-third of its rest length as it passes by an observing station.

What is the speed of this spaceship, as determined by the observing station, expressed as a multiple of c?

$L = \frac{L_0}{\gamma}$ $\gamma = \frac{L_0}{L} = 3$

$\sqrt{1 - \frac{v^2}{c^2}} = \frac{1}{3}$ $1 - \frac{v^2}{c^2} = \frac{1}{9}$ $\frac{v^2}{c^2} = \frac{8}{9}$ $v = \frac{2\sqrt{2}}{3} c$

$\boxed{0.94 \ c}$

Question 11 (7 marks)

Tests of relativistic time dilation have been made by observing the decay of short-lived particles. A muon, travelling from the edge of the atmosphere to the surface of Earth, is an example of such a particle.

To model this in the laboratory, another elementary particle with a shorter half-life is produced in a particle accelerator. It is travelling at $0.99875c$ ($\gamma = 20$). Scientists observe that this particle travels 9.14×10^{-5} m in a straight line from the point where it is made to the point where it decays into other particles. It is not accelerating.

a. Calculate the lifetime of the particle in the scientists' frame of reference. 42 % av 0.9 — 2 marks

$t = \frac{d}{v}$

$t = \frac{9.14 \times 10^{-5}}{0.99875 \times 3 \times 10^{8}}$

3.05×10^{-13} s

38% av 0.8

b. Calculate the distance that the particle travels in the laboratory, as measured in the particle's frame of reference. — 2 marks

$L = \frac{L_0}{\gamma}$

$L = \frac{9.14 \times 10^{-5}}{20}$

4.6×10^{-6} m

c. Explain why the scientists would observe more particles at the end of the laboratory measuring range than classical physics would expect. 8 % av 0.8 — 3 marks

Due to the high speed in particle's frame of reference distance to the detector is reduced. Therefore more particles ablo to reach the detector before they decay.

Or Half-life as measured in scientist's frame of reference is increased due to the time dilation. Therefore fewer particles will decay before reaching the detector

SECTION B – continued

TURN OVER

Question 14 (3 marks)

An Earth-like planet has been discovered orbiting a distant star. A hypothetical mission to this planet is suggested. The planet is 1.0×10^{18} m from Earth. The spaceship suggested for the mission can travel at an average speed of $0.99c$. Take $\gamma = 7.1$ for this speed.

Scientists are concerned about the length of time the passengers would have to spend on the spaceship to travel to this planet.

Use principles of special relativity to estimate this time, in years, as measured on the spaceship.

$t = \frac{d}{v} = \frac{1.0 \times 10^{18}}{0.99 \times 3 \times 10^8} = 3.37 \times 10^9 \text{ s} = 106.8 \text{ years}$

$t_0 = \frac{t}{\gamma} = \frac{106.8}{7.1} = 15 \text{ years}$

or $L = \frac{L_0}{\gamma} = \frac{1 \times 10^{18}}{7.1} = 1.41 \times 10^{17} \text{ m}$ $t = \frac{d}{v} = \frac{1.41 \times 10^{17}}{0.99 \times 3 \times 10^8} = 4.7 \times 10^8 \text{ s}$

$= 15 \text{ years}$

15 years

Question 15 (2 marks)

An unstable subatomic particle, known as a π_0 meson, decays completely into electromagnetic radiation. The rest mass of this π_0 meson is 2.5×10^{-28} kg.

How much energy would be released by this π_0 meson if it decays at rest?

$E = m_0 c^2$

$= 2.5 \times 10^{-28} \times 9 \times 10^{16}$

2.3×10^{-11} J

Question 14 (2 marks) 5% av 0.3

Jani is stationary in a spaceship travelling at constant speed.

Does this mean that the spaceship must be in an inertial frame of reference? Justify your answer.

No.

Direction could be changing, for example in circular motion.

Question 15 (3 marks) 36% av 1.3

A stationary scientist in an inertial frame of reference observes a spaceship moving past her at a constant velocity. She notes that the clocks on the spaceship, which are operating normally, run eight times slower than her clocks, which are also operating normally. The spaceship has a mass of 10 000 kg.

Calculate the kinetic energy of the spaceship in the scientist's frame of reference. Show your working.

$\gamma = 8$

$E_k = (\gamma - 1) m_0 c^2$

$= (8-1) \times 10\,000 \times (3 \times 10^8)^2$

6.3×10^{21} J

Question 16 (2 marks) 53% av 1.1

Quasars are among the most distant and brightest objects in the universe. One quasar (3C446) has a brightness that changes rapidly with time.

Scientists observe the quasar's brightness over a 20-hour time interval in Earth's frame of reference. The quasar is moving away from Earth at a speed of $0.704c$ ($\gamma = 1.41$).

Calculate the time interval that would be observed in the quasar's frame of reference. Show your working.

$t = t_0 \gamma$

$t_0 = \frac{t}{\gamma} = \frac{20}{1.41}$

14.2 h

Question 16

In a particle accelerator, magnesium ions are accelerated to 20.0% of the speed of light.

Which one of the following is closest to the Lorentz factor, γ, for the magnesium ions at this speed?

A. 1.02
B. 1.12
C. 1.20
D. 2.24

$$\gamma = \frac{1}{\sqrt{1-0.2^2}}$$

Question 17

The lifetime of stationary muons is measured in a laboratory to be 2.2 μs. The lifetime of relativistic muons produced in Earth's upper atmosphere, as measured by ground-based scientists, is 16 μs.

The resulting time dilation observed by the scientists gives a Lorentz factor, γ, of

A. 0.14
B. 1.4
C. 3.5
D. 7.3

$$t = t_0 \gamma$$
$$\gamma = \frac{t}{t_0} = \frac{16}{2.2}$$

Question 18

If a particle's kinetic energy is 10 times its rest energy, E_{rest}, then the Lorentz factor, γ, would be closest to

A. 9
B. 10
C. 11
D. 12

$$E = (\gamma - 1) m_0 c^2$$
$$\gamma - 1 = 10$$

Question 17 (3 marks)

A spaceship is travelling from Earth to the star system Epsilon Eridani, which is located 10.5 light-years from Earth as measured by Earth-based instruments.

If the spaceship travels at $0.85c$ ($\gamma = 1.90$), determine the duration of the flight as measured by the astronauts on the spaceship travelling to Epsilon Eridani. Take one light-year to be 9.46×10^{15} m. Show your working.

$t_{Earth} = \frac{10.5}{0.85} = 12.35$ years

$t_{spaceship} = \frac{t_{Earth}}{\gamma} = \frac{12.35}{1.9} = 6.5$

6.5 years

Question 18 (3 marks)

Alien astronauts are travelling between star systems aboard a cube-shaped spaceship, as shown in Figure 16. The sides of the cube along the x-axis, y-axis and z-axis measure 3.20×10^3 m in the spaceship's frame of reference.

The spaceship passes Bob, who is on a space station, at speed $v = 0.990c$ ($\gamma = 7.09$).

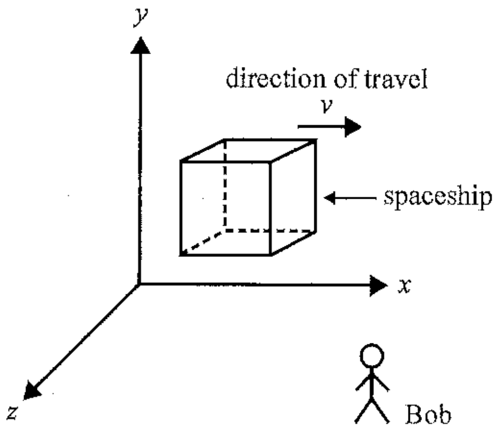


Figure 16

In the table below, determine the dimensions of the cube-shaped spaceship as measured from Bob's frame of reference and explain your reasoning.

$L = \frac{L_0}{\gamma} = \frac{3.2 \times 10^3}{7.09}$
$= 4.5 \times 10^2$

length of side along x-axis	4.5×10^2	m
length of side along y-axis	3.2×10^3	m
length of side along z-axis	3.2×10^3	m

Reasoning Length contraction only occurs in the direction of travel.

Question 19 (2 marks)

In a nuclear fusion reaction in the sun's core, two deuterium nuclei, each with a mass of 3.3436×10^{-27} kg, fuse to produce one helium-4 nucleus with a mass of 6.6465×10^{-27} kg.

Ignore the kinetic energy of the nuclei before the reaction.

Calculate the energy released. Show your working.

$\Delta m = 2 \times 3.3436 \times 10^{-27} - 6.6465 \times 10^{-27} = 4.07 \times 10^{-29}$

$E = \Delta m c^2 = 4.07 \times 10^{-29} \times 9 \times 10^{16}$

3.7×10^{-12} J

END OF QUESTION AND ANSWER BOOK

Question 11 (3 marks) 9 %

What is the second postulate of Einstein's theory of special relativity regarding the speed of light? Explain how the second postulate differs from the concept of the speed of light in classical physics.

The speed of light in a vacuum is independent of the relative motion of the source and observer (1m)
In classical physics speed depends on relative motion of source and observer – ~~if they moving in opposite dirn approaching speed ↑~~, ~~if moving away speed ↓~~
if they moving in the opposite directions speed ↑, if moving in the same direction speed ↓.

Question 12 82 %

A high-energy proton is travelling through space at a constant velocity of 2.50×10^8 m s^{-1}.

The Lorentz factor, γ, for this proton would be closest to

A. 1.81
B. 2.44
C. 3.27
D. 3.39

$$\gamma = \frac{1}{\sqrt{1-\left(\frac{2.5}{3}\times 10^8\right)^2}}$$

Question 13 56 %

Matter is converted to energy by nuclear fusion in stars.

If the star Alpha Centauri converts mass to energy at the rate of 6.6×10^9 kg s^{-1}, then the power generated is closest to

A. 2.0×10^{18} W
B. 2.0×10^{18} J
C. 6.0×10^{26} W
D. 6.0×10^{26} J

$$E = mc^2$$
$$E = 6.6\times 10^9 \times (3\times 10^8)^2$$
$$= 6\times 10^{26}\ \text{J}$$

Question 11 (4 marks)

An astronaut has left Earth and is travelling on a spaceship at $0.800c$ ($\gamma = 1.67$) directly towards the star known as Sirius, which is located 8.61 light-years away from Earth, as measured by observers on Earth.

a. How long will the trip take according to a clock that the astronaut is carrying on his spaceship? Show your working. 2 marks

$t = \frac{s}{v} = \frac{8.61}{0.8} = 10.76$ years in Earth frame of reference 21%

$t_0 = \frac{t}{\gamma} = \frac{10.76}{1.67} = 6.44$ or

6.44 years

b. Is the trip time measured by the astronaut in **part a.** a proper time? Explain your reasoning. 2 marks

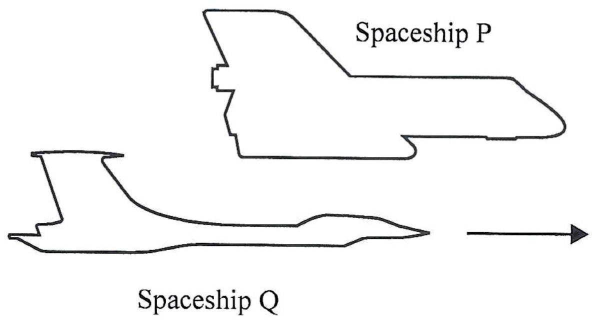
Yes, proper time. 24%
Clock is stationary in the astronauts frame of reference.

$L = \frac{8.61}{1.67} = 5.15$ light years (distance contruction for austronaut)

$t_0 = \frac{s}{v} = \frac{5.15}{0.8} = 6.44$

Question 13

Joanna is an observer in Spaceship P and is watching Spaceship Q fly past at a relative speed of $0.943c$ ($\gamma = 3.00$). She observes a stationary clock measuring a time interval of 75.0 s between two events in Spaceship Q. This is a proper time interval.



Which one of the following is closest to the time interval observed between the two events in Spaceship P's frame of reference?

A. 15.0 s

B. 25.0 s

C. 125 s

D. 225 s

$t = t_0 \gamma = 75 \times 3$

Question 10 (4 marks)

Jacinta is standing still while observing a spaceship passing Earth at a speed of $0.984c$.

a. Calculate γ for this speed, correct to three significant figures. Show your working. 2 marks

$$\gamma = \frac{1}{\sqrt{1-\left(\frac{v}{c}\right)^2}} = \frac{1}{\sqrt{1-0.984^2}} = 5.61$$

$\boxed{5.61}$

b. The spaceship is travelling to the Alpha Centauri star system in a straight line at this speed. In Jacinta's frame of reference, this distance is measured to be 4.37 light-years (that is, it would take light 4.37 years to travel this distance).

Calculate the time that would be measured by Jacinta for the spaceship's journey, correct to three significant figures. Show your working. 2 marks

$$t = \frac{d}{v} = \frac{4.37}{0.984} = 4.44$$

$\boxed{4.44}$ years