Year 12 Physics 3A 3B

Special Relativity Practice Questions

Question 1

In the science fiction TV series Star Trek, the starship Enterprise is accelerated to a speed faster than the speed of light ("warp speed") for travel between star systems or galaxies. Explain why is it impossible to travel at or faster than the speed of light?

(2)

Question 2

Two identical atomic clocks of extreme accuracy are synchronized at a space station in deep space. One of the clocks is put on a rocket and moves at a speed close to the speed of light relative to the space station.

(a) Explain how time is progressing on the moving clock as viewed from the space station. (1)

(b) Explain the 'paradox' in this situation. (1)

Question 3

The starship Enterprise travels from Earth to Alpha Centauri (4.2 light-years away). One of the crew has an identical twin who remains on Earth. Ignore any acceleration of the Enterprise or gravity differences as this then requires consideration of the General Theory of Relativity which is beyond our course.

The Enterprise has a constant speed of 0.97*c* (*c* = speed of light). At this speed, how many years will it take to travel to Alpha Centauri as seen from Earth? (2)

The equation that governs length contraction is as follows: $l = l_0 . \sqrt{1 - \frac{v^2}{c^2}}$

l = contracted length moving at speed v, $\boldsymbol{l_0}$ = length in a stationery reference frame

The equation that governs time dilation is as follows: $t_v = \frac{t_o}{\sqrt{1 - \frac{v^2}{c^2}}}$

t_0 = Proper time – the time elapsed for a an event to occur for an observer at rest relative to the event e.g the half-life of a radioactive substance, the time taken for the path between 2 locations in space (A and B) to move past a spaceship, the time between ticks on a clock that marks 1 second of time elapsed on that clock.

t = Dilated time - the time elapsed for the same event to occur for an object that is moving at speed v relative to an observer. e.g the half-life of the same substance within an object moving at speed v, the time taken for the spaceship to travel though space between locations A and B, the time between ticks on a clock that marks 1 second of time elapsed on that clock.

(c) At this speed what spatial dimension is contracting in the frame of reference of the Earth?

(1)

(d) At this speed what spatial dimension is contracting in the frame of reference of the Enterprise?

(1)

(e) Use the time dilation equation to calculate the time elapsed on the Enterprise as it travels between Earth and Alpha Centauri. Give your answer in years.

(3)

(f) Use the length contraction equation and the equation $v_{av} = \frac{s}{t}$ to confirm the time taken to travel to Alpha Centauri from the perspective of the Enterprise crew. Give your answer in years.

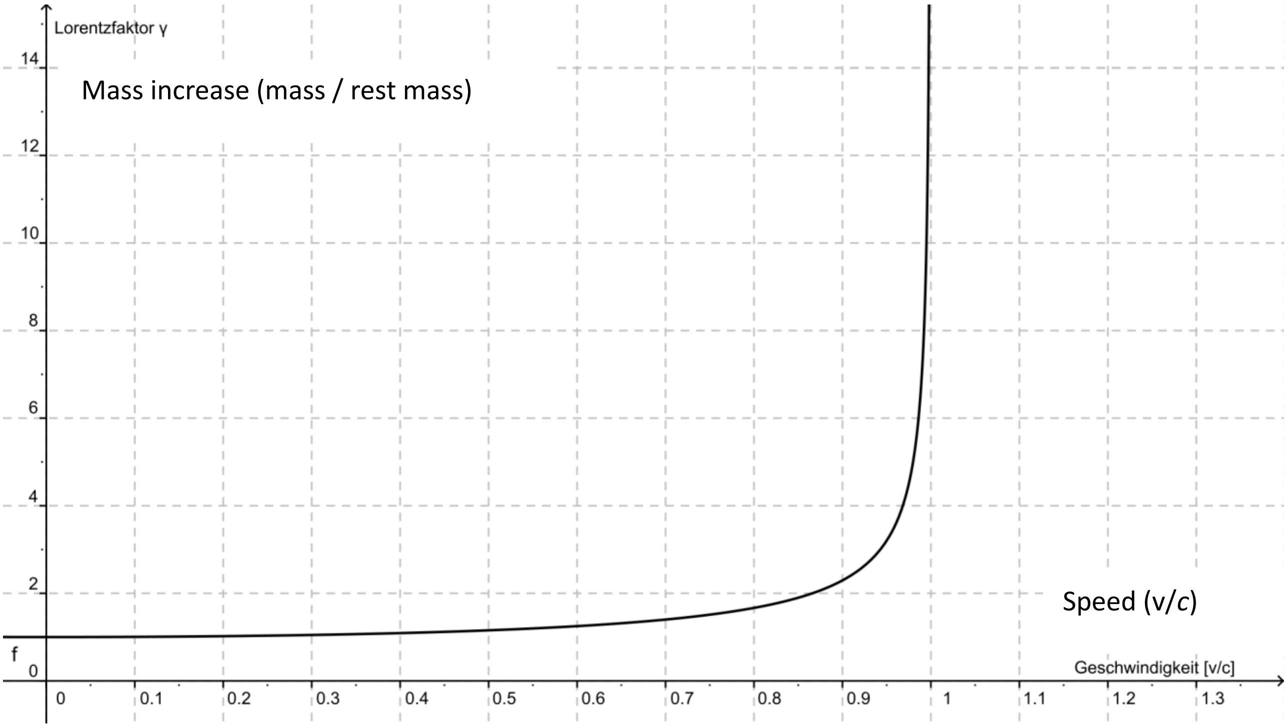
(4)

(g) What can you say about the relative age of the two twins when the Enterprise reaches Alpha Centauri?

(2)

Question 4

The following graph shows the factor by which mass increases with increasing velocity approaching the speed of light.



A proton of rest mass 1.67×10^{-27} kg is accelerated in the Large Hadron Collider until it reaches 0.95*c* (*c* = speed of light).

(a) Estimate the relativistic mass of the proton from the graph. (2)

(b) What is the reason for this apparent increase in mass? (2)

Einstein derived the mathematical equation showing how mass changes with speed.

$$m_v = \frac{m_o}{\sqrt{1-\frac{v^2}{c^2}}}$$

Where m_0 = rest mass and m_v = relativistic mass at speed v (kg).

(c) Using the equation above, calculate the mass of the proton when it is moving at 0.99*c*.

(2)

(d) Why is it impossible for the proton to travel at or faster than the speed of light? (2)

Question 5

A freelance motoring journalist was caught speeding at 231 km h^{-1} during a test drive in a 110 km h^{-1} zone.

The $470,000 Ferrari California he was driving was seized by police under the WA hoon laws.

(a) A police car approaching the Ferrari from the opposite direction at 110 km h^{-1} recorded his speed on its radar. What speed was the Ferrari doing in the reference frame of the police car?

(1)

(b) If the police car was following the Ferrari at 110 km h^{-1}, what speed would it register on the radar?

(1)

(c) Is it necessary to take into account time and distance effects due to relativity in this question? Explain.

(2)

Question 6

The Andromeda galaxy is receding from Earth at about 0.3*c* (*c* = speed of light).

In the search for extraterrestrial life, a radio signal is sent from Earth into space towards Andromeda. At what speed is the radio signal measured from Andromeda? Explain your answer.

(2)

Question 7

24 Global Positioning Satellites (GPS) at an altitude of 20 200 kilometres allow positions on Earth to be accurately determined to within 15 metres. About 10 satellites are visible to any ground-based receiver. Each satellite continually transmits messages which include the time the message was sent. The receiver measures the time of each message from the satellites and computes the distance to each satellite and then determines its position on the Earth's surface.

Over a period of exactly 24 hours the total time difference between the clock in the orbiting satellite and the clock in the GPS receiver is 3.80×10^{-5} s.

(a) According to the Special Theory of Relativity would the clocks on the moving satellites be running at a slower or faster rate as viewed from Earth? Explain.

(2)

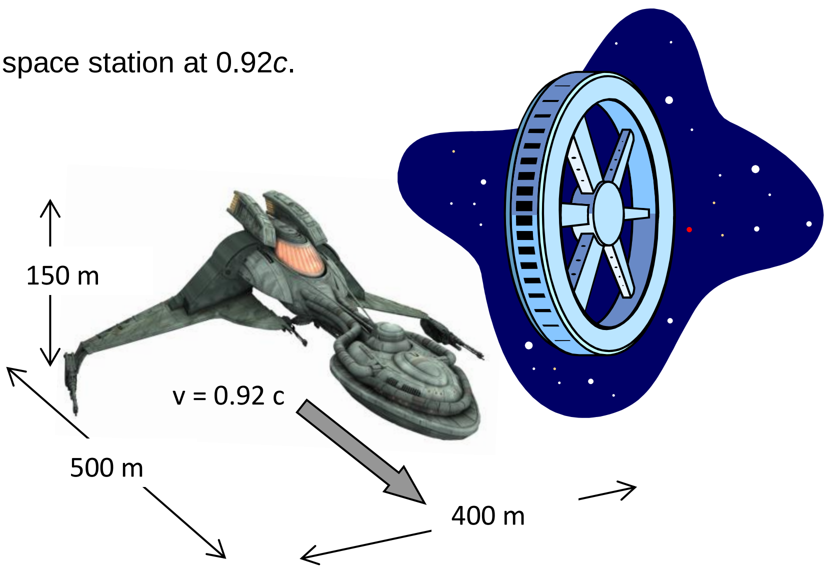
(b) Which other theory of Einstein has a greater effect on the timing errors of the GPS system.

(1)

Question 8

A Klingon battleship passes by a Star Fleet space station at 0.92*c*.

a. What aspects of the Klingon ship's spatial dimensions are changed from the perspective of the space station?



(2)

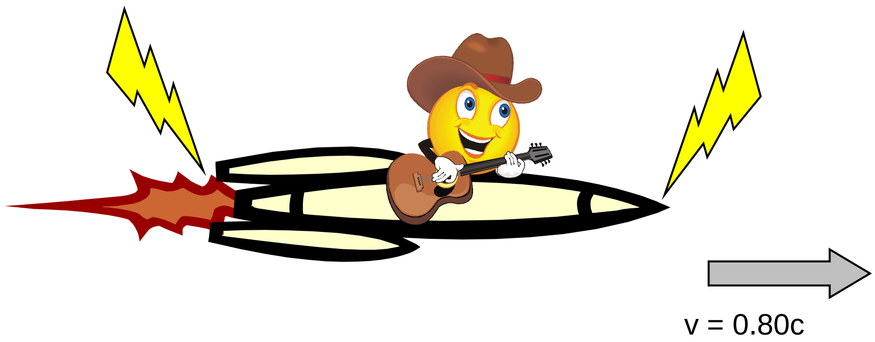
b. How does the Klingon warship perceive any changes in the 3D space it travels through compared to its view when at rest with the space station?

(2)

Question 9

Raymond the space cowboy is moving past you at 80% of the speed of light when from his point of view he sees lighting strike the front and back of his rocket at the same time. Do the lightning strikes occur simultaneously in your frame of reference? If yes explain why. If not explain which order you see the lightning strikes from your stationery frame of reference.

(3)



Question 10

Muons are leptons formed when cosmic radiation impacts air molecules 10 km to 60 km up in the Earth's atmosphere. The mean-life of a muon is 2.20×10^{-6} s. Muons travel at speeds of up to 0.999c and can penetrate deep into rock. They are detectable deep underground and underwater.

Rossi and Hall in 1940 measured muon impacts on a scintillation counter at an altitude of 3000 metres (568 counts h^{-1}) and at sea level (412 counts h^{-1}). From the perspective of Earth practically all muons should have decayed by the time they reach Earth if relativistic effects are not taken into account but only 3 mean-lives seem to have elapsed for them from an altitude of 60 km.

(a) What distance would muons be expected to travel in 3 of their mean-lives in their own reference frame

(2)

(b) Explain why the Muons are able to survive a journey of this length at the speed they travel?

(3)