Exam Papers Practice

Galilean & Special Relativity

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Course	HL IB Physics
Section	Space, Time & Motion
Topic	Galilean & Special Relativity
Difficulty	Medium

To be used by all students preparing for HL IB Physics
Students of other boards may also find this useful

1

The correct answer is **D** because:

- If the object is travelling at 0 m s^{-1}, then $\gamma = 1$
  - $\gamma = \dfrac{1}{\sqrt{1-\dfrac{0^2}{c^2}}} = \dfrac{1}{\sqrt{1-0}} = \dfrac{1}{1} = 1$
  - Therefore the graph begins at $\gamma = 1$
  - This eliminates options **B** & **C**
- As the speed tends toward the speed of light, the gamma value tends toward an infinite value
  - $\gamma = \dfrac{1}{\sqrt{1-\dfrac{c^2}{c^2}}} = \dfrac{1}{\sqrt{1-1}} = \dfrac{1}{\sqrt{0}} = \infty$
  - The square root of zero is zero, and if you divide something by zero you get infinity
  - Therefore, the shape of the graph is an asymptote tending to infinity at the speed of light
- This is answer option **D**

2

The correct answer is **D** because:

- The known quantities are:
  - Person A's frame of reference as the stationary observer = S
  - Person B's frame of reference as the moving observer = S'
  - The speed of the moving reference frame (Person B) (taking to the left as the negative direction), $v = -10$ m s^{-1}
  - The speed of the moving object (Person C) as measured by the stationary observer, $u = 8$ m s^{-1}
  - The speed of the moving object (Person C) as measured from the moving reference frame (Person B) = u'
- From the data booklet:
  - $u' = u - v$
- Substituting in the known values to calculate u'
  - $u' = 8 - (-10) = 8 + 10 = 18 \text{ m s}^{-1}$
- This is answer **D**

You would also get the same answer if you assigned the positive direction to be to the right:

- $u' = 10 - (-8) = 10 + 8 = 18 \text{ m s}^{-1}$

The trickiest thing about this question is assigning each value to its correct inertial reference frame.

The non-primed reference frame is always used for the stationary observer, and the primed reference frame is used for the moving observer. *v* is always the speed of the moving reference frame as measured by the stationary observer. *u* is the speed of the observed object as measured from the stationary reference frame, and *u'* is the speed of the observed object as measured from the moving reference frame. Understanding this method of assignment removes the most cumbersome layer of complexity from the questions, so take the time to get to grips with that and it will make relativity questions much easier.

3

The correct answer is **B** because:

- The known values are:
  - The reference frame of the stationary observer (Twin B on Earth) = *S*
  - The reference frame of the moving observer (Twin A on the space ship) = *S'*
  - The speed of the moving reference frame (Twin A on the space ship), $v = 0.85c$
  - Time passed for Twin B on Earth, $\Delta t = 47 - 31 = 16$ years
- From the data booklet:
  - $\Delta t = \gamma \Delta t_0$
  - Where:
    - Δt is the time measured by the stationary observer between Twin A departing and Twin A returning
    - This is the time interval as measured by Twin B

- Δt_0 is the proper time measured from within the reference frame in which the two events occur in the same place (i.e leaving Earth and returning to Earth and all the time in between)
- This is the proper time as measured by Twin A

- Rearranging to make Δt_0 the subject
  - $\Delta t_0 = \frac{\Delta t}{\gamma}$
- Calculating the Lorentz factor
  - $\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} = \frac{1}{\sqrt{1 - \frac{0.85c^2}{c^2}}} = \frac{1}{\sqrt{1 - 0.85^2\frac{c^2}{c^2}}} = \frac{1}{\sqrt{1 - 0.7225}} = 1.898$
- Substituting the known values into the proper time equation
  - $\Delta t_0 = \frac{16}{1.898} = 8.4 \text{ years}$
- Calculating the age of Twin A upon their return
  - 31 + 8.4 = 39.4 = 39 years old
- This is answer **B**

Answer **A** is incorrect because the Lorentz factor has been calculated incorrectly.

Answer **C** is incorrect because no time dilation has occurred.

Answer **D** is incorrect because the value of Δt has been used as proper time.

As always with relativity questions, the hardest part is assigning the values to the correct reference frames. It can be really helpful to write out each value with its description so that you are clear on each from the start and can refer back to them if you get confused within the calculation.

This question is actually a version of what Einstein referred to as the Twin Paradox. The paradox is that if you perform this calculation from the perspective of the moving reference frame, then you get the opposite answer. From the moving reference frame, the twin on Earth has aged less than the twin on the space ship. This begs the question, who is correct? They cannot both be correct. The answer is that the twin in the spaceship would actually have to accelerate during their trip to be able to make it back to Earth by changing direction in some way. At which point the reference frame of the twin in space is no longer inertial, and so the rules applied by special relativity no longer work. Therefore, the correct ages of the twins are correct from the stationary reference frame, that is the twin on Earth. Which means that the twin on Earth really will have aged more than the twin in space!

4

The correct answer is **C** because:

- The time axis (or y-axis) on a spacetime diagram is labelled as *ct*
- Therefore any value of time (in seconds) can be converted into metres by multiplying it by the speed of light *c*
- Event A and Event B happen 10 seconds apart
- Event A and Event B are 10 graduations apart on the time *ct* axis
- Therefore, 10 s = 10 graduations
    - Hence, 1 graduation = 1 s
- $1 \text{ s} \times (3.00 \times 10^8 \text{ m s}^{-1}) = 3.00 \times 10^8 \text{ m}$
- This is answer **C**

It can be confusing at first to think of time being measured in meters, but we do this in real life, just the other way around. You might say place X is 10 minutes away from here, meaning that it takes 10 minutes to travel the distance between here and place X.

To put time *ct* into perspective, you can think of it as a light-second. It's the distance that light can travel in one second which is 3.00×10^8 m, which in context is roughly 7 times around the Earth.

5

The correct answer is **B** because:

- Maxwell's theory of electromagnetism was based on constants that were independent of the motion of the source or the observer, and his equations predicted a value for the speed of propagation of electromagnetic radiation
    - $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$
        - Where, μ_0 = permittivity of free space
        - And, ε_0 = Permeability of free space
        - Hence, c = the speed of light
    - Therefore, we know that the speed of light does not change if either the source or the observer is moving
- The second postulate of special relativity states that the speed of light in a vacuum is the same in all inertial reference frames
- Therefore, the second postulate, the constancy of the speed of light could be predicted from Maxwell's theory of electromagnetism
- This is answer **B**