

### Faster than the Speed of Light Key Info

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

$v$  = speed object is travelling at.

$c$  = speed of light (300,000,000 m/s or  $3 \times 10^8$  m/s).

This is called the “Lorentz Transformation”. It allows us to calculate the observed length, time and mass of an object when it is travelling close to the speed of light. You need to calculate  $\gamma$  for a scenario and then apply it to the relevant relativistic equation.

- **Length contraction** states that the original Length ( $L_o$ ) of an object gets smaller, according to an external (stationary) observer, when travelling close to the speed of light ( $c$ ). This new observed length is  $L$ .

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

- **Time dilation** states that a moving clock will slow down, according to an external (stationary) observer, if it is travelling close to the speed of light.  $T$  = slower time,  $T_o$  = time on clock at rest

$$T = \gamma T_o$$

- **Mass increases**, according to an external (stationary) observer, when an object is travelling close to the speed of light.  $M$  = increased/travelling mass,  $M_o$  = original mass at rest

$$M = \gamma M_o$$

**Einstein's relativity problems – Use “Key info sheet” to help you. You will need a calculator and an experimental mind!**

1. Showing that you need to be travelling close to the speed of light for changes in time, mass and length to be significant:  
Steps:
  - Choose Time, Length or Mass to investigate
  - Choose any value for  $L_o$ ,  $T_o$ , or  $M_o$ .
  - Try different values for  $v$  in m/s, your velocity, increasing it towards the speed of light, and substitute it in to the equation for  $\gamma$
2. Why did Einstein say that no object can travel at the speed of light i.e.  $v = 300,000,000$  m/s? (Hint – try to plug this in to the equation for  $\gamma$ .)
3. What happens to the value of  $\gamma$  when you try to travel above the speed of light?
4. Twins are born at the same time on earth. At the age of 10, one of them (Callum) decides to go on an adventure in to space. He travels in a spaceship at 99% the speed of light for 5 years. However, he misses his brother (Angus), who is still on Earth, so returns, taking him another 5 years. Upon returning, Callum is shocked to find his twin brother Angus with grey hair and a zimmer frame! Use time dilation to calculate the age of
  - a) Callum?
  - b) Angus?
5. Show that if you travel at 90% the speed of light, then your mass will approximately double. This was mentioned in the documentary
6. A train has a length of 100m when stationary. You stand on the platform at the station, and it travels past you at 250,000,000 m/s. What length do you see the train to be?
7. An object travelling close to the speed of light appears to be 2000kg to a stationary observer. When still, the object has a mass of 762kg. At what speed must it have been travelling?
8. Satellites travel can at 14,000 km/hr. Can you show that in 1 day, time runs slower on one of these satellites by 7 microseconds ( $7 \times 10^{-6}$ s), as stated in the documentary? You will need to use one of Einstein's equations!

**General Questions on topic**

9. What is a thought experiment?
10. Why are neutrinos hard to detect?

11. What reasons are there for doubting the figures detected by the OPERA experiment?
12. Explain the joke:  
“A barman says “sorry, we don’t serve neutrinos”.... A neutrino walks in to a bar.
13. The documentary said that it took 2.4ms for the neutrinos to travel the 730km from CERN to Gran Sasso. What speed did they travel at in m/s?
14. Is this an average or an instantaneous speed? Explain your answer.
15. Compare the measured value to by the Italian scientists to Einstein’s value for the speed of light. What is the percentage difference?
16. If the neutrinos were to follow Einstein’s rules and not exceed the speed of light, estimate by calculation a time it could have taken the neutrinos to travel the 730km.
17. Physicists measured the neutrinos to arrive 60 nanoseconds (ns) early. Express 60ns in standard form and as a decimal.
18. The documentary referred to satellites and GPS systems. It stated that satellites orbit the earth at 14,000 km/h. What is this speed in m/s?
19. What is this speed as a percentage or fraction of the speed of light?

### **Questions from video:**

1. 350 years ago, how did people think light travelled?
2. What is the medium called that light was thought to travel through?
3. What are particles of light called?
4. What does light have to travel through to be absolute?
5. What did Einstein say had to be compensated for the speed of light to be a constant?
6. How much slower is time on a satellite compared to time on Earth?
7. What did Einstein say happened to an object’s energy, and therefore its mass, when it travels close to the speed of light?
8. How many of the fundamental subatomic particles are known as neutrinos?
9. What is one of the main problems of neutrinos?
10. How did we discover neutrinos?

11. Why, according to Einstein's theory, can neutrinos not travel faster than the speed of light?
12. What was the OPERA experiment designed to test?
13. What material is used to detect the arriving neutrinos? Why?
14. How "early" did the neutrinos arrive?
15. When the 1980s supernova was detected, what reached the Earth first?
16. What 2 arguments are given to suggest that objects can travel faster than the speed of light?
17. What do the "Einstein" and "Quantum" worlds describe?
18. What is string theory?
19. What does string theory need the universe to have?
20. What is one of the theories to explain why the neutrinos appeared to travel faster than the speed of light?