Exercise 14 – Special Relativity

Past paper Homework Questions

1. The length of a spaceship at rest is L.

   This spaceship passes a planet at a speed of $0.95c$.

   Which row in the table gives the measured lengths of the spaceship according to an observer on the spaceship and an observer on the planet?

	Length measured by observer on spaceship	Length measured by observer on planet
A	L	L
B	L	less than L
C	less than L	L
D	less than L	less than L
E	greater than L	less than L

2. A spacecraft travels at a constant speed of $0.70c$ relative to the Earth.

   A clock on the spacecraft records a flight time of 3·0 hours.

   A clock on Earth records this flight time to be

   A   1·6 hours

   B   2·1 hours

   C   4·2 hours

   D   5·5 hours

   E   5·9 hours.

3. A spaceship on a launch pad is measured to have a length L. This spaceship has a speed of $2.5 \times 10^8\,\mathrm{m\,s^{-1}}$ as it passes a planet.

   Which row in the table describes the length of the spaceship as measured by the pilot in the spaceship and an observer on the planet?

	Length measured by pilot in the spaceship	Length measured by observer on the planet
A	L	less than L
B	L	greater than L
C	L	L
D	less than L	L
E	greater than L	L

4. A spaceship is moving with a constant speed of $0.6c$ towards the Earth. The spaceship emits a beam of light towards the Earth. An astronaut in the spaceship and an observer on Earth both measure the speed of the emitted light.

   Which row in the table shows the speed of the emitted light as measured by the astronaut and by the observer on Earth?

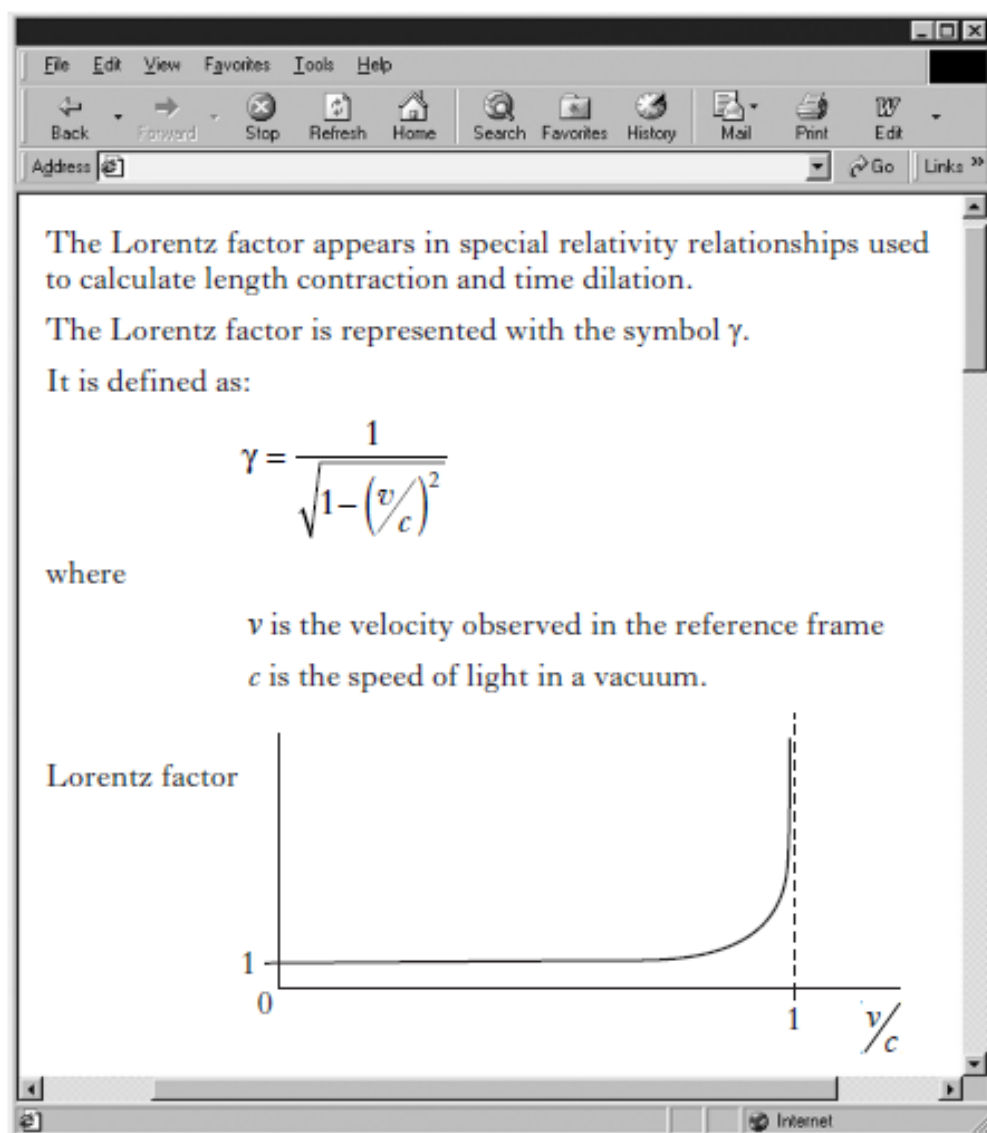 | | Speed of emitted light as measured by astronaut | Speed of emitted light as measured by observer on Earth |
   |---|---|---|
   | A | $0.4c$ | $1.6c$ |
   | B | c | c |
   | C | c | $1.6c$ |
   | D | $1.6c$ | $0.4c$ |
   | E | $1.6c$ | c |

5. A spacecraft is travelling at a constant speed of $0.60c$ relative to the Moon.

An observer on the Moon measures the length of the moving spacecraft to be 190 m.

The length of the spacecraft as measured by an astronaut on the spacecraft is

A   120 m

B   152 m

C   238 m

D   297 m

E   300 m.

6. A page from a website on special relativity is shown.

The Lorentz factor appears in special relativity relationships used to calculate length contraction and time dilation.

The Lorentz factor is represented with the symbol γ.

It is defined as:

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

where

   v is the velocity observed in the reference frame

   c is the speed of light in a vacuum.

Lorentz factor

(a) Explain what is meant by the term *length contraction*.   1

(b) Calculate the Lorentz factor when the ratio $\frac{v}{c} = 0.80$.   2

(c) Length contraction calculations use the relationship

$$l' = l\sqrt{1-\left(\frac{v}{c}\right)^2}$$

where the symbols have their usual meanings.

State this relationship in terms of *l'*, *l* and γ.   1

(d) Explain, in terms of the Lorentz factor, why an observer can ignore relativistic effects for an object which is moving with a velocity much less than *c*.   2

(6)

7. A physics student notices that the digital clock in the family car loses one minute every six months.

The student states "This must be due to time dilation as the car is driven at motorway speeds for much of the time."

Use your knowledge of physics to comment on the student's statement.   (3)

8.   Muons are sub-atomic particles produced when cosmic rays enter the atmosphere about 10 km above the surface of the Earth.
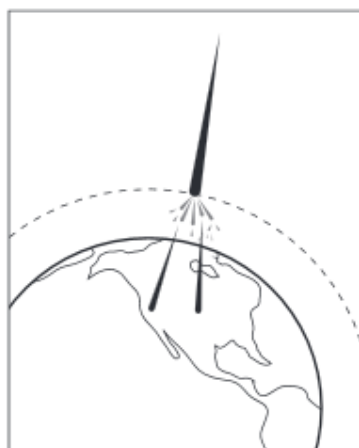
Muons have a mean lifetime of $2\cdot2 \times 10^{-6}$ s in their frame of reference. Muons are travelling at 0·995c relative to an observer on Earth.

(a) Show that the mean distance travelled by the muons in their frame of reference is 660 m.   2

(b) Calculate the mean lifetime of the muons as measured by the observer on Earth. **3**

(c) Explain why a greater number of muons are detected on the surface of the Earth than would be expected if relativistic effects were not taken into account. **1**

(6)

9. Two physics students are in an airport building on their way to visit CERN.

(a) The first student steps onto a moving walkway, which is travelling at $0\cdot83\,\text{m}\,\text{s}^{-1}$ relative to the building. This student walks along the walkway at a speed of $1\cdot20\,\text{m}\,\text{s}^{-1}$ relative to the walkway.

The second student walks alongside the walkway at a speed of $1\cdot80\,\text{m}\,\text{s}^{-1}$ relative to the building.
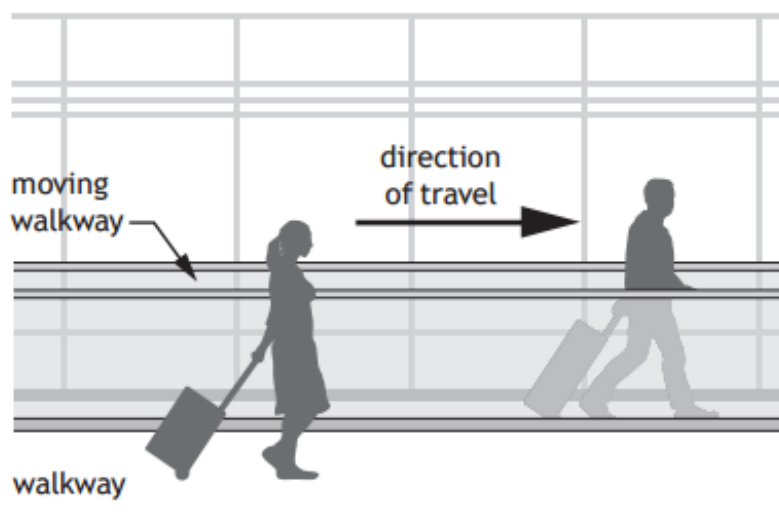
Determine the speed of the first student relative to the second student. **2**

(b) On the plane, the students discuss the possibility of travelling at relativistic speeds.

(i) The students consider the plane travelling at $0\cdot8c$ relative to a stationary observer. The plane emits a beam of light towards the observer.

State the speed of the emitted light as measured by the observer.

Justify your answer. **2**

(ii) According to the manufacturer, the length of the plane is 71 m.

Calculate the length of the plane travelling at $0\cdot8c$ as measured by the stationary observer. **3**

(iii) One of the students states that the clocks on board the plane will run slower when the plane is travelling at relativistic speeds.

Explain whether or not this statement is correct. **1**   **(8)**

Total 28