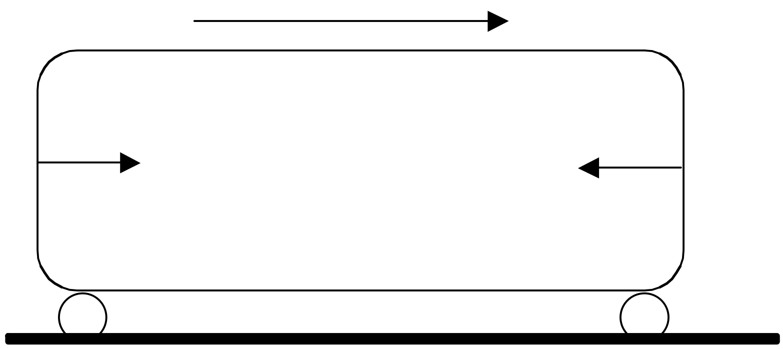
Answers to Coursebook questions – Chapter H1

1 No, some things may be 'relative' in relativity but not all is relative.

For one thing, a rotating earth means that it is not in an inertial frame.

2 One example is: a train moves to the right with respect to the ground. Two signals are emitted from the front and the back of the train at the same time as far as an observer in the train is concerned.



An observer in the middle of the train will receive the signals at the same time. Because the arrival of the signals occurs at the same point in space, the arrival of the signals will be simultaneous for the ground observer as well. But according to the ground observer, the observer in the middle of the train is moving away from the signal from the left. The signals are moving at the same speed (c) and so the signal from the left must have been emitted first.

See also **additional question A3** for another example.

3 The ice cube will fall after a time given by $y = \frac{1}{2}gt^2 \Rightarrow t = \sqrt{\frac{2y}{g}} = \sqrt{\frac{2\times 1.40}{9.8}} = 0.53\text{s}$

for all three observers.
According to A the ice cube will fall vertically down, exactly below the point where it was released, $x_A = 0$.
According to B the ice cube has a horizontal velocity of $5.0 - 2.0 = 3.0\ \text{m s}^{-1}$ and so will land a distance of $x_B = 3.0 \times 0.53 = 1.59\ \text{m}$ to the right.
According to the ground observer it will land a distance of $x_C = 5.0 \times 0.53 = 2.65\ \text{m}$ to the right. Notice the Galilean relativity relations: $x_B = x_C - v_B t$, $x_A = x_C - v_A t$.

4 The acceleration must be very small so as to be negligible. The acceleration due to the rotation on its axis is $a = 0.034\ \text{m s}^{-2}$ (see **Q11** on page 125 in *Physics for the IB Diploma*) and that due to the rotation around the sun is $a = 5.95 \times 10^{-3}\ \text{m s}^{-2}$ (see **Q5** on page 124 in *Physics for the IB Diploma*).
In addition, to really consider an observer on earth as being in a true inertial frame there can be no gravity, and this can happen only in a frame of reference that is freely falling above the surface of the earth. In such a frame, there is no gravity.

5 You can think of many such experiments. One is to let a ball drop from rest. The ball will fall vertically down (as far as you are concerned) in exactly the same way as if the train were at rest.

6 No we cannot, since the galvanometer would show the same current irrespective of whether it is the coil or the magnet that moves with respect to the ground.

7 You can hang a pendulum from the ceiling. If the train accelerates, the string will not be vertical. If the string is displaced in a given direction, the direction of acceleration will be opposite to that direction.

8 The surface of water in a bucket in a rotating frame of reference would not be flat.

9 If one inertial observer measures that there is a force, and hence acceleration, other inertial observers must agree. According to the observer moving along with the proton, the proton is at rest so it cannot have a magnetic force on it ($F = qvB$ and $v = 0$).
So the electric charges in the wire must exert an electric force that is equal to the magnetic force (in magnitude and direction) it experiences according to an observer at rest with respect to the wire.

10 **a** The question does not make it clear that the signals are emitted at the **same time** according to the train observer. For this observer the doors will open at the same time, namely $\dfrac{\frac{1}{2}\times 5400000}{300000} = 9\,\text{s}$ after emission.

b According to the observer on the ground, the signals are emitted at the same time and move at the same speed (c). But the left door is moving towards the signal, whereas the right door is moving away and so the left door will open first.

Additional problems

A1 In a certain inertial reference frame S, lightning strikes at $x = 3\times 10^8$ m.
An observer is standing still at the position $x = 6\times 10^8$ m.
Light from the strike arrives at the observer when his clock shows $t = 3$ s.
What are the co-ordinates of the event 'lightning strikes' according to this observer?

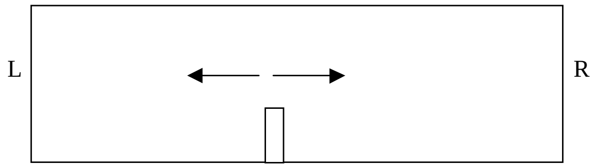
Answer

Light will cover the distance $\Delta x = 6\times 10^8 - 3\times 10^8 = 3\times 10^8$ m in a time of

$$\frac{\Delta x}{c} = \frac{3\times 10^8}{3\times 10^8} = 1\,\text{s}.$$

The event 'lightning strikes' thus occurred at $t = 3 - 1 = 2$ s, at position $x = 3\times 10^8$ m.
All observers in frame S agree that these are the co-ordinates of the event 'lightning strikes'.

A2 A box moves to the right with speed v relative to the ground. Two light signals are emitted towards the left and right ends of the box from a point midway in the box. The signals are emitted simultaneously according to an observer inside the box.



Do the signals arrive simultaneously at L and at R according to the observer inside the box?

You must answer the question quantitatively both in Galilean and in Einstein relativity.

a State the speed of the left and of the right moving signal according to the observer on the ground **in Galilean relativity**.

b Calculate the relative speed of the left moving signal with respect to L and of the right moving signal with respect to R, **in Galilean relativity**.

c Hence determine whether the signals arrive at L and R at the same time according to the observer on the ground **in Galilean relativity**.

d Repeat questions **a** and **b in Einstein relativity**.

e Hence show that **in Einstein relativity** the signals will not arrive simultaneously according to the ground observer and determine which signal arrives first.

Answer

a The left moving signal has speed $c - v$ and the right moving signal a speed $c + v$.

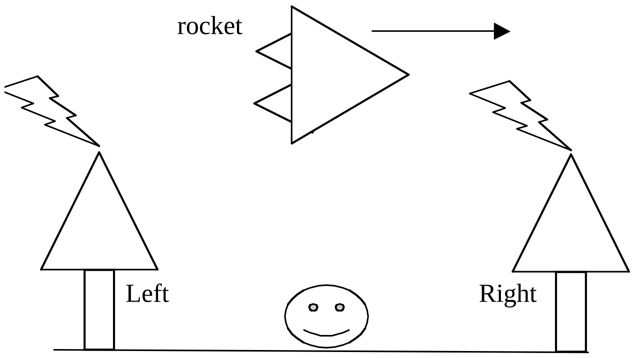
b The relative speed of the left moving signal with respect to L is, as far as the ground observer is concerned, equal to $(c - v) + v = c$.
The relative speed of the right moving signal with respect to R is $(c + v) - v = c$.

c Since the signals approach the ends with the same speed, they will arrive at the same time.

d Both signals have speed c (a postulate of relativity) according to the ground observer. The relative speed of the right signal with respect to the front of the box is $c - v$. Similarly, the relative speed of the left moving signal with respect to the back of the box is $c + v$.

e It is then clear that the left moving signal will reach the back of the box first since it has greater relative speed and the same distance to cover.

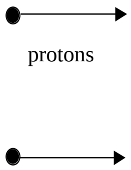
A3 According to the ground observer, lightning strikes two trees at the same time as the rocket passes by. The ground observer is half way between the trees. Which tree is hit first by lightning according to the rocket observer?



Answer

Light from the lightning strikes arrives at the ground observer at the same time. Thus the rocket observer measures that light arrives at the ground observer at the same time as well since the arrivals occur at the same point in space. But according to the rocket observer, the ground observer is moving away from the light from the right tree. The light from both trees travels at the same speed (c) according to the rocket. For light to arrive at the same time, the signal from the right tree must have been emitted first according to the rocket observer.

A4 Consider two protons both of which are moving with equal velocities with respect to the lab.



An observer moving along with the protons measures an electric force of repulsion between the protons. How does an observer at rest in the lab explain the force on the protons?

Answer

The observer moving along with the protons will measure an electric force $F = \mathrm{e}E$, where E is the electric field caused by one of the protons at the position of the other. The observer in the lab will measure an electric force $F_\mathrm{e} = \mathrm{e}E'$ and a magnetic force $F_m = \mathrm{e}vB'$ since the lab observer sees a moving proton which is equivalent to a current and a current will produce a magnetic field. The total force measured by the lab observer is thus $F = \mathrm{e}E' + \mathrm{e}vB'$. The conclusion of this is that the two observers do not agree on what electric and magnetic fields exist in this situation.

