Section 3.3.7 – Classical Relativity

Classical relativity

Nothing is ever truly stationary. You may well be sitting or standing still when you read these notes on Special Relativity and you are indeed travelling at 0 ms^{-1} relative to the ground. However, the earth is spinning on its axis at 1000 mile/hour. It is also rotating around the sun at a further 30 km/sec. The Milky Way itself is also rotating at 500,000+ miles/hour. And of course the universe is also expanding.

To say you are not moving when sitting still is accurate but only **relative to the ground.**

Example 1

You are sitting on a train at a station when you your train begins to move and you see a neighbouring train moving past your window. It's only when the last carriage of the neighbouring train disappears that you realise that you are still stationary at the station platform and it was the neighbouring train that was actually moving.

https://www.youtube.com/watch?v=AKhvqO5UBsA
[Without the background vision you cannot tell which of the trains is actually moving or stationary]

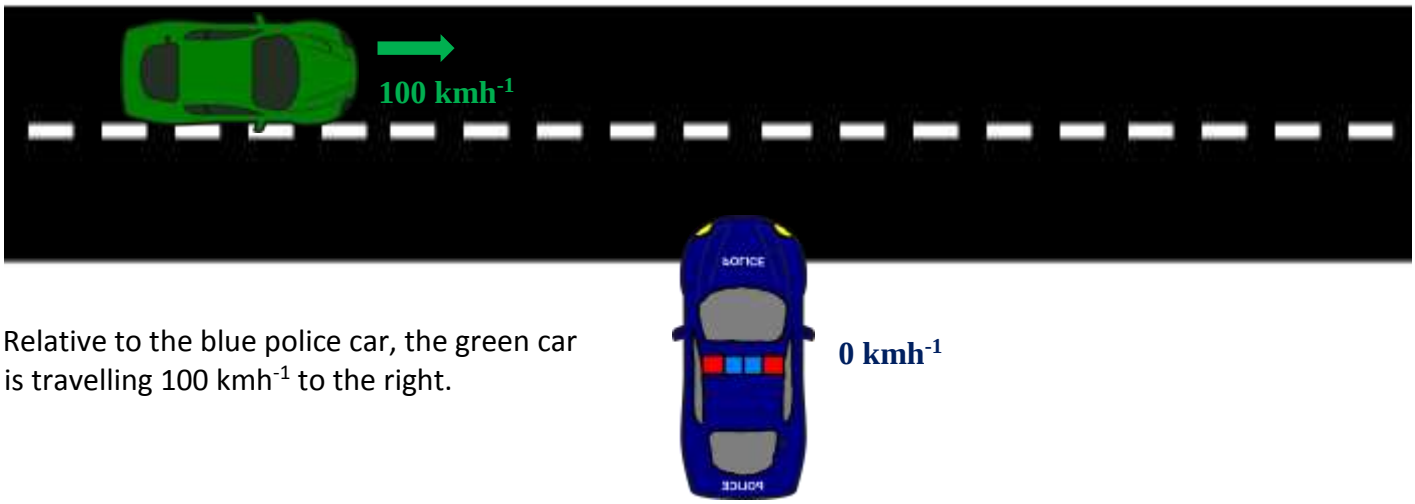
What you experience is relativity. Relativity means the **apparent motion** of an object is affected by the **motion of the observer**. That is, **motion is relative**.

Example 2

Consider the green car in each of the following three scenarios. In each case the speedometer in the green car displays 100 kmh^{-1}. For each case, what would the police measure the speed of the green car relative to its own speed?

Scenario A

Green car is travelling at 100 kmh^{-1} to the right and police car is roadside stationary



Relative to the blue police car, the green car is travelling 100 kmh^{-1} to the right.

Scenario B

Green car is travelling at 100 kmh^{-1} to the right and police car is travelling at 100 kmh^{-1} to the left

Relative to the blue police car, the green car is travelling 200 kmh^{-1} to the right.
Speed (Green relative to Blue) = 100 kmh^{-1} + 100 kmh^{-1} = **<u>200 kmh^{-1} to the right</u>**

Scenario C

Green car is travelling at 100 kmh^{-1} to the right and police car is travelling at 120 kmh^{-1} to the right

Relative to the blue police car, the green car is travelling 20 kmh^{-1} to the left.
Speed (Green relative to Blue) = 120 kmh^{-1} - 100 kmh^{-1} = **<u>20 kmh^{-1} to the left</u>**

NB: All three measurements made by the blue police car **are correct**, relative to the police cars motion. In each scenario the police car has a **different inertial frame of reference.**

There is no such thing as an absolute measure of velocity. Nothing is truly standing still. All measurements are relative to the frame of reference you measure from.

<u>Frame of Reference</u>

A **frame of reference** is a set of coordinates that are used to measure the location of objects and track their motion.

In most every day scenarios we use the Earth's surface as our frame of reference. However, frames of reference can also be used for moving observers.

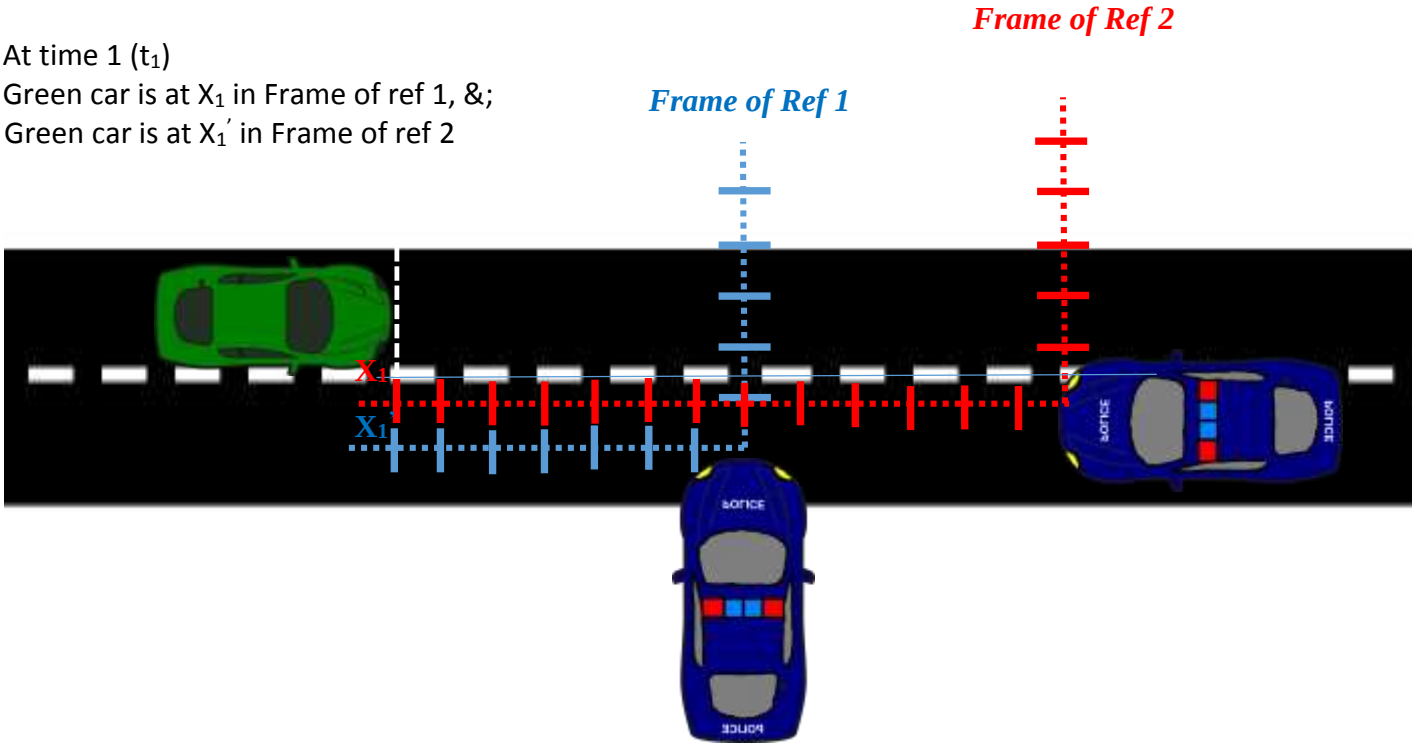
Each of the three scenarios in the previous example used a different frame of reference.

Frame of reference 1 – inside the green car
Frame of reference 2 – inside the stationary blue car
Frame of reference 3 – inside the blue car moving to the left at 100 kmh^{-1}
Frame of reference 4 – inside the blue car moving to the right at 120 kmh^{-1}

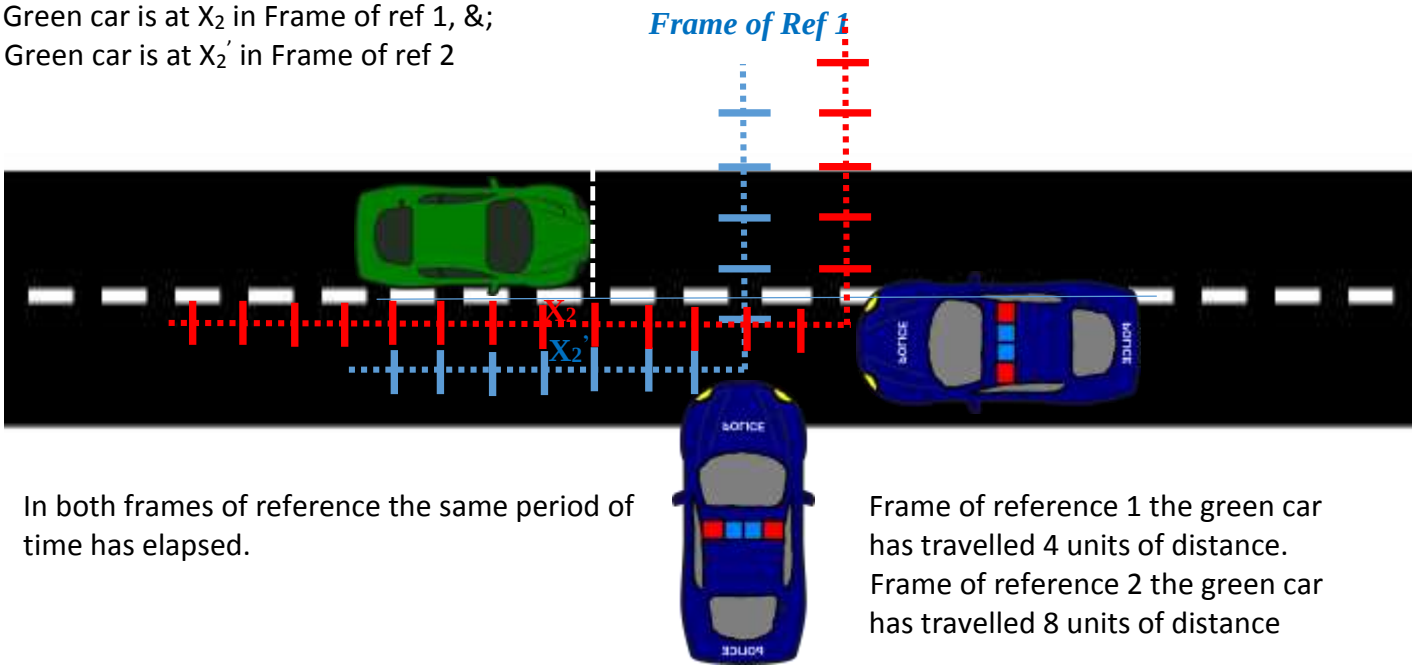
Example 3

Consider the green car ravelling to the right and its relative velocity from 2 different frames of reference. Frame of reference 1 is from the stationary police car, Frame of reference 2 is form the moving police car.

At time 1 (t_1)
Green car is at X_1 in Frame of ref 1, &;
Green car is at X_1' in Frame of ref 2



At time 2 (t_2) a short time later
Green car is at X_2 in Frame of ref 1, &;
Green car is at X_2' in Frame of ref 2

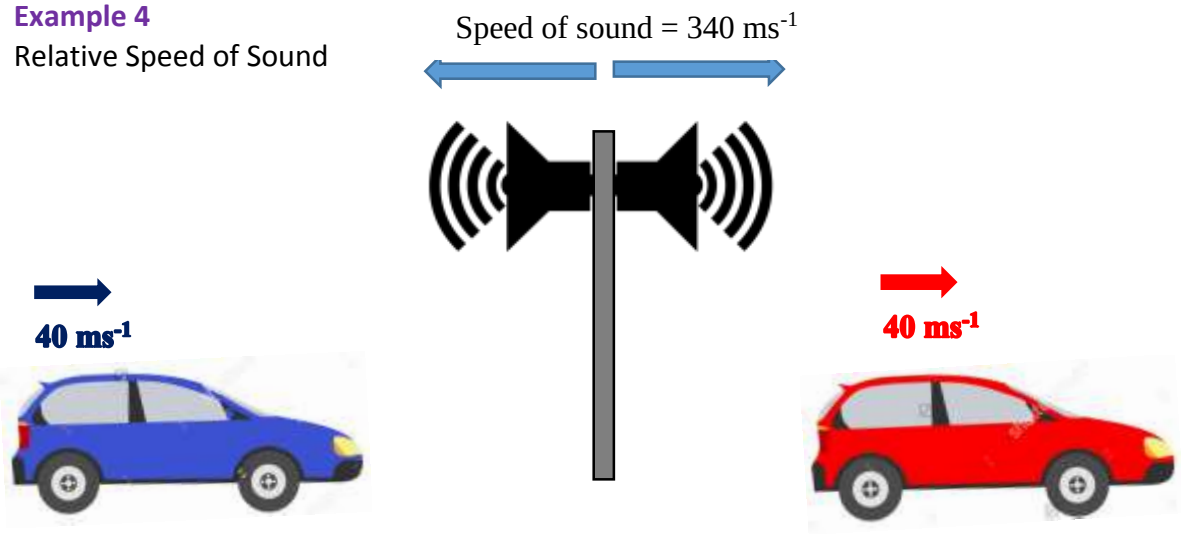


In both frames of reference the same period of time has elapsed.

Frame of reference 1 the green car has travelled 4 units of distance.
Frame of reference 2 the green car has travelled 8 units of distance

An **inertial frame of reference** is one that is **not accelerating**. An observer in an inertial frame of reference is either stationary or travelling at a constant velocity (ie. no acceleration can be detected).

Example 4
Relative Speed of Sound



What is the speed of sound:

1. Relative to the blue car travelling towards the sound source?
2. Relative to the red car travelling away from the sound source.

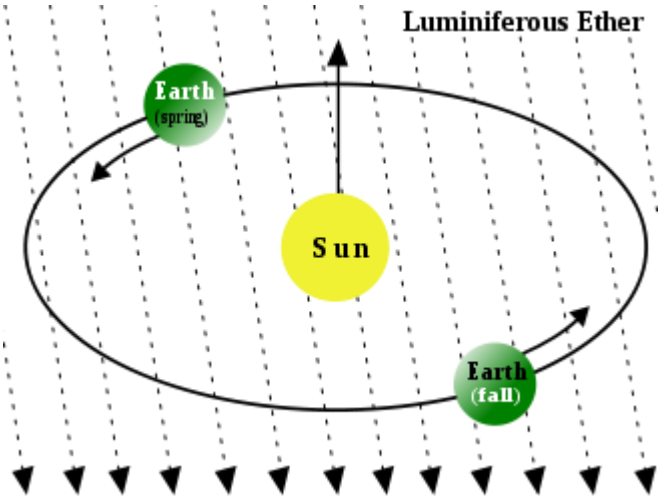
Answer:
The speed of sound relative to the blue car is = 340 ms^{-1} + 40 ms^{-1} = **380 ms^{-1}**
(The blue car is moving towards the source of the sound)

The speed of sound relative to the blue car is = 340 ms^{-1} - 40 ms^{-1} = **300 ms^{-1}**
(The blue car is moving away from the source of the sound)

Luminiferous Aether

For a period of time, people believed that light behaved like sound. Accordingly, it was believed that light must be ripples within some sort of medium that was found between the light source and an observer. Scientists gave this medium the name of the luminiferous aether.

It was even believed that the shape and direction of the tails of comets we created by aether drag. So convinced were scientists that the ether existed they even calculated its density, viscosity and refractive index.



The Michelson-Morley experiment

To test the presence of the luminiferous aether two scientists A. Michelson and E. Morley designed an experiment to detect the difference in the speed of light travelling both **parallel** and **perpendicular** to the Earth's motion. It was hypothesised that the speed of light (c) would be different at different orientations of the apparatus, much like the relative change in the speed of sound as one travels towards and away from a sound source.

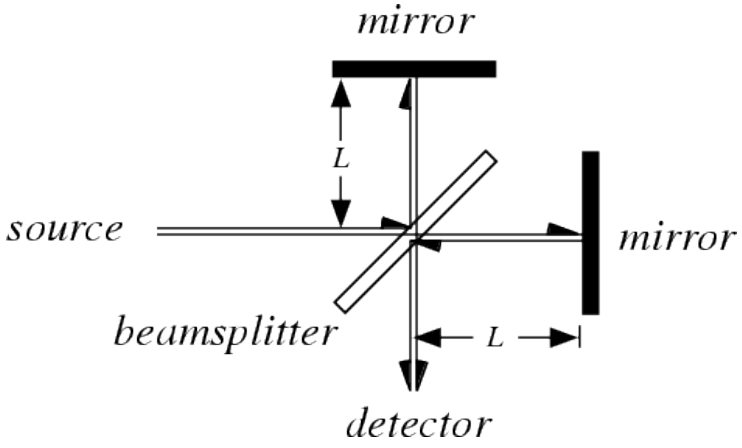


Figure 1
Michelson Morely apparatus

The apparatus used a half silvered mirror to split the beam of light. One beam travelled along a parallel plane to a mirror a fixed distance from the beam splitter. Whilst the other was reflected in a perpendicular plane to a mirror also the same fixed distance from the beam splitter.

The reflected light from both mirrors was collected at a detector and the interference pattern analysed to compare the arrival times of each beam.

It was predicted that there would be a small, yet noticeable, difference in the arrival times of the two beams. This would result in in the two beams being "**out of phase**" and the production of an **interference pattern**.

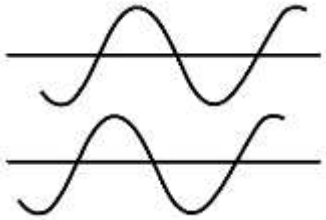


Figure 2
With light waves slightly "out of phase" interfere with each other and can produce an interference fringe/pattern.

However, to their surprise, Michelson and Morley found that no matter what the apparatus orientation, the two beams were always **in phase** and **no change in interference pattern** was observed.

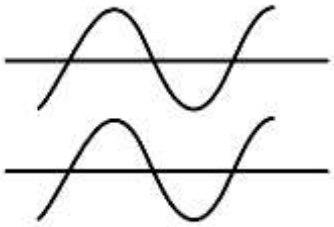


Figure 3
With light waves "in phase" no interference fringe/pattern is observed.

This famous "**null result**" proved that there was no luminiferous aether. This meant that there was there was no absolute reference frame at rest in space from which the absolute motions of celestial objects could be measured.

Therefore, all positions, time intervals, states of rest, motions, velocities, directions of motion, and trajectories of co-moving celestial objects must be completely **relative.** However, the speed of light was **not relative** to the inertial frame of reference.

Exam Styled Questions

Question 1

Which of the following factors affects the speed of light?

A. the electrical properties of the medium through which light is travelling
B. the speed of the observer of the light
C. the speed of the light-emitting source
D. none of the above; the speed of light never changes

B, C: wrong. D: speed changes with refractive index, A: correct, refractive index depends on electrical properties. Maxwell showed that the speed of electromagnetic waves, and therefore light, would depend only on the electromagnetic properties of the medium and not on any relative motion. The speed of light in a material medium is less than that in space.

A

Question 2

An alarm is sounding in the centre of a large indoor basketball court. A stationary player measures the speed of sound as 335 ms^{-1}. A player runs directly towards the alarm (at 5 ms^{-1}) and another runs directly away from the alarm (also at 5 ms^{-1}). As they run they both measure the speed of sound using a small portable device. The situation is shown in Figure 1.

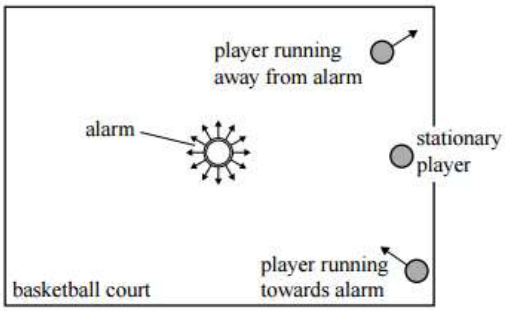


Figure 1

Which one of the following pairs of measurements is the best estimate of the speed of sound that would be measured by the running players?

	Player running away from alarm	Player running towards alarm
A.	335 m s^{-1}	335 m s^{-1}
B.	340 m s^{-1}	330 m s^{-1}
C.	325 m s^{-1}	345 m s^{-1}
D.	330 m s^{-1}	340 m s^{-1}

Observer moving towards source detects higher speed, while observe moving away detects a lower speed. Compare with a thrown stone.

D

Question 3
A quasar, a distant star, is visible to amateur astronomers. When observed, it is at a distance of 2.5×10^{25} m from Earth and is travelling away from Earth at a speed of 0.16c. Which of the following is the best statement about the light from the quasar?

A. The light from the quasar will be travelling slower than 3×10^8 ms^{-1} when the light reaches Earth.
B. The light from the quasar will be travelling faster than 3×10^8 ms^{-1} when the light reaches Earth.
C. The light from the quasar has taken 2.6×10^9 years to reach Earth.
D. The light from the quasar has not yet had time to reach Earth.

Speed of light is unchanged, so A and B are wrong. D: If the quasar can been seen, this must be wrong. C: Dist / speed gives the time in C

C

Question 4
One of Einstein's postulates for special relativity was that the laws of physics are the same in all inertial reference frames. Which of the following best describes the properties of an inertial reference frame?

A. Its movement is consistent with the general expansion of the universe.
B. No observer in the frame can detect any acceleration of the frame.
C. It is travelling at speeds much less than c.
D. It is travelling in a straight line.

Inertial reference frame is one traveling at a constant speed, so A, C are wrong and D could be accelerating in a straight line

B

Question 5
The Michelson–Morley experiment was an attempt to detect the motion of Earth through the aether. To achieve this, the speed of light was measured first in one direction and secondly in a perpendicular direction to the first direction. Which of the following best describes the result that Michelson and Morley found?

A. The result depended on where Earth was located in its orbit around the Sun.
B. The first value for the velocity of light was greater than the second.
C. The first value for the velocity of light was the same as the second.
D. The first value for the velocity of light was less than the second.

M&M found no change in the measured speed of light when measuring it in different directions. They could therefore detect no motion through the aether, so only C

C

Question 6

Two cars, travelling at the same speed, are approaching a country motel from opposite directions. In Figure 2 below they are equidistant from the motel at the same time, and simultaneously sound their horns to indicate the motel of their approach.

There is a strong wind blowing form the left, as shown. Relative to the ground, the cars are travelling slightly faster than the speed of the wind.

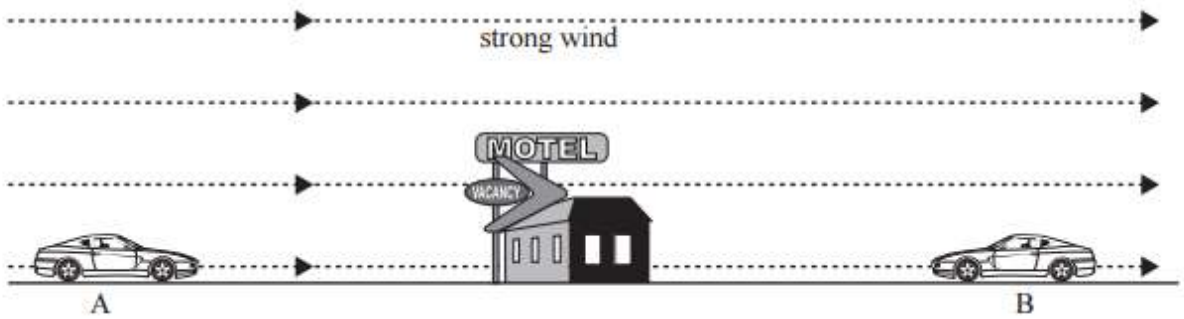


Figure 2

Which of the following options best describes which signal arrives first at the motel?

A. The sound signal from car A arrives first.
B. The sound signal from car B arrives first.
C. Both signals arrive at the same time.
D. The sound signal from car B never reaches the motel

For sound the speed of the medium affects the speed of the signal.

A

Question 7

Which of the following statements best describes what the Michelson–Morley experiment attempted to measure?

A. the speed of Earth through space
B. changes in the speed of Earth through space
C. accuracy obtainable with an optical interferometer
D. differences in the speed of light in different directions

A: No, B: No, C: No.

D

Question 8

On a planet a long way away, a racing car is moving at high speed (0.9c) along a straight track. It is heading straight for a post. Jim is standing next to the post. The situation is shown in Figure 3.

Figure 3

When the racing car is 1.00 km from the post (as measured by Jim), the driver sends a flash of light from the car. Which of the following is closest to the time that the flash of light takes to reach the post (as measured by Jim)?

A. 1.5 microseconds
B. 1.8 microseconds
C. 3.3 microseconds
D. 3.7 microseconds

In Jim's frame distance = 1.0km, speed = c, so time = $1.0 \times 10^{-3} / (3.0 \times 10^{8}) = 3.3 \times 10^{-6}$ s

C