Einstein's theory of special relativity worksheet answers

VCAA 2005

A Year 12 physics class is studying Einstein's special relativity. The teacher postulates a thought experiment: Imagine you are travelling at a speed of 3×10^8 m s^{-1} alongside a beam of light. What would you measure the speed of a beam of light to be?

Two students put up their hands to offer an answer.

Hilary says: You would measure the beam of light to be moving away from you at 3×10^8 m s^{-1}.

Ryan says: You would measure the beam of light to be at rest with respect to yourself: that is, its speed would be 0 m s^{-1}.

Question 2 (3 marks, 27%)

Which student's answer is consistent with Einstein's special theory of relativity? In the space below, write your choice and explain your reasoning.

Hilary was correct, as the speed of light is invariant in inertial frames of reference.

VCAA 2007

A plane travelling relative to the air at a speed of 170 m s^{-1} is 3.00 km from the control tower. The plane is late because of a headwind of 50 m s^{-1}. To let the control tower know that the plane is nearby, the pilot sounds a siren which sends a high frequency sound pulse towards the control tower. The speed of sound in air is 340 m s^{-1}.

Question 2 (3 marks, 8%)

How long does it take for the sound to reach the control tower?

The speed of sound was 290 $\mathbf{m\ s^{-1}}$ (340 – 50). So the time taken was $\frac{3000}{290} = \mathbf{10.3}$

A spacecraft is approaching Earth at a speed of 0.1000 c. When the pilot measures the distance to the control tower to be 90 000 km (9.0000×10^7 m), a signal is sent to inform the control tower of the spacecraft's approach.

The speed of light can be taken as 3.0×10^8 m s^{-1}.

Question 3 (2 marks, 53%)

Which of the options **(A–D)** below is the best estimate of the time it takes the signal to reach the control tower, according to the pilot?

A. 0.290 s **B.** 0.300 s **C.** 0.310 s **D.** 3.000 s

Since the speed of light is independent, the time was $\frac{90000}{3\times10^8} = \mathbf{0.3}$ s, which was option B.

VCAA 2008

Question 6 (86%)

The results of the Michelson–Morley experiment supported Einstein's later postulates of the special theory of relativity.

Which one of the following is a postulate of Einstein's theory that was supported by the Michelson Morley experiment?

A. $E = m c^2$.

B. The speed of light has a constant value for all observers.

C. Light is a wave.

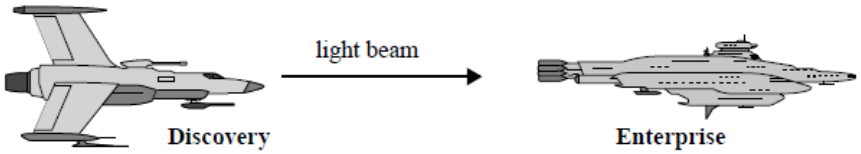
D. The speed of light depends on the speed of the observer's frame of reference.

ANS: B

VCAA 2009

Question 1 (88%)

Two spaceships, **Discovery** and **Enterprise**, are both travelling relative to an inertial frame of reference at 0.8 *c* in the same direction. Spaceship **Discovery** shines a light beam forward towards **Enterprise** as shown



What is the speed of the light beam according to the captain on spaceship **Enterprise**?

A. 0.2 *c* **B.** 0.8 *c* **C.** *c* **D.** 1.8 *c*

ANS: C

VCAA 2010

Question 1 (61%)

On a planet a long way away, a racing car is moving at high speed (0.9*c*) along a straight track. It is heading straight for a post. Jim is standing next to the post. The situation is shown in Figure 1

Figure 1

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

ANS: C

VCAA 2010

Question 12 (75%)

A conservation scientist is using a stun dart fired from a rifle to tranquilise a kangaroo to tag it for conservation research.

He is travelling in a specially designed vehicle at a speed V in a straight line. He fires a dart from his rifle straight ahead.

The dart has a speed U, measured relative to his rifle. At the same time, a flash of light is emitted from the laser sight mechanism on his rifle. This is shown in Figure 4 below.

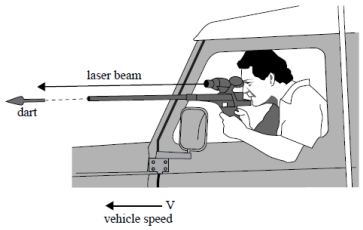


Figure 4

Which one of the following choices is the best estimate of the speed of the dart and the light flash, as measured by a stationary observer on the ground?

	Speed of **dart** relative to stationary observer	Speed of **light flash** relative to stationary observer
A.	$U + V$	c
B.	$U + V$	$V + \sqrt{\frac{V^2}{c^2}}$
C.	$U - V$	$V + c$
D.	U	c

ANS: A

Question 5 (16%)

Two physics students are conducting accurate experiments to test Newton's second law of motion ($\Sigma F = ma$). Each student is in a windowless railway carriage. One carriage (carriage A) is moving at a constant velocity of $0.9c$.

The other carriage (carriage B) is moving at 10 m/s and decelerating.

Which one of the following best describes the likely results of their experiments?

A. Only the experiment in carriage A confirms Newton's second law of motion.

B. Only the experiment in carriage B confirms Newton's second law of motion.

C. Neither experiment confirms Newton's second law of motion.

D. Both experiments confirm Newton's second law of motion.

ANS: A

VCAA 2011

Question 5 (60%)

In deep space, a spaceship, A, passes a second spaceship, B, at a relative speed of 0.5c. at this instant, each spaceship sends a radio message to their home base that is the same distance away from each spaceship.

Which of the following statements about the arrival time of the message at the home base is correct?

- **A.** Both signals will arrive at the same time.
- **B.** The signal from spaceship A will arrive later than the signal from spaceship B.
- **C.** The signal from spaceship A will arrive later than the signal from spaceship B.
- **D.** Spaceship A has a value of $\gamma = 1.15$ and this will mean that its signal will arrive approximately 15% sooner than the signal from spaceship B.

ANS: A

VCAA 2012

Question 1 (25%)

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

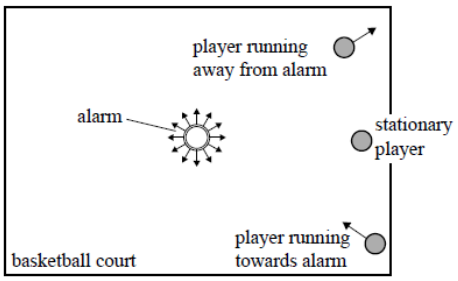
C. the speed of the light-emitting source

D. none of the above; the speed of light never changes

ANS: A

Question 2 (68%)

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

ANS: D

Question 5 (90%)

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.

ANS: C

VCAA 2013

Question 1 (78%)

James is stationary ($v = 0$) on a footpath while Amanda drives past at a constant speed of 60 km h^{-1}.

Which one of the following statements is correct?

A. Amanda is in a non-inertial reference frame because she is moving relative to James.

B. James must be in a non-inertial reference frame because he is stationary at the moment.

C. James is not stationary in his reference frame because he is moving in Amanda's reference frame.

D. Amanda is stationary in her reference frame even though she is moving in James's reference frame.

ANS: D

Question 2 (37%)

Students use sound to test the ideas of the Michelson–Morley experiment. They conduct an experiment on an outdoor basketball court on a windy day.

Student A stood at the western end and created a loud pulse of sound. Student B stood 30.0 m away at the eastern end with a sound detector, as shown in Figure 1.

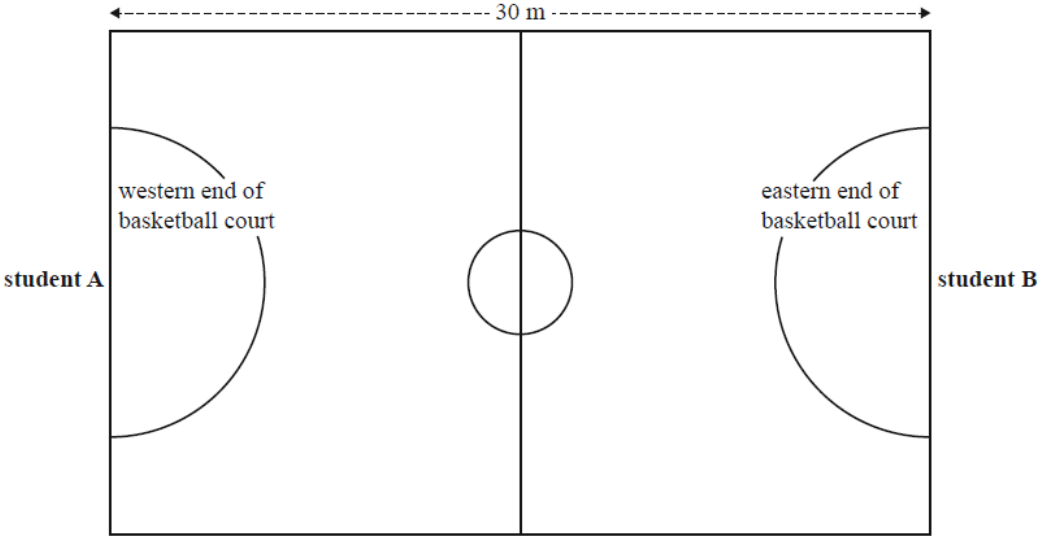


Figure 1

They found that the sound travelling towards the eastern end took 0.0857 s to reach student B.

Student B, at the eastern end, then created a loud pulse of sound. This time the sound travelling towards the western end took 0.0909 s to reach student A.

Which one of the following best explains their observations?

A. The wind was blowing to the east at 10 m/s.

B. The wind was blowing to the east at 20 m/s.

C. The wind was blowing to the west at 20 m/s.

D. The speed of sound is the same in all inertial reference frames.

$(340 + v) \times 0.0857 = 30$, $v = 10$

$(340 - v) \times 0.0909 = 30$, $v = 10$

ANS: A

Question 4 (81%)

The spaceship *Andromeda* (A) is travelling at 0.7*c* towards the asteroid Ceres (C). It sends a light pulse to the nearby ship *Bradbury* (B), which is approaching the asteroid from the far side at 0.8*c*, as shown in Figure 2.

Figure 2

The speed of the light pulse as measured from each body is

A. greatest for A and least for B.

B. greatest for B and least for A.

C. greatest for C and least for B.

D. the same for each body

ANS: D

VCAA 2014

Question 1 (52%)

The concept of an 'inertial frame' is widely used in physics.

Which one of the following statements best describes an inertial frame?

A. a frame in which relativistic effects do not occur

B. a frame in which Newton's first law of physics is always obeyed

C. a frame in which all time measurements result in proper time

D. a frame whose acceleration is small compared to *g*

ANS: B

Question 2 (84%)

A number of experiments have played a part in the history of the theory of relativity.

Which one of the following is true about the Michelson–Morley experiment?

A. More accurate versions of this experiment produced results that were significantly different from the original results.

B. It was only ever interpreted as confirming Einstein's postulate regarding the speed of light.

C. It was designed to prove Einstein's postulate regarding the speed of light.

D. It did not detect a difference between the speed of light in directions parallel to Earth's motion through space and in directions perpendicular to that motion.

ANS: D

VCAA 2015

Question 1 (74%)

One key postulate of Einstein's special theory of relativity can be described as

A. $E = mc2$.

B. nothing can travel faster than the speed of light.

C. the laws of physics are the same in all inertial (non-accelerated) frames of reference.

D. all inertial observers obtain the same result when measuring the time and position of an event.

ANS: C

Question 2 (32%)

The following statements reflect views held before Einstein proposed the special theory of relativity.

Which one of these views is now still considered to be true?

A. The observed speed of light in a medium depends on the speed of an observer relative to that medium.

B. The speed of light in a region depends only on the values of electric and magnetic properties of that region.

C. Light is a wave comprising oscillating electric and magnetic fields that cannot travel through empty space.

D. The inertial frame of a medium in which light is travelling is a special frame and, in that frame, the speed of light is *c.*

Option C was incorrect as light propagates through space. Options A and D implied that the speed of light is different for different observers. One of Einstein's postulates is that the speed of light is the same for all observers.

ANS: B

VCAA 2016

Question 2 (45%)

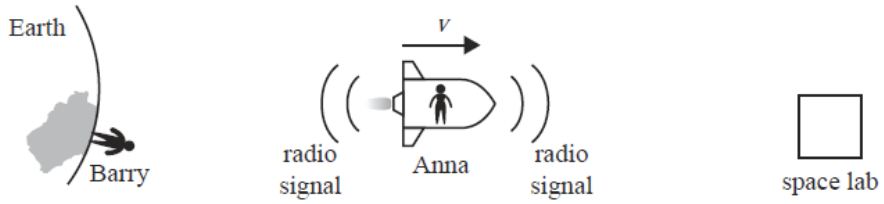


Figure 2

When Anna is halfway between Earth and the space lab, she sends a radio pulse towards Earth and towards the space lab, as shown in Figure 2.

As observed by Anna, which one of the following statements correctly gives the order in which this signal is received by Barry and by the space lab?

A. Barry receives the signal first.

B. The space lab receives the signal first.

C. The signal is received by Barry and the space lab at the same time.

D. It is not possible to predict since special relativity applies to light but not to radio signals.

Anna sends the two pulses simultaneously from her perspective and both pulses travel at the same speed. The space lab is moving towards her while Barry moves away, so she will see the signal reach the spacelab first as it will travel a shorter distance. **ANS: B**

Question 3 (79%)

Figure 3 shows Carla moving towards a loudspeaker at a speed of v_C and Han running towards a light source at speed v_H.

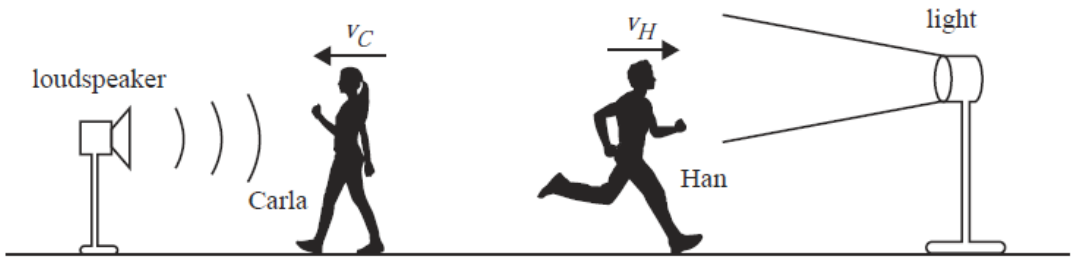


Figure 3

Which of the following correctly shows the speed of sound relative to Carla and the speed of light relative to Han? (The speed of sound in air is v_S.)

	Speed of sound relative to Carla	Speed of light relative to Han
A.	v_S	c
B.	$v_S + v_C$	$c + v_H$
C.	$v_S + v_C$	c
D.	$v_S - v_C$	$c - v_H$

ANS: C

Question 4 (75%)

Michelson and Morley conducted an important experiment on the propagation of light in 1887. However, the experiment failed to show an effect that was expected by many physicists of that time. A number of theories were proposed to explain this result.

Which one of the following statements best describes the most important step in knowledge of physics that followed from this Michelson–Morley result?

A. Einstein's first postulate on the laws of physics removed the problem of the Michelson–Morley result.

B. Einstein's second postulate on the speed of light directly explained the Michelson–Morley result.

C. The concept of an 'aether' (a medium that allowed light to propagate) was upheld.

D. Maxwell's equations were shown to be incorrect.

ANS: B

Question 11 (49%)

Which statement best describes the speed of light in various media, including a vacuum?

A. The speed of light in a material will vary if the material is moved at a high speed relative to a light source.

B. The speed of light in a material depends only on the amount of length contraction of the material.

C. The speed of light in a medium depends only on the electrical and magnetic properties of the medium.

D. The speed of light in a medium depends directly on the mass density of the material.

ANS: C

VCAA 2017

Question 10 (75%)

A student sits inside a windowless box that has been placed on a smooth-riding train carriage. He conducts a series of motion experiments to investigate frames of reference.

Which one of the following observations is correct?

A. The results when the train accelerates are identical to the results when the train is at rest.

B. The results when the train accelerates differ from the results when the train is in uniform motion in a straight line.

C. The results when the train is at rest differ from the results when the train is in uniform motion in a straight line.

D. The results when the train accelerates are identical to the results when the train is in uniform motion in a straight line.

Experiments conducted in inertial (non-accelerating) frames will be identical. Experiments conducted in accelerating frames will differ from experiments conducted in inertial frames. **ANS: B**

VCAA 2018

Question 14 (5%) (2 marks)

Jani is stationary in a spaceship travelling at constant speed.

Does this mean that the spaceship must be in an inertial frame of reference? Justify your answer.

Constant speed is not the same as constant velocity, and that the ship in question could be travelling in a circular path or it could be in orbit and still be traveling at a constant speed. Therefore, the spaceship may not be in an inertial frame of reference.

VCAA 2019

Question 11 (?%) (3 marks)

What is the second postulate of Einstein's theory of special relativity regarding the speed of light? Explain how the second postulate differs from the concept of the speed of light in classical physics.

The speed of light in a vacuum is independent of the relative motion of the source and observer.
Classically, speed depends on relative motion of source and observer:

- *If relative motion is approaching speed is increased*
- *If relative motion is away speed would decrease*

The speed of light would not necessarily be constant for all observers