IB · HL · Physics

2 hours 13 questions

Structured Questions

Galilean & Special Relativity

Reference Frames (HL) / Newton's Postulates of Time & Space / Galilean Relativity (HL) / Postulates of Special Relativity (HL) / Lorentz Transformations (HL) / Velocity Addition Transformations (HL) / Space-Time Interval (HL) / Time Dilation (HL) / Length Contraction (HL) / Simultaneity in Special Relativity (HL) / Space-Time Diagrams (HL) / Muon Lifetime Experiment (HL)

Easy (5 questions)	/38
Medium (4 questions)	/47
Hard (4 questions)	/37
Total Marks	**/122**

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Easy Questions

1 (a) State the two postulates of Special Relativity.

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(2 marks)

(b) Explain the term *inertial reference frame*.

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(1 mark)

(c) Person A on Train A is travelling north through the countryside. Person B is working from home in a farmhouse and watches Train A as it passes. Person C on Train C is traveling South on a parallel line. Person B sees Train A travelling at 50 m s^{-1} and Train C travelling at 35 m s^{-1}.

Calculate the velocity of Train A relative to Train C.

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(2 marks)

(d) A motorway runs parallel to the train tracks. Person D in Car D is travelling northbound at a speed of −40 m s^{-1} from the reference frame of Train A.

Determine the velocity of Car D from the reference frame of Person B.

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(3 marks)

2 (a) Explain what is meant by the term *proper length*.

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(1 mark)

(b) Explain what is meant by the term *proper time*.

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(1 mark)

(c) Proper length and proper time are said to be invariant.

Explain what is meant by the term *invariant*.

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(1 mark)

(d) Name one other invariant quantity.

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(1 mark)

3 (a) An event occurs in inertial reference frame S at the following coordinates:

- x = 60 m
- y = 30 m
- z = 15 m
- t = 20 s

A second inertial reference frame, S ', moves relative to S at a velocity of 0.5c. At t = 0 s, t' = 0 s.

Calculate the Lorentz factor for this moving reference frame.

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(1 mark)

(b) Determine the location of the x value in the moving reference frame, S'.

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(2 marks)

(c) State the coordinates of y and z in the S' reference frame.

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(2 marks)

(d) Determine the t coordinate in the S' reference frame.

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(1 mark)

4 (a) Arcturus is a bright star 37 light-years away from Earth.

State how long it takes light to reach Earth from Arcturus.

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(1 mark)

(b) 'The laws of physics permit travel to Arcturus in less time than it takes light to travel from Arcturus to Earth, without travelling faster than the speed of light.'

State whether you agree or disagree with the statement above. Explain your answer.

You should assume that technology has advanced enough to make deep space travel possible and focus only on the laws of physics.

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(3 marks)

(c) Determine how many years as measured on Earth it would take the spaceship to travel to Arcturus at a constant velocity of 0.8*c* relative to a stationary observer.

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(3 marks)

(d) Determine the time taken to travel to Arcturus from the reference frame of the spaceship.

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(4 marks)

5 (a) Muons are created in the upper atmosphere and have an average life-span of 2.2 μs. Muons travel at approximately 98% of the speed of light.

Show that muons can travel around 650 m in a life-time.

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(2 marks)

(b) Muons are created at a height of approximately 10 km above the surface of the Earth. However, detectors at the Earth's surface detect significant amounts of muons.

Name the two consequences of special relativity that make this phenomenon possible.

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(2 marks)

(c) Determine the dilated life-span of the muon from the Earth's reference frame.

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(3 marks)

(d) Determine the contracted length experienced by the muon in the muon's reference frame.

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(2 marks)

Medium Questions

1 (a) Describe the difference between Galilean relativity and special relativity.

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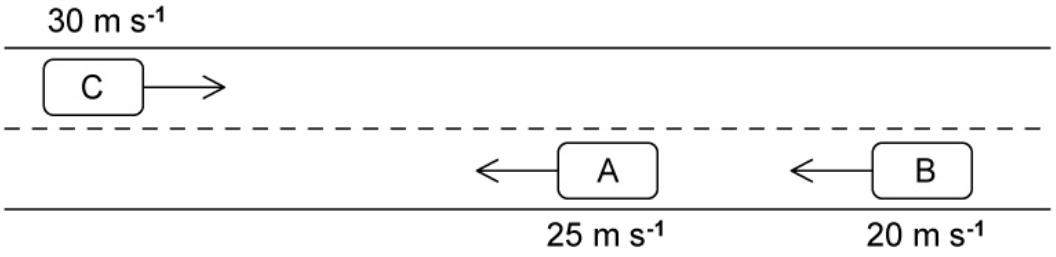
(2 marks)

(b) Car A travels at a constant velocity of 25 m s^{-1} relative to the road. Car B travels on the same road behind Car A at a constant velocity of 20 m s^{-1} relative to the road. Car C travels in the opposite direction to Cars A & B on the same road at a constant velocity of 30 m s^{-1} relative to the road.



Using ideas from Galilean relativity, explain why there is no such thing as 'true' velocity. You should include the velocity of Car A as an example in your answer.

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(4 marks)

(c) As Car A passes a stationary observer on the side of the road, a child in the back seat of Car A throws a teddy bear at the windscreen. The teddy bear moves at a constant velocity of 2 m s^{-1} relative to the passengers in Car A.

Calculate the velocity of the teddy bear as measured by the stationary observer on the side of the road.

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(2 marks)

(d) Determine the velocity of the teddy bear from the reference frame of Car C.

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(2 marks)

2 (a) A scientist on Earth is observing a flashing light 6.5×10^{15} m away. The scientist observes that the time between flashes is 32 s. A spaceship travelling at $0.8c$ also observes the flashing light. The spaceship passes Earth at exactly the time of a flash.

Calculate the distance from the spaceship to the flash at $t = 32$ s as measured by the crew on the spaceship.

(4 marks)

(b) Determine the time between flashes as measured from Earth.

(3 marks)

(c) The spaceship launches a probe toward the flashing light. The probe travels at $0.9c$ relative to the spaceship.

Calculate the speed of the probe as measured from Earth.

(3 marks)

(d) The probe sends a radio signal back to the spaceship transmitting data collected by the probe.

The radio signal travels at a constant velocity of *c* as measured by the spaceship.

Suggest a value for the velocity of the radio signal as measured from Earth. Explain your answer.

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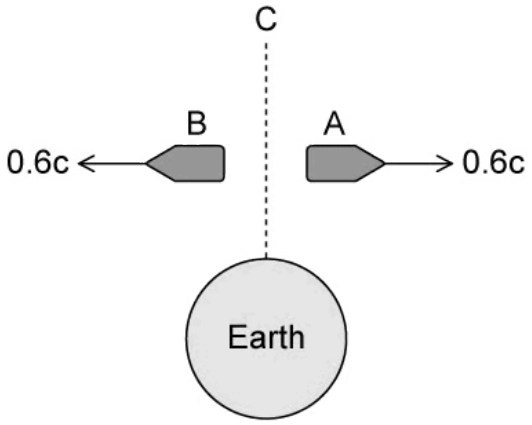
(3 marks)

3 (a) Spaceships A and B pass each other at point C where an observer is watching them from Earth. Spaceships A and B are identical and both travel at 0.6*c* in opposing directions as measured by the observer on Earth. The observer on Earth measures the separation of the spaceships increasing at a rate of 1.2*c*.



The observer claims they have disproved the law that nothing can travel faster than the speed of light.

Explain how the observer is mistaken.

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(2 marks)

(b) Spaceship A fires a laser beam out ahead just as it passes Earth.

Show that from the reference frame of an observer on Earth, the laser beam would be measured to travel at the speed of light, *c*.

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(3 marks)

(c) Spaceship D also passes point C at time $t = 0$. Spaceship D is travelling at $0.85c$ in the same direction as Spaceship B.

The observer on Earth detects a flash of light from Spaceship A at $t = 480$ s at a distance of 5.40×10^{10} m from point C.

The observer on Earth detects a flash of light from Spaceship D at $t = 555$ s at a distance of 7.65×10^{10} m from point C.

Determine whether the flashes occurred simultaneously for the observer on Earth.

(5 marks)

(d) Explain whether Flash A is detected before, after, or at the same time as Flash D for Spaceship B.

(4 marks)

4 (a) State and explain one piece of experimental evidence that supports the theory of special relativity.

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(3 marks)

(b) Muons are unstable particles that are created in the Earth's upper atmosphere. Muons have an average half-life of 1.49 μs as measured from the reference frame where the muon is at rest. Muons travel at a speed of 0.987*c* towards the surface of the Earth relative to Earth.

A detector positioned at 5196 m above the surface of the Earth detects muons at a rate of 3.2×10^4 per hour.

A second detector is positioned at ground level.

Calculate the half-life of the muons as measured by an observer on Earth.

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(2 marks)

(c) Calculate the distance between the detectors as measured from the reference frame of the muon.

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(1 mark)

(d) Suggest a prediction for the number of muons per hour detected by the detector on the ground.

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(4 marks)

Hard Questions

1 (a) A distant quasar is found to be moving away from Earth at a speed of 0.754c. Between Earth and the quasar lies a galaxy named ASG4-RD. The quasar is moving away from ASG4-RD at a speed of 0.629c.

Determine the recessional speed of the galaxy ASG4-RD relative to Earth.

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(2 marks)

(b) The spacecraft Lyra, in orbit around Earth, is sent by Mission Control to collect data on the galaxy ASG4-RD.

The Lyra travels at 0.555c relative to Earth in the x direction toward ASG4-RD. Part-way into it's mission, the Lyra sends the following message to Mission Control.

Collision of two asteroids detected at location ($x = 4.163 \times 10^{10}$ m, $t = 332$ s)

Determine the coordinates of the asteroid collision relative to Earth.

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(5 marks)

(c) The Lyra continues on its mission to ASG4-RD.

Determine the speed with which the Lyra would need to travel for the crew of the Lyra to age 10 years on the journey whilst 100 years passes for Mission Control.

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(2 marks)

2 (a) The Starship Phoenix travels 12 light years from Earth to the planet Okoye. The Phoenix travels at a constant velocity for the duration of the journey, and the crew stays on the planet Okoye for 2 years before returning at the same constant speed.

28 years have passed on Earth by the time the crew of the Phoenix returns.

Assume any time accelerating is negligible and that the distance between Earth and Okoye remains constant for the two years.

Calculate the speed of the Phoenix in metres per second.

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(2 marks)

(b) Determine how much time had passed for the crew of the Phoenix between leaving Earth and returning to Earth.

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(2 marks)

(c) Explain the difference in measured time between the crew of the Phoenix and the observers on Earth.

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(3 marks)

3 (a) The spaceships Centaurus and Auriga approach Earth from opposite directions at a speed of 2.394×10^8 m s^{-1} relative to each other. The length of each spaceship as measured in its rest frame is 9680 m.

Determine the length of the Centaurus as measured from the Auriga.

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(3 marks)

(b) The Centaurus and the Auriga fly past one another. As each crew sees the other ship approach, they measure the time it takes for the nose of their own vessel to pass the entire length of the other spacecraft.

Calculate:

(i) The time measured by the Centaurus for the Auriga to completely fly past it.
(ii) The amount of time that passes for the the crew of the Auriga.

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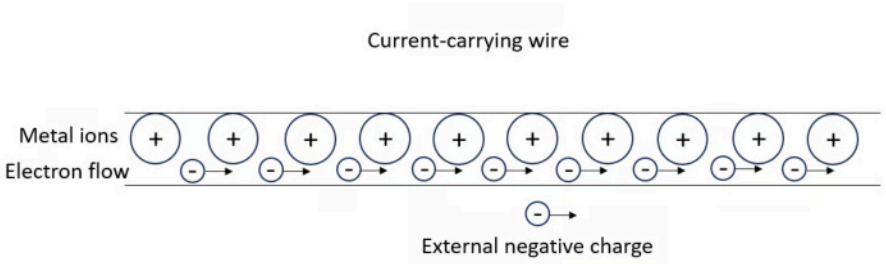
(4 marks)

(c) An engineer and a junior engineer are fixing an electrical wire on the Centaurus.

The engineer explains how special relativity is responsible for the fact that from the inertial reference frame of a stationary observer, an externally moving negative charge is attracted to a current carrying wire due to the magnetic field induced by the current. However, from the moving reference frame of the external negative charge, the negative charge is attracted to the wire due to the electric field induced by the current.



Use the phenomenon of length contraction to explain why this is the case.

(4 marks)

4 (a) A spaceship passes by Earth travelling at a speed of 0.679*c*. As it passes Earth, it launches a rocket out in front of the spaceship. The rocket travels at 0.967*c* relative to the spaceship.

Determine the speed of the rocket relative to Earth:

(i) Using Galilean relativity.
(ii) Using special relativity.

(3 marks)

(b) Sketch a spacetime diagram for the motion of the rocket for the *S* reference frame.

(2 marks)

(c) Add to your diagram form part (b) the axes for the *S*′ reference frame and draw the world line for the rocket from the *S*′ reference frame.

(5 marks)