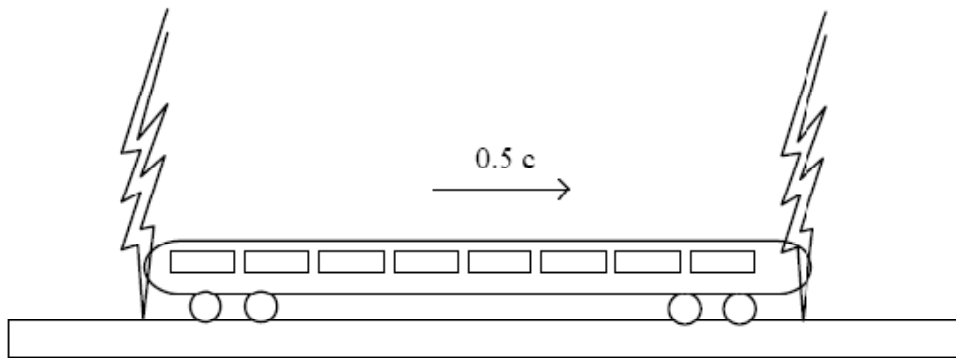


**Relativity and simultaneity**

(a) State the **two** postulates of the special theory of relativity.

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Einstein proposed a ‘thought experiment’ along the following lines. Imagine a train of proper length 100 m passing through a station at half the speed of light. There are two lightning strikes, one at the front and one at the rear of the train, leaving scorch marks on both the train and the station platform. Observer S is standing on the station platform midway between the two strikes, while observer T is sitting in the middle of the train. Light from each strike travels to both observers.



(b) If observer S on the station concludes from his observations that the two lightning strikes occurred simultaneously, explain why observer T on the train will conclude that they did **not** occur simultaneously.

(c) Which strike will T conclude occurred first?

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(d) What will be the distance between the scorch marks on the *train*, according to T and according to S?

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(e) What will be the distance between the scorch marks on the *platform*, according to T and according to S?

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**Space capsule**

Two space travellers Lee and Anna are put into a state of hibernation in a ventilated capsule in a spaceship, for a long trip to find another habitable planet. They eventually awake, but do not know whether the ship is still travelling or whether they have landed. They feel attracted toward the floor of the capsule, an experience rather like weak gravity. Lee says the spaceship must have landed on a planet and they are experiencing its gravitational attraction. Anna says the spaceship must be accelerating and the capsule floor is pushing on them.

- (a) Hoping to decide which of them is right, they try an experiment. They release a hammer in mid air, and it accelerates straight to the floor. Does this observation help them decide? How would *each* of them explain the motion of the hammer?

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- (b) They propose another experiment, namely to shine monochromatic light from the floor to the ceiling of the capsule and use sensitive apparatus to detect any change in frequency.

- (i) How would Lee explain how a redshift arises, viewing the radiation as photons moving in a gravitational field?

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- (ii) How would Anna explain how a redshift arises, viewing the radiation in terms of wavefronts arriving at a detector whose speed is increasing?

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- (c) Can Lee and Anna perform *any* experiment in the capsule which could distinguish whether they are on the surface of a planet or accelerating in space? .....

State why: .....

- (d) Later they notice that the gravitational-like sensation starts diminishing gradually, until they eventually 'float weightless' in the capsule. Lee suggests that they must have taken off from the planet, and as they got further away its gravitational attraction diminished until it was negligible. Anna suggests that the spaceship must have gradually reduced its thrust and acceleration to zero. Which explanation is feasible, or is there no way to tell who is right? Explain.

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**Decay in flight**

An unstable nucleus is moving with velocity  $0.5 c$  relative to the laboratory. While moving it decays by emitting an electron in the same direction of travel as the nucleus, at a speed of  $0.7 c$  relative to the nucleus.

- (a) If one attempted to use Galilean kinematics, what speed would be predicted for the electron relative to the laboratory?

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- (b) Using relativistic kinematics, calculate the speed of the electron as measured in the laboratory frame.

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- (c) Viewed from the laboratory frame, how much faster is the electron travelling than the nucleus?

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**Relativity and simultaneity**

(a) [1] for each postulate. [2]

(b) Could give sketch of situation (not required however):

Then show train moved a bit, toward one platform scorch mark and away from the other. Given that S sees flashes, travelling toward S with speed of light, as simultaneous. Observer T, moving relative to S, will be in a different position from S when flashes arrive, so for T they will *not* arrive simultaneously. The one coming from the front of the train will arrive first.

Since the speed of light for T will also be  $c$ , (irrespective of fact that T is moving relative to S), T will explain the different times of arrival, having travelled equal distances, as due to the flashes not having occurred simultaneously.

[1] for explanation of flashes not arriving simultaneously for T.

[1] for speed of light still  $c$  for T.

[1] for infer flashes did not occur simultaneously.

[1] for overall understanding, coherence and quality.

(c) T will say the front strike occurred first.

(d) For T: 100 m [1]

$$\begin{aligned} \text{For S: } & \frac{100}{\gamma} \text{ [1]} \\ & = \frac{100}{1.15} = 85 \text{ m [1]} \end{aligned}$$

(e) For S: 85 m (Simultaneous marking of train and platform at ends, and train is length contracted according to S). [1]

$$\text{For T: } \frac{85 \text{ m}}{\gamma} = \frac{85}{1.15} = 74 \text{ m [1]}$$

### Space capsule

- (a) Experiment does not help distinguish. [1]  
Lee would explain acceleration as due to gravitational force on the hammer. [1]  
Anna would say that if the spaceship is accelerating, the floor of the capsule accelerates toward the hammer [1],  
which just remains in the state of motion it had when released. [1] Hammer has not accelerated.  
(The above allocation is a guide: be flexible in awarding marks for explanations, looking for overall understanding.)
- (b) *Second experiment:*
- (i) Photons would lose energy as they go up against the gravitational field, thus photon frequency would decrease slightly, *i.e.* red shift.
- (ii) Each wave front of light would be detected in a frame which was moving slightly faster than the previous one, so that frequency of wave fronts detected would be less, *i.e.* shifted toward the red.
- (c) No. Equivalence principle [1].  
(Actually no or yes! A planetary gravitational field is not uniform, though very nearly so across the capsule. So, if they released two objects simultaneously, one above the other, the distance between them would increase as they fell (slightly). No student is likely to think of this, but accept either answer no or yes with supporting statement.)
- (d) Anna is likely to be right. [1]  
If a spaceship had taken off from the planet, there would have been a stage where sensation **increased** during blastoff, only later diminishing. [2]

**Decay in flight**

(a) Galilean:

$$0.5 c + 0.7 c = 1.2 c$$

(b) Relativistic:

Relativistic velocity addition:

$$u = \frac{(u' + v)}{\left( \frac{1 + u'v}{c^2} \right)} [1]$$

$$= \frac{(0.7 c + 0.5 c)}{\left( \frac{1 + 0.7 c \times 0.5 c}{c^2} \right)} [1]$$

$$= \left( \frac{1.2 c}{1 + 0.35} \right)$$

$$= \left( \frac{1.2}{1.35} \right) c$$

$$= 0.89 c [1]$$

(c)  $v = v_{\text{electron}} - v_{\text{nucleus}} [1]$

$$0.89 c - 0.5 c = 0.39 c [1]$$