

SPACE 4

Current and emerging understanding about time and space has been dependent upon earlier models of the transmission of light

2001

Question 16 (4 marks)

Muons are very short-lived particles that are created when energetic protons collide with each other. A beam of muons can be produced by very-high-energy particle accelerators.

The high-speed muons produced for an experiment by the Fermilab accelerator are measured to have a lifetime of 5.0 microseconds. When these muons are brought to rest, their lifetime is measured to be 2.2 microseconds.

(a) Name the effect demonstrated by these observations of the lifetimes of the muons.

1

(b) Calculate the velocity of the muons as they leave the accelerator.

3

Assessors report & Marking criteria

This question tested candidates' understanding of the time dilation effect of relativity, although some candidates did not recognise time dilation as the relevant concept. Most candidates were not able to manipulate the time dilation equation sufficiently well to achieve the correct answer.

Criteria	Marks
• Time dilation	1

Criteria	Marks
• Calculates the correct answer (units necessary)	3
EITHER • Time dilation equation correctly stated. Then with t_r and t_0 incorrectly substituted (but with answer appropriate to incorrect substitution) and recognition that the answer is physically absurd ($\frac{v^2}{c^2} < 0$) OR • Algebraic errors (but with answer pertinent to incorrect manipulation)	2
EITHER • Time dilation equation (correct) OR • Incorrect use of equation leading to correct calculation ending with $\frac{v^2}{c^2} < 0$. No recognition of physical absurdity OR • Gives correct value but shows no working (units may be omitted)	1

Suggested Answer – SUCCESS ONE

Question 19 (4 marks)

How does Einstein's Theory of Special Relativity explain the result of the Michelson–Morley experiment?

4

Assessors report & Marking criteria

This question assessed candidates' understanding of the Michelson-Morley experiment and its connection with the theory of special relativity. Many candidates were able to discuss relativity in the terms required by the question, however the link between relativity and the Michelson-Morley experiment was generally not well expressed. Many candidates included points not relevant to the results of the Michelson-Morley experiment.

Criteria	Marks
• An accurate understanding of the results of the Michelson-Morley experiment • An understanding of the Special Theory of Relativity • Demonstrates the link between the Michelson-Morley experiment and the Special Theory of Relativity	4
EITHER • Demonstrates some understanding of both the Michelson-Morley experiment and the Special Theory of Relativity OR • Demonstrates an accurate understanding of either the Michelson-Morley experiment or the Special Theory of Relativity	2–3
EITHER • Reference to the constant speed of light OR • Reference to no aether	1

Suggested Answer – SUCCESS ONE

- 2 A spaceship is travelling at a very high speed. What effects would be noted by a stationary observer?

- (A) Time runs slower on the spaceship and it contracts in length.
 (B) Time runs faster on the spaceship and it contracts in length.
 (C) Time runs slower on the spaceship and it increases in length.
 (D) Time runs faster on the spaceship and it increases in length.

Question 19 (4 marks)

In one of Einstein's famous thought experiments, a passenger travels on a train that passes through a station at 60% of the speed of light. According to the passenger, the length of the train carriage is 22 m from front to rear.

- (a) A light in the train carriage is switched on. Compare the velocity of the light beam as seen by the passenger on the train and a rail worker standing on the station platform.

1

- (b) Calculate the length of the carriage as observed by the rail worker on the station platform.

3

Assessors report & Marking criteria

- (a) A small number of candidates gave answers related to the time at which the passenger and worker saw the light, that is, they answered in terms of relativity of simultaneity.
 (b) This part was generally well answered. The most common errors involved transposing l_v and l_o not squaring (v^2/c^2). Many candidates did not use a methodical approach (Equation---> substitution---> answer).

Criteria	Marks
<ul style="list-style-type: none"> Correctly states ratio is 1:1 OR <ul style="list-style-type: none"> Velocity is seen to be the same value 	1
Criteria	Marks
<ul style="list-style-type: none"> Identifies the length contraction equation and calculates the correct answer 	3
<ul style="list-style-type: none"> Length contraction equation used correctly but student makes algebraic errors such as <ul style="list-style-type: none"> no square root/squaring fraction is inverted fraction is not subtracted from 1 	2
<ul style="list-style-type: none"> Correct choice of equation but incomplete or incorrect substitutions OR <ul style="list-style-type: none"> Length contraction equation used but l_v and l_o transposed so that the incorrect answer 27.5 m obtained 	1

Suggested Answer – SUCCESS ONE

Question 20 (3 marks)

A student is investigating inertial and non-inertial frames of reference. The student carries out a series of activities on a boat floating on a large, calm lake. The boat remained level during these activities.

3

Each activity and the student's observed results are recorded in the table.

Activity	Observation
Dropped a ball from a set height	Ball fell vertically with increasing velocity
Rolled a ball from one side of the boat to the other	Ball rolled across the floor with a constant velocity
Rolled a ball from the back of the boat towards the front of the boat	Ball rolled across the floor with a constant velocity

Justify the student's conclusion that: 'The boat can be regarded as an inertial frame of reference'.

Assessors report & Marking criteria

Many candidates failed to give the relevant information required in order to justify the conclusion. A significant number of candidates failed to refer to the observations made on the boat. Most candidates could describe an inertial frame of reference. The best candidates were succinct and their answers displayed a logical process.

Criteria	Marks
<ul style="list-style-type: none"> Falling ball's acceleration due to gravitational force only Balls moving horizontally do not exhibit acceleration An inertial frame of reference is defined or described correctly 	3
<ul style="list-style-type: none"> Any two of the above criteria 	2
<ul style="list-style-type: none"> Falling ball's acceleration due to gravitational force only OR <ul style="list-style-type: none"> Balls moving horizontally do not exhibit acceleration OR <ul style="list-style-type: none"> An inertial frame of reference is defined or described correctly 	1

Suggested Answer – SUCCESS ONE

Question 18 (6 marks)

Michelson and Morley set up an experiment to measure the velocity of Earth relative to the aether.

- (a) Outline TWO features of the aether model for the transmission of light. 2

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- (b) Recount the Michelson and Morley experiment, which attempted to measure the relative velocity of Earth through the aether, and describe the results they anticipated. 4

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Assessors report & Marking criteria

- (a) Most candidates did not correctly give two features of the aether model and instead gave two properties of aether.
- (b) Good responses consisted of a series of succinct, sequential steps, with a description of the anticipated result and using key phrases such as 'interferometer' and 'interference pattern'. Neat, labelled diagrams of the interferometer were a feature of many responses. Weaker responses illustrated poor understanding of the apparatus or procedure used by Michelson and Morley, or of the theoretical concepts involved.

Criteria	Marks
• Aether is medium for propagation of light/EM radiation and one other feature	2
• Aether is medium for propagation of light/EM radiation OR another feature	1

Criteria	Marks
<ul style="list-style-type: none"> Constructed an interferometer which splits a single beam of light and sent them on perpendicular paths and reflected them back Observed an interference pattern when light beams returned The arms of apparatus rotated through 90° and experiment repeated It was expected that the two interference patterns would be different since the earth's passage through the aether would affect the velocity of light 	4
• Includes three points from above	3
• Includes two points from above	2
OR	
• Correct diagram of interferometer	1
• Used an interferometer or description of interferometer	
OR	
• Use of interference patterns	
OR	1
• Any other one correct point from above	

Suggested Answer – SUCCESS ONE

Question 26 (6 marks)

Describe Einstein’s contributions to Special Relativity and to Quantum Theory and how these contributions changed the direction of scientific thinking in the Twentieth Century.

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Assessors report & Marking criteria

Many responses included some description of Einstein’s contribution to Special Relativity and to Quantum Theory, but few successfully linked the contributions to how they changed the direction of scientific thought in the 20th century.

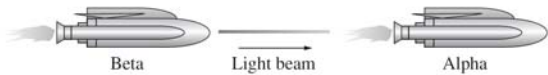
Criteria	Marks
• Describes a contribution to each field and how each contribution changed scientific thinking in the 20 th Century	6
• Description of a contribution to each field and how at least one contribution changed scientific thinking in the 20 th Century	5
• Describes a contribution to each field • OR • Describes a contribution to one field and how the contribution changed scientific thinking in the 20th century	4
• Description of contribution to one field and mentions a point from another	3
• Any relevant points from each field OR • Description of a contribution to one field	2
• Any one relevant point from either field	1

Suggested Answer – SUCCESS ONE

4 An object of rest mass 8.0 kg moves at a speed of 0.6c relative to an observer.
What is the observed mass of the object?

- (A) 6.4 kg
- (B) 10.0 kg
- (C) 12.5 kg
- (D) 13.4 kg

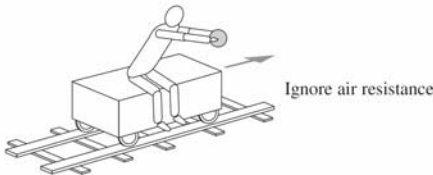
5 Two spaceships are both travelling at relativistic speeds. Spaceship Beta shines a light beam forward as shown.



What is the speed of the light beam according to an observer on spaceship Alpha?

- (A) The speed of the light beam is equal to c.
- (B) The speed of the light beam is less than c.
- (C) The speed of the light beam is greater than c.
- (D) More information is required about the relative speed of the spaceships.

6 A ball is dropped by a person sitting on a vehicle that is accelerating uniformly to the right, as shown by the arrow.



Which of the following represents the path of the ball, shown at equal time intervals, observed from the frame of reference of the vehicle?

(A)

(B)

(C)

(D)

2005

Question 17 (6 marks)

Einstein's 1905 theory of special relativity made several predictions that could not be verified for many years.

- (a) State ONE such prediction. 1

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- (b) Describe an experiment to test this prediction. 2

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- (c) Explain how technological advances since 1905 have made it possible to carry out this experiment. 3

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Assessors report & Marking criteria

- (a) Better responses to this question began with a simple statement such as 'time dilation'.
- (b) Better responses described a valid experiment for the statement in part (a) eg one involving two atomic clocks, one on a high speed jet and the other earth-bound.
- (c) Better responses provided a clear explanation of how the nominated technological advances allowed the experiment to be successfully completed.
Weaker responses did not link parts (a), (b) and (c).

Criteria	Marks
• Correctly states one prediction	1
Criteria	Marks
• Identifies and provides features and characteristics of the correct experiment	2
• Identifies the correct experiment	1
Criteria	Marks
• Names and describes two advances and relates them to the experiment	3
• Names two advances OR • Names and describes one advance and relates it to the experiment	2
• Names one advance	1

Suggested Answer – SUCCESS ONE

Question 18 (4 marks)

The idea of a universal aether was first proposed to explain the transmission of light through space. Michelson and Morley attempted to measure the speed of Earth through the aether.

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Evaluate the impact of the result of the Michelson and Morley experiment on scientific thinking.

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Assessors report & Marking criteria

Better responses discussed the impact on the scientific community of the result of the Michelson-Morley experiment and its implication for the existence of the aether. This shifted scientific thinking from classical theory to relativity.

Criteria	Marks
• Makes a judgement of the impact of the result based on evidence provided	3–4
• Relates the results to Einstein's Special Theory of Relativity	2
• States the result of the Michelson and Morley experiment	1

Suggested Answer – SUCCESS ONE

2006

- 3 What is the main reason why the Michelson-Morley experiment is considered important?
- (A) It shows the existence of the aether.
 - (B) It suggests that light is an electromagnetic wave.
 - (C) It indicates that light can exhibit interference effects.
 - (D) It provides experimental support for the theory of relativity.

Question 25 (6 marks)

- (b) In a special investigation, the voltage between the cathode and the anode is increased so that an electron gains a velocity of $0.60c$, where c is the speed of light. The electron starts from rest at the cathode. 2

Calculate the mass of this electron in the laboratory frame of reference.

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- (c) The distance between the anode and the screen, as measured in the electron's frame of reference, is 0.24 m . 2

Calculate this distance as measured in the laboratory frame of reference.

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Assessors report & Marking criteria

- (c) The better responses manipulated the equation to provide a correct interpretation about the frame of reference.

Criteria	Marks
• Correctly outlines roles of the deflection plates and the electrodes in the electron gun	2
• Correctly outlines role of either the deflection plates or the electrodes in the electron gun	1
Criteria	Marks
• Correctly identifies and substitutes data into equation	2
• Identifies correct equation	1
Criteria	Marks
• Correctly identifies and substitutes data into equation	2
• Identifies correct equation	1

Suggested Answer – SUCCESS ONE

2007

- 2 A spaceship sitting on its launch pad is measured to have a length L . This spaceship passes an outer planet at a speed of $0.95c$.

Which observations of the length of the spaceship are correct?

	Observer on the spaceship	Observer on the planet
(A)	No change	Shorter than L
(B)	No change	Greater than L
(C)	Shorter than L	No change
(D)	Greater than L	No change

Question 18 (7 marks)

- (a) How has our understanding of time been influenced by the discovery of the constancy of the speed of light?

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- (b) A piece of radioactive material of mass 2.5 kilogram undergoes radioactive decay. How much energy is released if 10 grams of this mass are converted to energy during the decay process?

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- (c) A mass is moving in an inertial frame of reference at a velocity v relative to a stationary observer. The observer measures an apparent mass increase of 0.37%.

Calculate the value of v in m s^{-1} .

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Assessors report & Marking criteria

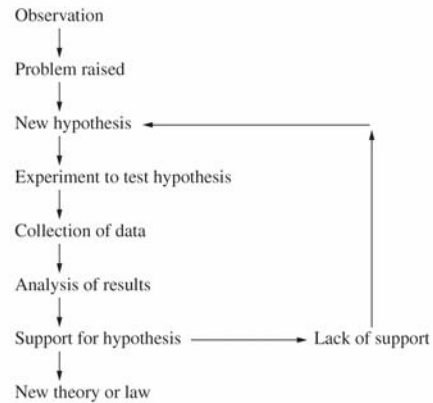
- (a) Better responses provided supporting evidence for the link between the constancy of the speed of light and time, for example time dilation.
- (b) In better responses, candidates correctly substituted into the correct equation.
- (c) Best responses correctly rearranged the relevant equation to calculate the velocity.

Criteria	Marks
<ul style="list-style-type: none"> Refers to c as a constant, so time is relative to observer Refers to c as a constant, so time can be used to define length OR <ul style="list-style-type: none"> States an example of time dilation of a rapidly moving object 	2
<ul style="list-style-type: none"> Refers to c as a constant, so time is relevant to observer OR <ul style="list-style-type: none"> Refers to c as a constant, so that time can be used to define length OR <ul style="list-style-type: none"> States an example of time dilation of a rapidly moving object 	1
Criteria	Marks
<ul style="list-style-type: none"> Identifies correct formula AND correctly substitutes 	2
<ul style="list-style-type: none"> Identifies correct formula 	1
Criteria	Marks
<ul style="list-style-type: none"> Identifies correct formula and correctly substitutes Manipulates correct formula to extract v 	3
<ul style="list-style-type: none"> Identifies correct formula and correctly substitutes 	2
<ul style="list-style-type: none"> Identifies correct formula 	1

Suggested Answer – SUCCESS ONE

Question 19 (6 marks)

This flowchart represents one model of scientific method used to show the relationship between theory and the evidence supporting it.



Analyse Einstein's Theory of Special Relativity and the evidence supporting it as an application of this model of scientific method.

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Assessors report & Marking criteria

In better responses, candidates stated Einstein's theory as a hypothesis and then linked it to the parts of the Scientific Method by indicating some or all of the testable predictions that arose from it.

Criteria	Marks
<ul style="list-style-type: none"> Demonstrates a thorough knowledge of scientific method and Einstein's Theory of Special Relativity and the evidence supporting it Identifies the evidence to support Einstein's Theory of Special Relativity Outlines the development and acceptance of the theory Links the development of the theory and the evidence supporting it to the steps in the model of scientific method Demonstrates coherence and logical progression and includes correct use of scientific principles and ideas 	5-6
<ul style="list-style-type: none"> Demonstrates knowledge of scientific method and Einstein's Theory of Special Relativity and the evidence supporting it AND EITHER <ul style="list-style-type: none"> Describes the development and acceptance of the theory and evidence used to support it OR <ul style="list-style-type: none"> Describes some aspects of the theory, some evidence supporting it and attempts to relate this to the steps in the model of scientific method 	3-4
<ul style="list-style-type: none"> Demonstrates a limited knowledge of scientific method and Einstein's Theory of Special Relativity AND EITHER <ul style="list-style-type: none"> Describes some aspects of Einstein's theory OR <ul style="list-style-type: none"> Describes some parts of the model of scientific method including 3 steps 	1-2

Suggested Answer – SUCCESS ONE

