Turning Points in Physics 3

1.

(a)

A student models a spacecraft journey that takes one year. The spacecraft travels directly away from an observer at a speed of 1.2×10^7 m s^{-1}. The student predicts that a clock stationary relative to the observer will record a time several days **longer** than an identical clock on the spacecraft.

Comment on the student's prediction. Support your answer with a time dilation calculation.

[4 marks]

(b)

In practice, the gravitational field of the Sun affects the motion of the spacecraft and it does not travel directly away from the Earth throughout the journey.

Explain why this means that the theory of special relativity cannot be applied to the journey.

[2 marks]

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2.

Cosmic rays detected on a spacecraft are protons with a total energy of 3.7×10^9 eV.

Calculate the velocity of the protons as a fraction of the speed of light.

[3 marks]

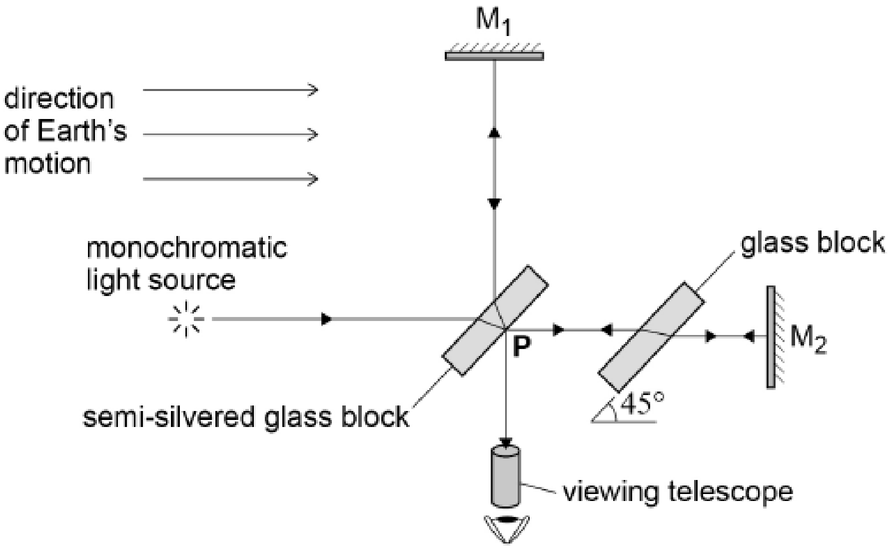
proton velocity = ____________________ c

3.

Figure 6 shows a diagram of the Michelson-Morley interferometer that was used to try to detect the absolute motion of the Earth through the ether (æther).

Light from the monochromatic source passes through the semi-silvered glass block and takes two different paths to the viewing telescope. The two paths, PM_1 and PM_2, are the same length. Interference fringes are observed through the viewing telescope.

Figure 6



It was predicted that when the interferometer was rotated through 90° the fringe pattern would shift by 0.4 of the fringe spacing.

(a)

Explain how the experiment provided a means of testing the idea that the Earth had an absolute motion relative to the ether.

Your answer should include:

- an explanation of why a shift of the fringe pattern was predicted
- a comparison of the results of the experiment to the prediction
- the conclusion about the Earth's absolute motion through the ether.

[6 marks]

(b)

The Michelson-Morley experiment provides evidence for one of the postulates of Einstein's theory of special relativity.

State this postulate.

[1 mark]

(c)

State the other postulate of Einstein's theory of special relativity.

[1 mark]

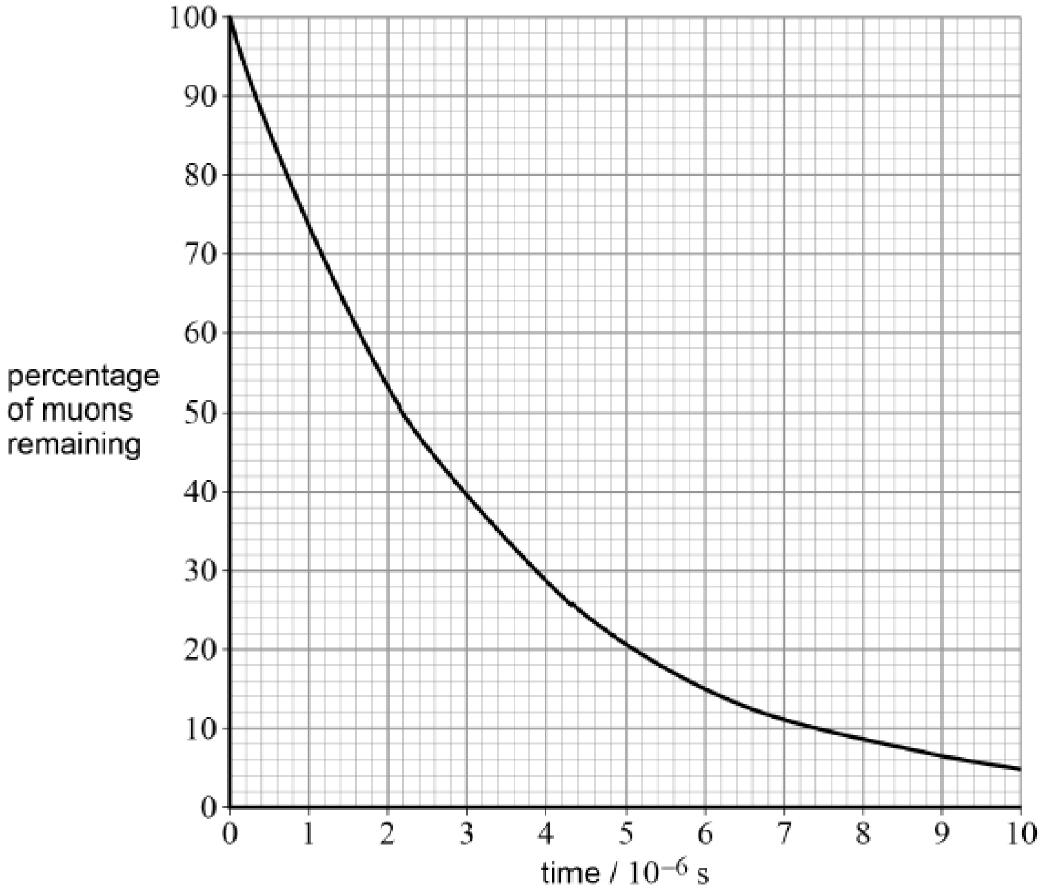
(d)

One consequence of the special theory of relativity is length contraction.

Experimental evidence for length contraction is provided by the decay of muons produced in the atmosphere by cosmic rays.

Figure 7 shows how the percentage of the number of muons remaining in a sample changes with time as measured by an observer in a frame of reference that is stationary relative to the muons.

Figure 7



In a particular experiment, muons moving with a velocity $0.990c$ travel a distance of 1310 m through the atmosphere to a detector.

Determine the percentage of muons that reach the detector.

[4 marks]

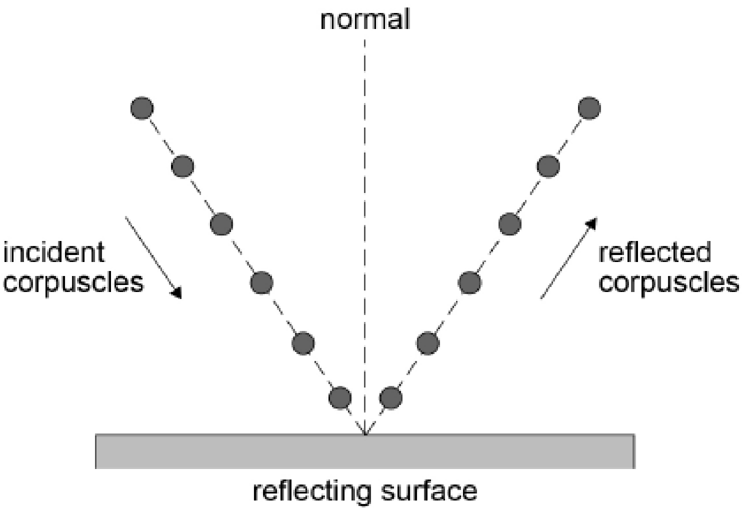
percentage = ____________________________ %

4.

Newton used a corpuscular theory of light to explain reflection.

Figure 2 shows how corpuscles would reflect from a horizontal surface.

Figure 2



(a)

What happens to the horizontal and vertical components of the velocity of the corpuscles, according to the theory, when they are reflected?

Tick (✓) **one** box.

[1 mark]

Horizontal component of velocity	**Vertical component of velocity**	**Tick the correct box**
Unchanged	Changed	
Changed	Unchanged	
Unchanged	Unchanged	
Changed	Changed	

(b)

Newton used the corpuscular theory to explain the refraction of light at an interface between air and water.

Huygens used the wave theory to explain the refraction of light at the interface.

Discuss the evidence that led to the rejection of Newton's corpuscular theory.

In your answer you should include
- how each theory explains refraction
- how experimental evidence led to the acceptance of the wave theory.

[6 ma

(c)

Light is now known to behave as an electromagnetic wave.

Describe a plane-polarised electromagnetic wave travelling through a vacuum.
You may wish to draw a labelled diagram.

[3 marks]

5.

Table 1 shows data of speed v and kinetic energy E_k for electrons from a modern version of the Bertozzi experiment.

Table 1

v / 10^8 m s^{-1}	E_k / MeV
2.60	0.5
2.73	0.7
2.88	1.3
2.96	2.6
2.99	5.8

(a)

Classical mechanics predicts that $E_k \propto v^2$.

Deduce whether the data in **Table 1** are consistent with this prediction.

[2 marks]

(b)

Discuss how Einstein's theory of special relativity explains the data in **Table 1**.

[4 marks]

(c)

Calculate, in J, the kinetic energy of one electron travelling at a speed of $0.95c$.

[3 marks]

kinetic energy = ____________________ J

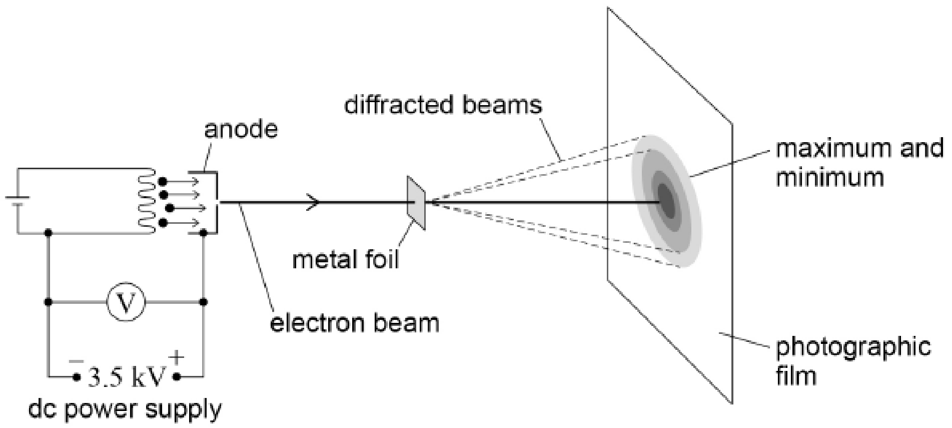
6.

Figure 3 shows part of the apparatus used to investigate electron diffraction.

Electrons were accelerated through a potential difference to form a beam which was then incident on a thin metal foil.

Regions of maximum and minimum intensity formed on a photographic film behind the foil.

Figure 3



(a)

State de Broglie's hypothesis.

[2 marks]

(b)

The voltmeter in **Figure 3** shows a reading of 3.5 kV.

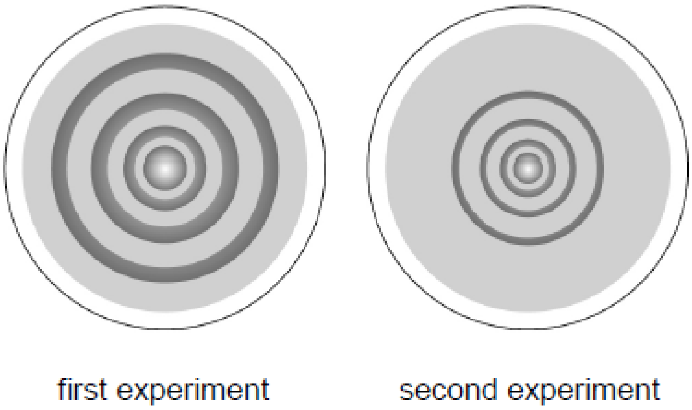
Determine whether this voltmeter reading is consistent with a de Broglie wavelength for the electrons in the beam of about 0.02 nm.

[2 marks]

(c)

The experiment is repeated using a similar arrangement to that shown in **Figure 3**.
Figure 4 shows the diffraction patterns from the two experiments.

Figure 4



State and explain **two** independent changes that could be made to the arrangement in **Figure 3** to produce the result shown for the second experiment in **Figure 4**.

[4 marks]

First change ____

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Second change ____

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