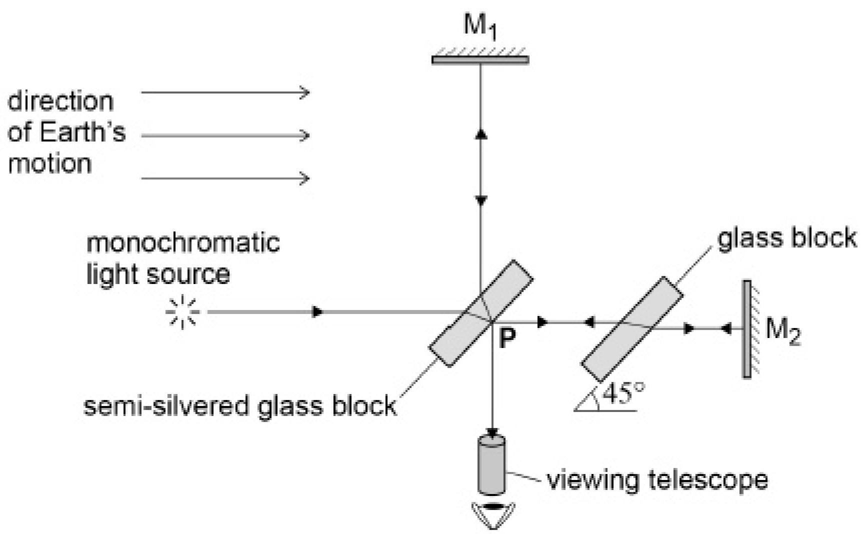
4 **Figure 1** shows a diagram of the Michelson-Morley interferometer that was used to try to detect the absolute motion of the Earth through the ether (æther).

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 1



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)

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

State this postulate.

(1)

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

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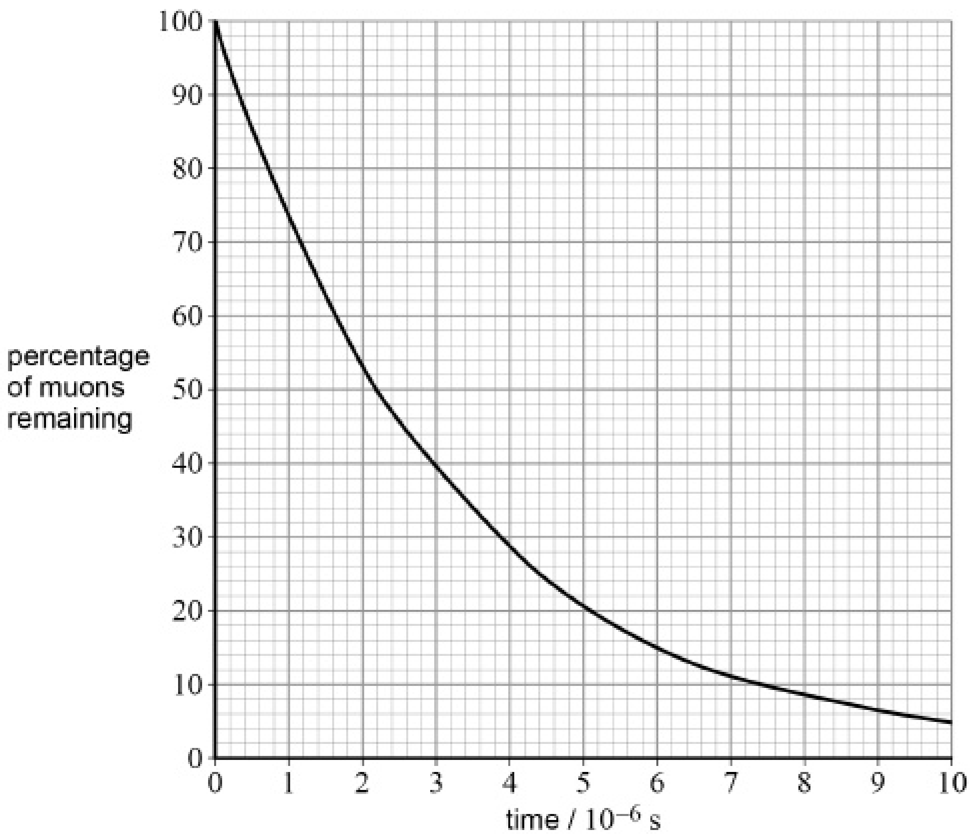
(1)

(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 2 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 2



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.

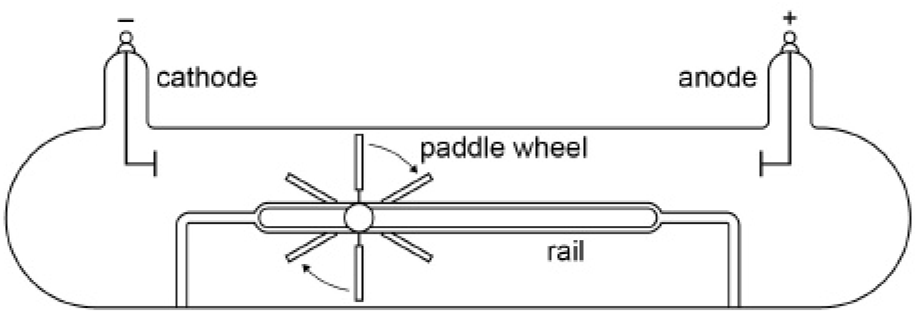
percentage = ____________________ %

(4)

(Total 12 marks)

5 The diagram shows a gas discharge tube devised by William Crookes in one of his investigations.

When a large potential difference is applied between the cathode and anode the paddle wheel is seen to rotate and travel along the rail towards the anode.



(a) Explain how this experiment led Crookes to conclude that cathode rays are particles and that these particles caused the movement of the paddle.

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(2)

8 (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.

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(4)

(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.

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(2)
(Total 6 marks)

13 (a) Bertozzi's experiment was designed to test the relationship between the kinetic energy of an electron and its speed as predicted by the theory of special relativity.

Describe Bertozzi's experiment.

Your answer should include:

- a diagram of the experimental arrangement
- details of how the kinetic energy and the speed were measured.

(6)

(b) A scientist conducts an experiment similar to Bertozzi's experiment and reports that when the electron speed is 2.93×10^8 m s^{-1} the measured kinetic energy is 2.4 MeV.

Determine whether these data are consistent with the result expected using the theory of special relativity.

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(4)

(Total 10 marks)

14 In a transmission electron microscope (TEM) electrons are accelerated by a potential difference V between a cathode and anode. The de Broglie wavelength λ of the accelerated electrons depends on V.

(a) Identify which of the following represents the relationship between λ and V. Ignore relativistic effects.

Tick (✓) the correct answer in the right−hand column

	✓ if correct
$\lambda \propto \sqrt{V}$	
$\lambda \propto V$	
$\lambda \propto \frac{1}{V}$	
$\lambda \propto \frac{1}{\sqrt{V}}$	

(1)