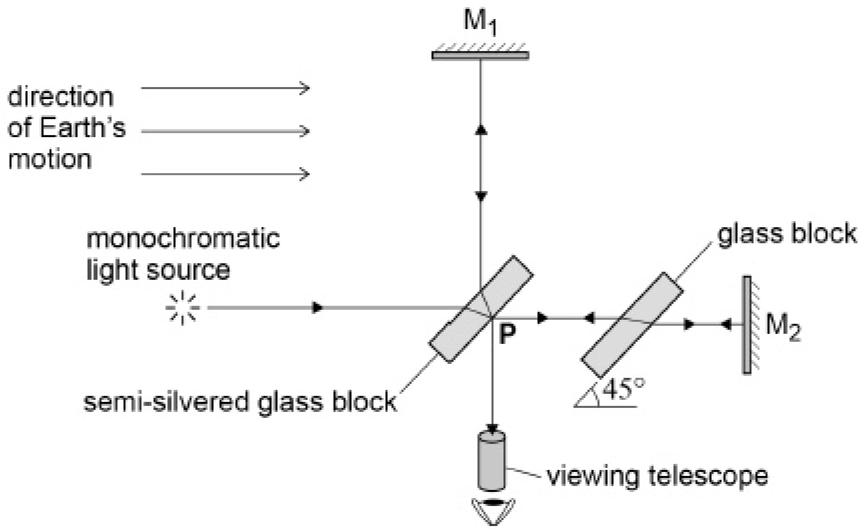
4 **Figure 1** shows a diagram of the Michelson-Morley interferometer that was used to try to detect the absolute motion of the Earth through the ether (æther).

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.

It was expected that the time there and back along PM2 would be greater than the time via PM1 since the ether was thought to exist and that earth was moving through it. This would effectively mean that the velocity of light would be altering. In other words the ether was the medium through which light traveled, or could be thought of as an absolute reference frame against which everything could be measured.

The coherent light would therefore have a phase difference introduced and so a interference pattern would be expected.

When the apparatus was rotated by 90 degrees the effect of the ether on the relative velocities would swap, meaning that the interference pattern would move. (The pattern would be the same, it would move slightly)

No such movement was seen.

This meant that the Newton's laws did not apply to light.
No absolute motion for the earth could be detected - ie the light took the same time to travel each way.
Ether did not exist - ie E/M waves didn't need a medium

(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.

see above

(6)

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

State this postulate.

Speed of light invariant in free space (vacuum). IE speed to light does not change

(1)

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

Laws apply across INERTIAL reference frames - ie frames that are not accelerating and hence at constant velocity

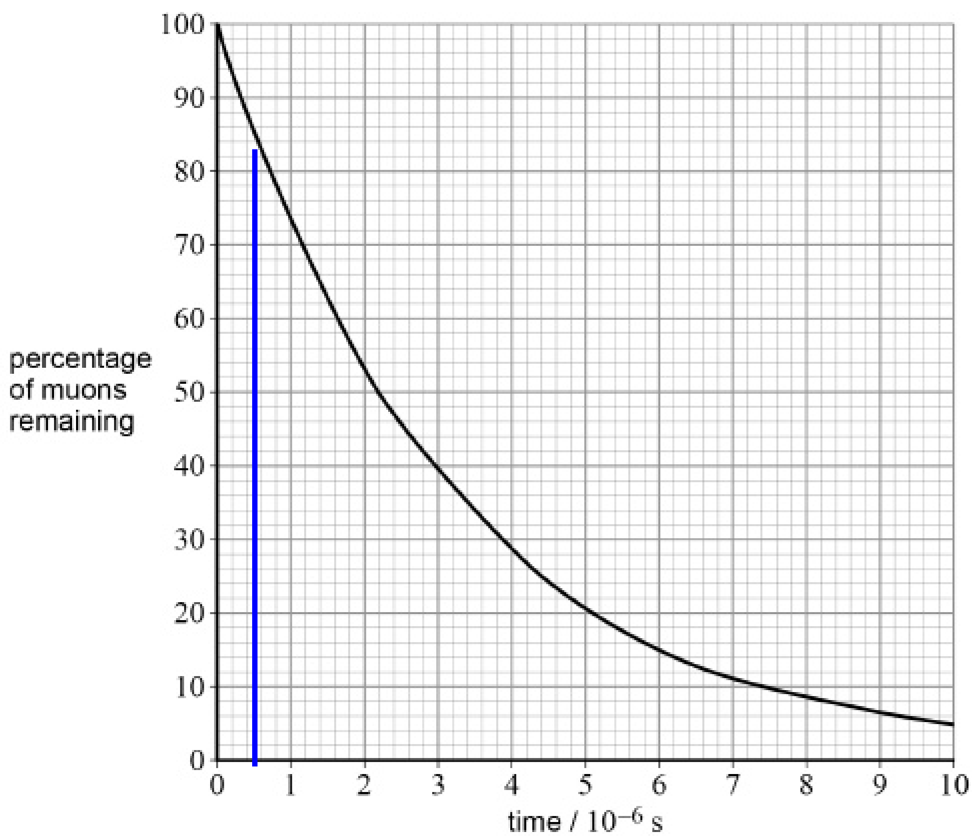
(1)

(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.

Stationary obserer realtive to the muon would be riding along with it
these time measurements are not made by a in a non-moving frame since the muon is moving so they will give t, not t0.
v=d/t so t = 1310/(0.99xC)=4.41x10^-6s. this is t

$$t = \frac{t_0}{\sqrt{1 - \frac{v^2}{c^2}}} \Rightarrow t_0 = t\sqrt{1 - 0.990^2}$$

$$t_0 = 5.84 \times 10^{-7}\ s$$

percentage = 82 ± 1 %

(4)

(Total 12 marks)

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.

$v = \frac{d}{t}$

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

Student is stationary wrt the clock therefore measures proper time.
t0=365*24*60*60s =3.1536x10^7

$$t = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$$

t=3.1561259x10^7 - yes, lots of figures - justified???

so dilation is t-t0 = 25259s => 0.29 days
So time gets longer, but not as much as pupil suggested

(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.

it is accelerating because it has a curved path. (Or it is not in an intertial frame - where N1 is obeyed)

and Special relativity requires no accel/intertial frame

(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.

____

____

____

____

____

____

____

____

(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)