(d) One consequence of the special theory of relativity is length contraction. (1

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

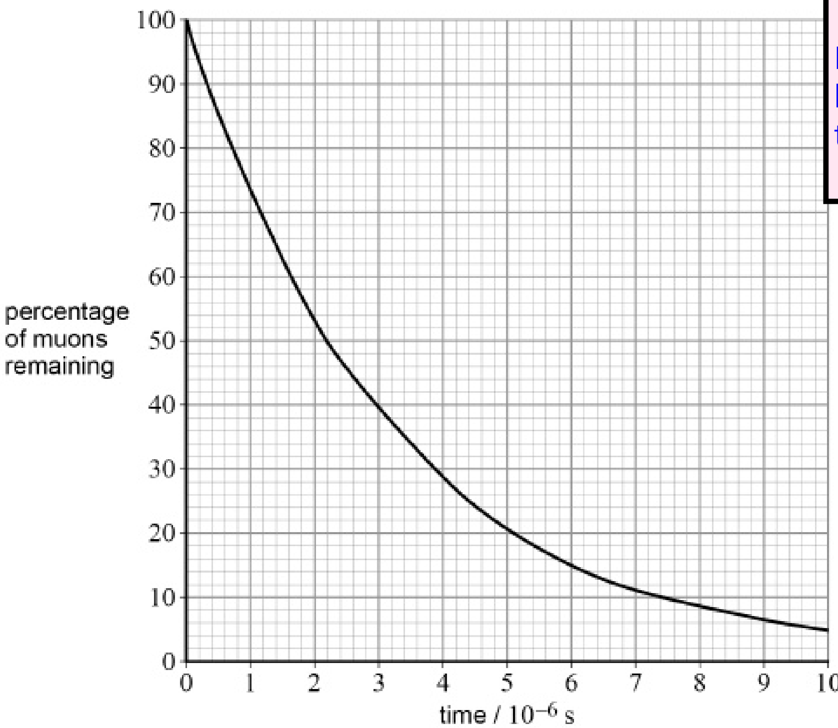
Figure 2 shows how the percentage of the number of muons remaining in a sample changes with time as measured by an observer in a frame of reference that is stationary relative to the muons.

In a particular experiment, muons moving with a velocity 0.990*c* travel a distance of 1310 m through the atmosphere to a detector. **(1)**

Determine the percentage of muons that reach the detector.

from observers perspective it takes 1310/.99c seconds to travel = 4.41x10^-6s - the observer is not stationary relative to the muon so this is t

From the muon's perspective this is going to be shorter The muon is obv stationary relative to itself and so we want to get t₀



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

$t_0 = 4.41\times10^{-6}\left(\sqrt{1-0.99^2}\right)$

$t_0 = 6.2\times10^{-7}$ s

From graph this gives ~ 82%

Do not write outside the box

0 4 . 1 State what is meant by an inertial frame of reference.

[1 mark]

newton's first law applies - moving at a constant velocity

0 4 . 2 A pair of detectors is set up to measure the intensity of a parallel beam of unstable particles.
In the reference frame of the laboratory, the detectors are separated by a distance of $45\ \text{m}$. The speed of the particles in the beam is $0.97c$.

The intensity of the beam at the second detector is 12.5% of the intensity at the first detector.

Calculate the half-life of the particles in the reference frame in which they are at rest.

[4 marks]

$12\frac{1}{2}\%$ is 3 half lives.

t of flight from observer $= \frac{45}{0.97c} = 1.54 \times 10^{-7}$ s

This is t, not t_0. We need t_0

$t_0 = t\sqrt{1 - \frac{v^2}{c^2}} = 3.76 \times 10^{-8}$ s

$t_{1/2} = t_0/3$

half-life = 1.3×10^{-8} s

0 4 . 3 In calculations involving time dilation, it is important to identify proper time.

Identify the proper time in the calculation in Question **04.2**.

[1 mark]

As measured by by the particle moving - like sitting on the particle with a clock, traveling along with it

6

END OF QUESTIONS

2020

Do not write outside the box

0 4 . 1 A muon travels at a speed of $0.95c$ relative to an observer.

The muon travels a distance of 2.5×10^3 m between two points in the frame of reference of the observer.

Calculate the distance between these two points in the frame of reference of the muon.

[2 marks]

muon is doing the moving so we are after the proper length l_0

$L\sqrt{1-\frac{v^2}{c^2}} = L_0 = 780\text{ m}$

distance = ____________________ m

0 4 . 2 Measurements of muons created by cosmic rays can be used to demonstrate relativistic time dilation.

State the measurements made and the observation that provides evidence for relativistic time dilation.

[2 marks]

muons decay and we know the half life when they are stationary. Measure the intensity at the top of a mountain and the bottom. Compare. You get many more at the bottom than expected. This means that time for the muon's clock time as run a bit slower and therefore fewer particles will have decayed. So time has dilated for the muon

Do not write outside the box

0 4 . 3 As the muons travel through the atmosphere, their speeds are reduced by interaction with the particles in the air.

Discuss, with reference to relativity, the effect that this reduction of speed has on the rate of detection of the muons on the surface of the Earth.

[3 marks]

their speeds are reduced so for both frames they will take longer.

Also the time dilation effect is reduced as per the Lorentz factor. This means that there will be more decays

7

END OF QUESTIONS

0 4 **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

0.073

0.094

0.156

0 4 . 1 Classical mechanics predicts that $E_k \propto v^2$.

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

[2 marks]

$\frac{E_k}{v^2} = \text{const}$

not constant

Do not write outside the box

0 4 . 2 Discuss how Einstein's theory of special relativity explains the data in **Table 1**.

[4 marks]

Particles mass increases as they get faster so therefore Ek goes up more than expected.

v has an upper limit and the Lorentz factor increases rapidly as you get closer to c meaning that the mass increases rapidly too

The increase in Ek si therefore due to the rapid increase in mass

0 4 . 3 Calculate, in J, the kinetic energy of one electron travelling at a speed of $0.95c$.

[3 marks]

$m = \frac{m_0}{\sqrt{1 - v^2/c^2}}$ $\quad m_0 = 9.11 \times 10^{-31}$ kg

$\therefore$ now $m = 2.9 \times 10^{-30}$ kg

So $E_k = \frac{1}{2} \times 2.9 \times 10^{-31} \times (0.95c)^2$

$= 1.2 \times 10^{-13}$ J

kinetic energy = ____________ J

9

END OF QUESTIONS