Answer ALL questions.

All multiple choice questions must be answered with a cross ☒ in the box for the correct answer from A to D. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

1 Which of the following particles is an example of a fundamental particle?

☐ **A** nucleus

☐ **B** neutrino

☐ **C** pion

☐ **D** proton

(Total for Question 1 = 1 mark)

16 A muon (μ) is a lepton with a mass of 106 MeV/c^2.

(a) Calculate the mass of a muon in kg.

(3)

Mass of muon = ... kg

(b) Muons are produced from the decay of pions in the upper atmosphere.

An example of this decay is given by the equation

$$\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$$

(i) Explain how this decay obeys the laws of conservation of charge, baryon number and lepton number.

(3)

(ii) The masses of these three particles, in MeV/c^2, are given below.

π^-	μ^-	$\bar{\nu}_\mu$
140	106	≈0

Explain why the total kinetic energy of the products of this decay is approximately 34 MeV. Assume the π^- is stationary.

(2)

(iii) State which two conservation laws could be used to calculate the kinetic energy of the μ^- and the $\overline{\nu}_\mu$ just after the decay of the π^-.

(2)

*(iv) The muons are produced at a height of 10 km in the atmosphere. The velocity of the muons is $0.99c$. The average lifetime for muons is normally 2.2 μs and yet muons produced in the upper atmosphere are found in significant numbers at sea level.

Discuss this apparent anomaly.

(6)

(Total for Question 16 = 16 marks)

9 Electric and magnetic fields can be used in particle accelerators.

Which row in the table correctly describes the use of electric and magnetic fields in the particle accelerator indicated?

	Particle accelerator	Magnetic field	Electric field
☒ **A**	cyclotron	not used	used to accelerate particles
☒ **B**	cyclotron	used to accelerate particles	used to accelerate particles
☒ **C**	linac	used to accelerate particles	not used
☒ **D**	linac	used to accelerate particles	used to accelerate particles

(Total for Question 9 = 1 mark)

10 Which of the following particle equations is correct for the decay of a proton within a nucleus?

☒ **A** $p \rightarrow n + \beta^+$

☒ **B** $p \rightarrow p + \beta^+$

☒ **C** $p \rightarrow n + \beta^+ + \nu$

☒ **D** $p \rightarrow p + \beta^+ + \nu$

(Total for Question 10 = 1 mark)

15 The discovery of the Higgs particle was an important contribution to our understanding of particle physics.

(a) Describe the standard model for subatomic particles. You should identify the fundamental particles and the composition of the particles we can observe.

(5)

(b) The mass of the Higgs particle is 2.2×10^{-25} kg.

Calculate this mass in GeV/c^2.

(3)

Mass = ... GeV/c^2

(c) The Higgs particle was discovered using the Large Hadron Collider (LHC) in 2012. Two beams of very high energy protons, moving in opposite directions, were made to collide.

(i) Explain the need for such high energy collisions.

(3)

(ii) The beams of protons are contained within a ring of superconducting magnets.

Calculate the momentum of a proton in a beam.

(3)

magnetic field strength = 8.3 T
circumference of the ring = 27 km

Momentum = ...

(iii) State the total momentum of the products of the collision between the two beams of protons.

(1)

Total momentum = ...

(d) The LHC accelerates protons until they gain energies of about 7 TeV.

A student used the equation $E_k = \frac{p^2}{2m}$ to predict the energy of a proton in the beam, using the momentum calculated in (c)(ii), but found the energy was far higher than 7 TeV.

Explain why.

(2)

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(Total for Question 15 = 17 marks)