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

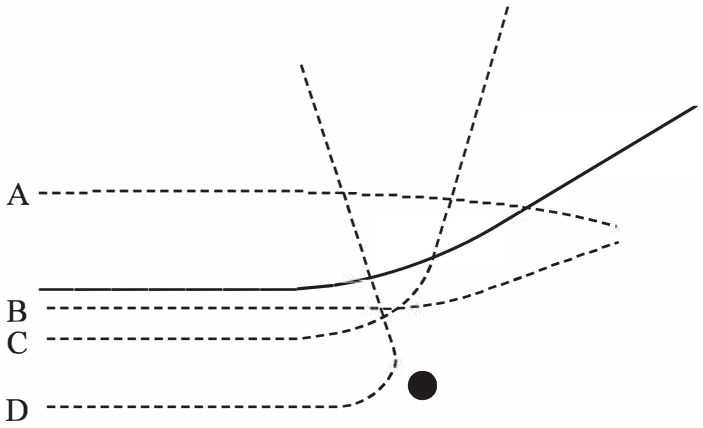
☐ **C** pion

☐ **D** proton

(Total for Question 1 = 1 mark)

(Total for Question 2 = 1 mark)

10 The solid line shows the path of an alpha particle as it passes close to a nucleus.



Another alpha particle approaches the nucleus with the same initial kinetic energy.

Which dashed path is possible for this alpha particle?

☒ **A**

☒ **B**

☒ **C**

☒ **D**

(Total for Question 10 = 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)

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 is an example of a scalar quantity?

☒ **A** displacement

☒ **B** energy

☒ **C** momentum

☒ **D** velocity

(Total for Question 1 = 1 mark)

2 Which row of the table summarises the mass and charge of an antineutron?

	Mass / u	Charge / e
☒ **A**	0	0
☒ **B**	0	−1
☒ **C**	1	0
☒ **D**	1	+1

(Total for Question 2 = 1 mark)

3 The distance between a proton and an electron is r. The electrostatic force is F.

The distance between the proton and electron is doubled.

Which of the following is equal to the electrostatic force at this separation?

☒ **A** $2F$

☒ **B** $\frac{F}{2}$

☒ **C** $\frac{F}{3}$

☒ **D** $\frac{F}{4}$

(Total for Question 3 = 1 mark)

4 Which of the following is a base SI unit?

☒ **A** ampere

☒ **B** coulomb

☒ **C** joule

☒ **D** newton

(Total for Question 4 = 1 mark)

5 A high-energy proton can interact with a photon to produce two particles.

Which of the following could be the two particles produced?

☒ **A** $n + \pi^0$

☒ **B** $n + \pi^+$

☒ **C** $\pi^0 + \pi^+$

☒ **D** $\pi^- + \pi^+$

(Total for Question 5 = 1 mark)

7 The intensity of light incident on a light dependent resistor (LDR) can vary both its electrical resistance R and the number of charge carriers per unit volume n. The light intensity on an LDR is increased.

Which row of the table describes the effect on R and n?

	R	n
☒ **A**	decreases	decreases
☒ **B**	decreases	increases
☒ **C**	increases	decreases
☒ **D**	increases	increases

(Total for Question 7 = 1 mark)

8 A proton has a mass of 1.67×10^{-27} kg.

Which of the following shows the conversion of this mass to GeV/c^2 ?

☒ **A** $\dfrac{1.67 \times 10^{-27} \times 1.60 \times 10^{-10}}{(3.00 \times 10^{8})^2}$

☒ **B** $\dfrac{1.67 \times 10^{-27} \times 1.60 \times 10^{-19}}{(3.00 \times 10^{8})^2}$

☒ **C** $\dfrac{1.67 \times 10^{-27} \times (3.00 \times 10^{8})^2}{1.60 \times 10^{-10}}$

☒ **D** $\dfrac{1.67 \times 10^{-27}}{1.60 \times 10^{-10} \times (3.00 \times 10^{8})^2}$

(Total for Question 8 = 1 mark)

9 The blade of a lawnmower rotates at a speed of 50 revolutions per second.

Which of the following is the angular speed of the blade in rads s^{-1}?

☒ **A** 7.96

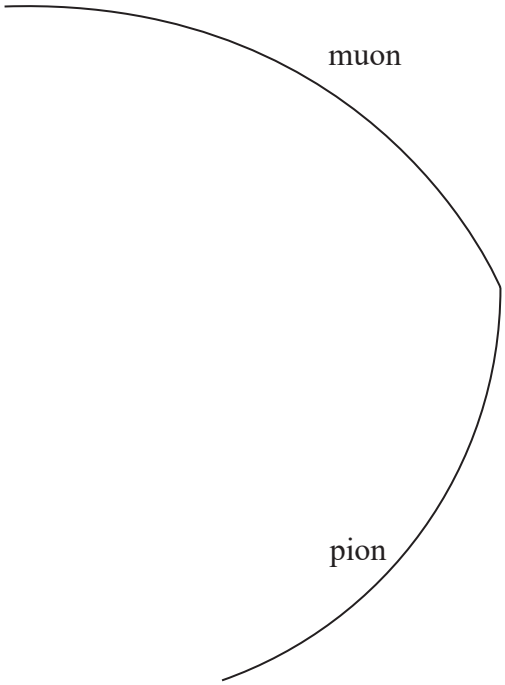
☒ **B** 15.9

☒ **C** 157

☒ **D** 314

(Total for Question 9 = 1 mark)

18 A negatively charged pion decays into a muon and an antineutrino. The diagram shows tracks in a particle detector formed in such an event.



(a) Deduce whether the antineutrino is charged, giving two reasons for your decision.

(2)

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(b) Write a particle equation to represent this decay.

(1)

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(c) According to the standard model, the pion and muon are classified within two different groups of particles.

State which group each particle belongs to and describe the two groups.

(4)

(d) The momentum of the pion just before it decays is 9.1×10^{-20} N s.

Determine the magnetic flux density of the magnetic field which acts in the detector and state its direction.

Scale of diagram 1 cm represents 10 cm

pion charge = -1.6×10^{-19} C

(4)

Magnetic flux density = ...

Direction of magnetic field = ...

(e) Use a vector diagram to determine the momentum of the antineutrino.

The initial momentum of the muon is 1.59×10^{-19} N s.

(5)

Momentum of antineutrino = ...

Direction of antineutrino = ...

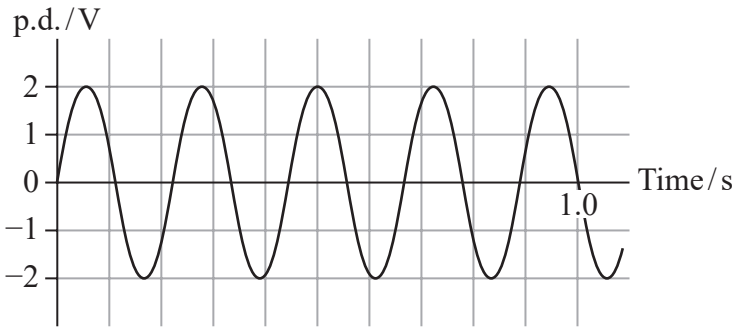
(Total for Question 18 = 16 marks)

TOTAL FOR PAPER = 90 MARKS

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 The graph shows how a potential difference (p.d.) varies with time.



Which of the following is correct?

☒ **A** The frequency is 4.5 Hz.

☒ **B** The peak value is 4.0 V.

☒ **C** The period is 0.20 s.

☒ **D** The root mean square value of p.d. is 1.0 V.

(Total for Question 1 = 1 mark)

2 The π^- particle has a mass of 140 MeV / c^2.

Which row of the table is correct for the antiparticle of a π^-?

	Particle classification	Mass / MeV/c^2
☒ **A**	Baryon	+140
☒ **B**	Baryon	−140
☒ **C**	Meson	+140
☒ **D**	Meson	−140

(Total for Question 2 = 1 mark)

15 At the beginning of the 20th century, Rutherford carried out large-angle alpha particle scattering experiments using gold ($^{197}_{79}$Au) foil.

The vast majority of the alpha particles went straight through the foil whilst a few were deflected straight back.

(a) Describe how the model of the atom changed, as a consequence of these experiments.

(4)

(b) In one experiment the alpha particles had an initial energy of 7.7 MeV.

Calculate the distance of closest approach of the alpha particles to the nucleus of a gold atom. Assume that the gold nucleus remains at rest.

(4)

Distance of closest approach = ...

(c) Rutherford also carried out the experiment with aluminium ($^{27}_{13}$Al) foil.
The aluminium foil had the same thickness as the gold foil and the alpha particles had the same initial kinetic energy.

The following observations were made.

Observation 1:
The fraction of alpha particles scattered at any particular angle for aluminium foil was always much less than for gold foil.

Observation 2:
The alpha particles scattered from aluminium foil had less kinetic energy than the alpha particles scattered from gold foil.

Explain how these observations can be used to deduce how an aluminium nucleus compares to a gold nucleus.

(4)

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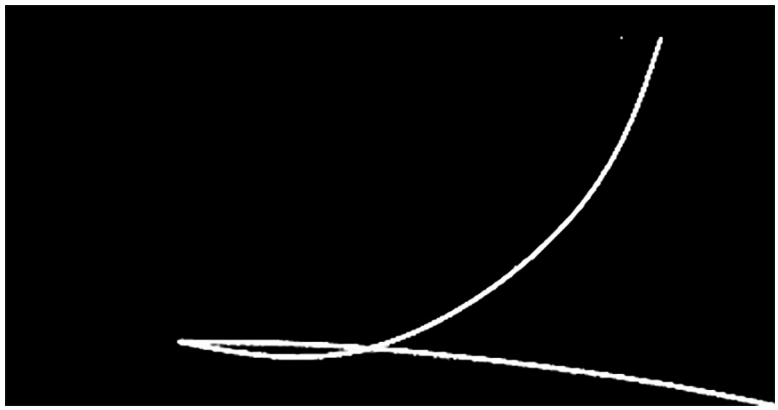
(Total for Question 15 = 12 marks)

16 The bubble chamber photograph shows tracks made by a proton and a pion. The proton and pion were both created by the decay of a lambda particle. No other particles were produced.



*(a) Explain how observations and measurements from the photograph can be used to establish information about the lambda particle.

(6)

(b) The lambda particle consists of up, down and strange quarks.

Explain how the conservation of charge, baryon number and lepton number apply to the decay of the lambda particle.

(3)

(c) Write an equation to represent the decay of the lambda (Λ) particle.

(1)

(d) The rest mass of the lambda particle is 1115 MeV / c^2.

(i) Calculate this mass in kg.

(3)

Mass = ... kg

(ii) The rest mass of a proton is 940 MeV / c^2. The rest mass of a pion is 140 MeV / c^2.

The kinetic energy of the lambda particle just before decay is 4.95 GeV.

Calculate the total kinetic energy of the proton and pion in MeV.

(3)

Total kinetic energy = ... MeV

(Total for Question 16 = 16 marks)

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 A particle has a mass of 1 u and a charge of -1.6×10^{-19} C.

Which of the following could be the particle?

☒ **A** antiproton

☒ **B** electron

☒ **C** neutron

☒ **D** positron

(Total for Question 1 = 1 mark)

2 The velocity v of a non-relativistic particle can be expressed in terms of combinations of the following quantities: kinetic energy E_k, momentum p and mass m.

Which of the following expressions is correct?

☒ **A** $v = \frac{p^2}{m}$

☒ **B** $v = \sqrt{\frac{2E_k}{m}}$

☒ **C** $v = \frac{E_k}{2p}$

☒ **D** $v = \frac{2E_k}{pm}$

(Total for Question 2 = 1 mark)

3 A ball is thrown with an initial horizontal component of velocity u and an initial vertical component of velocity v. The effects of air resistance are negligible.

Which of the following statements about the motion of the ball is **not** correct?

☒ **A** The magnitude of the acceleration in the vertical plane is g.

☒ **B** The horizontal component of velocity is constant.

☒ **C** The time taken for the ball to reach its maximum height is equal to $\frac{v}{g}$.

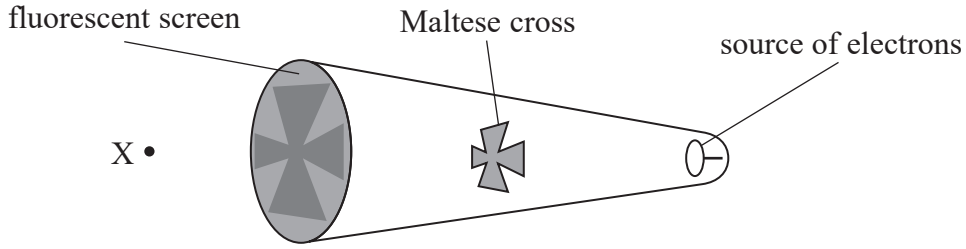
☒ **D** The maximum height of the ball depends on the values of u and v.

(Total for Question 3 = 1 mark)

Questions 4 and 5 refer to the information below.

A demonstration is carried out using a beam of electrons in an evacuated tube.

When electrons hit a fluorescent screen, light is emitted. A piece of metal, in the shape of a Maltese cross, stops electrons and produces a shadow on the screen as shown.



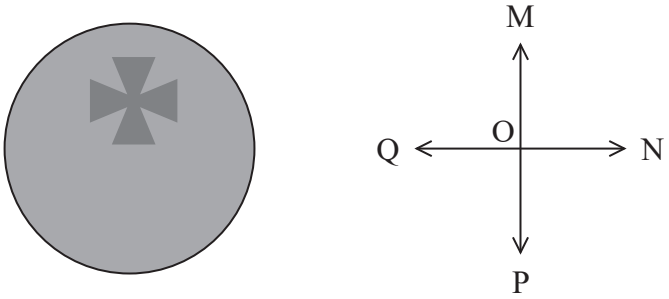
4 The electrons are produced by heating a metal filament.

Which of the following is the name of this process?

- ☒ **A** ionisation
- ☒ **B** scattering
- ☒ **C** the photoelectric effect
- ☒ **D** thermionic emission

(Total for Question 4 = 1 mark)

5 The screen is viewed by an observer at point X in the diagram above. A magnetic field is directed at the beam of electrons. This causes the shadow to move upwards on the screen in the direction OM.



In which of the following directions is the magnetic field acting as seen by this observer?

- ☒ **A** OM
- ☒ **B** ON
- ☒ **C** OP
- ☒ **D** OQ

(Total for Question 5 = 1 mark)

Questions 9 and 10 refer to the information below.

Alpha particle scattering investigations were first carried out in the early part of the 20th century.

9 An alpha particle with initial kinetic energy 8.8×10^{-13} J approaches a nucleus of a gold $\left({}^{197}_{79}\text{Au}\right)$ atom.

Which of the following is an equation for the closest distance r, in metres, between the alpha particle and the nucleus?

☒ **A** $r = 8.99 \times 10^{9} \left(\dfrac{2 \times 1.6 \times 10^{-19} \times 79 \times 1.6 \times 10^{-19}}{8.8 \times 10^{-13}} \right)$

☒ **B** $r = \dfrac{2 \times 1.6 \times 10^{-19} \times 197 \times 1.6 \times 10^{-19}}{8.99 \times 10^{9} \times 8.8 \times 10^{-13}}$

☒ **C** $r = 8.99 \times 10^{9} \left(\dfrac{8.8 \times 10^{-13}}{4 \times 1.6 \times 10^{-19} \times 79 \times 1.6 \times 10^{-19}} \right)$

☒ **D** $r = 8.99 \times 10^{9} \left(\dfrac{2 \times 79}{8.8 \times 10^{-13}} \right)$

(Total for Question 9 = 1 mark)

10 Which of the following conclusions could **not** be made as a result of these investigations?

☒ **A** The atom is mostly empty space.

☒ **B** The atom is neutral.

☒ **C** The nucleus is charged.

☒ **D** The nucleus is very small compared to the atom.

(Total for Question 10 = 1 mark)

15 A series of experiments was carried out in the 1970s to investigate the structure of protons using the linac at Stanford, USA.

*(a) Explain how an electron is accelerated in a linac.

(6)

(b) The electron leaves the accelerator with a high energy.

Explain why electrons need high energies to investigate the structure of a proton.

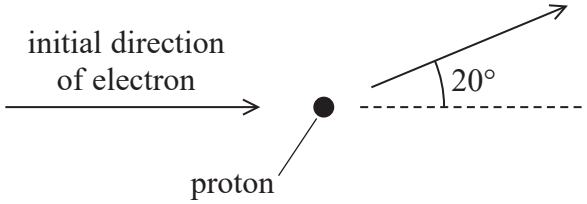
(2)

(c) An electron leaves the accelerator with a momentum of 20 GeV/c.

(i) Explain, with reference to base units, why GeV/c can be used as a unit of momentum.

(2)

(ii) An electron with initial momentum 20 GeV/c collides with a stationary proton. After the collision the electron is deflected by an angle of 20° as shown and its momentum is 9.1 GeV/c. The momentum of the proton after the collision is 11.9 GeV/c.



Deduce whether the law of conservation of momentum is obeyed.

(3)

(iii) The collisions between electrons and the protons in these experiments are sometimes inelastic.

State what is meant by an inelastic collision.

(1)

(Total for Question 15 = 14 marks)

17 A cosmic ray, consisting of a fast-moving proton, collides with a proton within the nucleus of an atom in the upper atmosphere. Three particles, a proton, a neutron and a pion result from the collision.

(a) Write a particle equation for this collision.

(2)

.....

.....

(b) The table shows the properties of two quarks.

Quark	Charge / *e*
u	+2/3
d	−1/3

Give the quark structure for each of the particles produced by this collision.

(3)

.....

.....

.....

.....

(c) The mass of a pion is 140 MeV/c^2.

Calculate the mass of the pion in kg.

(3)

.....

.....

.....

.....

.....

Mass = ... kg

(d) The mass of a neutron is about the same as the mass of a proton. A student suggests that the minimum kinetic energy the cosmic ray proton would need to create the pion in this collision is 140 MeV.

Discuss whether this suggestion is correct. Your answer should include reference to the laws of conservation of momentum and conservation of energy.

(4)

(Total for Question 17 = 12 marks)

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 One isotope of oxygen is $^{17}_{8}O$.

Which row of the table shows the number of neutrons and the number of protons in a nucleus of $^{17}_{8}O$?

		Number of neutrons	Number of protons
☒	**A**	8	9
☒	**B**	8	17
☒	**C**	9	8
☒	**D**	17	8

(Total for Question 1 = 1 mark)

2 A subatomic particle consists of the quark combination u $\bar{s}$.

Which of the following is the classification for this particle?

☒ **A** baryon

☒ **B** lepton

☒ **C** meson

☒ **D** nucleon

(Total for Question 2 = 1 mark)

3 A charged capacitor is discharged through a resistor. The potential difference across the capacitor halved in a time t. The time constant is T.

Which of the following is the equation for t?

☒ **A** $t = \dfrac{\ln 2}{T}$

☒ **B** $t = \ln \dfrac{1}{2T}$

☒ **C** $t = T \ln \dfrac{1}{2}$

☒ **D** $t = T \ln 2$

(Total for Question 3 = 1 mark)

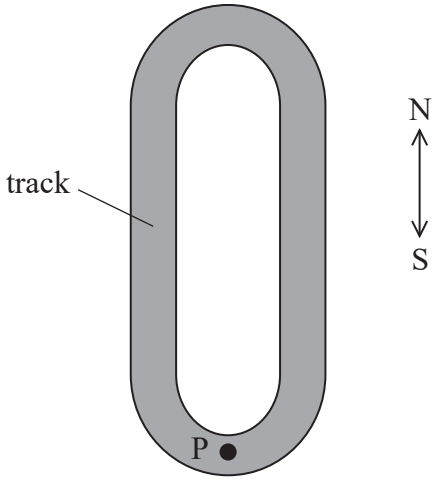
4 Muons created in the upper atmosphere can travel towards the Earth's surface at speeds close to the speed of light. Changes to the mass and average lifetime of the muons can then be observed.

Which row of the table describes these changes when muons travel at speeds close to the speed of light?

		Mass	Average lifetime
☒	**A**	increases	increases
☒	**B**	increases	decreases
☒	**C**	decreases	increases
☒	**D**	decreases	decreases

(Total for Question 4 = 1 mark)

5 The plan view of a model racing car track is shown. Friction acts between a model racing car and the track. A car is moving round the track with a constant speed and reaches point P. Arrows indicating directions North and South are also shown.



The car then slides off the track at P.

Which of the following is the reason why the car slides off the track?

☒ **A** The centripetal force is acting in the N direction.

☒ **B** The centripetal force is acting in the S direction.

☒ **C** The frictional force is equal to the centripetal force.

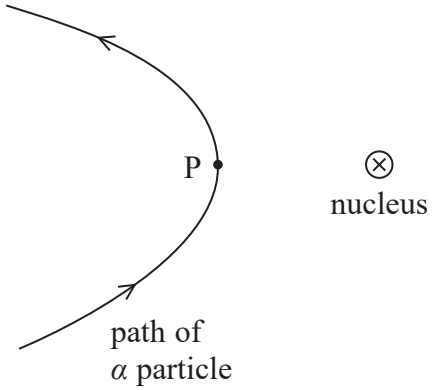
☒ **D** The frictional force is not large enough.

(Total for Question 5 = 1 mark)

Questions 8 and 9 refer to the information below.

Alpha particle scattering investigations were first carried out in the early part of the 20th century.

The diagram shows the path of an α particle that is being deflected by the nucleus of a gold atom. The closest distance of approach of the α particle to the nucleus is at point P.



8 Which row in the table describes the speed and potential energy of the α particle at point P on this path?

	Speed at P	Potential energy at P
☒ **A**	greatest	greatest
☒ **B**	greatest	least
☒ **C**	least	greatest
☒ **D**	least	least

(Total for Question 8 = 1 mark)

9 Which of the following can be concluded about a gold atom from the deflection of this α particle?

☒ **A** The atom contains electrons.

☒ **B** The atom has zero charge.

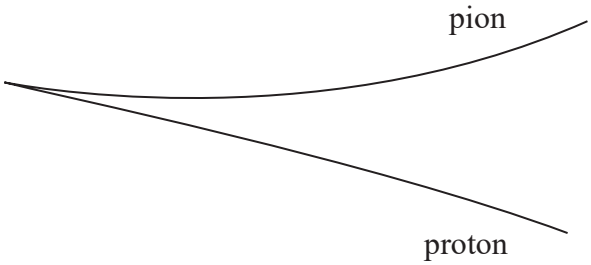
☒ **C** The nucleus is very small compared to the atom.

☒ **D** The nucleus of the atom is positively charged.

(Total for Question 9 = 1 mark)

15 A delta particle decays into a proton and a pion.

(a) The diagram shows tracks in a particle detector formed when the delta particle decays.



(i) State why it can be concluded from the diagram that the delta particle is neutral.

(1)

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.....

(ii) Deduce the charge on the pion.

(2)

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.....

.....

.....

(iii) Complete the particle equation for the decay of the delta (Δ^0) particle.

(1)

$\Delta^0 \rightarrow$

(iv) State why the delta particle must be classified as a baryon based on the evidence of its decay.

(1)

.....

.....

(v) Explain how the momentum of the proton compares with the momentum of the pion.

(3)

(b) The mass of the delta particle is 1232 MeV/c^2.

(i) Calculate the mass of the delta particle in kg.

(3)

Mass = ... kg

(ii) The mass of the proton is 939 MeV/c^2 and the mass of the pion is 139 MeV/c^2.

Explain why the sum of the masses of the two particles after the decay is not equal to the mass of the delta particle.

(3)

(Total for Question 15 = 14 marks)