Questions

Q1.

The Large Hadron Collider is designed to accelerate protons to very high energies for particle physics experiments.

Very high energies are required to

☒ **A** annihilate protons and antiprotons.

☒ **B** allow protons to collide with other protons.

☒ **C** create particles with large mass.

☒ **D** to produce individual quarks.

(Total for question = 1 mark)

Q2.

Pions are the lightest mesons. A negative pion (π^-) has a mass of 2.48×10^{-28} kg.

Which of the following is the mass of the π^- in in MeV/c^2?

☒ **A** 1.4×10^8

☒ **B** 1.4×10^2

☒ **C** 4.7×10^{-7}

☒ **D** 3.6×10^{-24}

(Total for question = 1 mark)

Q3.

The SI unit for mass is the kilogram. However, particle physicists often use the alternative unit

☒ **A** MeV

☒ **B** MeV/c

☒ **C** MeV/c^2

☒ **D** MeV^2/c^2

(Total for question = 1 mark)

Q4.

Which of these is **not** made from quarks?

☒ **A** proton

☒ **B** neutron

☒ **C** lepton

☒ **D** meson

(Total for question = 1 mark)

Q5.

Pions belong to a group of particles called mesons. Pions can be used in a form of radiotherapy to treat brain tumours.

The table lists some quarks and their charges.

Quark	Charge/*e*
u	+2/3
d	−1/3
s	−1/3

From the list below circle the quark combination which could correspond to a π^- pion.

(1)

dds $\bar{u}d$ $\bar{u}\bar{u}\bar{d}$ $\bar{s}u$

Q6. A muon has a mass of 106 MeV/c^2.

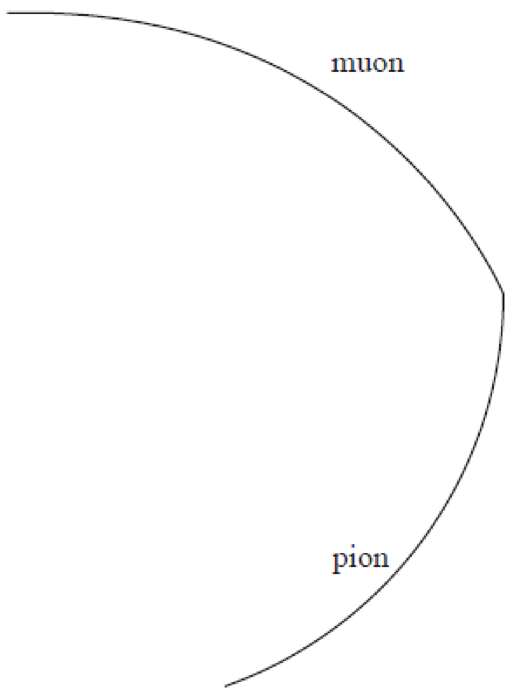
The mass of a muon, to two significant figures, is

- **A** 1.7×10^{-11} kg
- **B** 5.7×10^{-20} kg
- **C** 1.9×10^{-28} kg
- **D** 1.9×10^{-34} kg

(Total for Question = 1 mark)

Q7.

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



Write a particle equation to represent this decay.

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(Total for question = 1 mark)

Q8.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

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 = 1 mark)

Q9.

The Large Hadron Collider is designed to accelerate protons to very high energies for particle physics experiments.

Very high energies are required to

☒ **A** annihilate hadrons.

☒ **B** collide hadrons.

☒ **C** create particles with large mass.

☒ **D** create individual quarks.

(Total for question = 1 mark)

Q10.

Answer the question with a cross in the box you think is correct (☒). If you change your mind about an answer, put a line through the box (☒) and then mark your new answer with a cross (☒).

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 = 1 mark)

Q11.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

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 = 1 mark)

Q12.

At the end of the 19th century, J.J. Thompson used electric and magnetic fields to deflect beams of charged particles. A photograph of his apparatus is shown.

Electrons were accelerated through a potential difference to produce a beam of high-energy electrons. The beam was then deflected in perpendicular directions by the magnetic and electric fields. The final position of the beam on the screen was determined by the charge and mass of the electrons.

In his original experiments, Thompson determined the specific charge of a range of particles. His results indicated that the specific charge of an electron is about 2000 times bigger than that for a hydrogen ion.

Deduce what conclusion can be made from this information.

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(Total for question = 1 mark)

Q13. The diagram shows the tracks from an event at a point P in a bubble chamber. A magnetic field is directed into the page.

The tracks cannot show the production of a proton-antiproton pair with equal kinetic energies because

☒ **A** the curvature is perpendicular to the magnetic field.

☒ **B** the tracks curve in different directions.

☒ **C** the tracks have different curvatures.

☒ **D** there is no track before point P.

(Total for Question = 1 mark)

Q14.

The equation $\Delta E = c^2 \Delta m$ can be used with data at the back of this paper to calculate

☒ **A** the kinetic energy of an electron.

☒ **B** the energy produced when a lambda particle decays.

☒ **C** the energy of the photons produced when a proton and an antiproton annihilate.

☒ **D** the mass of uranium that produces 50 MJ of energy in a nuclear reactor.

(Total for question = 1 mark)

Q15.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

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 = 1 mark)

Q16.

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

☒ **A** nucleus

☒ **B** neutrino

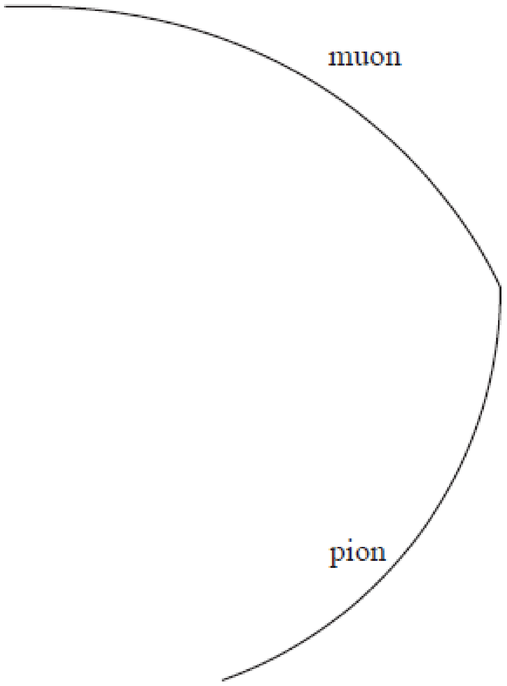
☒ **C** pion

☒ **D** proton

(Total for question = 1 mark)

Q17.

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



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

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(Total for question = 2 marks)

Q18.

The neutral lambda Λ^0 particle is a baryon of mass 1116 MeV/c^2 and contains one strange quark.

The table shows quarks and their relative charge.

Quark	Charge / *e*
u	+2/3
d	–1/3
s	–1/3

State, with justification, the quark content of a Λ^0 particle.

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(Total for question = 2 marks)

Q19.

The neutral lambda Λ^0 particle is a baryon of mass 1116 MeV/c^2 and contains one strange quark.

The table shows quarks and their relative charge.

Quark	Charge / *e*
u	+2/3
d	–1/3
s	–1/3

Lambda particles were first detected in experiments which made use of cosmic rays entering the atmosphere. Cosmic rays are mainly high-energy protons which have a mass less than that of a lambda particle.

Explain why a cosmic ray could lead to the creation of a lambda particle.

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(Total for question = 2 marks)

Q20.

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

Calculate the mass of a muon in kg.

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Mass of muon = ... kg

(Total for question = 3 marks)

Q21.

The neutral lambda Λ^0 particle is a baryon of mass 1116 MeV/c^2 and contains one strange quark.

The table shows quarks and their relative charge.

Quark	**Charge / *e***
u	+2/3
d	–1/3
s	–1/3

The Λ^0 particle cannot be directly observed in particle experiments, however some of the decay products can.

Explain why the Λ^0 particle cannot be directly observed but information about it can be obtained by studying its decay particles.

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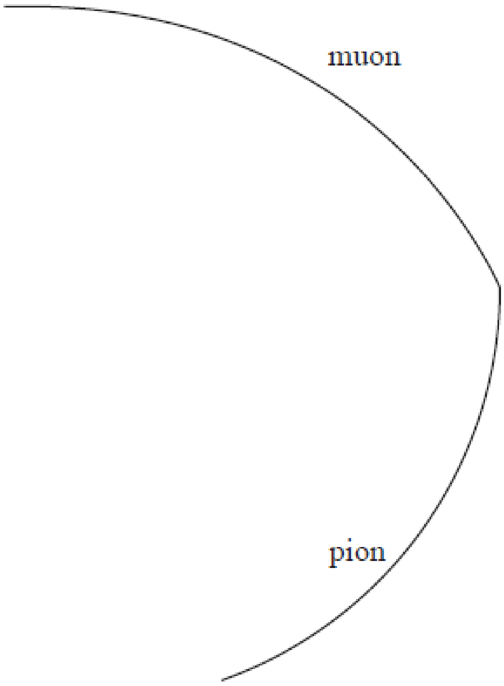
(Total for question = 3 marks)

Q22.

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



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.

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(Total for question = 4 marks)

Q23.

Protons interact with particles in the upper atmosphere and create new particles. Pions can be produced from high energy proton collisions.

(i) State why the following reaction is not possible.

$$p + p \rightarrow \mathrm{p} + p + \pi^{-}$$

(1)

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(ii) State one similarity and one difference between the electric field of a proton and the electric field of a π^{-}.

(2)

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Q24.

The neutral lambda Λ^0 particle is a baryon of mass 1116 MeV/c^2 and contains one strange quark.

The table shows quarks and their relative charge.

Quark	Charge / *e*
u	+2/3
d	–1/3
s	–1/3

Calculate the mass of the Λ^0 particle in kg.

(3)

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Mass of Λ^0 particle = ... kg

(Total for question = 3 marks)

Q25.

Pions belong to a group of particles called mesons. Pions can be used in a form of radiotherapy to treat brain tumours.

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

Calculate the mass of a pion in kg.

(3)

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Mass = ...

Q26.

A high energy proton collides with a stationary proton and a π^0 particle is produced.
The equation for the reaction is

$$p + p \rightarrow p + p + \pi^0$$

(i) Explain why the proton must have a high energy in order for this reaction to occur.

(2)

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(ii) The rest mass of the π^0 is $\frac{1}{7}$ of the rest mass of a proton.

In this reaction the total kinetic energy of the particles decreases.

Calculate the minimum decrease in kinetic energy if the reaction is to occur.

rest mass of proton = 938 GeV/c^2

(2)

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Minimum decrease in kinetic energy = ...

Q27.

Phosphogypsum is a by-product in the manufacture of fertiliser. It is slightly radioactive because of the presence of radium-226, a radioisotope with a half-life of 1600 years.

It must be stored securely as long as the activity of the radium-226 it contains is greater than 0.4 Bq per gram of phosphogypsum.

Radium-226 decays to radon-222 by alpha emission.

Determine the energy released in MeV in the decay of a single nucleus of radium-226.

(5)

mass of radium-226 nucleus = 225.97713 u
mass of radon-222 nucleus = 221.97040 u
mass of α particle = 4.00151 u

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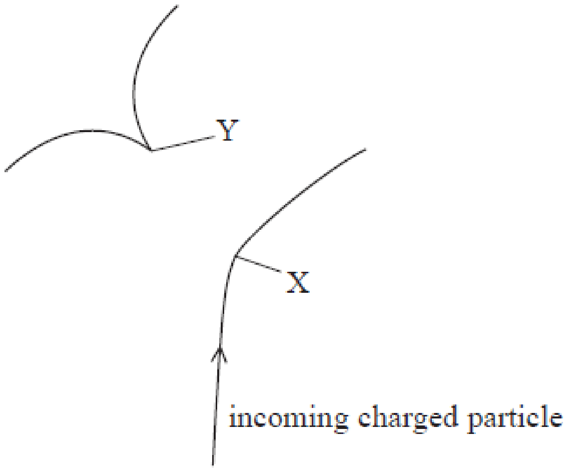
Energy released = ... MeV

(Total for question = 5 marks)

Q28.

The diagram shows the tracks produced in a bubble chamber.



At X an incoming charged particle interacts with a stationary proton.

Describe and explain what can be deduced about the interaction at X and subsequent events. You may add to the diagram to help your answer.

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Q29. The table gives some of the properties of the up, down and strange quarks.

Type of quark	Charge/*e*	Strangeness
u	+2/3	0
d	–1/3	0
s	–1/3	–1

There are nine possible ways of combining u, d and s quarks and their antiquarks to make nine different mesons. These are listed below

$u\bar{u}$ $u\bar{d}$ $u\bar{s}$ $d\bar{d}$ $d\bar{u}$ $d\bar{s}$ $s\bar{s}$ $s\bar{u}$ $s\bar{d}$

(a) From the list select the four strange mesons and state the charge and strangeness of each of them.

(4)

Meson	Charge/*e*	Strangeness

(b) Some of the mesons in the list have zero charge and zero strangeness.

Suggest what might distinguish these mesons from each other.

(1)

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(Total for Question = 5 marks)

Q30.

The neutral lambda Λ^0 particle is a baryon of mass 1116 MeV/c^2 and contains one strange quark.

The table shows quarks and their relative charge.

Quark	Charge / *e*
u	+2/3
d	–1/3
s	–1/3

A student suggests five ways a Λ^0 particle might decay. These are

$$\Lambda^0 \rightarrow p + \pi^-$$
$$\Lambda^0 \rightarrow e^+ + e^-$$
$$\Lambda^0 \rightarrow n + \pi^0$$
$$\Lambda^0 \rightarrow n$$
$$\Lambda^0 \rightarrow p + \pi^0$$

Deduce which of these decay processes are **not** possible.

(6)

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(Total for question = 6 marks)

Q31.

The photograph is an image of the paths of particles obtained from an early particle detector, the cloud chamber.

Modern particle detectors such as the ones at CERN still work on the basic principle that charged particles cause ionisation of the material through which they pass. These ionisations can be tracked and recorded. Magnetic fields are used to deflect the particles so that their properties can be investigated.

(a) State what is meant by ionisation in this context.

(1)

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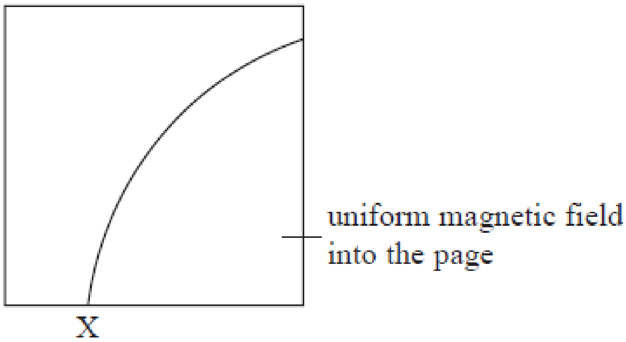
(b) The diagram below shows the ionisation path of a particle when it is in the region of a uniform magnetic field. The particle enters the field at X.



State how we know that the particle is negatively charged.

(1)

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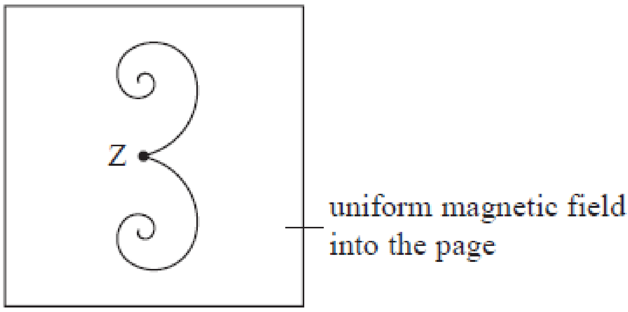
(c) The diagram below shows an event occurring in the same magnetic field.



Point Z is where a high energy photon interaction occurs which causes two particles to be formed.

Describe, with reasons, what can be deduced about the photon and the two particles that are formed in this interaction.

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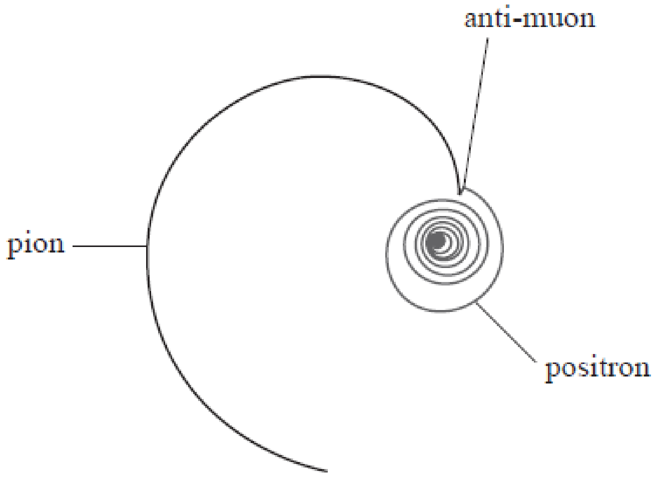
(Total for question = 7 marks)

Q32.

Pions have a short half-life and decay into muons.

The diagram shows the tracks from the decay of a pion in a bubble chamber.



The pion decays into an anti-muon and muon neutrino.
The anti-muon then decays into a positron and an electron neutrino.
The magnetic field acts out of the page.

Use the diagram and the information given to explain what conclusions can be made about the particles in this interaction.

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Q33.

* Particle accelerators accelerate particles to very high speeds before collisions occur.
New particles are created during the collisions.

Two particles of the same type can undergo two kinds of collision.

Fixed target: a high speed particle hits a stationary particle.

Colliding beams: two particles travelling at high speeds, in opposite directions, collide head-on.

By considering the conservation of energy and momentum, explain which type of collision is able to create a new particle with the largest mass.

(6)

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(Total for question = 6 marks)

Q34.

The following passage is adapted from a recent article in a British newspaper:

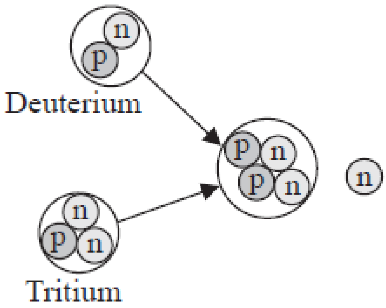
"Every year, one typical coal-fired power station devours several million tonnes of fuel and produces even more carbon dioxide. That volume of carbon dioxide is damaging the atmosphere and, in the longer term, the fuel will run out. It is clear that the world needs an alternative for generating energy.

Nuclear fusion looks like offering a solution to the problem. Using the equivalent of a bath tub of water, fusion has the potential to deliver the same amount of energy as 100 tonnes of coal.

There would be no carbon dioxide emission, it would be inherently very safe, and would not produce any significant radioactive waste."

(Adapted from an article in The Observer newspaper, Sunday 16th September 2012)

(a) The latest proposed fusion reactor will fuse deuterium and tritium, which are isotopes of hydrogen. This fusion reaction is illustrated below.



(i) Complete the nuclear equation below to represent this fusion reaction.

(2)

$$^{\cdots}_{\cdots}H + ^{\cdots}_{\cdots}H \rightarrow ^{\cdots}_{\cdots}He + ^{\cdots}_{\cdots}n$$

(ii) Calculate the energy released in the fusion of one deuterium nucleus with one tritium nucleus.

Particle	Mass / GeV/c^2
Proton	0.938272
Neutron	0.939566
Deuterium	1.875600
Tritium	2.808900
Helium	3.727400

(2)

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Energy released = ...

(iii) Explain why most of the energy released in the fusion of one deuterium nucleus with one tritium nucleus is transferred to kinetic energy of the neutron.

(3)

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(b) A sample of tritium is produced. Tritium is unstable and decays by β^- emission with a half-life of 12.3 years.

Calculate the time taken, in years, for the activity of the sample to fall to 10% of its initial value.

(3)

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Time taken = ... years

*(c) The article states that "it would be inherently very safe, and would not produce any significant radioactive waste."

Comment on this statement and outline the technical difficulties of producing a practical nuclear fusion reactor.

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(Total for question = 15 marks)

Q35.

A treatment for brain tumours involves firing a beam of pions at the tumour. Pions exist for a very short time. During treatment many pions hit the tumour just as they decay.

This causes the cells in the tumour to fragment, which kills them with no harmful effect to the surrounding tissue.

Pions belong to a group of sub-atomic particles called mesons. There are three types of pion: π^- π^+ π^0.

(a) The following table lists some quarks and their charge.

Quark	Charge/*e*
u	+2/3
d	−1/3
s	−1/3
c	+2/3

State a possible quark combination for a π^-

(1)

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(b) Pions are produced when protons, accelerated in a cyclotron, are aimed at a target of beryllium and interact with protons in the beryllium.

Identify the type of pion produced in the following interaction.

$$p + p \rightarrow p + p + \pi$$

(1)

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(c) The π^- mesons used for a treatment have a speed of 2.3×10^8 m s^{-1} and a range in air of 5.9 m.

Calculate the time for which these π^- mesons exist.

(2)

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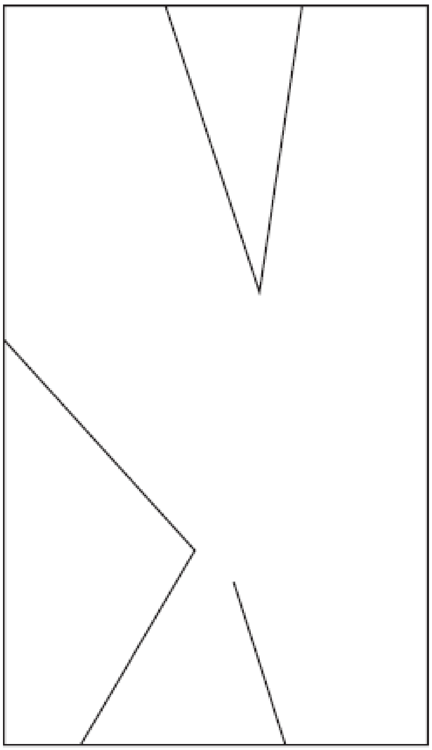
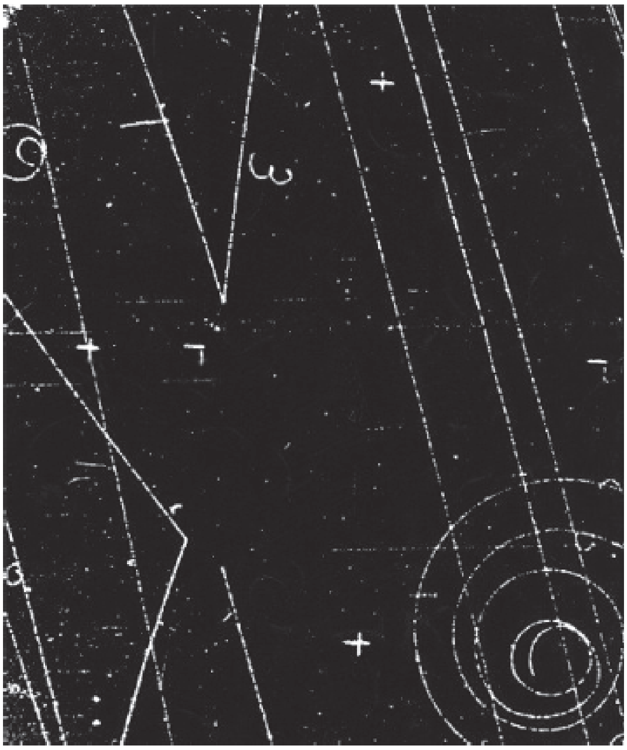
Time = ...

*(d) The photograph shows what happens in a Bubble Chamber when some pions enter at the bottom and travel upwards. One pion has been identified by X in the photograph and the simplified line diagram shows the visible tracks of the pion and subsequent decay products.



X



X

Explain what can be deduced about the sequence of the events shown in the line diagram.

(6)

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(e) If very high speed protons are fired at beryllium, the following interaction occurs

$$p + p = p + p + p + \overline{p}$$

(i) State the name of the particle $\overline{p}$ and give its properties.

(2)

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(ii) State what is likely to happen to the $\overline{p}$ particle.

(1)

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(Total for question = 13 marks)

Q36. Hadrons are a group of particles composed of quarks. Hadrons can be either baryons or mesons.

(a) (i) State the quark structure of a baryon.

(1)

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(ii) State the quark structure of a meson.

(1)

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(b) State **one** similarity and **one** difference between a particle and its antiparticle.

(2)

Similarity

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Difference

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(c) (i) The table gives some of the properties of up, down and strange quarks.

Type of quark	**Charge/*e***	**Strangeness**
u	+2/3	0
d	–1/3	0
s	–1/3	–1

One or more of these quarks combine to form a K^+, a meson with a strangeness of +1.

Write down the quark combination of the K^+.

(1)

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(ii) The K^+ can decay in the following way

$$K^+ \rightarrow \mu^+ + \nu_\mu$$

K^- is the antiparticle of the K^+.

Complete the equation below by changing each particle to its corresponding antiparticle in order to show an allowed decay for the K^- meson.

(2)

$$K^- \rightarrow$$

(iii) The rest mass of the K^+ is 494 MeV/c^2.

Calculate, in joules, how much energy is released if a K^+ meets and annihilates a K^-.

(3)

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Energy = ... J

(Total for Question = 10 marks)

Q37.

Pions (π^+, π^-, π^0) are created in the upper atmosphere when cosmic rays collide with protons. Pions are unstable and decay rapidly.

(a) Pions are the lightest of the hadrons. Charged pions (π^+ and π^-) decay to produce muons which then decay to positrons or electrons.

(i) A positive pion π^+ has a quark composition $u\bar{d}$.

State with a justification the possible quark compositions of a neutral pion π^0.

(2)

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(ii) Muons are examples of leptons whereas pions are examples of mesons.
State a structural difference between leptons and mesons.

(1)

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(b) Muons with a speed of 0.99*c* travel a distance of 15 km to reach the surface of the Earth from the upper atmosphere.

(i) Show that the time it takes a muon to travel this distance is about 51 μs.

(2)

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(ii) The muons are unstable particles.
Calculate the fraction of muons which would remain after a time of 51 μs.

half-life of muon = 2.2 μs

(4)

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Fraction = ...

(iii) In fact the fraction of muons reaching the surface of the Earth is about 0.1 Explain the discrepancy.

(4)

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(Total for question = 11 marks)

Q38.

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

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)

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(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)

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

(2)

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* (iv) The muons are produced at a height of 10 km in the atmosphere. The velocity of the muons is 0.99 *c*. 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.

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(Total for question = 13 marks)

Q39.

Subatomic particles such as pions are produced after collisions between protons that have been accelerated in a cyclotron.

*(a) Explain briefly the role of electric and magnetic fields in the cyclotron.

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(b) The mass of a pion is 2.5×10^{-28} kg.

Calculate the mass of a pion in GeV/c^2.

(3)

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Mass = ... GeV/c^2

(c) The table shows the charge of some quarks.

Type of quark	Charge/*e*
u	+2/3
d	−1/3
s	−1/3

Explain what is meant by a charge of +2/3

(1)

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(d) The omega (Ω) minus particle consists of three strange quarks and is produced by the following interaction.

$$K^- + p \rightarrow K^+ + K^0 + \Omega^-$$

Kaons are mesons and consist of a strange quark and either an up or a down quark.

(i) Complete the table to show a possible quark combination for each kaon.

(3)

Particle	Quark combination
K^-	
K^+	
K^0	

(ii) The total mass of the particles produced in this interaction is greater than the total mass of the two particles that collided.
Explain this increase in mass.

(3)

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(Total for question = 15 marks)

Q40.

In 2011 physicists at the Relativistic Heavy Ion Collider (RHIC) announced the creation of nuclei of anti-helium-4 which consists of anti-protons and anti-neutrons instead of protons and neutrons.

(a) 'Ordinary' helium-4 is written as $^{4}_{2}He$

What do the numbers 4 and 2 represent?

(2)

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(b) In the RHIC experiment, nuclei of gold $^{197}_{79}Au$ travelling at speeds greater than 2.99×10^8 m s^{-1}, in opposite directions, collided, releasing energies of up to 200 GeV. After billions of collisions, 18 anti-helium nuclei had been detected.

(i) What is meant by 'relativistic' in the collider's name?

(1)

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(ii) State why it is necessary to use very high energies in experiments such as these.

(1)

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(iii) Show that the mass of a stationary anti-helium nucleus is about 4 GeV/c^2.

(4)

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(iv) State why the small number of anti-helium nuclei produced only survive for a fraction of a second.

(1)

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(v) A slow moving anti-helium nucleus meets a slow moving helium nucleus. If they were to combine to produce 2 high energy gamma rays, calculate the frequency of each gamma ray.

(2)

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Frequency = ...

(c) There are two families of hadrons, called baryons and mesons. Baryons such as protons are made of three quarks.

(i) Describe the structure of a meson.

(1)

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(ii) Up quarks have a charge of +2/3e and down quarks a charge of −1/3e. Describe the quark composition of anti-protons and anti-neutrons and use this to deduce the charge on each of these particles.

(4)

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(Total for question = 16 marks)

Q41.

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)

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

Calculate this mass in GeV/c^2.

(3)

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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)

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(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

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Momentum = ...

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

(1)

Total momentum = ...

(d) 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 = 17 marks)