Name: _____

Edexcel Particle accelerators

Date:

Time:

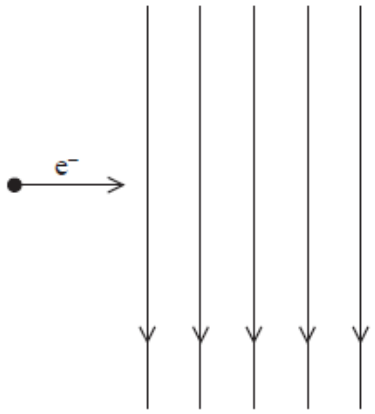
Total marks available:

Total marks achieved: _____

Questions

Q1.

An electron travelling horizontally enters a uniform electric field which acts vertically downwards as shown in the diagram.



Which of the following statements is **incorrect**?

- **A** The electron follows a parabolic path.
- **B** The electron accelerates while in the field.
- **C** The electric force on the electron acts downwards.
- **D** The speed of the electron increases.

(Total for question = 1 mark)

Q2. A cyclotron is a type of particle accelerator. It consists of two metal Dees which are connected to a high frequency voltage supply and are in a strong magnetic field.

The particles change their speed because

- **A** of the magnetic field they are in.
- **B** the voltage supply is alternating.
- **C** there is a potential difference between the two Dees.
- **D** the magnetic field is at right angles to the Dees.

(Total for Question = 1 mark)

Q3. Charged particles are travelling at a speed v, at right angles to a magnetic field of flux density B. Each particle has a mass m and a charge Q.

Which of the following changes would cause a decrease in the radius of the circular path of the particles?

☒ **A** an increase in B

☒ **B** an increase in m

☒ **C** an increase in v

☒ **D** a decrease in Q

(Total for Question = 1 mark)

Q4.

Electrons are released from a heated metal filament.

This process is known as

☒ **A** excitation.

☒ **B** ionisation.

☒ **C** photoelectric emission.

☒ **D** thermionic emission.

(Total for question = 1 mark)

Q5.

As a particle accelerates in a linear accelerator (linac), it passes through tubes that get progressively longer.
Which of the following statements is the correct reason for making the tubes longer?

☒ **A** The particles gain more energy within each tube.

☒ **B** The frequency of the accelerating voltage increases.

☒ **C** The accelerating particles spend the same time in each tube.

☒ **D** The accelerating particles gain mass.

(Total for question = 1 mark)

Q6.

The tubes of a linear accelerator (linac) get progressively longer down its length because

☒ **A** the accelerating particles become relativistic.

☒ **B** the frequency of the applied potential difference changes.

☒ **C** the accelerating particles must spend the same time in each tube.

☒ **D** the accelerating particles gain mass.

(Total for question = 1 mark)

Q7.

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 (☒).

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 = 1 mark)

Q8.

The process by which electrons are released from a heated metal filament in an electron beam tube is called

☒ **A** excitation.

☒ **B** ionisation.

☒ **C** photoelectric emission.

☒ **D** thermionic emission.

(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 protons and antiprotons.

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

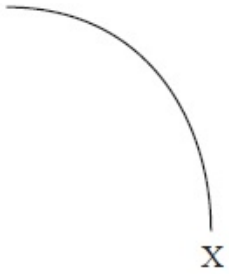
☒ **C** create particles with large mass.

☒ **D** to produce individual quarks.

(Total for question = 1 mark)

Q10. Scientists studying anti-matter recently observed the creation of a nucleus of anti-helium 4, which consists of two anti-protons and two anti-neutrons.

The diagram represents the path of a proton through a magnetic field starting at point X.



Add to the diagram the path of an anti-helium 4 nucleus also starting at point X and initially travelling at the same velocity as the proton.

Explain any differences between the paths.

(5)

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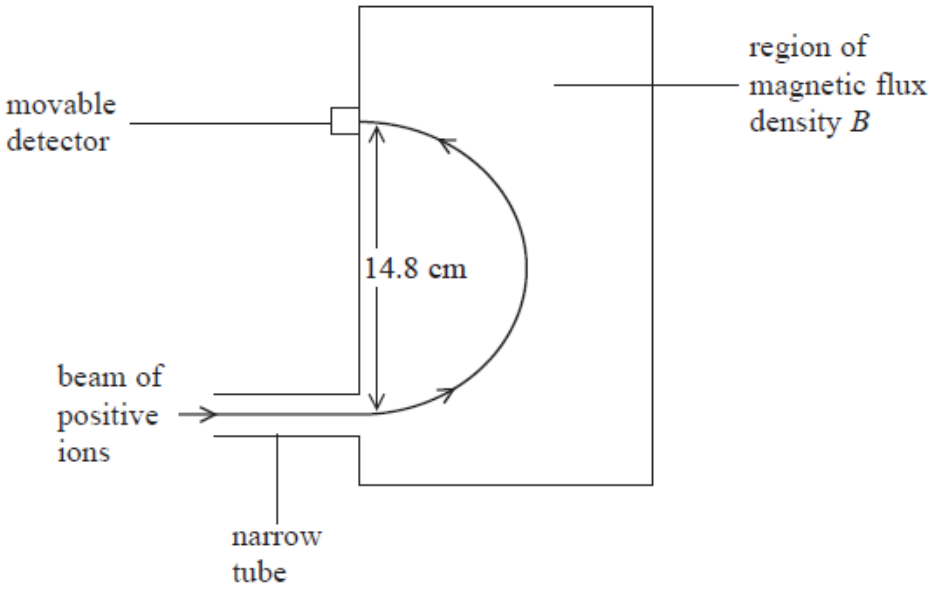
(Total for Question = 5 marks)

Q11.

A mass-spectrometer is an instrument that is used to measure the masses of molecules. Molecules of a gas are ionised and travel through a vacuum in a narrow tube. The ions enter a region of uniform magnetic flux density *B* where they are deflected in a semicircular path as shown.



(a) State why it is necessary for the molecules to be ionised.

(1)

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(b) State the direction of the magnetic field.

(1)

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(c) The ions have a charge of $+e$ and a speed of 1.20×10^5 m s^{-1}. When B has a value of 0.673 T, the ions are detected at a point where the diameter of the arc is 14.8 cm.

Calculate the mass of an ion.

(3)

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Mass of an ion = ...

(d) Ions with a smaller mass but the same charge and speed are also present in the beam. On the diagram sketch the path of these ions.

(1)

(Total for question = 6 marks)

Q12.

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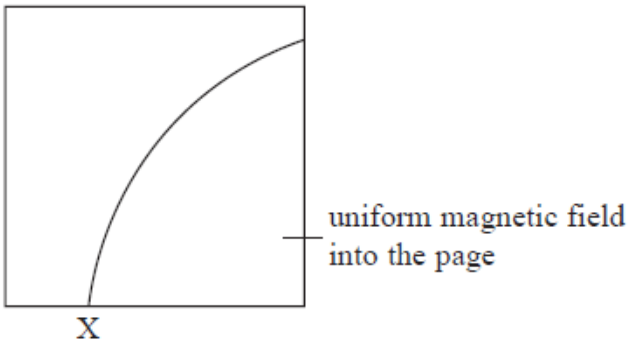
(b) The diagram below shows the ionisation path of a particle when it is in the region of a uniform magnetic field. The particle enters the field at X.



State how we know that the particle is negatively charged.

(1)

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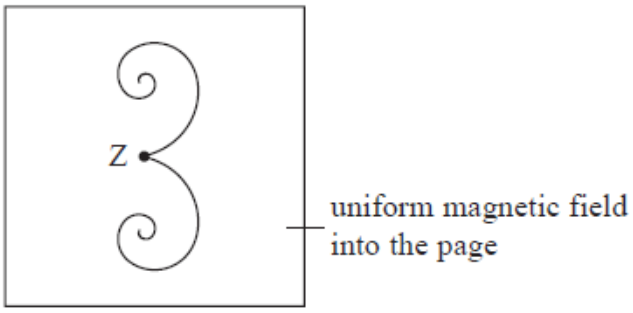
(c) The diagram below shows an event occurring in the same magnetic field.



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.

(5)

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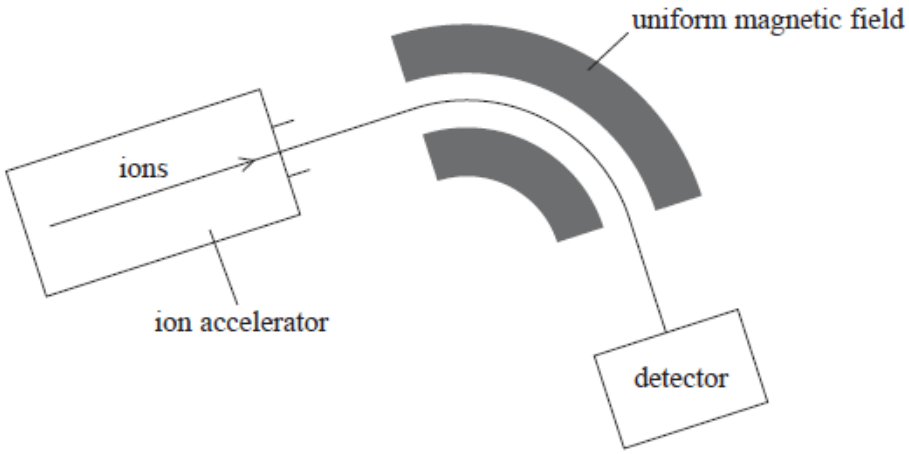
(Total for question = 7 marks)

Q13.

Mass spectrometry is a technique used to separate ions based on their charge to mass ratio.

The atoms in a sample are ionised and then accelerated and formed into a fine beam. This beam is passed into a region of uniform magnetic field and the ions are deflected by different amounts according to their mass.



Analysis of mass spectrometer data shows that chlorine exists in nature as two isotopes, chlorine-35 and chlorine-37.

After passing through the velocity selector the ion beam enters a region of uniform magnetic flux density 0.35 T with the ions travelling at right angles to the field direction.

(i) Explain why the ions travel in a circular path.

(2)

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(ii) Calculate the radius of the circular path.

(2)

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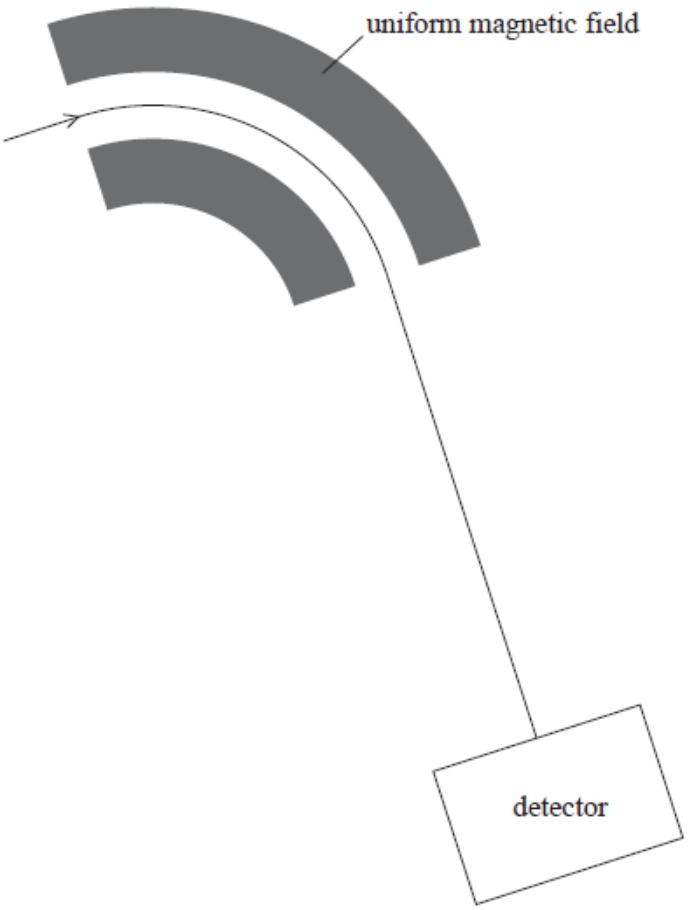
Radius = ...

(iii) The diagram shows the path of the chlorine-35 ions in the field. Chlorine-37 ions enter the magnetic field with the same velocity.



1. Add another line to the diagram to show the path of these chlorine-37 ions.

(1)

2. Explain any differences in the paths.

(2)

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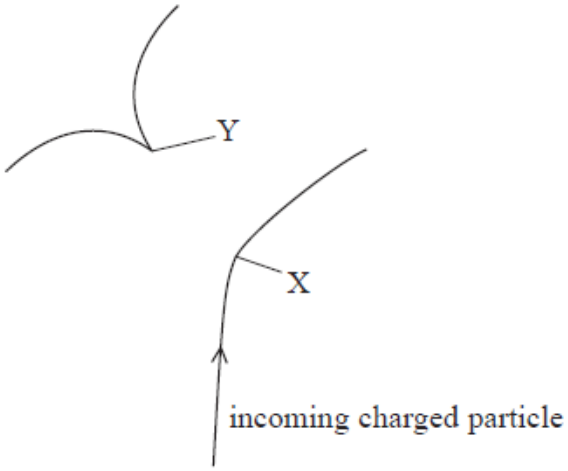
(Total for question = 7 marks)

Q14.

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.

(5)

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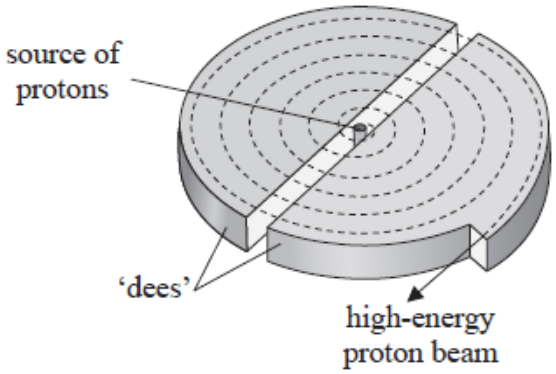
Q15.

Proton beam therapy is being introduced in the UK as a new cancer treatment.

A beam of protons is accelerated by a cyclotron to an energy of 23 MeV and is then focused onto a tumour.



* Explain how the cyclotron produces the high-energy proton beam.

(6)

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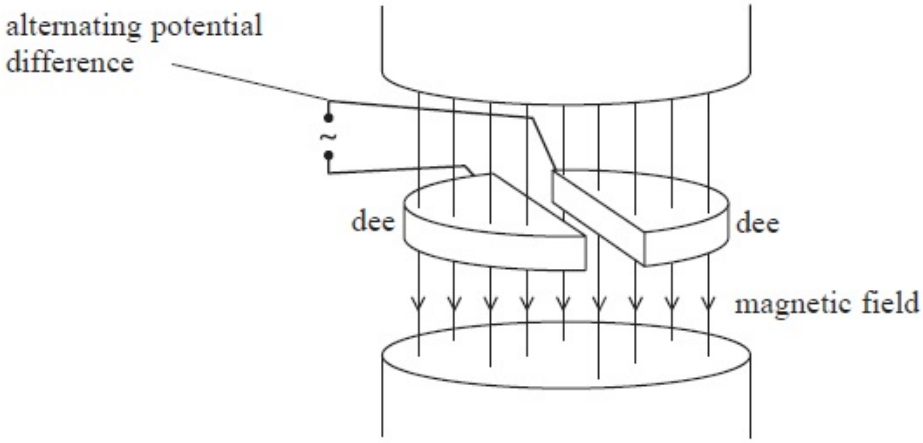
(Total for question = 6 marks)

Q16. * The diagram shows the basic structure of a cyclotron.



With reference to the magnetic field and the alternating potential difference explain how the cyclotron produces a beam of high speed particles.

(4)

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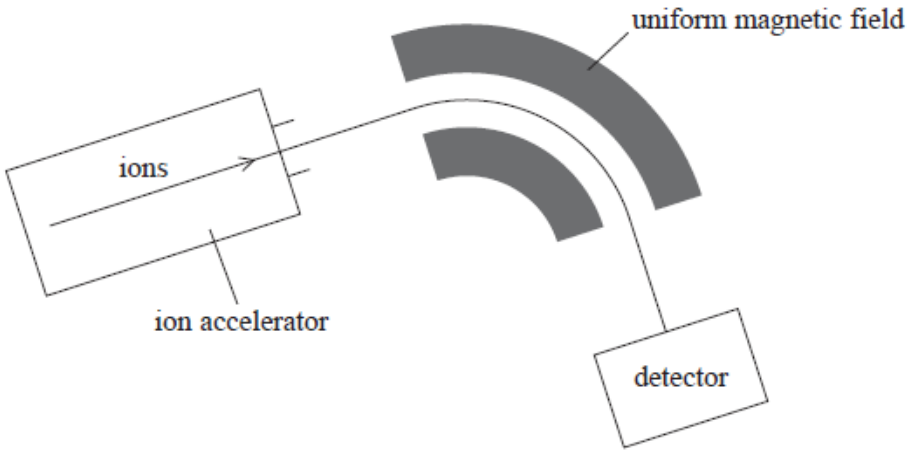
(Total for Question = 4 marks)

Q17.

Mass spectrometry is a technique used to separate ions based on their charge to mass ratio.

The atoms in a sample are ionised and then accelerated and formed into a fine beam.
This beam is passed into a region of uniform magnetic field and the ions are deflected by different amounts according to their mass.



Analysis of mass spectrometer data shows that chlorine exists in nature as two isotopes, chlorine-35 and chlorine-37.

In a mass spectrometer, chlorine-35 ions are accelerated through a potential difference of 8.50 kV to produce an ion beam.

Show that the speed of singly ionised chlorine-35 atoms is about 2.2×10^5 m s^{-1}.

mass of an ion of chlorine-35 = 34.97 u

(4)

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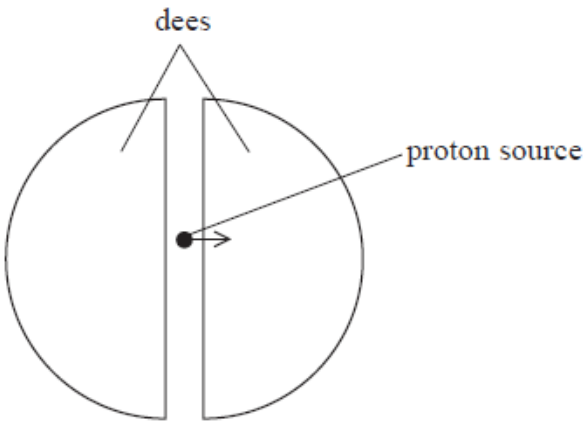
(Total for question = 4 marks)

Q18.

A cyclotron is a particle accelerator which can be used to accelerate protons. The cyclotron consists of two semicircular electrodes called 'dees'. An alternating potential difference is applied across the gap between the dees. A uniform magnetic field is applied at right angles to the plane of the dees.



(i) Complete the diagram to show the path of the protons.

(1)

(ii) State the direction of the magnetic field needed in order to produce the path you have sketched.

(1)

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(iii) Explain how the kinetic energy of the protons is increased as they follow the path you have shown.

(3)

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(iv) Show that the magnetic flux density B of the applied magnetic field is given by

$$B = \frac{2\pi f m}{e}$$

where f is the frequency of the alternating potential difference, m is the mass of the proton and e is the charge on the proton.

(3)

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(v) In a particular cyclotron B is 1.2 mT.
Calculate the frequency f of the alternating potential difference.

(2)

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f = ...

Q19.

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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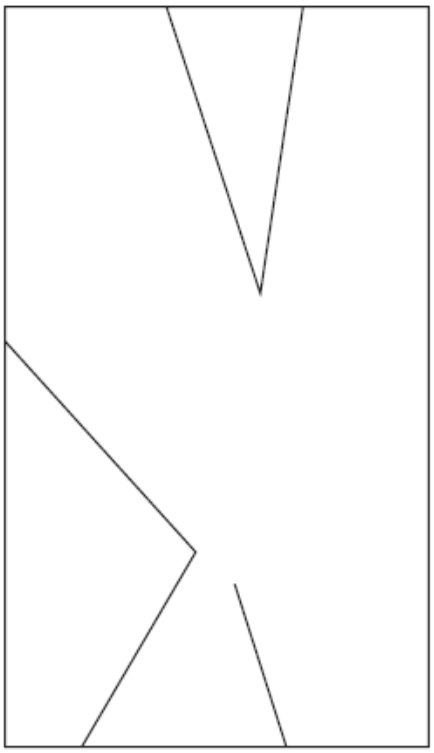
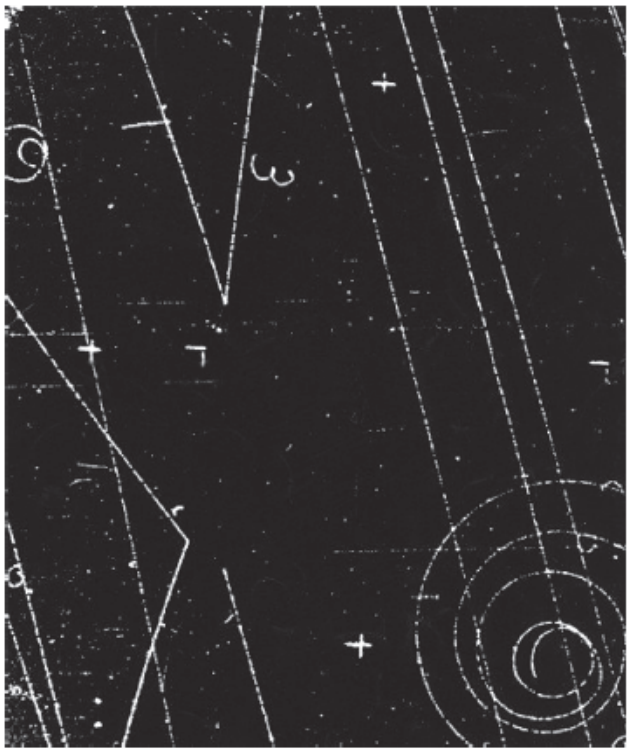
Time = ...

*(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 $\overline{\mathrm{p}}$ particle.

(1)

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(Total for question = 13 marks)

Q20.

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.

(5)

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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)

Q21.

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 $^{4}_{2}\mathrm{He}$

What do the numbers 4 and 2 represent?

(2)

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(b) In the RHIC experiment, nuclei of gold $^{197}_{79}\mathrm{Au}$ 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)

Q22.

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)