PEARSON EDEXCEL A-LEVEL PHYSICS · 9PH0

PHYSICS



EXAM QUESTION PACK

TOPIC 8: NUCLEAR AND PARTICLE PHYSICS

NUCLEAR STRUCTURE AND PARTICLE ACCELERATORS

SCORE	PERCENTAGE
/353	%

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Q1.

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 ☒.

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

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 = 1 mark)

Q2. The nucleus of one of the isotopes of nickel is represented by ${}^{60}_{28}\text{Ni}$.

Which line correctly identifies a neutral atom of this isotope?

	Number of protons	Number of neutrons	Number of electrons
☐ **A**	28	32	28
☐ **B**	28	32	32
☐ **C**	28	60	28
☐ **D**	60	28	28

(Total for Question = 1 mark)

Q3. Select the row in the table that correctly identifies the composition of a $^{235}_{92}U^{+}$ ion.

		Number of protons	Number of neutrons	Number of electrons
☐	**A**	92	143	91
☐	**B**	92	143	92
☐	**C**	92	235	91
☐	**D**	93	235	92

(Total for Question = 1 mark)

Q4.

A radioactive isotope of aluminium is $^{25}_{13}\mathrm{Al}$

Select the row in the table that correctly identifies a neutral atom of this isotope.

	Neutrons	Protons	Electrons
☐ **A**	12	13	12
☐ **B**	13	12	13
☐ **C**	13	12	12
☐ **D**	12	13	13

(Total for question = 1 mark)

Q5.

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.

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.

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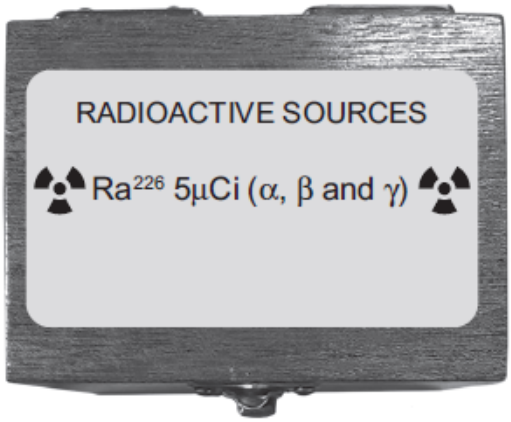
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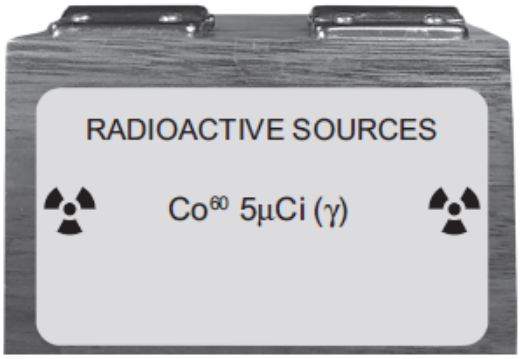
Distance of closest approach = ...

(Total for question = 4 marks)

Q6.

The photograph shows the containers of two radioactive sources kept in a school.





The isotope Ra 226 undergoes a series of decays until it produces the stable isotope Pb 206.

Determine the number of α particles and β particles emitted during this process to complete the nuclear equation.

(3)

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$$^{226}_{88}\text{Ra} \rightarrow {}^{206}_{82}\text{Pb} + \underline{\quad} \times \underline{\quad\alpha\quad} + \underline{\quad} \times \underline{\quad\beta\quad}$$

Q7.

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

What do the numbers 4 and 2 represent?

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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?

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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.

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

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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.

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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.

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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.

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(Total for question = 16 marks)

Q8.

The number of neutrons in a nucleus of $^{238}_{92}U$ is

- ☒ **A** 92
- ☒ **B** 146
- ☒ **C** 238
- ☒ **D** 330

(Total for question = 1 mark)

Q1.

When alpha particles are directed at a thin gold foil it is found that most of the alpha particles go straight through undeflected. However a very small number are scattered through angles greater than 90°.

Which of the following is **not** a valid conclusion?

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

☒ **B** The nucleus must be positively charged.

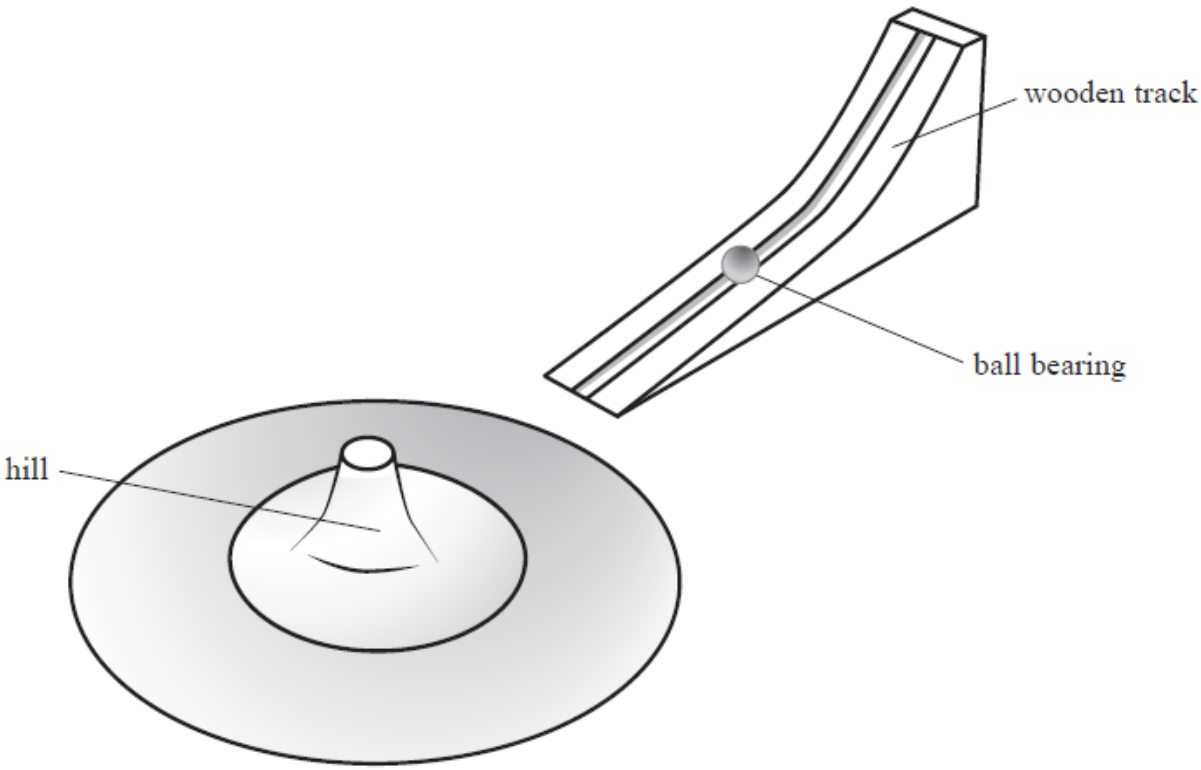
☒ **C** The nucleus must contain most of the mass of the atom.

☒ **D** There is a large charge concentration in the centre of the atom.

(Total for question = 1 mark)

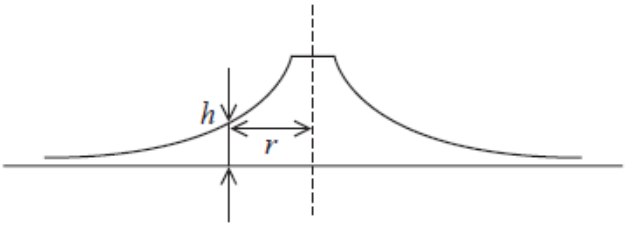
Q2.

The diagram shows a model used to demonstrate alpha particle scattering. A ball bearing is set rolling on a wooden track. The track is positioned so that the ball bearing rolls onto a metal sheet with a curved surface known as a 'hill'.

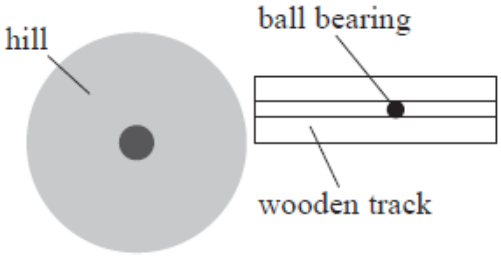


The diagram shows a vertical cross-section through the hill. The surface is curved so that the height of a point *h* on the curved surface is inversely proportional to the distance *r* from the

centre of the hill.



A plan view of the arrangement is shown.



The wooden track is moved to different positions and the ball bearing is released.

Describe the results of the alpha particle scattering experiment and how these can be demonstrated by moving the wooden track to different positions.

(4)

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(Total for question = 4 marks)

Q3.

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 ☒.

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

century.

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.

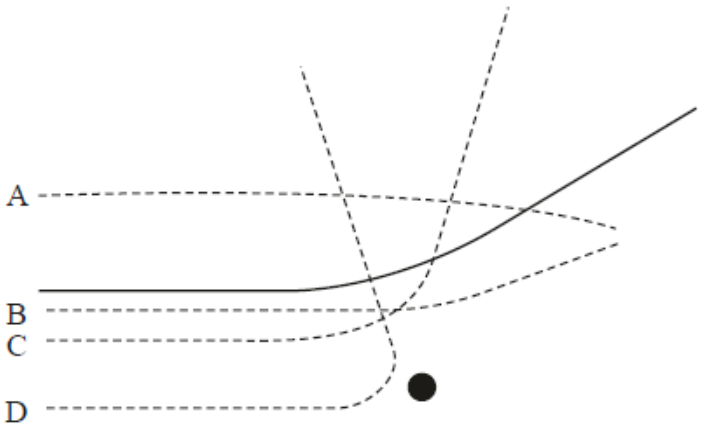
☒ **C** The nucleus is charged.

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

(Total for question = 1 mark)

Q4.

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 = 1 mark)

Q5.

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.

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

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(Total for question = 4 marks)

Q6.

Early in the twentieth century physicists observed the scattering of alpha particles after they had passed through a thin gold foil. This scattering experiment provided evidence for the structure of the atom.

(a) State why it is necessary to remove the air from the apparatus that is used for this experiment.

(1)

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(b) From the results of such an experiment give **two** conclusions that can be deduced about the nucleus of an atom.

(1)

Conclusion 1

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Conclusion 2

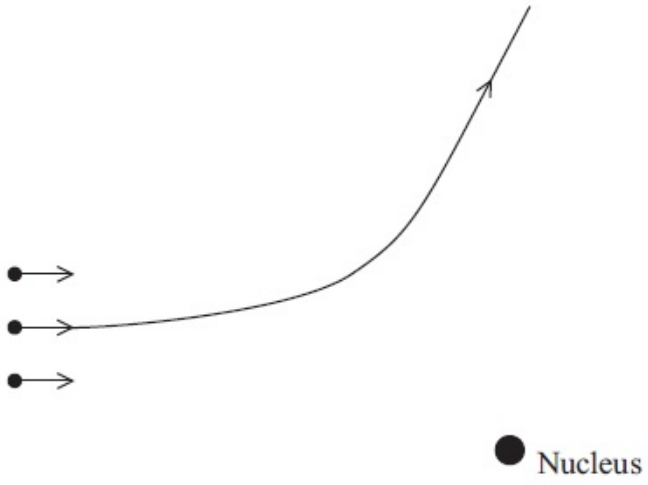
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(c) The diagram shows three α-particles, all with the same kinetic energy. The path followed by one of the particles is shown.

Add to the diagram to show the paths followed by the other two particles.

(3)



(Total for question = 6 marks)

Q7.

The following extract is taken from a quote by Rutherford, speaking about the scattering of alpha particles by a thin gold foil.

> We knew the alpha particle was a very fast, massive particle with a great deal of energy, and the chance of an alpha particle being scattered backward was very small. Then I remember two or three days later Geiger coming to me in great excitement and saying "We have been able to get some of the alpha particles coming backward …" It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you.

(a) Rutherford compared the scattering of alpha particle through large angles to firing "a 15-inch shell at a piece of tissue paper and it came back and hit you."

Explain, with reference to the properties of the alpha particle, why a relatively large force is needed to deflect alpha particles through a large angle.

(2)

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(b) Before the alpha particle scattering experiment, scientists believed that the mass and charge of an atom were uniformly distributed throughout the atom in a radius of about 1.4×10^{-10} m. Following the scattering experiments, a model of the atom was developed in which there was a concentrated centre of charge called the nucleus.

Assess the validity of this model of the atom given that the magnitude of the force required to scatter these alpha particles by a large angle is about 2.0 N. You should include a calculation in your answer.

proton number of gold = 79

(5)

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Q8.

Which of the following is **not** a valid conclusion from Rutherford's alpha scattering experiment?

☒ **A** The nucleus is charged.

☒ **B** The nucleus contains neutrons and protons.

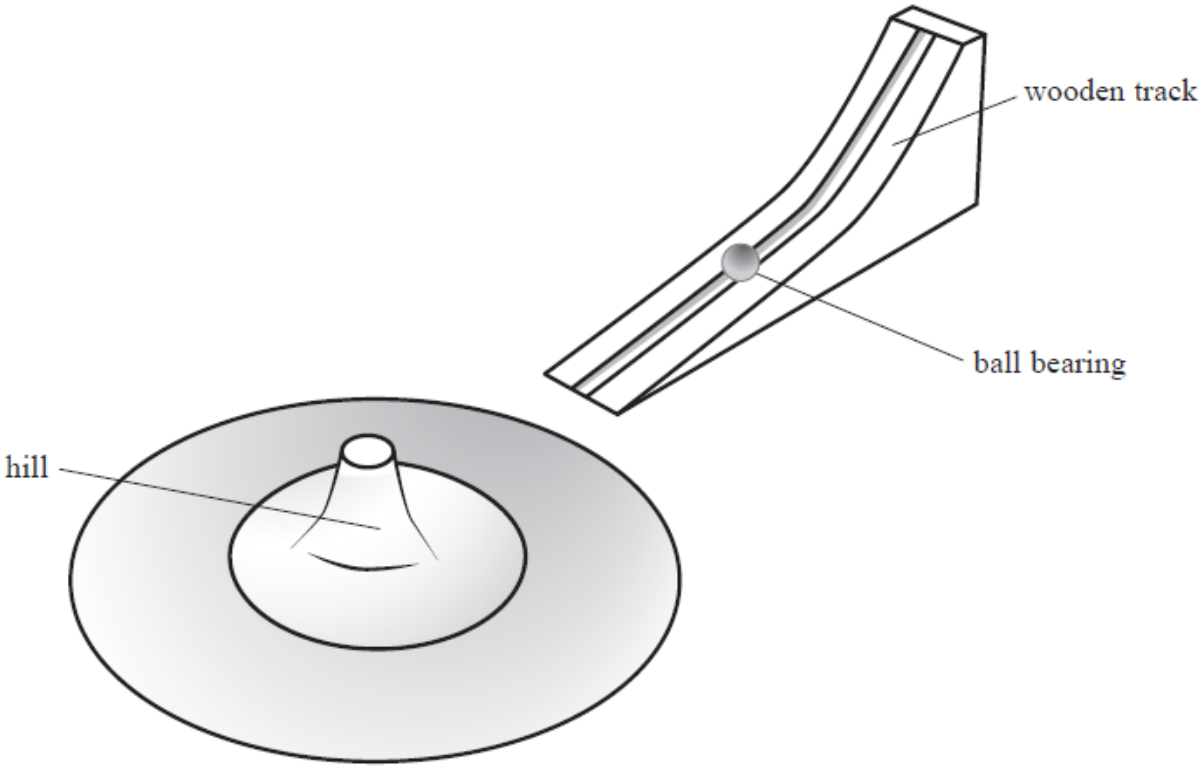
☒ **C** The nucleus contains most of the mass of the atom.

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

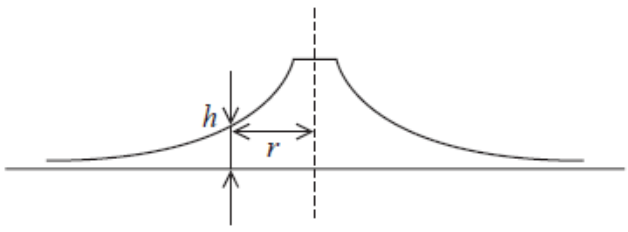
(Total for question = 1 mark)

Q9.

The diagram shows a model used to demonstrate alpha particle scattering. A ball bearing is set rolling on a wooden track. The track is positioned so that the ball bearing rolls onto a metal sheet with a curved surface known as a 'hill'.



The diagram shows a vertical cross-section through the hill. The surface is curved so that the height of a point *h* on the curved surface is inversely proportional to the distance *r* from the centre of the hill.



Explain why the hill is suitable as a model for the electric field surrounding the nucleus of an atom.

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(Total for question = 3 marks)

Q10.

The alpha particle scattering experiment led to a number of observations and conclusions.

Which row in the table gives a correct observation and corresponding conclusion from the alpha particle scattering experiment?

(1)

	Observation	Conclusion
☒ **A**	Most alpha particles come straight back.	The nucleus is charged.
☒ **B**	Most alpha particles come straight back.	The atom is mainly empty space.
☒ **C**	Most alpha particles go straight through.	The atom is mainly empty space.
☒ **D**	Most alpha particles go straight through.	The nucleus is charged.

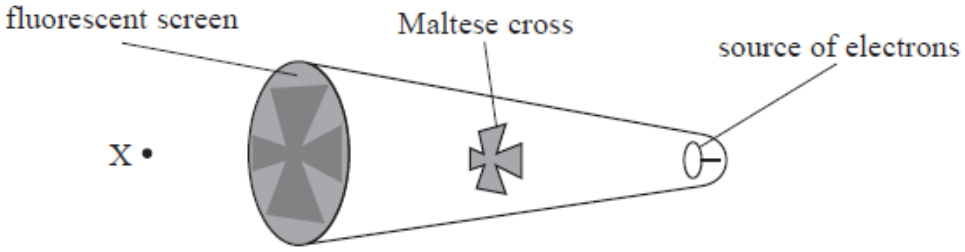
(Total for question = 1 mark)

Q1.

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 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.



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 = 1 mark)

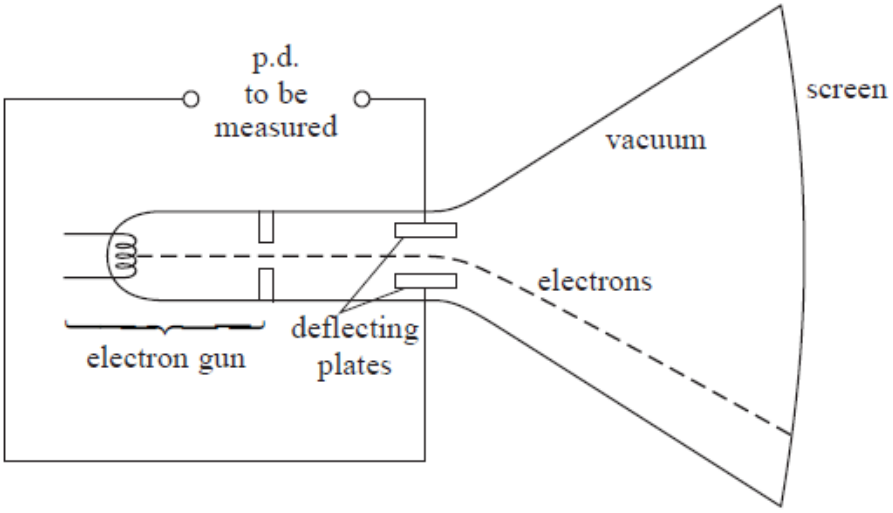
Q2.

Cathode ray tubes are used in oscilloscopes.



The diagram shows a simplified cathode ray tube that can be used to determine the magnitude and polarity of a potential difference (p.d.).

The cathode ray tube consists of an electron gun, a pair of deflecting plates and a fluorescent screen.



(a) The electron gun includes a filament. When this filament is heated, electrons are released and are accelerated by a p.d. of 1.5 kV to form an electron beam.

(i) Name the process by which electrons are released from the heated filament.

(1)

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(ii) Show that the maximum velocity of the electrons is about 2×10^7 m s^{-1}.

(2)

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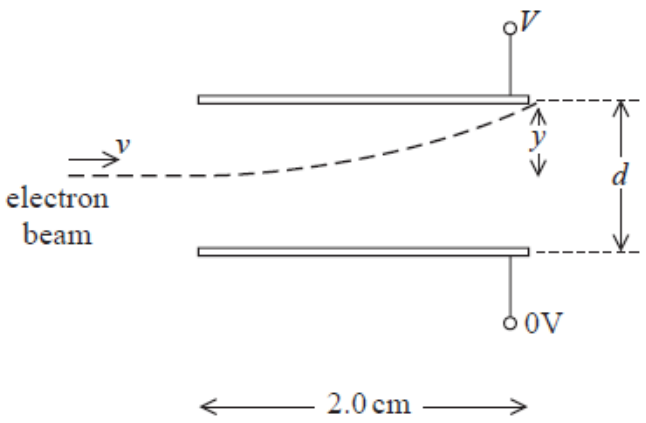
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(b) The electron beam then enters a uniform electric field between the two parallel horizontal deflecting plates. The magnitude and direction of the deflection is determined by the p.d. *V* that is applied across the plates.

The diagram shows one possible path of the electron beam as it passes between the plates.



(i) Show that the acceleration of an electron, of mass m and charge Q, is given by

$$\frac{VQ}{dm}$$

(2)

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(ii) Calculate the magnitude of the vertical deflection y of the beam as it leaves the plates.

$V = 50$ V
$d = 0.01$ m

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y = ...

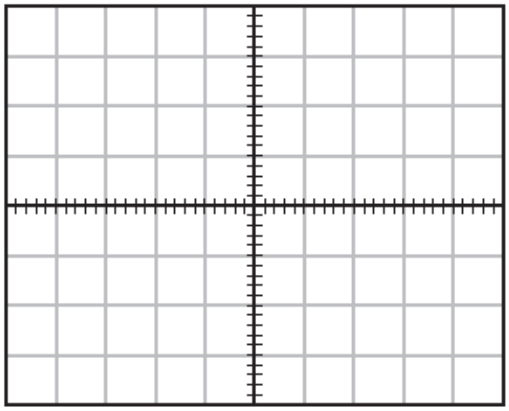
(c) A laboratory oscilloscope with the time base turned off operates in the same way as this simplified cathode ray tube. A student uses an oscilloscope in this way to monitor an alternating p.d. of 53 V_{rms}

On the grid, draw the trace that would be seen on the screen.

(4)

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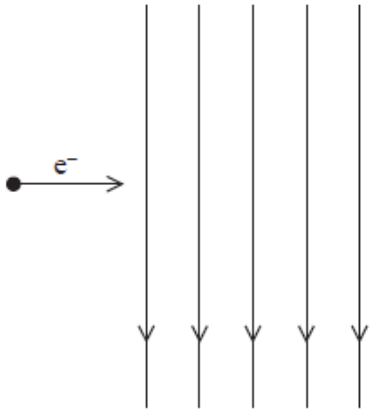


1 square = 25 V

(Total for question = 14 marks)

Q3.

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)

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.

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

☒ **A** excitation.

☒ **B** ionisation.

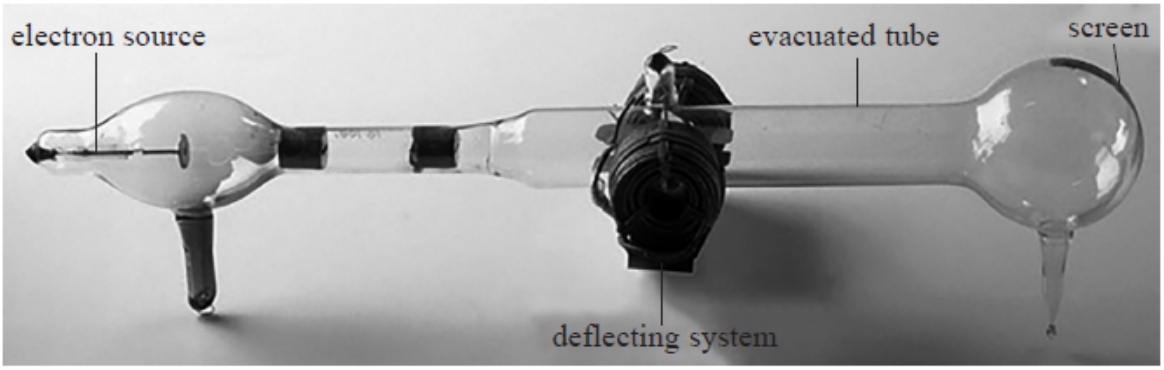
☒ **C** photoelectric emission.

☒ **D** thermionic emission.

(Total for question = 1 mark)

Q6.

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



© Science Museum London

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.

Explain how electrons from the source become a beam of high-energy electrons.

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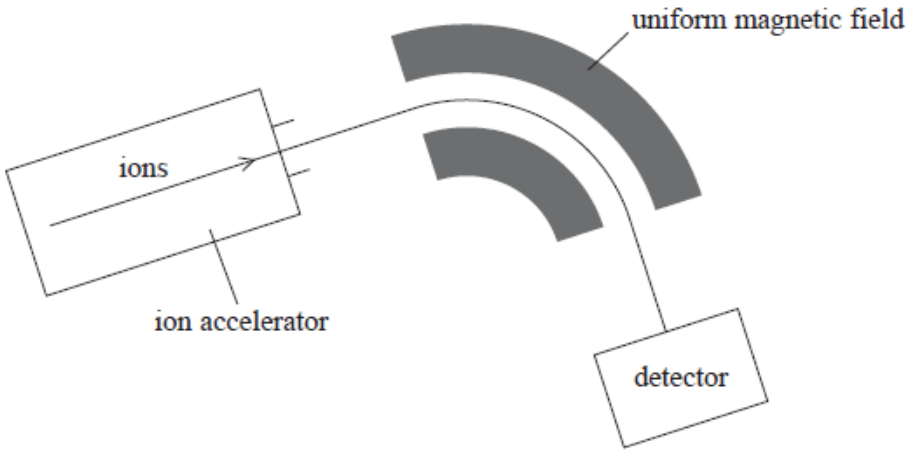
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(Total for question = 2 marks)

Q1.

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

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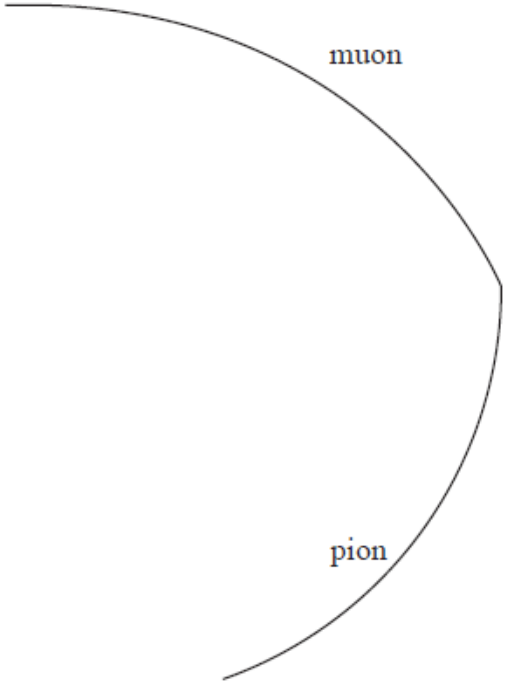
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(Total for question = 4 marks)

Q2.

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)

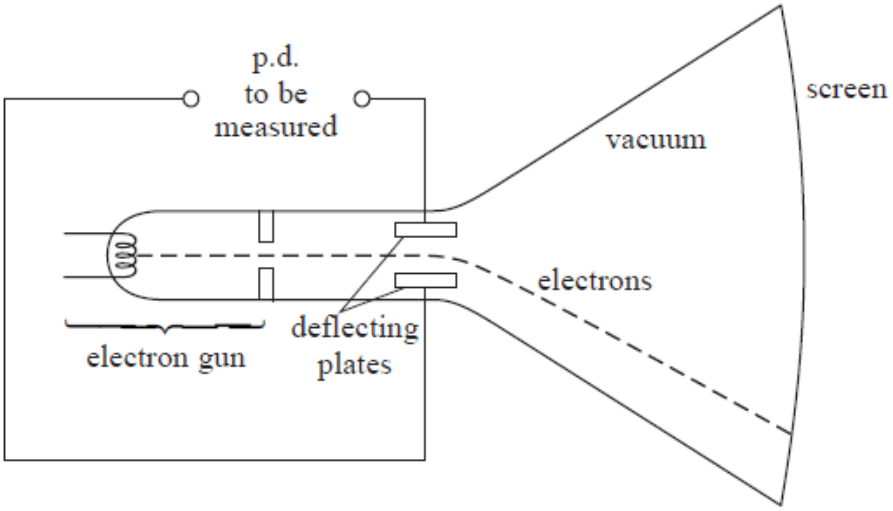
Q3.

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The diagram shows a simplified cathode ray tube that can be used to determine the magnitude and polarity of a potential difference (p.d.).

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(a) The electron gun includes a filament. When this filament is heated, electrons are released and are accelerated by a p.d. of 1.5 kV to form an electron beam.

(i) Name the process by which electrons are released from the heated filament.

(1)

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(ii) Show that the maximum velocity of the electrons is about 2×10^7 m s^{-1}.

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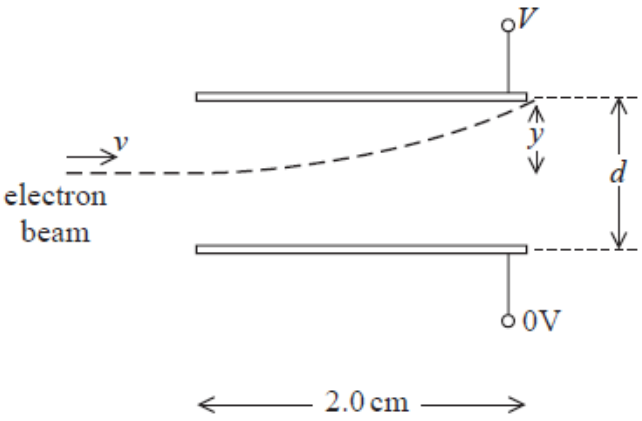
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(b) The electron beam then enters a uniform electric field between the two parallel horizontal deflecting plates. The magnitude and direction of the deflection is determined by the p.d. *V* that is applied across the plates.

The diagram shows one possible path of the electron beam as it passes between the plates.



(i) Show that the acceleration of an electron, of mass m and charge Q, is given by

$$\frac{VQ}{dm}$$

(2)

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(ii) Calculate the magnitude of the vertical deflection y of the beam as it leaves the plates.

$V = 50$ V
$d = 0.01$ m

(5)

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$y =$ .....

(c) A laboratory oscilloscope with the time base turned off operates in the same way as this simplified cathode ray tube. A student uses an oscilloscope in this way to monitor an alternating

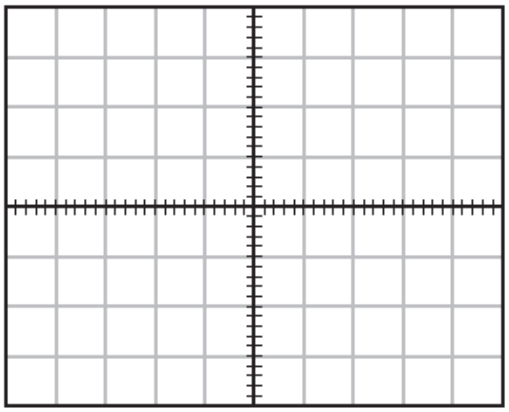
p.d. of 53 V_{rms}

On the grid, draw the trace that would be seen on the screen.

(4)

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(Total for question = 14 marks)

Q4. 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.

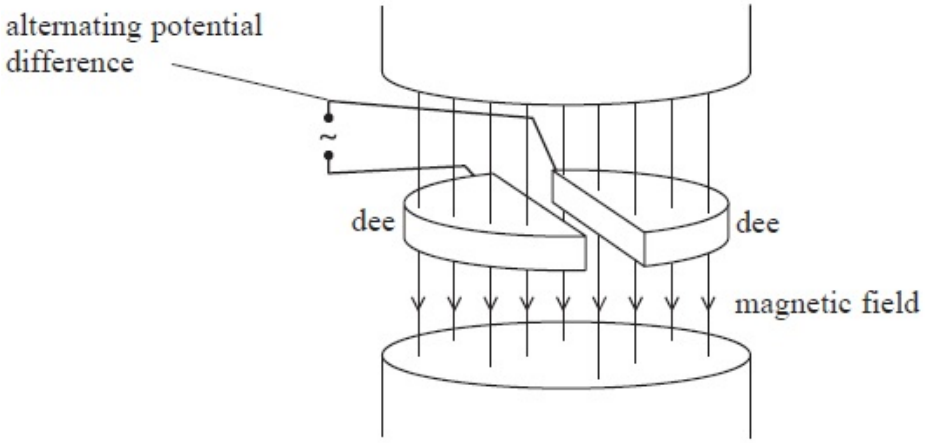
☒ **B** the voltage supply is alternating.

☒ **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)

Q5. * 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.

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(Total for Question = 4 marks)

Q6.

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

* Explain how an electron is accelerated in a linac.

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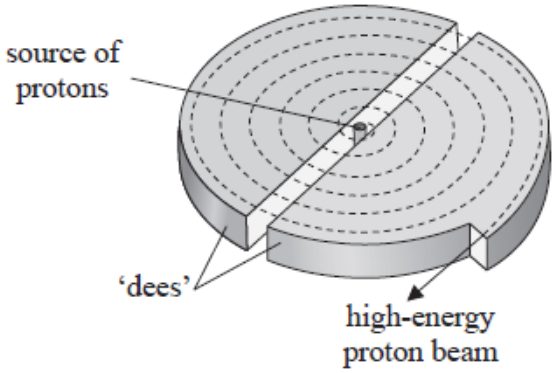
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(Total for question = 6 marks)

Q7.

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.

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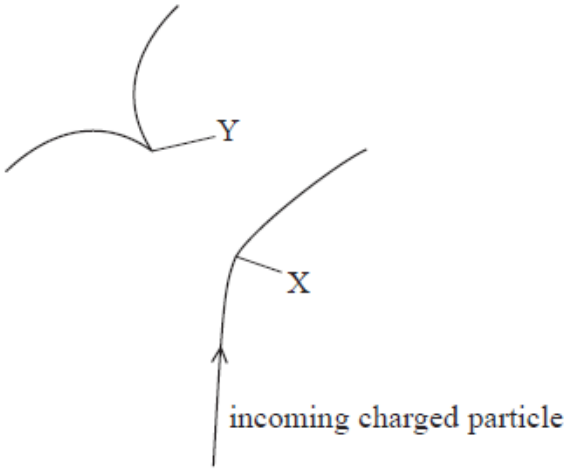
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(Total for question = 6 marks)

Q8.

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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Q9.

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.

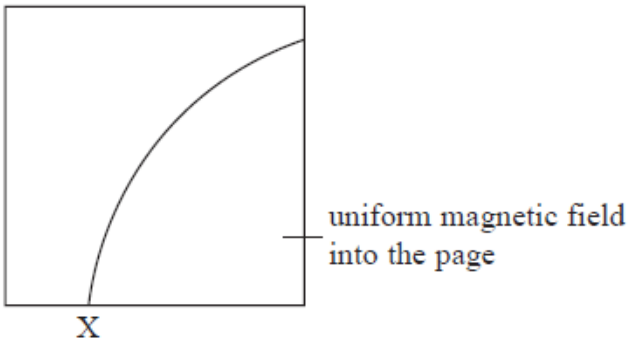
(a) State what is meant by ionisation in this context.

(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.

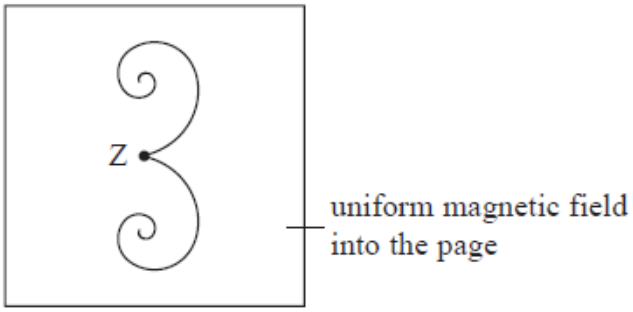
(1)

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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)

Q10.

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.



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

(6)

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(Total for question = 6 marks)

Q11.

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)

Q12.

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)

Q13.

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)

Q14.

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)

.....

(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)

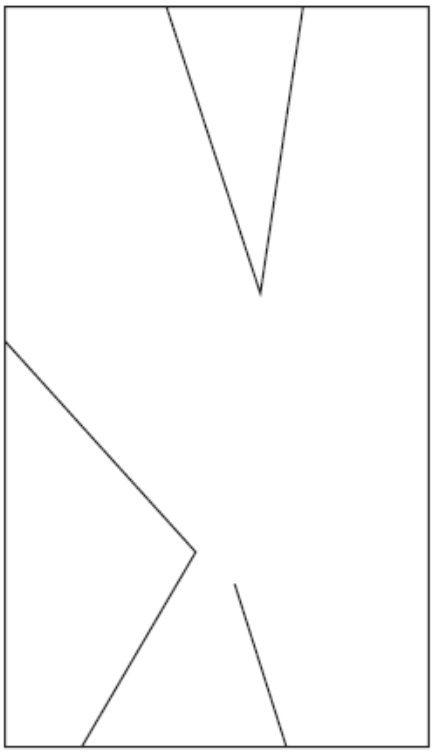
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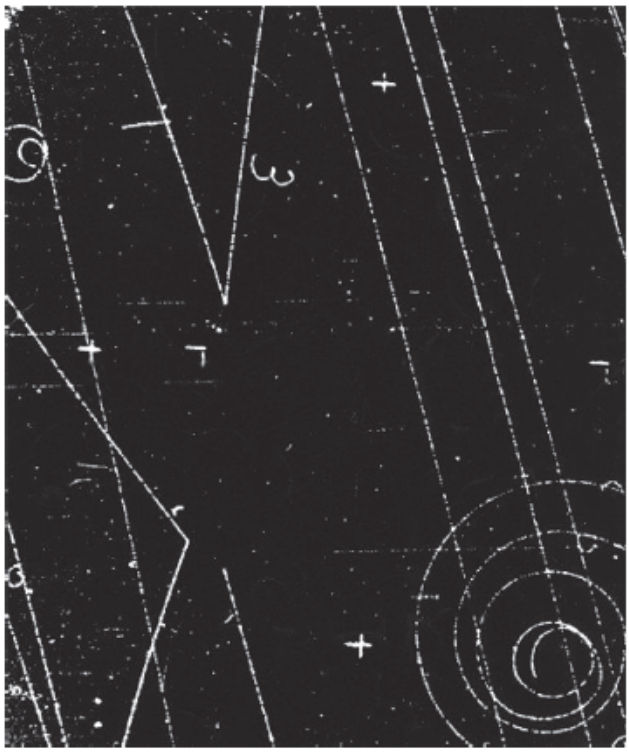
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Time = ...

*(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)

Q15.

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)

Q1. 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

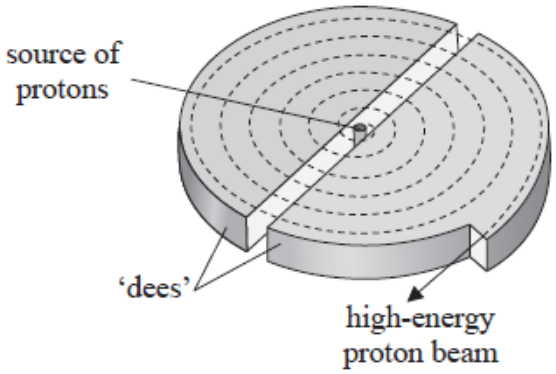
☒ **D** a decrease in Q

(Total for Question = 1 mark)

Q2.

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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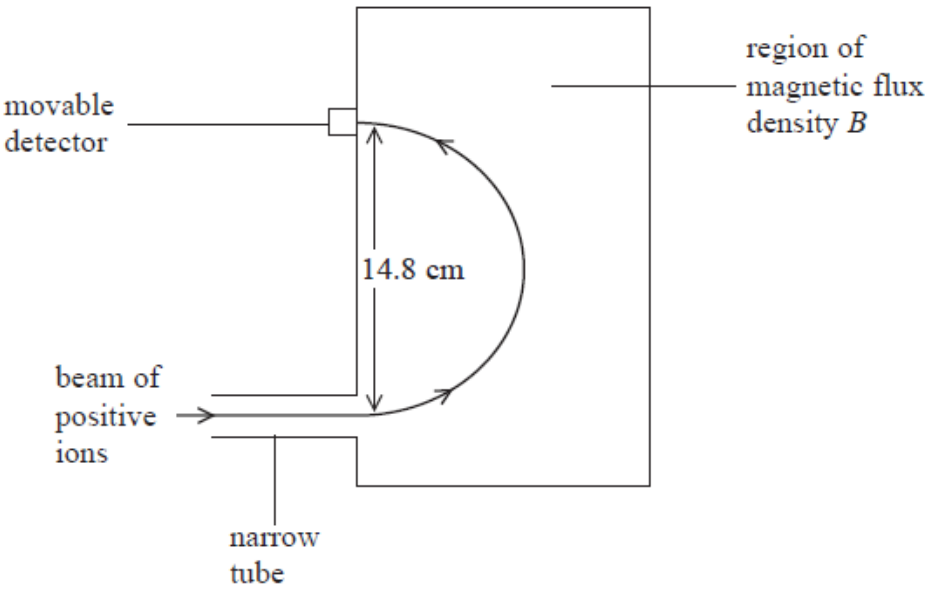
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(Total for question = 6 marks)

Q3.

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.

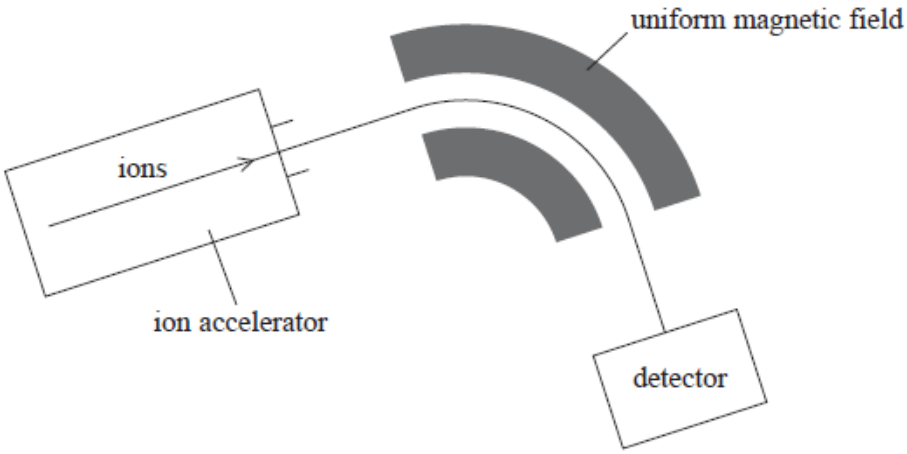
(1)

(Total for question = 6 marks)

Q4.

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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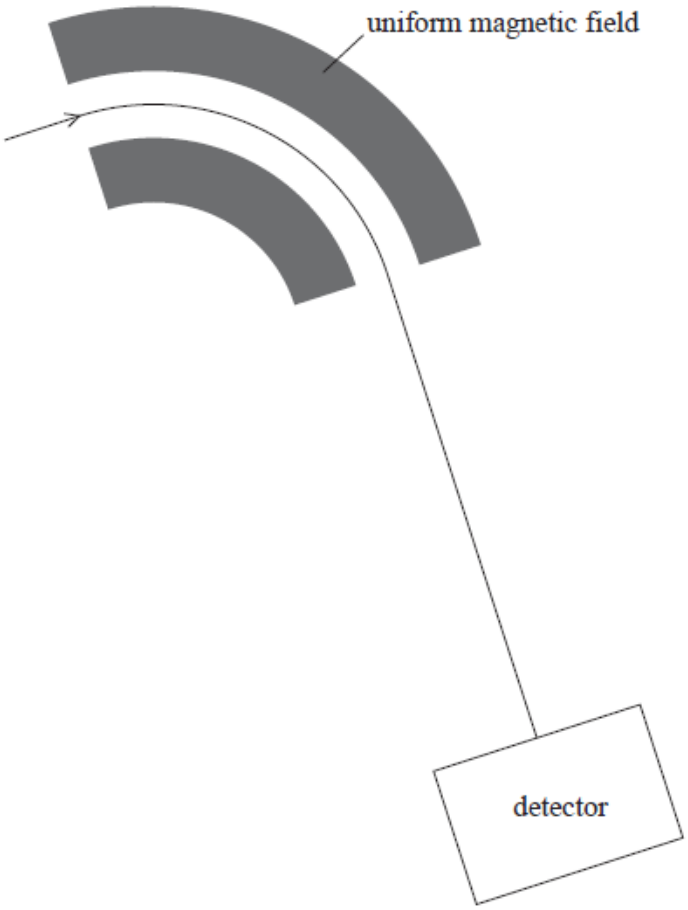
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Radius = ...

(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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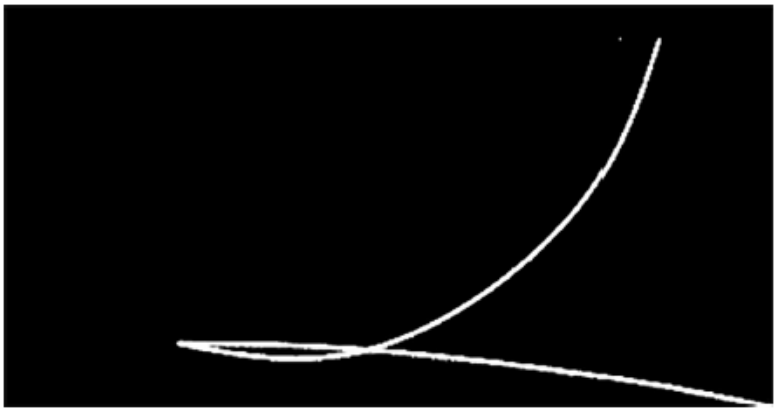
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(Total for question = 7 marks)

Q5.

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.



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

(6)

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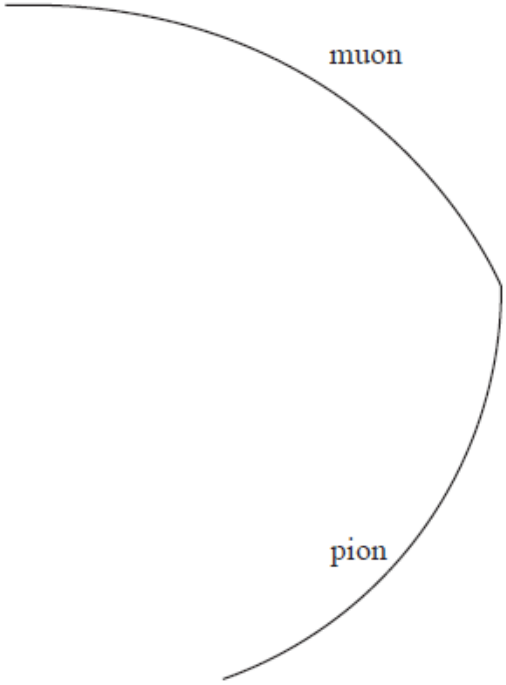
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(Total for question = 6 marks)

Q6.

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



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)

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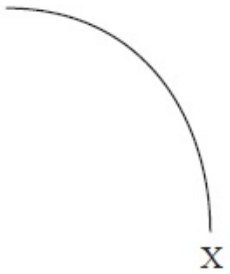
Magnetic flux density = ...

Direction of magnetic field = ...

(Total for question = 4 marks)

Q7. 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.

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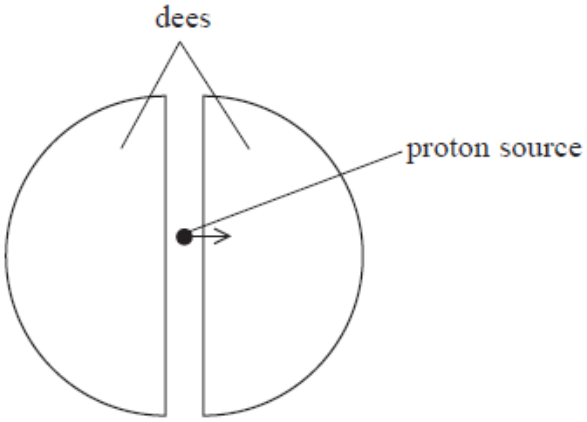
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(Total for Question = 5 marks)

Q8.

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 = ...

Q9.

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)

Q1. 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.

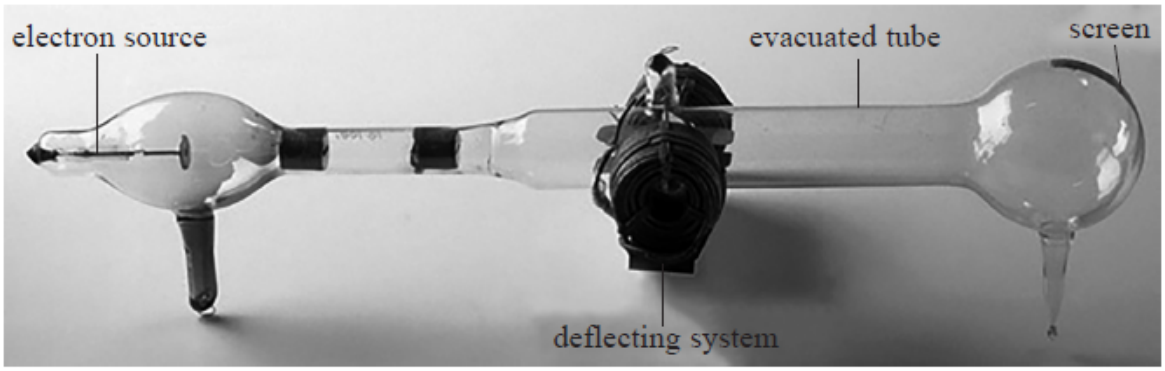
☒ **C** the tracks have different curvatures.

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

(Total for Question = 1 mark)

Q2.

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.



© Science Museum London

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.

(1)

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(Total for question = 1 mark)

Q3.

* 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)

Q4.

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 = ...

Q5.

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

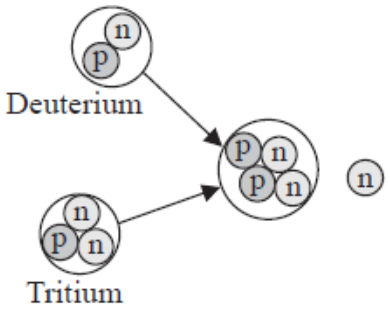
"Every year, one typical coal-fired power station devours several million tonnes of fuel and produces even more carbon dioxide. That volume of carbon dioxide is damaging the atmosphere

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)

$$\text{.....}^{\text{.....}}\text{H} + \text{.....}^{\text{.....}}\text{H} \rightarrow \text{.....}^{\text{.....}}\text{He} + \text{.....}^{\text{.....}}\text{n}$$

(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.

(5)

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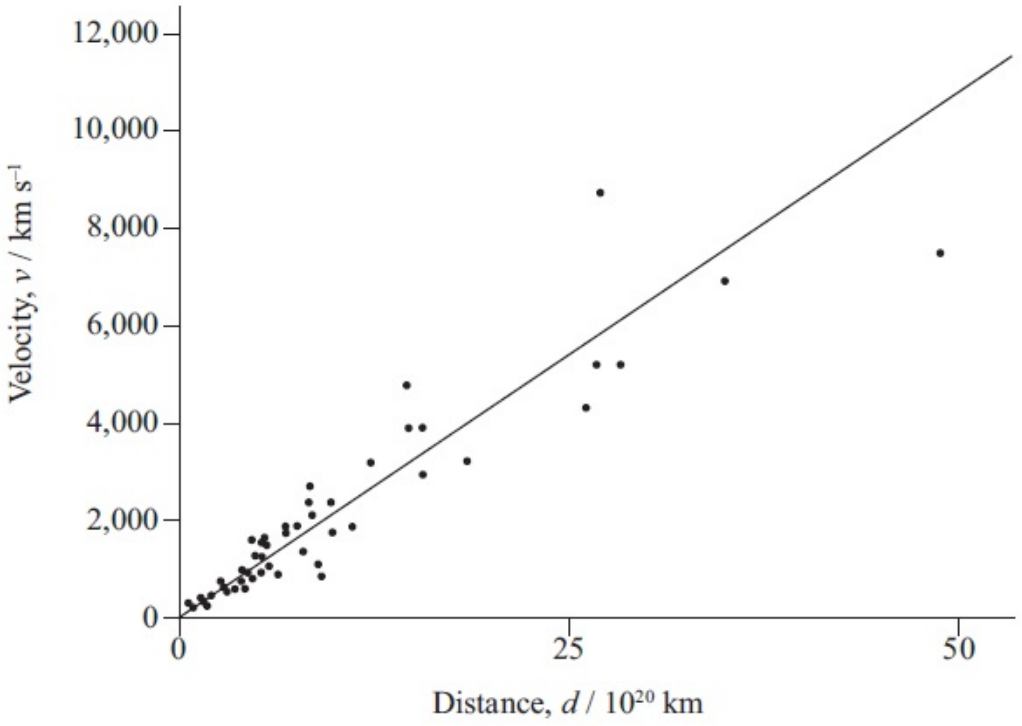
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(Total for question = 15 marks)

Q6.

The graph shows how the velocity varies with distance for a number of distant galaxies. All the galaxies are receding from Earth, and there appears to be a linear relationship between the velocity of recession and the distance to the galaxy.



(a) Use the graph to estimate an age for the Universe

(4)

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Age of the Universe = ...

*(b) Describe how astronomers would have determined the velocity of each galaxy.

(5)

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*(c) Scientists are uncertain about the ultimate fate of the Universe.

Explain why.

(3)

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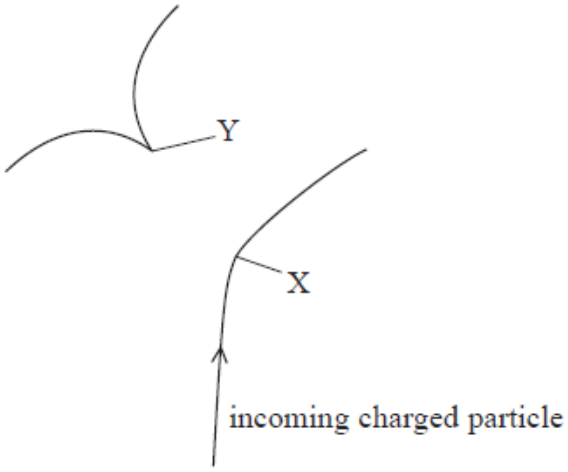
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(Total for question = 12 marks)

Q7.

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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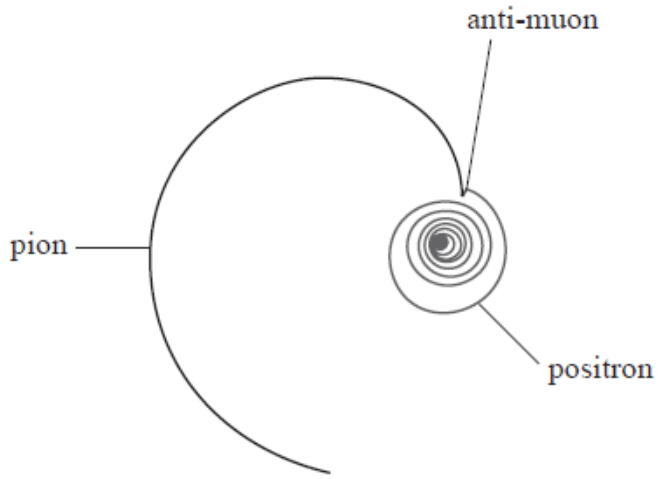
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Q8.

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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Q9.

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.

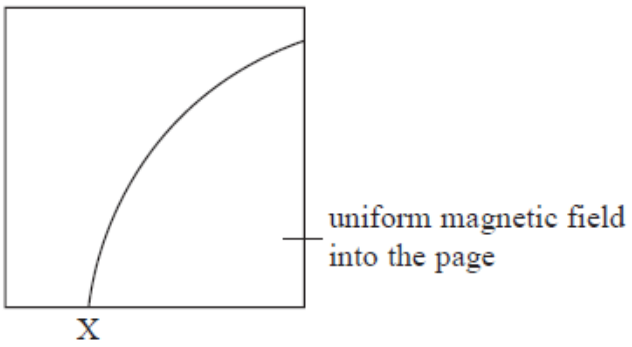
(a) State what is meant by ionisation in this context.

(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.

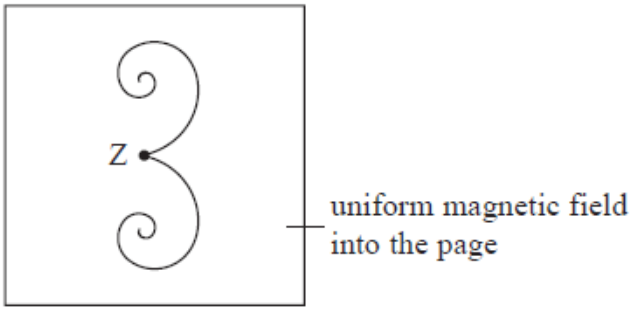
(1)

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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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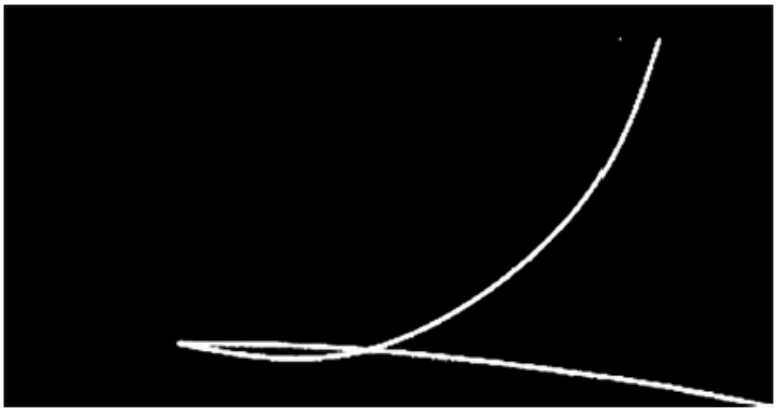
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(Total for question = 7 marks)

Q10.

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.



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

(6)

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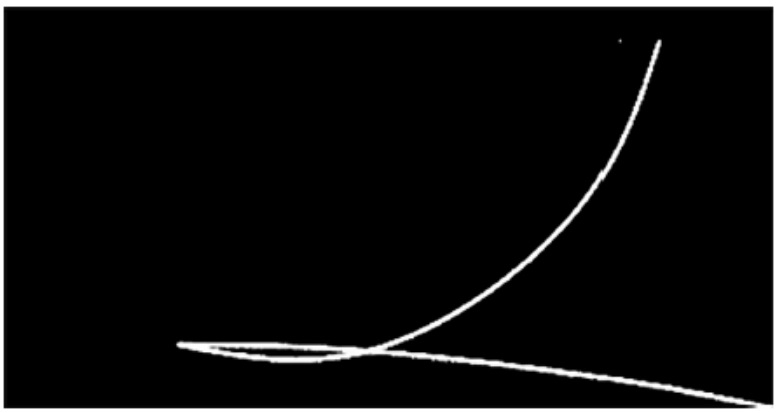
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(Total for question = 6 marks)

Q11.

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.



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

(i) Calculate this mass in kg.

(3)

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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)

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Total kinetic energy = ... MeV

(Total for question = 6 marks)

Q12.

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.

(3)

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(Total for question = 3 marks)

Q13.

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)

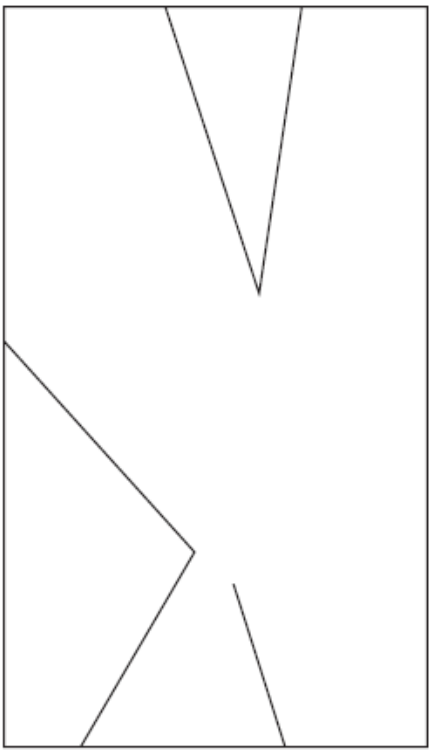
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Time = ...

*(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)

Q14.

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

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

(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^-	$\overline{\nu}_\mu$
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)

Q15.

According to astronomers in Denmark and Australia a common type of active galactic nucleus (AGN) could be used as an accurate "standard candle" for measuring cosmic distances. The technique has been used to measure distances corresponding to redshifts significantly larger than was previously possible.

(a) (i) State what is meant by a standard candle.

(1)

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(ii) Explain how a standard candle is used to measure cosmic distances.

(2)

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(b) (i) State what is meant by redshift.

(1)

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(ii) Calculate the distance to a galaxy with a redshift $z = 0.12$

$H_0 = 2.1 \times 10^{-18}\ s^{-1}$

(2)

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Distance to galaxy = ...

*(c) Discuss how astronomers were led to propose the existence of dark matter and the consequences of its existence for the ultimate fate of the universe.

(3)

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(d) Explain why the observable universe has a finite size.

(2)

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(Total for Question = 11 marks)

Q1.

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

The electron leaves the accelerator with a high energy.

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

(2)

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(Total for question = 2 marks)

Q2.

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)

Q3.

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)

Q4.

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)