Name: _____

Particle accelerators LEGACY

Questions

Date:

Time:

Total marks available:

Total marks achieved: _____

Questions

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. 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)

Q3. 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)

Q4.

Select one answer from A to D and put a cross in the box (☒)

The process by which electrons are released from a heated filament is known as

☒ **A** thermionic emission.

☒ **B** photoelectric emission.

☒ **C** ionisation.

☒ **D** excitation.

(Total for Question = 1 mark)

Q5.

Particles may be accelerated in a cyclotron.
Which of the following statements is true for a cyclotron?

☒ **A** Particles travel in a circular path of constant radius.

☒ **B** Protons and neutrons can be accelerated in a cyclotron.

☒ **C** Particles can be accelerated to speeds up to 3.2×10^8 m s^{-1}.

☒ **D** A magnetic field is used to keep particles moving in a circular path.

(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.

Select one answer from A to D and put a cross in the box (☒)

The diagram shows the path of an electron in a bubble chamber.

Which of the following can you deduce from the diagram?

☒ **A** The electron is moving anti-clockwise.

☒ **B** The electron is moving clockwise.

☒ **C** The magnetic field is acting out of the page.

☒ **D** The speed of the electron is increasing.

(Total for Question = 1 mark)

Q8.

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.

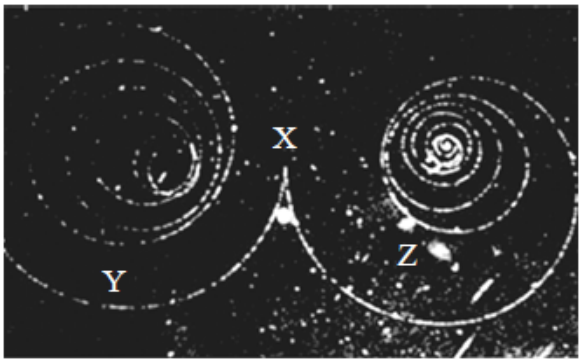
☒ **C** The accelerating particles spend the same time in each tube.

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

(Total for question = 1 mark)

Q9.

The photograph shows particle tracks from a particle detector.



Two new particles are created at point X. The tracks of the new particles are labelled Y and Z.

Why are Track Y and Track Z both spirals?

☒ **A** The magnetic field is oscillating.

☒ **B** The particles are gaining mass.

☒ **C** The particles are losing energy.

☒ **D** The speed of the particles is increasing.

(Total for question = 1 mark)

Q10.

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)

Q11.

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

☒ **A** excitation.

☒ **B** ionisation.

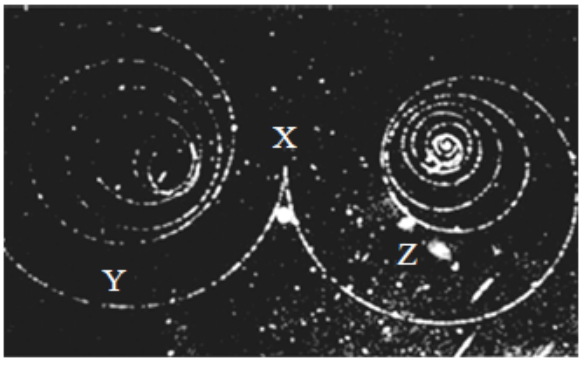
☒ **C** photoelectric emission.

☒ **D** thermionic emission.

(Total for question = 1 mark)

Q12.

The photograph shows particle tracks from a particle detector.



Two new particles are created at point X. The tracks of the new particles are labelled Y and Z.

Which of the following can be concluded from the tracks?

☒ **A** The magnetic field acts into the page.

☒ **B** The new particles are an electron and a positron.

☒ **C** The new particles have opposite charge.

☒ **D** The particle at Y is positively charged.

(Total for question = 1 mark)

Q13.

As a particle accelerates in a linac, it passes through drift tubes of increasing lengths. This is so that

☒ **A** the particle can be given more energy within each tube.

☒ **B** the frequency of the accelerating voltage can be constant.

☒ **C** the accelerating voltage can be as high as possible.

☒ **D** the time spent in the tube by the particle is longer.

(Total for question = 1 mark)

Q14.

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)

Q15.

A demonstration uses a beam of electrons in an evacuated tube. The electrons for the beam are produced by heating a metal filament.

This process is called

☒ **A** excitation.

☒ **B** ionisation.

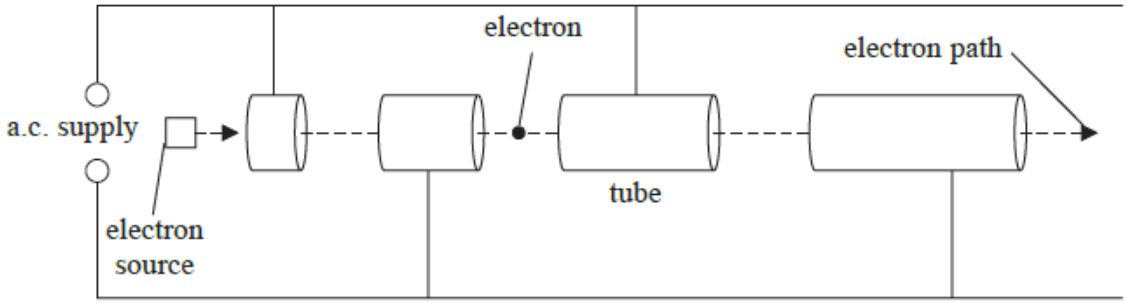
☒ **C** the photoelectric effect.

☒ **D** thermionic emission.

(Total for question = 1 mark)

Q16.

Bertozzi used an early type of linac to accelerate the electrons in his experiment. The diagram shows the essential structure of a modern linac.



In the first part of the accelerator the drift tubes gradually increase in length, but at the end of the accelerator, the tubes are of the same length.

(i) Explain why the tubes gradually increase in length in the first part of the accelerator.

(2)

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(ii) State why the tubes are the same length at the end of the accelerator.

(1)

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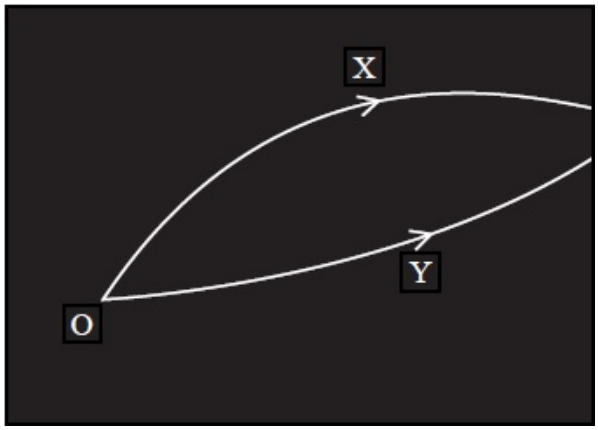
(Total for question = 3 marks)

Q17.

Select one answer from A to D and put a cross in the box (☒)

A particle detector shows tracks produced by two particles X and Y that were created by the decay of a lambda particle at O.



(i) Which of the following is a valid conclusion from these facts?

☒ **A** X is a negatively charged particle.

☒ **B** Y is a positively charged particle.

☒ **C** The lambda particle is neutral.

☒ **D** The magnetic field is acting into the plane of the paper.

(ii) Which of the following is a correct statement about momentum at the decay?

☒ **A** The vector sum of the momenta of X and Y must equal that of the lambda particle.

☒ **B** The momentum of X is equal to that of Y.

☒ **C** The total momentum of this system is zero.

☒ **D** The vector sum of the momenta of X and Y must equal zero.

(iii) Which of the following is a correct statement about energy at the decay?

☒ **A** The energy of X must be greater than that of Y.

☒

B The combined energy of X and Y must be more than the energy of the lambda particle.

☒ **C** The mass of the lambda particle must equal the combined energy of X and Y.

☒ **D** The mass energy of the lambda particle must equal the total energy of X and Y.

(Total for Question = 3 marks)

Q18.

A proton in a particle detector is travelling in a direction perpendicular to the magnetic field. The proton moves in a curved path. At one point the radius of the path is 0.091 m.

Show that the speed of the proton at this point is about 3×10^7 m s^{-1}.

magnetic flux density = 3.2 T

(3)

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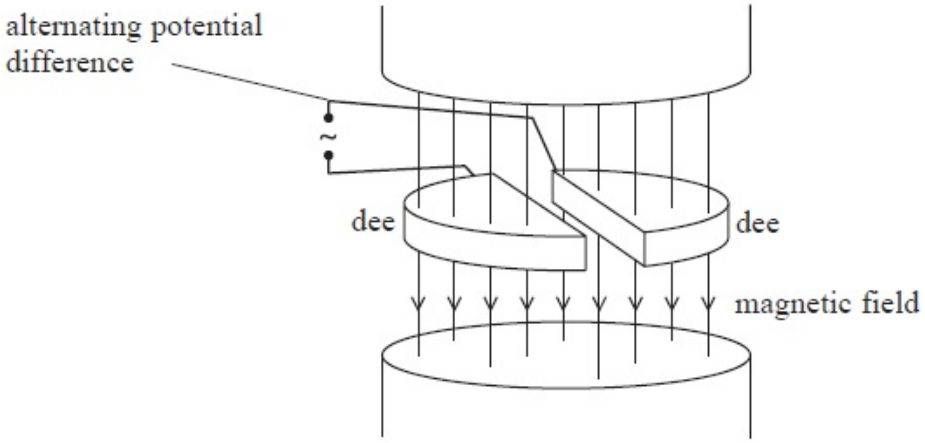
(Total for question = 3 marks)

Q19. * 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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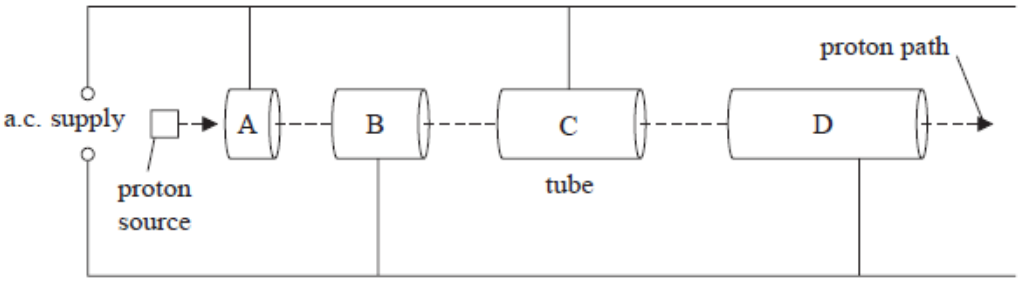
(Total for Question = 4 marks)

Q20.

* At CERN a linear accelerator (linac) is used to accelerate protons before they are injected into the Large Hadron Collider.
The diagram represents a simplified linac.



A, B, C and D represent drift tubes to which a large alternating potential is applied.

Explain how a proton is accelerated by the linac.

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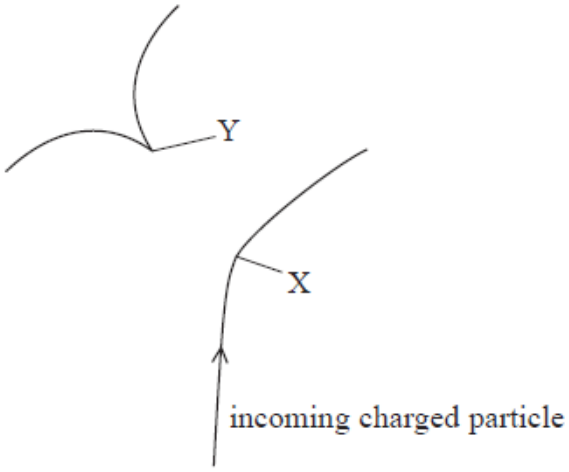
(Total for question = 4 marks)

Q21.

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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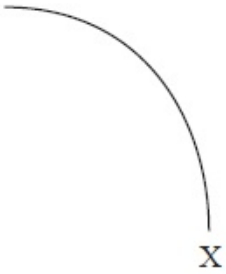
Q22. Scientists studying anti-matter recently observed the creation of a nucleus of anti-helium 4, which consists of two anti-protons and two anti-neutrons.

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)

Q23.

* A bubble chamber is a particle detector which makes use of electric and magnetic fields.

Explain the role of electric and magnetic fields in a particle detector.

(5)

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(Total for question = 5 marks)

Q24.

In his theory of special relativity, Einstein proposed that it is impossible for particles to travel faster than the speed of light.

In 1964 the physicist William Bertozzi performed an experiment to test Einstein's theory. Electrons were accelerated from rest through a potential difference (p.d.) and their kinetic energy was determined.

The electrons then travelled through a tube 8.4 m long and the time taken to travel this distance was measured. The speed of the electrons in the tube was then calculated.

The table shows results based on Bertozzi's experiment.

Kinetic energy of electron / 10^{-13} J	Speed of electron / 10^{8} m s^{-1}
0.8	2.60
1.6	2.73
2.8	2.89
4.8	2.95
7.2	2.96

(a) Calculate the p.d. needed to accelerate an electron from rest if it gains a kinetic energy of 7.2×10^{-13} J.

(2)

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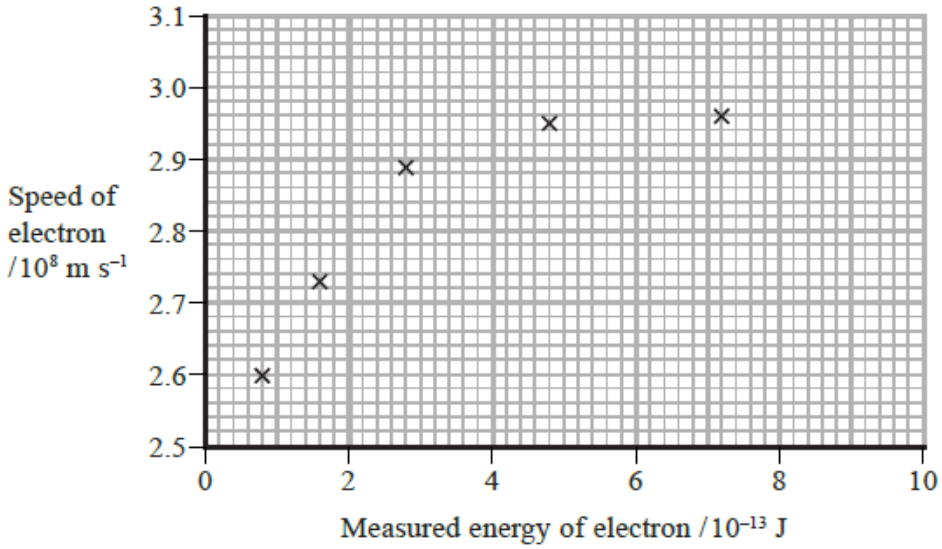
p.d. = ...

(b) The results are plotted on the graph below.



Use the graph to verify that Bertozzi's experiment supports Einstein's theory.

(2)

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(c) A student uses the equation $E_k = \frac{1}{2}mv^2$ and information from the data at the back of this paper to calculate values for the kinetic energy of the electrons in this experiment. When he compares his correctly calculated values with the measured values in the table, they are not the same. Explain why.

(2)

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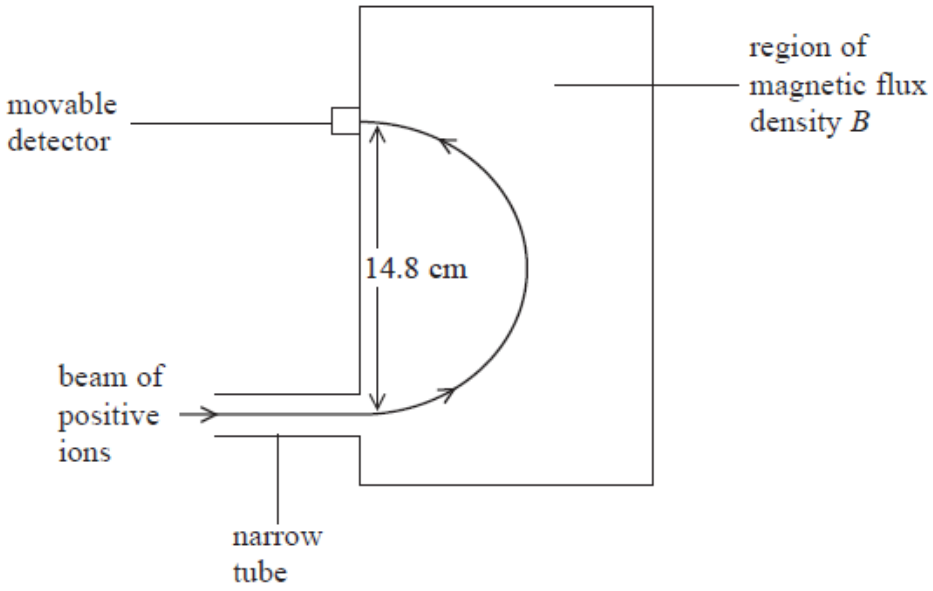
(Total for question = 6 marks)

Q25.

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 = ...

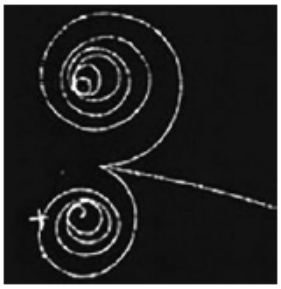
(d) Ions with a smaller mass but the same charge and speed are also present in the beam. On the diagram sketch the path of these ions.

(1)

(Total for question = 6 marks)

Q26.

The picture shows the tracks in a bubble chamber after an interaction. A photon enters from the left and collides with a stationary neutral hydrogen atom. An electron is ejected from the hydrogen atom and moves at high speed. An electron-positron pair is also created.



(a) State why the photon leaves no track.

(1)

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(b) Explain why the ejected electron undergoes less deflection than the electron-positron pair.

(2)

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(c) Show that charge is conserved in the interaction.

(2)

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(d) Explain why there is no track from the ionised hydrogen atom after the collision.

(2)

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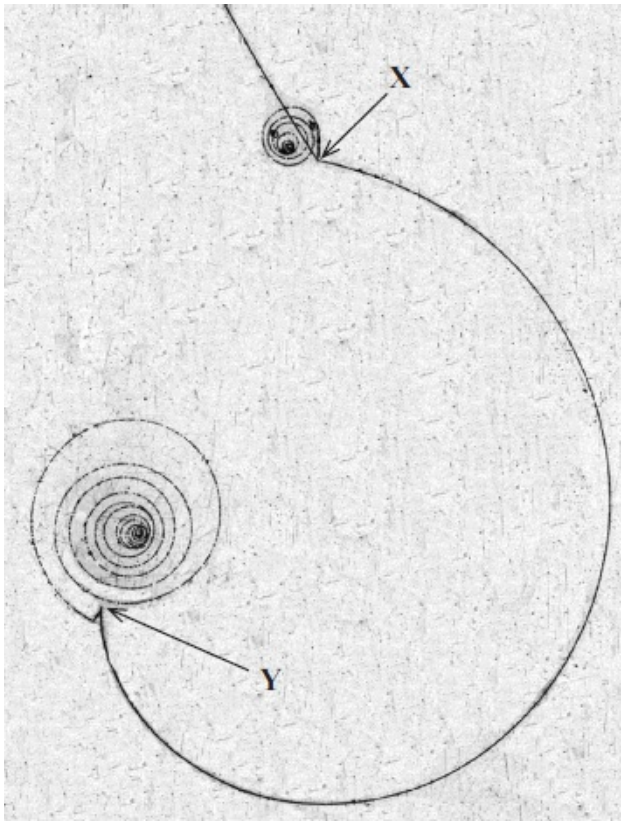
(Total for question = 7 marks)

Q27.

The photograph shows tracks in a particle detector.



(a) Explain the role of a magnetic field in a particle detector.

(2)

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(b) Explain how you can tell that track XY was produced by a particle moving from X to Y rather than from Y to X.

(2)

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(c) The particle that produced track XY was a π^+. Deduce the direction of the magnetic field in the photograph.

(1)

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(d) At Y, the π^+ decayed into a positively charged muon (μ^+) and a muon neutrino. The μ^+ has a very short range before decaying into various particles, including a positron which produced the final spiral.

(i) Give **two** reasons why you can deduce that the muon neutrino is neutral.

(2)

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(ii) Explain the evidence from the photograph for the production of the muon neutrino at Y.

(3)

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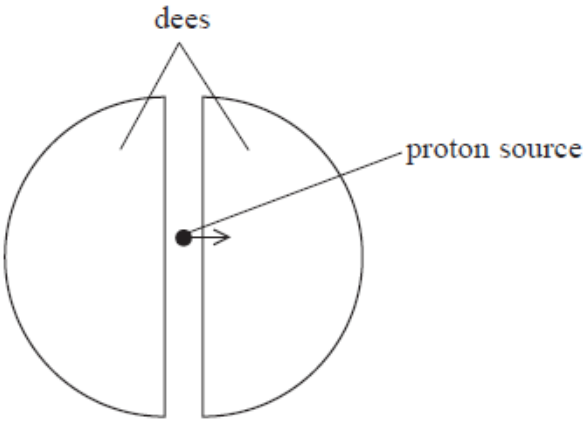
(Total for Question = 10 marks)

Q28.

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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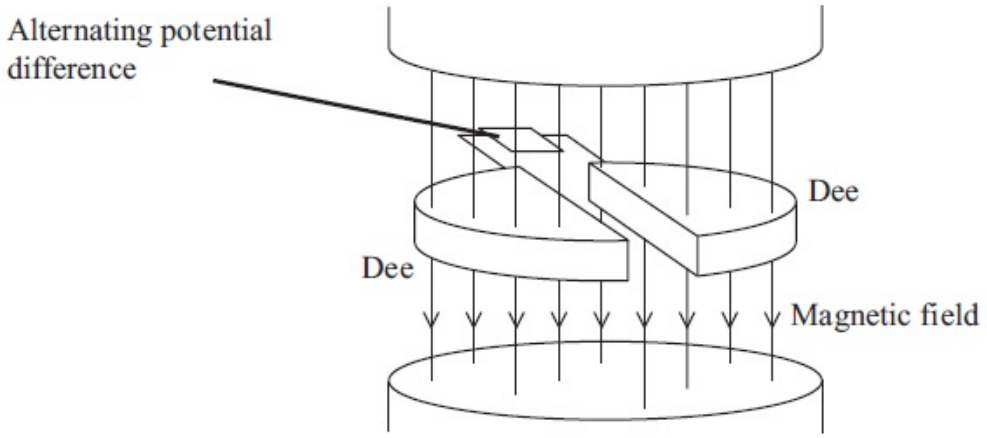
f = ...

Q29.

(a) A cyclotron can be used to accelerate charged particles.



Explain the purpose of the magnetic field in a cyclotron. You may add to the diagram if you wish.

(2)

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(b) A beam of low-speed protons are introduced into a cyclotron.

(i) Show that the number of revolutions per second, *f*, completed by the protons is given by

$$f = \frac{eB}{2\pi m}$$

where *e* is the electronic charge
B is the uniform magnetic flux density within the cyclotron
m is the mass of the proton

(3)

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(ii) An alternating potential difference is placed across the two dees to increase the energy of the protons.

Explain why the potential difference that is used is alternating.

(2)

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(iii) Initially, whilst the proton speeds are low, the frequency at which the potential difference has to alternate is constant.

Explain how the frequency must change as the protons gaine more and more energy.

(2)

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(c) In the Large Hadron Collider and CERN, protons follow a circular path with speeds close to the speed of light. X-rays can be produced by free protons which are accelerating.

Explain why this provides a source of X-rays even though the speeds of the protons are constant.

(2)

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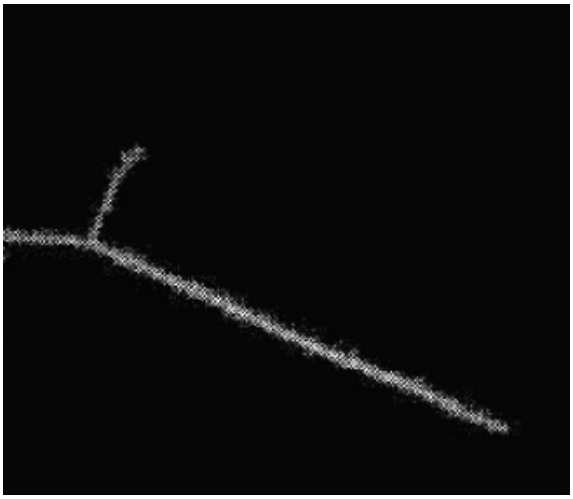
(Total for Question = 11 marks)

Q30.

A low-energy particle collides elastically with a stationary particle of the same mass.
The particle enters from the left of the photograph.



(a) State what is meant by collides *elastically.*

(1)

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(b) Sketch a labelled vector diagram to show how the momentum of the initial moving particle relates to the momenta of the two particles after the collision.

(2)

(c) Use your answers to (a) and (b) to confirm that the angle between the subsequent paths of both particles must be 90°.

(2)

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(d) (i) Explain the process by which a proton is given energy in a particle accelerator.

(3)

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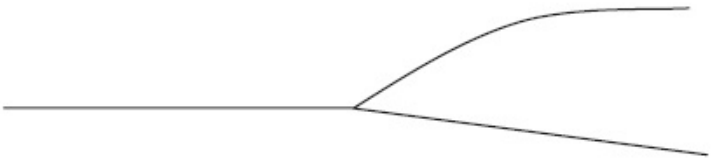
The diagram shows a collision between a high-energy proton (track from the left) and a stationary proton in a particle accelerator experiment.



(ii) Explain why the angle between the two paths is not 90°.

(2)

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(e) Deduce the direction of the magnetic field in this particle accelerator experiment. Circle the correct direction from those given below.

(1)

left to right across the paper out of the plane of the paper into the plane of the paper

(Total for Question = 11 marks)

Q31.

***** Pion radiotherapy is a new form of cancer treatment that has been extensively investigated for tumours of the brain. Pions are short lived sub-atomic particles and belong to a group called mesons.

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

Quark	Charge / *e*
Up (u)	$+\frac{2}{3}$
Down (d)	$-\frac{1}{3}$
Strange (s)	$-\frac{1}{3}$
Charm (c)	$+\frac{2}{3}$

On the list below circle the combination which could correspond to a π^+ pion.

(1)

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

(b) The mass of a pion is 0.14 GeV/c^2. Calculate the mass of a pion in kg.

(3)

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Mass =.....kg

(c) Pions can be produced by accelerating protons using a cyclotron. Briefly explain the role of electric and magnetic fields within a cyclotron.

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(d) When pions are used to treat brain tumours they are slowed by the tissue in the brain and cause little damage. When a pion is moving very slowly it may be absorbed by the nucleus of an atom. The atom nucleus then becomes unstable and breaks up into several fragments.

Explain why these fragments shoot out in all directions.

(3)

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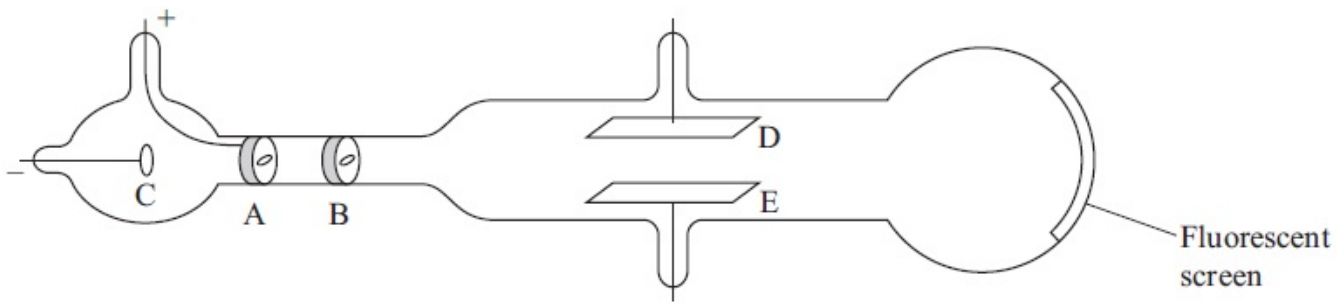
(Total for Question = 12 marks)

Q32.

J J Thomson is credited with the discovery of the electron. He measured the 'charge to mass ratio' *e/m* for the electron, using the apparatus shown.



A metal disc at C emits electrons. A positively-charged disc at A accelerates the electrons along the tube. Slits in A and B produce a narrow horizontal beam of electrons. An electric field is produced between plates D and E, which can be used to deflect the beam vertically. The final position of the beam is shown on a fluorescent screen at the end of the tube.

(a) Describe how a metal disc can be made to emit electrons.

(2)

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(b) The length of plates D and E is *l*. Thomson deduced that the vertical component v_v of velocity gained by the electrons as they leave the plates is given by

$$v_v = \frac{Ee}{m} \times \frac{l}{v}$$

where *E* is the electric field strength between the plates and *v* is the velocity with which the electrons entered the field.

Show that this expression is correct.

(3)

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(c) Thomson determined the angle θ at which the beam was deflected.

Suggest how this angle could be determined.

(3)

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(d) The angle θ is also given by

$$\tan\theta = \frac{Ee}{m} \times \frac{l}{v^2}$$

Show that this equation is correct.

(2)

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(e) Thomson replaced the electric field with a uniform magnetic field which acted over the same length as the plates. He adjusted the flux density B to obtain the same deflection on the screen.

For this arrangement he assumed that the vertical component of velocity gained by the electrons as they leave the plates is given by

$$v_{\mathrm{v}} = \frac{Bev}{m} \times \frac{l}{v}$$

(i) Thomson just replaced the term eE in the equation in part (b) with Bev.

Suggest why he did this.

(1)

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(ii) Give **two** reasons why the equation $v_v = \frac{Bev}{m} \times \frac{l}{v}$ is **not** correct.

(2)

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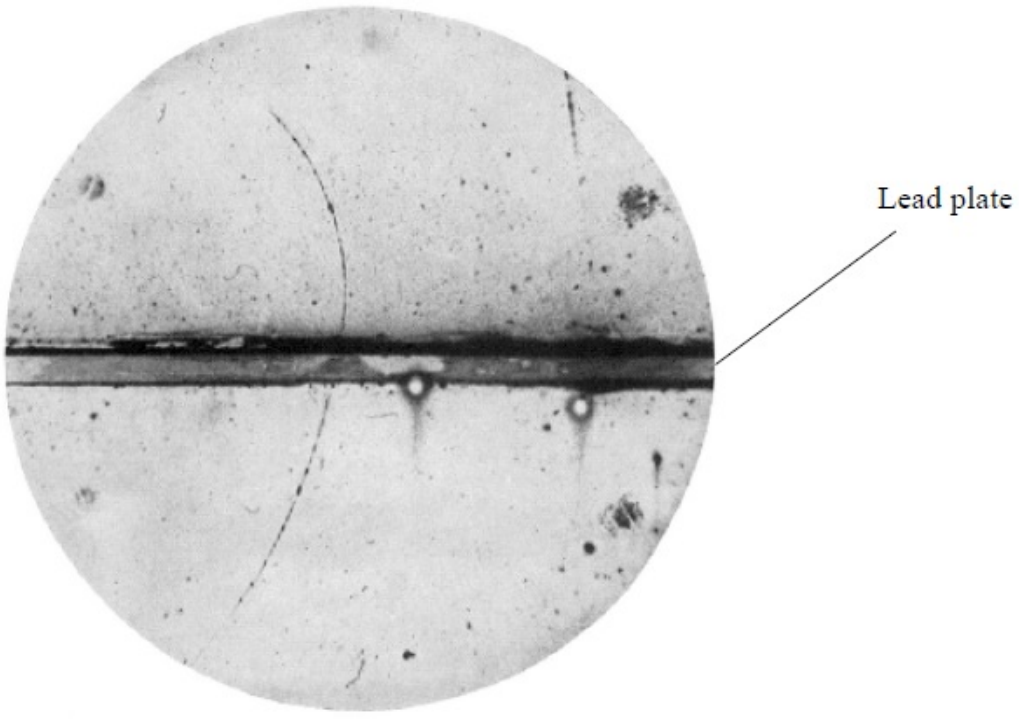
(Total for question = 13 marks)

Q33.

The photograph shows the track of a positively charged particle either side of a lead plate.



The particle was deflected by a magnetic field of magnetic flux density 1.5 T. The field is

perpendicular to the plane of the photograph.

(a) (i) Estimate the actual radius of the track above the lead plate.

The lead plate is 6 mm thick.

(3)

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Radius =.....

(ii) Calculate the momentum of this particle above the lead plate.
Particle charge = 1.6×10^{-19} C

(2)

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Momentum =.....

(b) Explain whether this particle was moving up or down through the lead plate.

(3)

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(c) On the list below circle the correct direction of the magnetic field.

(1)

Into the page from left to right down the page out of the page up the page

(d) This particle was identified as a positron.

(i) Calculate the speed of the positron while it is moving above the lead plate.

(2)

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Speed =.....

(ii) Comment on your answer.

(2)

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(Total for Question = 13 marks)

Q34.

(a) Describe the key observations of the aplha particle scattering experiments which led to Rutherford's nuclear model of the atom.

(3)

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(b) Experiments at Stanford University's linear accelerator (linac) accelerate electrons up to energies of 20 Ge V.

(i) State the main features of a linac.

(3)

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(ii) Calculate the de Broglie wavelength of 20 GeV electrons. At these energies, the following relativistic equation applies $E = pc$.

(3)

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De Broglie wavelength = ...

(iii) Suggest why these electrons would be particularly useful for investigating nuclear structure.

(1)

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(iv) These electrons can be aimed at a hydrogen target. Some of these electrons are scattered at large angles by the protons whilst others pass straight through.

Suggest what this tells you about the structure of a proton.

(2)

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(v) The scattering process is inelastic. What is meant by an inelastic collision?

(1)

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(Total for Question = 13 marks)

Q35.

Evidence for a charm quark was discovered in 1974 at the linear accelerator (linac) at Stanford University.

(a) Why do the tubes of a linac become progressively longer down its length?

(1)

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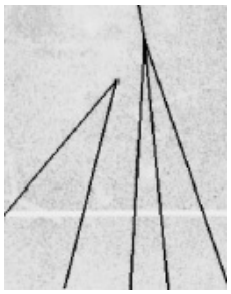
(b) This image shows the decay of a D^0 meson into a positively charged kaon and a negatively charged pion.



(i) Mark on the image the point P at which this decay occurs.

(1)

(ii) Give **two** reasons for choosing this point.

(2)

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(iii) Write an equation for this decay event.

(2)

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*(iv) State and discuss how three conservation laws apply to this decay event.

(6)

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(c) The table below shows some quarks and their properties.

Quark	Charge / e
Up (u)	$+\frac{2}{3}$
Down (d)	$-\frac{1}{3}$
Strange (s)	$-\frac{1}{3}$
Charm (c)	$+\frac{2}{3}$

(i) Circle the correct combination of quarks in the list below which corresponds to a D^0 meson.

(1)

$c\bar{u}$ cds $c\bar{s}$ cud

(ii) Suggest a possible quark combination of the positively charged kaon.

(1)

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(Total for Question = 14 marks)