Edexcel Physics Unit 4

Topic Questions from Papers

Particle Physics

SECTION B

Answer ALL questions in the spaces provided.

***8** Rutherford designed an experiment to see what happened when alpha particles were directed at a piece of gold foil. Summarise the observations and state the conclusions Rutherford reached about the structure of gold atoms.

(5)

(Total for Question 8 = 5 marks)

***14** 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 $\quad$ $\bar{d}\bar{d}\bar{d}$ $\quad$ $u\bar{d}$ $\quad$ $s\bar{c}$

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

(3)

....

....

....

....

....

....

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.

(5)

....

....

....

....

....

....

....

....

....

....

(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)

....

....

....

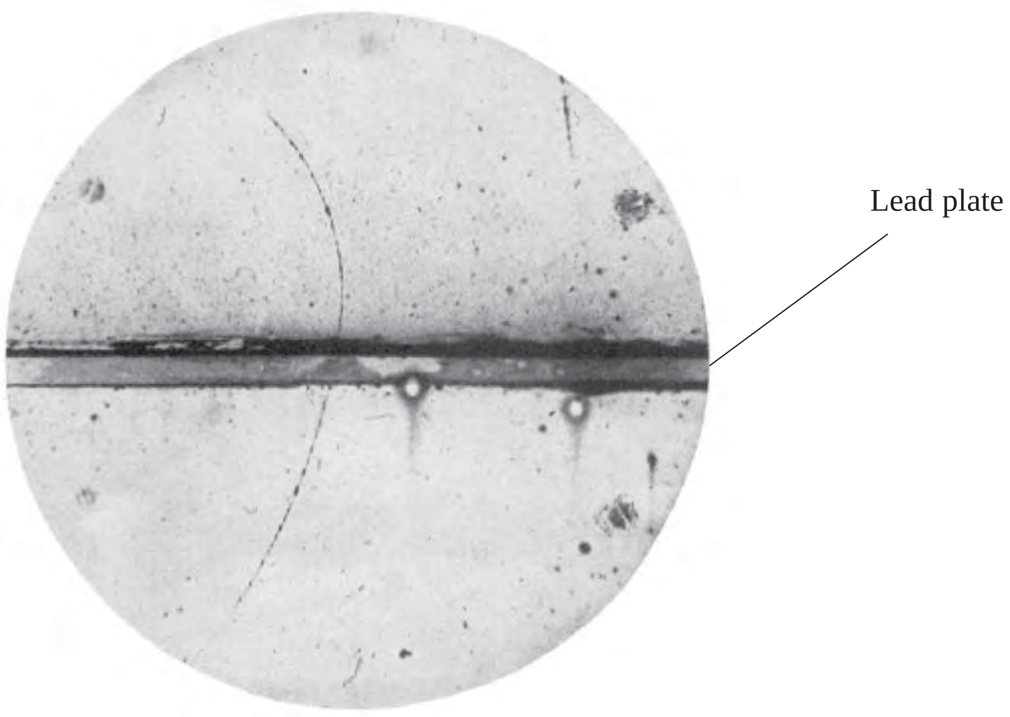
....

....

....

(Total for Question 14 = 12 marks)

15 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)

....

....

....

....

....

....

Radius = ...

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

(2)

....

....

....

....

Momentum = ...

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

(3)

....

....

....

....

....

....

(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)

Speed = ...

(ii) Comment on your answer.

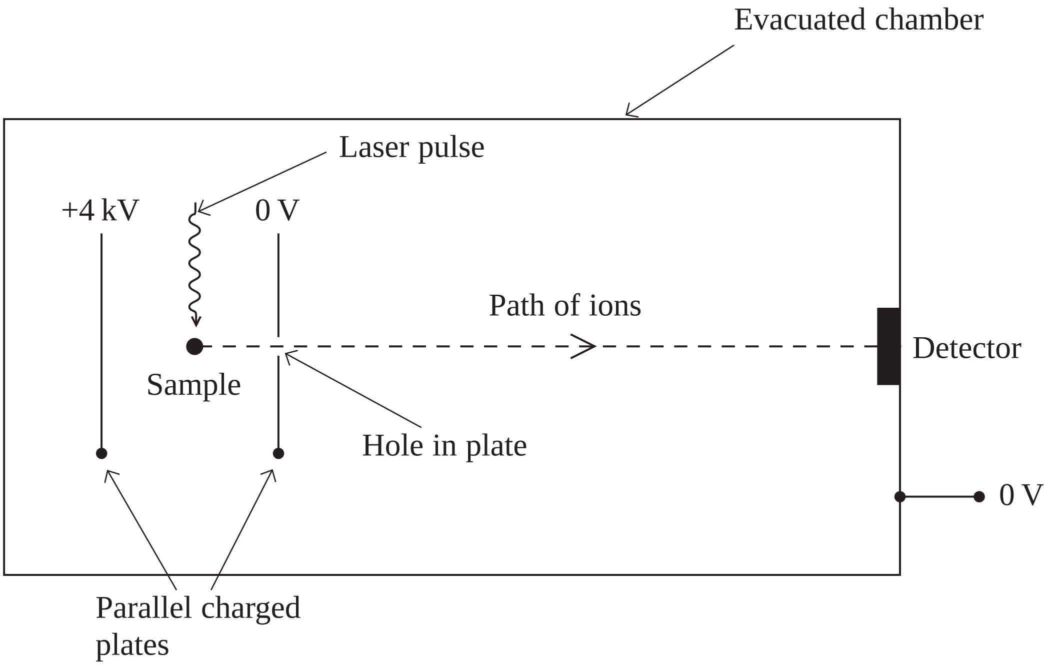
(2)

(Total for Question 15 = 13 marks)

TOTAL FOR SECTION B = 70 MARKS

TOTAL FOR PAPER = 80 MARKS

15 Time-of-flight mass spectroscopy uses the arrangement below to measure the mass of molecules. A laser pulse knocks an electron out of a molecule in a sample leaving it as a positively charged ion.



(a) Add to the diagram to show the electric field lines between the two plates.

(3)

(b) The sample is midway between the charged plates. Show that the speed, v, of an ion as it reaches the hole in the plate is given by

$$v = \sqrt{\frac{6.4\times10^{-16}\ \text{joule}}{m}}$$

where m is the mass of the molecule in kg.

(3)

....

....

....

....

....

....

(c) The distance between the hole in the plate and the detector is 1.5 m. The time taken for a molecule to cover this distance is 23 μs.

Calculate the mass of this molecule.

(3)

....

....

....

....

....

....

Mass = ...

(d) There is some uncertainty in the time a molecule with a particular mass will take to cover this distance.

Suggest **two** reasons for this.

(2)

1 ....

....

....

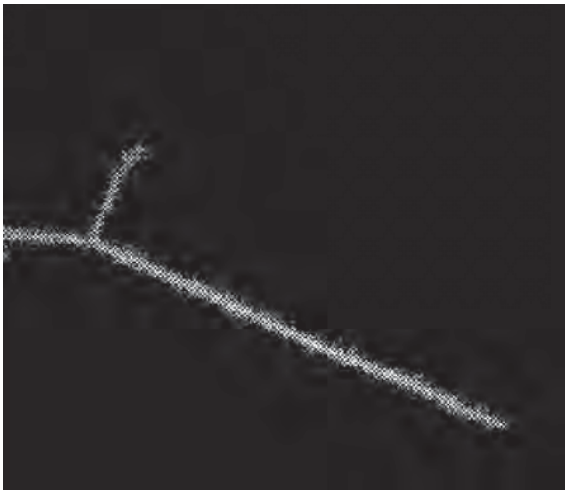
2 ....

....

....

(Total for Question 15 = 11 marks)

17 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)

....

....

(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)

....

....

....

....

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

(3)

....

....

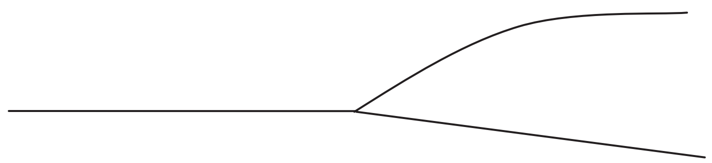
....

....

....

....

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)

....

....

....

....

(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 17 = 11 marks)

***18** In 1961 Murray Gell-Mann predicted the existence of a new particle called an omega (Ω) minus. It was subsequently discovered in 1964.

At this time the quark model consisted of three particles, the properties of which are given in the table.

Quark	**Charge**	**Predicted mass in MeV/c^2**
Up (u)	$+\frac{2}{3}$	4
Down (d)	$-\frac{1}{3}$	4
Strange (s)	$-\frac{1}{3}$	80

(a) Explain what a charge of $+\frac{2}{3}$ means.

(1)

....

....

(b) State the predicted mass of, and the charge on a $\bar{s}$.

(2)

....

....

(c) Convert 4 MeV/c^2 to kg.

(3)

....

....

....

....

....

....

Mass = ... kg

(d) The event which led to the discovery of the omega minus particle can be summarised as follows. A negative kaon collided with a stationary proton and produced a positive kaon, a neutral kaon and the omega minus.

(i) Kaons K consist of combinations of either an up or down quark plus a strange quark. The omega minus consists of three strange quarks.

Complete the following table by ticking the appropriate boxes.

(2)

	Meson	Baryon	Nucleon	Lepton
Negative kaon				
Omega minus				

(ii) Write an equation using standard particle symbols to summarise this event.

(2)

....

....

....

....

(iii) The negative kaon consists of $\bar{u}$ s. Deduce the quark structure of the other two kaons involved in this event.

(2)

....

....

....

....

(iv) The total mass of the three particles created after this event is larger than the total mass of the two particles before. Discuss the quantities that must be conserved in interactions between particles and use an appropriate conservation law to explain this increase in mass.

(5)

....

....

....

....

....

....

....

....

....

....

(Total for Question 18 = 17 marks)

TOTAL FOR SECTION B = 70 MARKS

TOTAL FOR PAPER = 80 MARKS

SECTION B

Answer ALL questions in the spaces provided.

11 A particle called a B meson has been observed to decay into an antiproton plus a lambda (Λ) particle. The lambda particle consisted of an up, a down and a charmed quark.
The following table summarises the charges on these quarks.

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

(a) Circle the correct word from the list below to describe the lambda particle.
(1)

Baryon   Lepton   Meson   Anti-particle

(b) Calculate the charge on the lambda particle.
(1)

....

....

Charge = ...

(c) Write an equation using standard particle symbols for this decay.
(2)

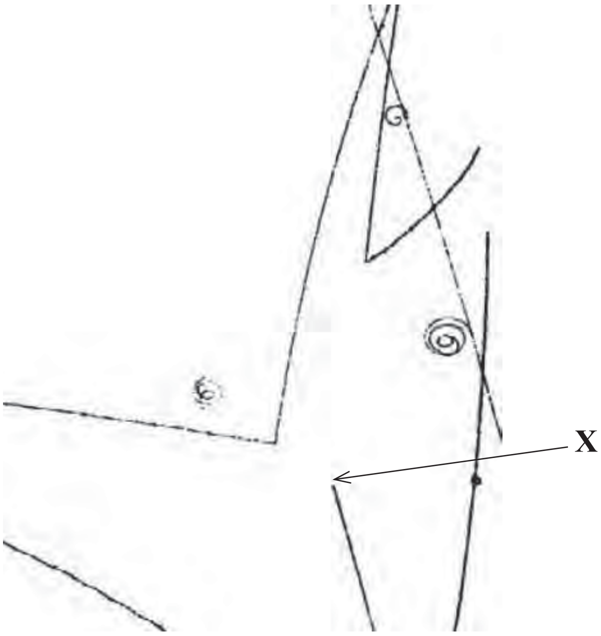
....

....

....

(Total for Question 11 = 4 marks)

***12** The photograph shows tracks produced by charged particles in a bubble chamber.



At X, an incoming charged particle interacts with a stationary proton to produce a neutral lambda particle and a neutral kaon particle. Both these particles later decay into other particles.

With reference to the photograph, describe and explain the evidence provided for this event.

(4)

....

....

....

....

....

....

....

....

(Total for Question 12 = 4 marks)

14 Muons have the same charge as electrons and can be produced by particle experiments. Muons belong to a family of fundamental particles called leptons. Muons have a short life and decay to electrons. Exotic atoms can be produced in which muons have been substituted for electrons. For example, muonic hydrogen consists of a proton and a muon.

(a) What is meant by a fundamental particle?

(1)

....

(b) Sketch the electric field around a muon.

(3)

(c) The mass of a muon is 106 MeV/c^2. Show that its mass is about 200 times that of an electron.

(3)

....

....

....

....

....

....

....

(d) Calculate the electric force between the muon and proton in the muonic hydrogen atom.

distance between muon and proton = 2.7×10^{-13} m

(2)

....

....

....

....

....

Electric force = ...

(e) Emission line spectra in the X-ray region of the electromagnetic spectrum can be detected from muonic hydrogen atoms.

Outline the atomic processes that produce emission spectra and suggest why they are X-rays in this case.

(3)

....

....

....

....

....

....

....

....

(Total for Question 14 = 12 marks)

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

(3)

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

(i) State the main features of a linac.

(3)

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

(3)

....

....

....

De Broglie wavelength = ...

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

(1)

....

....

....

(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)

....

....

....

....

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

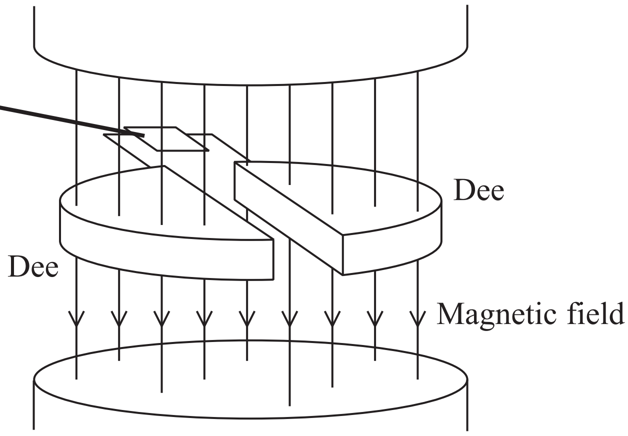
(1)

....

....

(Total for Question 16 = 13 marks)

17 (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)

....

....

....

(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)

....

....

....

....

....

....

....

(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)

....

....

....

....

(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 gain more and more energy.

(2)

....

....

....

....

(c) In the Large Hadron Collider at 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)

....

....

....

....

(Total for Question 17 = 11 marks)

SECTION B

Answer ALL questions in the spaces provided.

11 The de Broglie wave equation can be written $\lambda = \sqrt{\frac{h^2}{2mE_k}}$ where m is the mass of a particle and E_k is its kinetic energy.

(a) Derive this equation. Use the list of equations at the end of this question paper.

(2)

....

....

....

....

....

....

(b) An electron is accelerated through a potential difference of 2500 V.

Using the equation $\lambda = \sqrt{\frac{h^2}{2mE_k}}$ calculate the de Broglie wavelength of this electron.

(3)

....

....

....

....

....

....

....

Wavelength = ...

(Total for Question 11 = 5 marks)

16 (a) Sketch the electric field surrounding the gold nucleus drawn below.

(3)

(b) The spreadsheet shown approximately models the behaviour of an alpha particle as it approaches a gold nucleus.

The proton number of gold is 79.
mass of alpha particle = 6.64×10^{-27} kg

	A	**B**	**C**	**D**	**E**
1	**Distance from gold nucleus / m**	**Magnitude of force on alpha particle / N**	**Time interval / s**	**Velocity at end of time interval / m s^{-1}**	**Displacement of alpha particle in time interval / m**
2	8.60E-14	4.92E+00	1.00E-21	1.53E+07	1.56E-14
3	7.04E-14	7.34E+00	1.00E-21	1.42E+07	1.47E-14
4	5.57E-14	1.17E+01	1.00E-21	1.24E+07	1.33E-14
5	4.24E-14	2.02E+01	1.00E-21	9.34E+06	1.09E-14
6	3.15E-14	3.66E+01	1.00E-21	3.83E+06	6.58E-15
7	2.49E-14	5.84E+01	1.00E-21	−4.97E+06	−5.69E-16
8	2.55E-14	5.59E+01	1.00E-21	−1.34E+07	−9.18E-15
9	3.47E-14	3.02E+01	1.00E-21	−1.79E+07	−1.57E-14
10	5.03E-14	1.43E+01	1.00E-21	−2.01E+07	−1.90E-14

(i) Show how cell B3 is calculated.

(2)

....

....

....

....

P 3 8 4 1 6 A 0 1 4 2 4

(ii) Show how cell D5 is calculated.

(3)

....

....

....

....

(iii) Show how cell E6 is calculated.

(2)

....

....

(iv) Suggest a value for the maximum radius of a gold nucleus based on the results from this spreadsheet.

(1)

Maximum radius = ...

*(c) Describe the conclusions Rutherford reached about the structure of gold atoms as a result of the alpha particle scattering experiments.

(3)

....

....

....

....

....

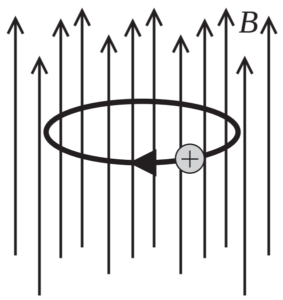
....

....

....

(Total for Question 16 = 14 marks)

17 A strong magnetic field of flux density B can be used to trap a positive ion by making it follow a circular orbit as shown.



(a) Explain how the magnetic field maintains the ion in a circular orbit. You may add to the diagram above if you wish.

(2)

....

....

(b) Show that the mass m of the ion will be given by

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

where q is the charge on the ion and f is the number of revolutions per second.

(3)

....

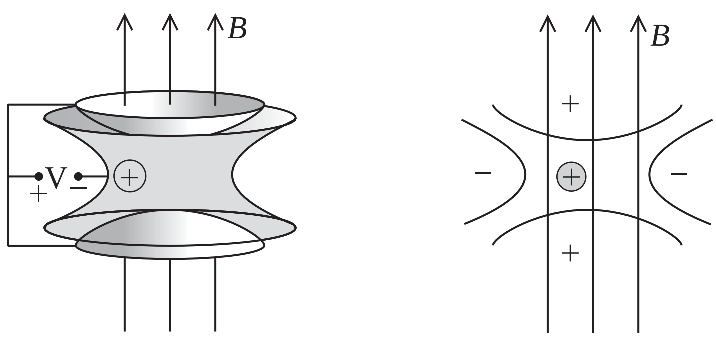
....

....

....

....

(c) The above arrangement will not prevent a positive ion from moving vertically. To do this, a weak electric field is applied using the arrangement shown below.



(i) Explain how the electric field prevents the ion moving vertically.

(2)

....

....

....

....

(ii) This device is known as a Penning Trap. It can be used to determine the mass of an ion to an accuracy of 3 parts in 10 million.

Confirm that the mass of a sulphur ion can be measured to the nearest 0.00001u.

mass of sulphur ion = 32.0645u

(2)

....

....

....

(iii) Under certain conditions nuclei of sulphur emit a gamma ray with a known energy of 2.2 MeV.

Calculate the resulting loss in mass of a sulphur ion in u and confirm that this value could be determined by the Penning Trap technique.

(4)

....

....

....

....

....

....

....

(Total for Question 17 = 13 marks)

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

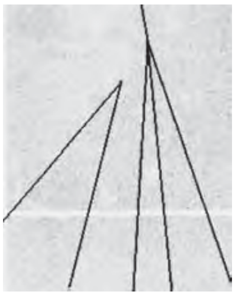
(a) Why do the tubes of a linac become progressively longer down its length?

(1)

....

....

(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)

....

....

....

....

(iii) Write an equation for this decay event.

(2)

....

....

....

....

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

(6)

....

....

....

....

....

....

....

....

....

....

....

....

Question 18 continues on the next page

(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)

....

....

(Total for Question 18 = 14 marks)

TOTAL FOR SECTION B = 70 MARKS

TOTAL FOR PAPER = 80 MARKS

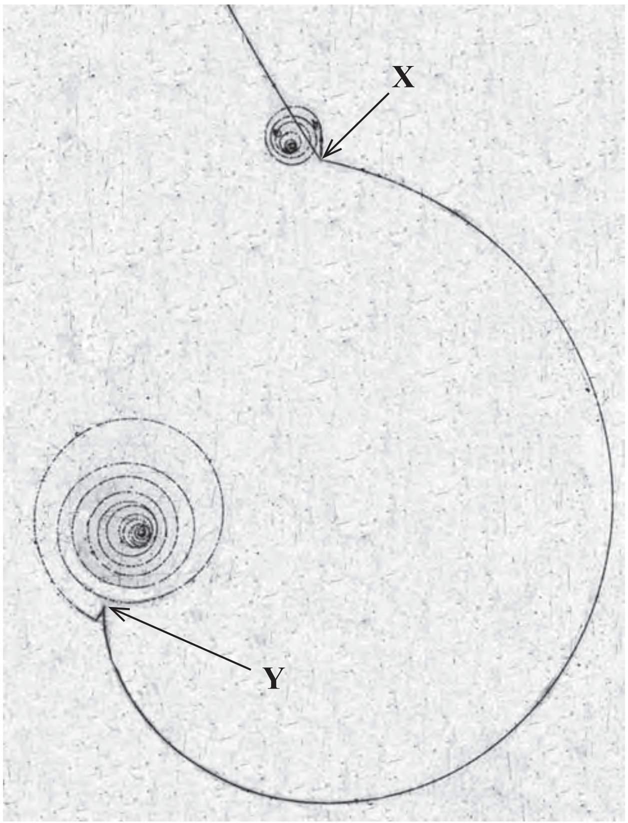
***13** At the beginning of the last century, experiments were performed using alpha particles and gold foil. The alpha particles were directed at the gold foil and a detector was used to see if and where they were scattered.

Summarise the results from these experiments and the conclusions that were drawn from them.

(5)

(Total for Question 13 = 5 marks)

14 The photograph shows tracks in a particle detector.



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

(2)

....

....

....

....

(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)

....

....

....

....

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

(1)

....

....

(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)

1..

....

....

2..

....

....

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

(3)

....

....

....

....

....

....

(Total for Question 14 = 10 marks)

17 Anti-hydrogen atoms have been created at CERN. An anti-hydrogen atom consists of an anti-proton and a positron.

(a) Compare the properties of an anti-hydrogen atom with a hydrogen atom.

(2)

....

....

....

....

(b) Calculate the electrostatic force of attraction between the positron and the anti-proton.

Assume that the radius of the anti-hydrogen atom is 5.3×10^{-11} m.

(3)

....

....

....

....

....

....

....

....

Force = ...

(c) Scientists want to find out if anti-hydrogen atoms emit the same spectra as hydrogen atoms. Anti-protons are relatively easy to contain, however, it is very difficult to contain anti-hydrogen atoms for any period of time.

Explain why it is difficult to contain anti-hydrogen atoms compared with anti-protons.

(2)

....

....

....

....

(d) The technology suggested in the science fiction series, Star Trek, for powering the Starship Enterprise relied on antimatter. When an anti-hydrogen atom meets a hydrogen atom, they annihilate and produce energy.

(i) How much energy, in joules, would be produced by the annihilation of just 1 milligram of anti-hydrogen atoms?

(3)

....

....

....

....

....

....

Energy = ... J

(ii) Anti-protons are required to produce anti-hydrogen atoms. The total production of anti-protons on Earth over the past 25 years adds up to only a few nanograms.

Suggest why so little anti-matter has been created.

(1)

....

....

(Total for Question 17 = 11 marks)

18 James Chadwick is credited with "discovering" the neutron in 1932.

Beryllium was bombarded with alpha particles, knocking neutrons out of the beryllium atoms. Chadwick placed various targets between the beryllium and a detector. Hydrogen and nitrogen atoms were knocked out of the targets by the neutrons and the kinetic energies of these atoms were measured by the detector.

(a) The maximum energy of a nitrogen atom was found to be 1.2 MeV.

Show that the maximum velocity of the atom is about 4×10^6 m s^{-1}.

mass of nitrogen atom = $14u$, where $u = 1.66 \times 10^{-27}$ kg

(3)

....

....

....

....

....

....

(b) The mass of a neutron is Nu (where N is the relative mass of the neutron) and its initial velocity is x. The nitrogen atom, mass $14u$, is initially stationary and is then knocked out of the target with a velocity, y, by a collision with a neutron.

(i) Show that the velocity, z, of the neutron after the collision can be written as

$$z = \frac{Nx - 14y}{N}$$

(3)

....

....

....

....

....

....

(ii) The collision between this neutron and the nitrogen atom is elastic. What is meant by an elastic collision?

(1)

....

....

(iii) Explain why the kinetic energy E_k of the nitrogen atom is given by

$$E_k = \frac{Nu(x^2 - z^2)}{2}$$

(2)

....

....

....

....

(c) The two equations in (b) can be combined and z can be eliminated to give

$$y = \frac{2Nx}{N + 14}$$

(i) The maximum velocity of hydrogen atoms knocked out by neutrons in the same experiment was 3.0×10^7 m s^{-1}. The mass of a hydrogen atom is 1u.

Show that the relative mass N of the neutron is 1.

(3)

....

....

....

....

....

....

(ii) This equation can **not** be applied to all collisions in this experiment.

Suggest why.

(1)

....

....

(Total for Question 18 = 13 marks)

TOTAL FOR SECTION B = 70 MARKS

TOTAL FOR PAPER = 80 MARKS

13 An electron and a positron annihilate with the emission of two photons of equal energy.

Calculate the wavelength of the photons.

(5)

Wavelength = ...

(Total for Question 13 = 5 marks)

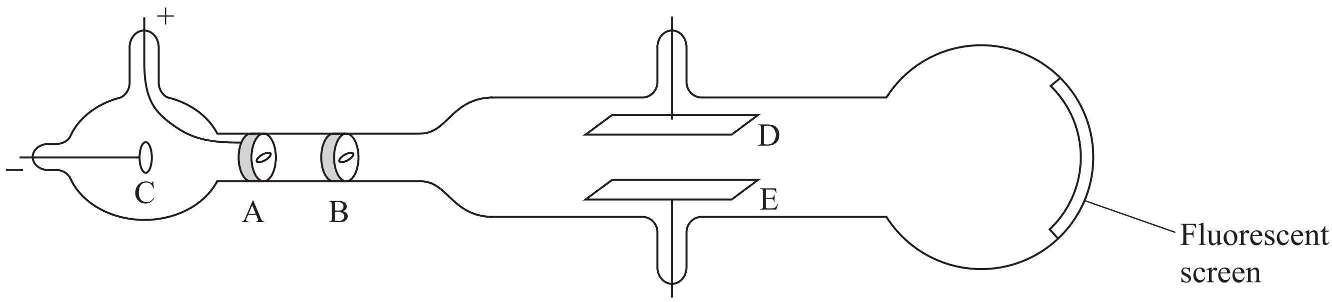
***14** A bubble chamber is a particle detector which makes use of electric and magnetic fields.

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

(5)

(Total for Question 14 = 5 marks)

17 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)

....

....

....

....

....

(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)

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

Suggest how this angle could be determined.

(3)

(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)

....

....

....

....

(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

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

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

Suggest why he did this.

(1)

....

....

....

....

....

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

(2)

1 ....

....

2 ....

....

(Total for Question 17 = 13 marks)

18 (a) Physicists were able to confidently predict the existence of a sixth quark. State why.

(1)

....

....

....

(b) The mass of the top quark was determined by an experiment. Collisions between protons and anti-protons occasionally produce two top quarks.

(i) How do the properties of a proton and an anti-proton compare?

(2)

....

....

....

....

(ii) After the collision the two top quarks move in opposite directions with the same speed.

Explain why.

(2)

....

....

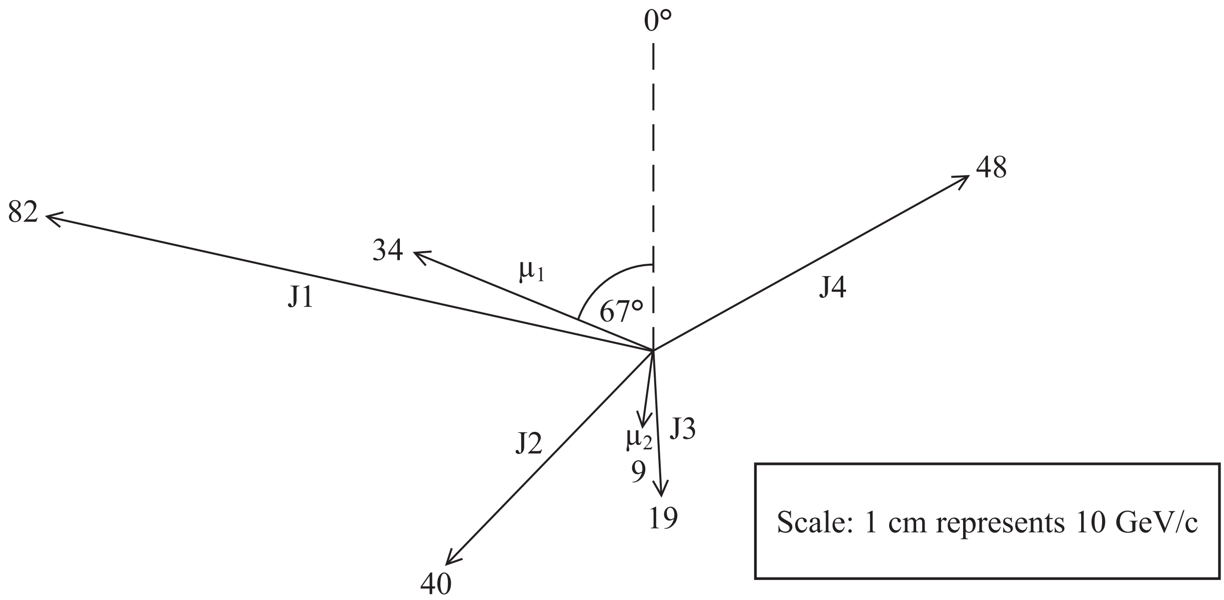
....

....

(c) The two top quarks decay rapidly into two muons and four jets of particles. These can be detected and their momenta measured.

The diagram shows an end-on view of the directions of the four jets (J1 to J4) of particles. The two muons are shown as μ_1 and μ_2. A muon neutrino is also produced but cannot be detected, so is **not** shown. Each momentum is measured in GeV/c.

The magnitude of the momentum for each particle or 'jet' is shown by the number printed at the end of each arrow.



(i) Explain why GeV/c is a valid unit for momentum.

(2)

....

....

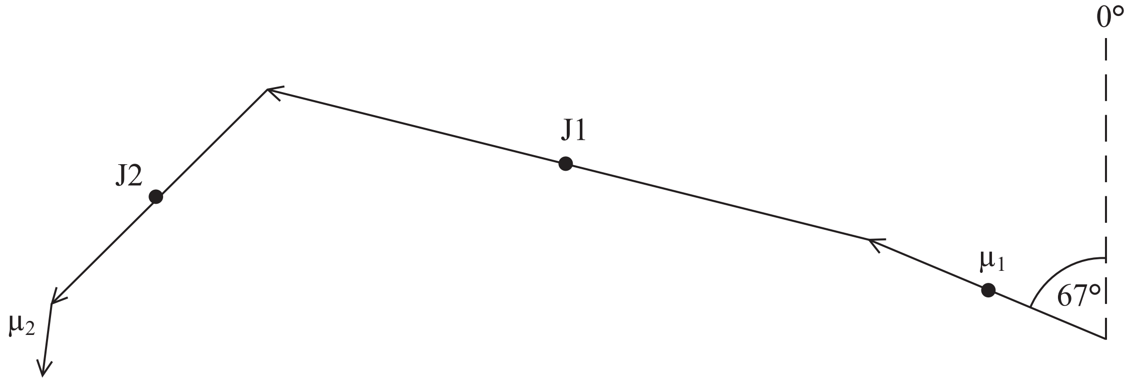
....

....

P 3 9 8 5 5 A 0 2 0 2 8

(ii) The vector diagram shown below is **not** complete. Add to the diagram arrows to represent the momenta of J3 and J4.

(2)



Scale: 1 cm represents 10 GeV/c

(iii) Complete the diagram to determine the magnitude of the momentum of the muon neutrino.

(1)

Momentum = ... GeV/c.

(iv) Show that the total energy of all the products of this event is about 300 GeV.

(1)

....

....

(v) Deduce the mass of a top quark in GeV/c^2.

(1)

....

....

(vi) Suggest why it took a long time to find experimental evidence for the top quark.

(2)

....

....

....

....

(Total for Question 18 = 14 marks)

TOTAL FOR SECTION B = 70 MARKS

TOTAL FOR PAPER = 80 MARKS

SECTION B

Answer ALL questions in the spaces provided.

11 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)

....

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

(2)

Conclusion 1 ....

....

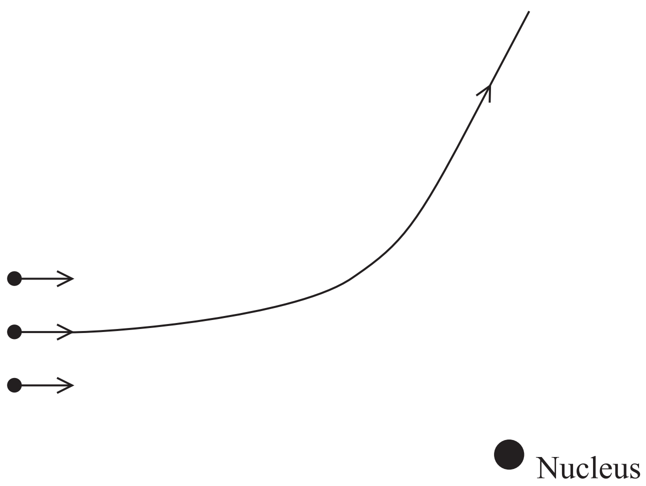
Conclusion 2 ....

....

(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 11 = 6 marks)

12 The electron in a hydrogen atom can be described by a stationary wave which is confined within the atom. This means that the de Broglie wavelength associated with it must be similar to the size of the atom which is of the order of 10^{-10} m.

(a) (i) Calculate the speed of an electron whose de Broglie wavelength is 1.00×10^{-10} m.

(3)

....

....

....

....

Speed = ...

(ii) Calculate the kinetic energy of this electron in electronvolts.

(3)

....

....

....

....

Kinetic energy = ... eV

(b) When β radiation was first discovered, it was suggested that there were electrons in the atomic nucleus, but it was soon realised that this was impossible because the energy of such an electron would be too great.

Suggest why an electron confined within a nucleus would have a much greater energy than the energy calculated in (a)(ii).

(2)

....

....

....

....

....

....

(Total for Question 12 = 8 marks)

17 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)

....

....

....

(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)

....

....

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

(1)

....

....

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

(4)

....

....

....

....

....

....

....

....

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

(1)

....

....

(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)

....

....

....

....

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)

....

....

....

(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)

....

....

....

....

....

....

....

....

(Total for Question 17 = 16 marks)

TOTAL FOR SECTION B = 70 MARKS

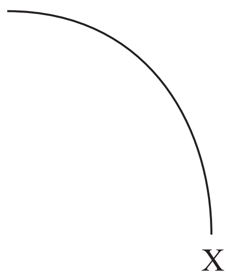
TOTAL FOR PAPER = 80 MARKS

SECTION B

Answer ALL questions in the spaces provided.

11 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)

....

....

....

....

....

....

....

....

....

....

(Total for Question 11 = 5 marks)

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

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

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

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

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

(4)

Meson	**Charge/*e***	**Strangeness**

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

Suggest what might distinguish these mesons from each other.

(1)

....

....

....

(Total for Question 12 = 5 marks)

13 In an experiment to investigate the structure of the atom, α-particles are fired at a thin metal foil, which causes the α-particles to scatter.

(a) (i) State the direction in which the number of α-particles detected will be a maximum.

(1)

....

(ii) State what this suggests about the structure of the atoms in the metal foil.

(1)

....

(b) Some α-particles are scattered through 180°.

State what this suggests about the structure of the atoms in the metal foil.

(2)

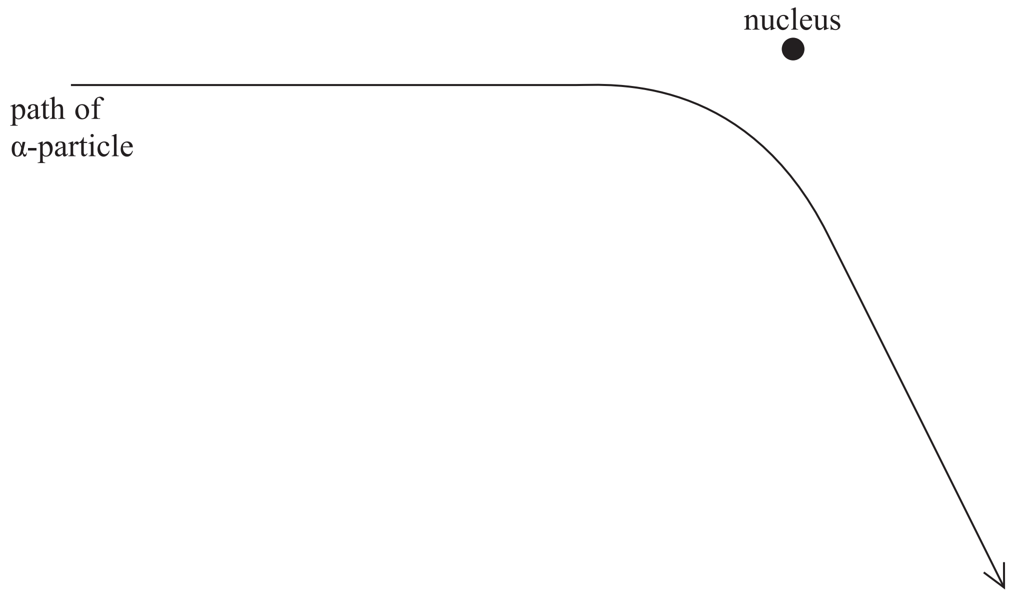
....

....

....

....

(c) The diagram shows the path of an α-particle passing near to a single nucleus in the metal foil.



(i) Name the force that causes the deflection of the α-particle.

(1)

....

(ii) On the diagram, draw an arrow to show the direction of the force acting on the α-particle at the point where the force is a maximum. Label the force F.

(2)

(iii) The foil is replaced by a metal of greater proton number.

Draw the path of an α-particle that has the same initial starting point and velocity as the one drawn in the diagram.

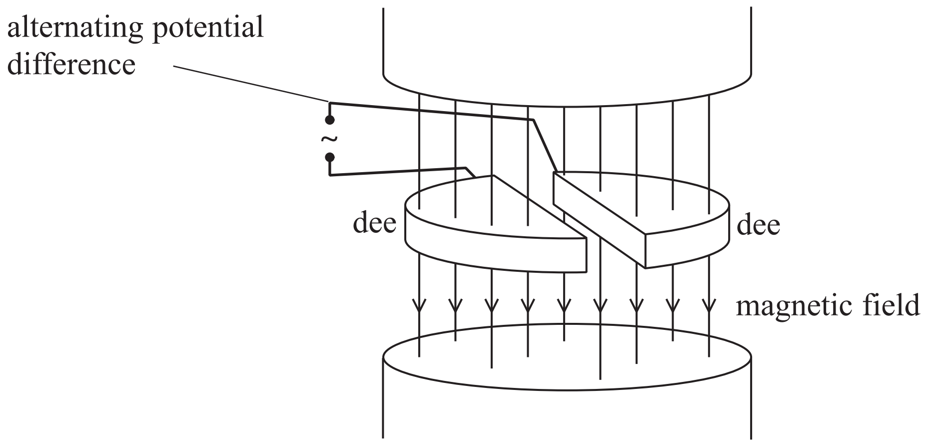
(2)

(Total for Question 13 = 9 marks)

SECTION B

Answer ALL questions in the spaces provided.

***11** 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)

....

....

....

....

....

....

....

....

....

....

(Total for Question 11 = 4 marks)

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

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

(1)

....

(ii) State the quark structure of a meson.

(1)

....

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

(2)

Similarity ....

....

Difference ....

....

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

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

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

Write down the quark combination of the K^+.

(1)

....

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

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

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

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

(2)

$$K^- \rightarrow$$

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

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

(3)

....

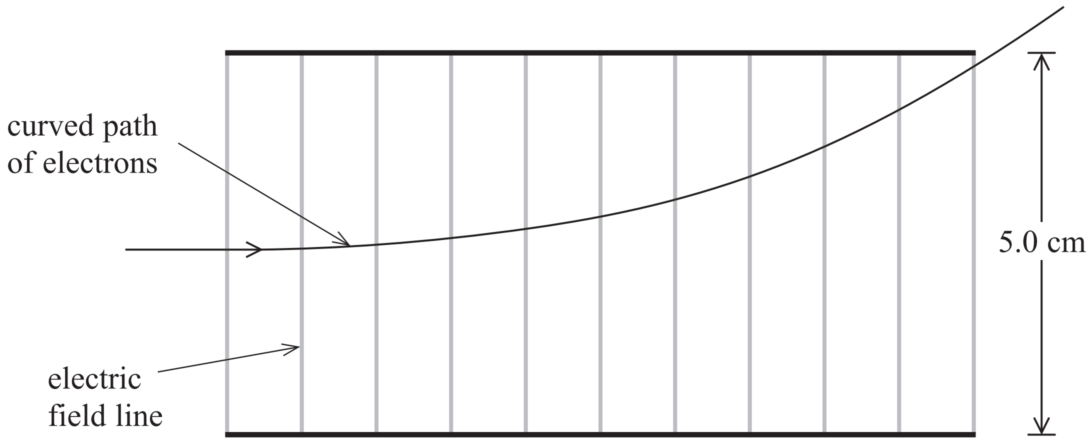
....

....

Energy = ... J

(Total for Question 14 = 10 marks)

17 A teacher uses an electron beam tube to demonstrate the behaviour of electrons in an electric field. The diagram shows the path of an electron in a uniform electric field between two parallel conducting plates.



(a) Mark on the diagram the direction of the electric field.

(1)

(b) The conducting plates are 5.0 cm apart and have a potential difference of 160 V across them.
Calculate the force on the electron due to the electric field.

(3)

....

....

....

....

....

Force = ...

(c) Explain why the path of the electron is curved between the plates and straight when it has left the plates.

(3)

....

....

....

....

....

....

(d) The electron was initially released from a metal by thermionic emission and then accelerated through a potential difference before entering the region of the electric field.

(i) State what is meant by thermionic emission.

(1)

....

....

(ii) In order to be able to just leave the plates as shown, the electron must enter the electric field between the plates with a speed of 1.2×10^7 m s^{-1}.

Calculate the potential difference required to accelerate an electron from rest to this speed.

(3)

....

....

....

....

....

Potential difference = ...

(Total for Question 17 = 11 marks)

List of data, formulae and relationships

Acceleration of free fall	$g = 9.81\ \text{m s}^{-2}$	(close to Earth's surface)
Boltzmann constant	$k = 1.38 \times 10^{-23}\ \text{J K}^{-1}$	
Coulomb's law constant	$k = 1/4\pi\varepsilon_0$ $= 8.99 \times 10^{9}\ \text{N m}^2\ \text{C}^{-2}$	
Electron charge	$e = -1.60 \times 10^{-19}\ \text{C}$	
Electron mass	$m_e = 9.11 \times 10^{-31}\ \text{kg}$	
Electronvolt	$1\ \text{eV} = 1.60 \times 10^{-19}\ \text{J}$	
Gravitational constant	$G = 6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2}$	
Gravitational field strength	$g = 9.81\ \text{N kg}^{-1}$	(close to Earth's surface)
Permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12}\ \text{F m}^{-1}$	
Planck constant	$h = 6.63 \times 10^{-34}\ \text{J s}$	
Proton mass	$m_p = 1.67 \times 10^{-27}\ \text{kg}$	
Speed of light in a vacuum	$c = 3.00 \times 10^{8}\ \text{m s}^{-1}$	
Stefan-Boltzmann constant	$\sigma = 5.67 \times 10^{-8}\ \text{W m}^{-2}\ \text{K}^{-4}$	
Unified atomic mass unit	$u = 1.66 \times 10^{-27}\ \text{kg}$	

Unit 1

Mechanics

Kinematic equations of motion	$v = u + at$ $s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$
Forces	$\Sigma F = ma$ $g = F/m$ $W = mg$
Work and energy	$\Delta W = F\Delta s$ $E_k = \frac{1}{2}mv^2$ $\Delta E_{grav} = mg\Delta h$

Materials

Stokes' law	$F = 6\pi\eta rv$
Hooke's law	$F = k\Delta x$
Density	$\rho = m/V$
Pressure	$p = F/A$
Young modulus	$E = \sigma/\varepsilon$ where Stress $\sigma = F/A$ Strain $\varepsilon = \Delta x/x$
Elastic strain energy	$E_{el} = \frac{1}{2}F\Delta x$

Unit 2

Waves

Wave speed	$v = f\lambda$
Refractive index	${}_1\mu_2 = \sin i/\sin r = v_1/v_2$

Electricity

Potential difference	$V = W/Q$
Resistance	$R = V/I$
Electrical power, energy and efficiency	$P = VI$ $P = I^2R$ $P = V^2/R$ $W = VIt$ $\% \text{ efficiency} = \dfrac{\text{useful energy output}}{\text{total energy input}} \times 100$ $\% \text{ efficiency} = \dfrac{\text{useful power output}}{\text{total power input}} \times 100$
Resistivity	$R = \rho l/A$
Current	$I = \Delta Q/\Delta t$ $I = nqvA$
Resistors in series	$R = R_1 + R_2 + R_3$
Resistors in parallel	$\dfrac{1}{R} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3}$

Quantum physics

Photon model	$E = hf$
Einstein's photoelectric equation	$hf = \phi + \frac{1}{2}mv^2_{max}$

Unit 4

Mechanics

Momentum	$p = mv$
Kinetic energy of a non-relativistic particle	$E_k = p^2/2m$
Motion in a circle	$v = \omega r$ $T = 2\pi/\omega$ $F = ma = mv^2/r$ $a = v^2/r$ $a = r\omega^2$

Fields

Coulomb's law	$F = kQ_1Q_2/r^2$ where $k = 1/4\pi\varepsilon_0$
Electric field	$E = F/Q$ $E = kQ/r^2$ $E = V/d$
Capacitance	$C = Q/V$
Energy stored in capacitor	$W = \frac{1}{2}QV$
Capacitor discharge	$Q = Q_0 e^{-t/RC}$
In a magnetic field	$F = BIl \sin\theta$ $F = Bqv \sin\theta$ $r = p/BQ$
Faraday's and Lenz's Laws	$\varepsilon = -d(N\phi)/dt$

Particle physics

Mass-energy	$\Delta E = c^2 \Delta m$
de Broglie wavelength	$\lambda = h/p$