Nuclear and Particle Physics QP2

1 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 ....

....

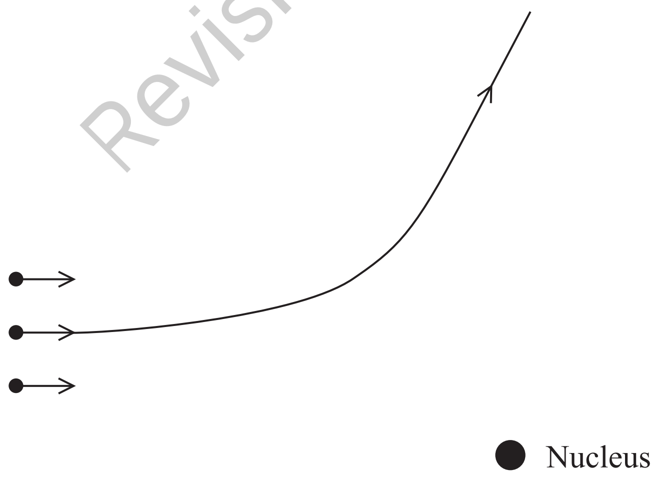
Conclusion 2 ....

....

(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)



2 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?

(2)

....

....

....

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

....

....

....

....

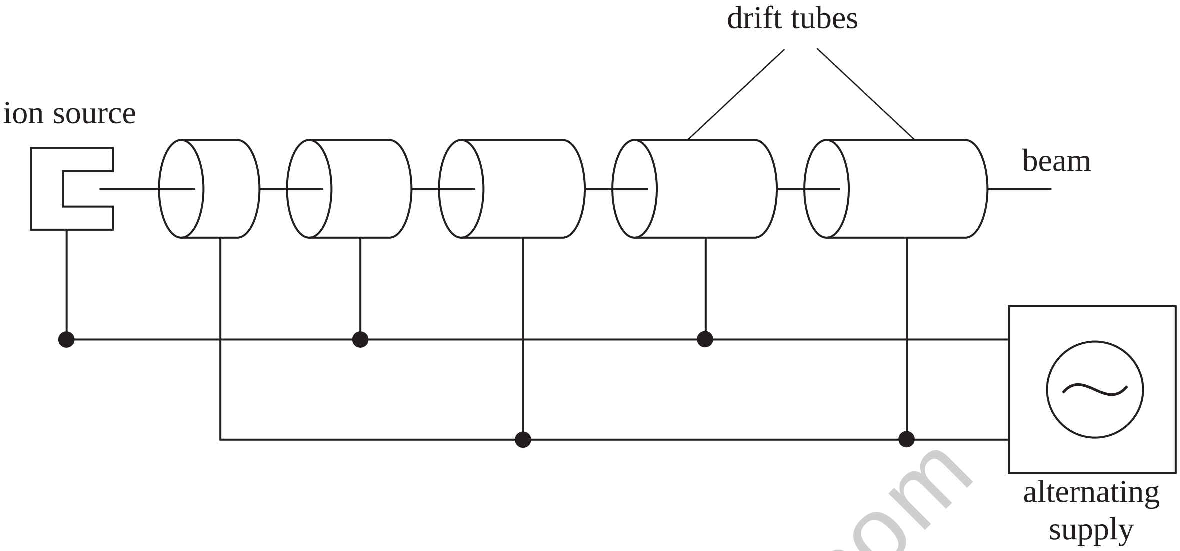
....

....

....

....

*3 The diagram shows the basic structure of a linac.



Explain how the linac produces a beam of high speed particles, making reference to the alternating supply and the lengths of the tubes.

(4)

4 (a) In 1962, the existence of a particle with strangeness −3 was predicted. Two years later it was identified in an experiment involving the interaction of a proton and a K− meson which has a strangeness of −1. The new particle was given the name omega, Ω.

The interaction, which conserves strangeness, was

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

(i) Deduce with reasons the charge on the Ω and whether it is a baryon or a meson.

(2)

....

....

....

....

(ii) Using the information given in the table below deduce the quark composition of each of the particles involved.

(4)

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

....

....

....

....

....

(b) In another experiment, involving a head-on collision between two protons, the following interaction was observed.

$$p + p \rightarrow p + 7\pi^+ + 7\pi^- + K^+ + \Lambda$$

mass of p = 938 MeV/c^2

mass of π^+ and π^- = 140 MeV/c^2

mass of K^+ = 494 MeV/c^2

mass of Λ = 1115 MeV/c^2

(i) Calculate the minimum kinetic energy of each proton, in MeV, for this interaction to occur.

(3)

....

....

....

....

....

....

....

....

....

Minimum kinetic energy = ...

(ii) This interaction would **not** have taken place if one of the protons had been stationary and the other had twice the calculated value of kinetic energy.

Explain why.

(2)

....

....

....

....

(Total for Question = 11 marks)

.

5 The table gives the quark structure of three particles.

The up quark has a charge of +2/3e and the down quark has a charge of –1/3e.

Particle	**Quarks**
neutron n	udd
pion π^-	$d\bar{u}$
delta Δ^-	ddd

(a) Show that udd is a possible combination of quarks for the neutron.

(1)

....

....

(b) State, in terms of quark structure, why the Δ^- is classed as a baryon and the π^- a meson.

(2)

....

....

(c) Another particle in the delta family, the Δ^{++}, is also composed of up and/or down quarks. Its decay is shown by

$$\Delta^{++} \rightarrow p + \pi$$

Deduce the quark content of the Δ^{++} and the charge on the pion.

(2)

....

Quark content of Δ^{++} ....

....

Charge on pion ....

(Total for Question = 5 marks)

6 The photograph shows the circular tunnel of the Large Hadron Collider (LHC), which is an underground particle accelerator. The circumference of the tunnel is 27 km.

*(a) In the LHC, a magnetic field allows charged particles to move at a constant speed in a horizontal circular path of the required radius.

By reference to the force acting on the charged particles, explain how this is achieved.

(4)

(b) In practice the LHC uses electric fields to accelerate the particles so that their momentum gradually increases.

State and explain how the magnetic field in the LHC must change as the momentum of the particles increases.

(2)

....

....

....

....

(c) (i) Collisions between particles in high-energy physics experiments often result in the production of an electron-positron pair.

Calculate the minimum energy, in joules, required to produce an electron-positron pair.

(2)

....

....

....

Minimum energy = ... J

(ii) By converting your minimum energy into MeV, give the rest mass of the electron in MeV/c^2.

(3)

....

....

....

Rest mass of electron = ... MeV/c^2

(Total for Question = 11 marks)

7 Between 1909 and 1911 Rutherford's alpha particle scattering experiment provided evidence for the nuclear model of the atom. Alpha particles were fired at a thin gold foil and their paths observed.

(a) Describe the observations from the alpha particle scattering experiment.

(3)

....

....

....

....

....

....

(b) An alpha particle approaches a gold nucleus. It reaches a distance of 4.5×10^{-14} m from the gold nucleus. Calculate the force between the alpha particle and the gold nucleus.

proton number for gold = 79

(3)

....

....

....

....

....

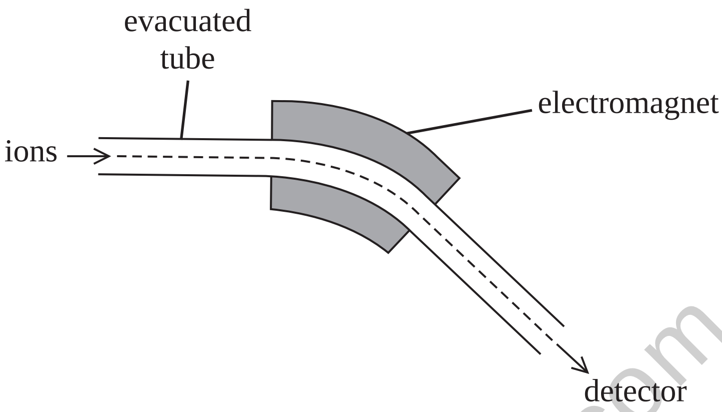
....

Force = ...

(Total for Question = 6 marks)

8 A mass spectrometer is a device used to identify atoms by measuring the mass-charge ratio $\frac{m}{Q}$ of their ions.

Ionised atoms in a vacuum are accelerated from rest through a potential difference V and then enter an evacuated tube.



(a) An ion of mass m is accelerated to a velocity v.
Show that the mass-charge ratio of the ion is given by

$$\frac{m}{Q} = \frac{2V}{v^2}$$

(2)

....

....

....

....

*(b) The electromagnet shown in the diagram provides a magnetic field which is used to deflect the ion along the tube of the spectrometer.

Explain how a magnetic field can be used to deflect the ion into a circular path.

(3)

....

....

....

....

....

....

....

....

(c) An atom of bromine is ionised by the removal of one electron. It is accelerated through a potential difference of 3.0 kV and then enters the tube. The ionised atom is deflected by a magnetic field of magnetic flux density 0.15 T.

Calculate the radius of curvature r of the tube.

mass of bromine ion = 80 u

(4)

....

....

....

....

....

....

....

....

....

r = ...

(Total for Question = 9 marks)

9 The equation for β+ decay is

$$p \rightarrow n + e^{+} + v_{e}$$

(a) Using information in the table, describe how a proton changes into a neutron.

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

(2)

....

....

....

....

(b) With reference to the charges of the particles, show that this decay is possible.

(2)

....

....

....

....

(c) The kinetic energy of the positron is 1.58 MeV. It annihilates with a stationary electron and two photons of equal energy are emitted.

Calculate the wavelength of the emitted photons.

mass of stationary electron = 0.511 MeV/c^2
mass of stationary positron = 0.511 MeV/c^2

(4)

Wavelength = ...

(d) Linear accelerators (linacs) can produce electrons with energies up to 20 GeV.

(i) Calculate the de Broglie wavelength associated with 20 GeV electrons. At these energies, the energy and momentum of a particle are connected by the relativistic equation $E = pc$.

(3)

Wavelength = ...

(ii) Experiments have been carried out where these 20 GeV electrons are aimed at a hydrogen target which consists of protons. Suggest, with reasons, what happens to the path of the electrons.

(2)

....

....

....

....

(Total for Question = 13 marks)