1 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.

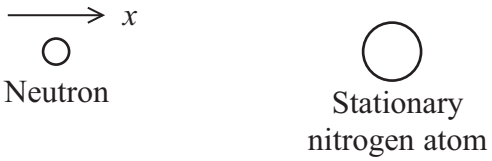
(a) The maximum energy of a nitrogen atom was found to be 1.2 MeV.

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

mass of nitrogen atom $14u$, where u 1.66×10^{-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

$$z = \frac{\mathrm{N}x - 14y}{\mathrm{N}}$$

(3)

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

(1)

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(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)

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(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 30×10^7 m s ^{1}. The mass of a hydrogen atom is $1u$.

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

(3)

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

Suggest why.

(1)

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(Total for Question 13 marks)

2 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)

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Charge .....

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

(2)

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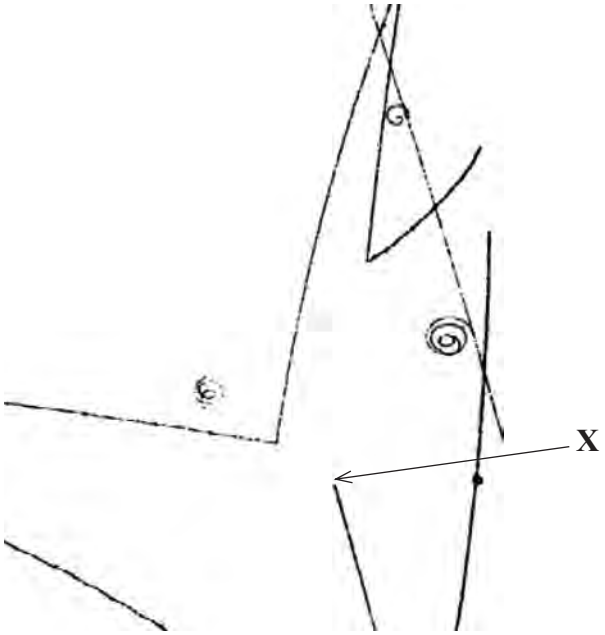
(Total for Question 4 marks)

***3** 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)

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(Total for Question 4 marks)

4 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 .....

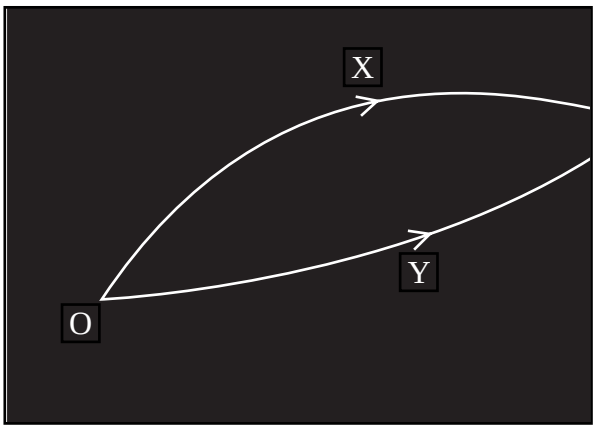
(e) Emission line spectra in the X-ray region of the electromagnetic spectrum can be detected from muonic hydrogen atoms.

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

(3)

(Total for Question 12 marks)

5 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)

6 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)

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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.

(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 = 12 marks)

*7 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)

(Total for Question = 6 marks)

8 (a) State what is meant by the de Broglie wavelength.

(2)

(b) An electron is accelerated from rest, in a vacuum, through a potential difference of 500 V.

(i) Show that the final momentum of the electron is about 1×10^{-23} N s.

(3)

(ii) Calculate the de Broglie wavelength for this electron.

(2)

de Broglie wavelength =

(Total for Question = 7 marks)