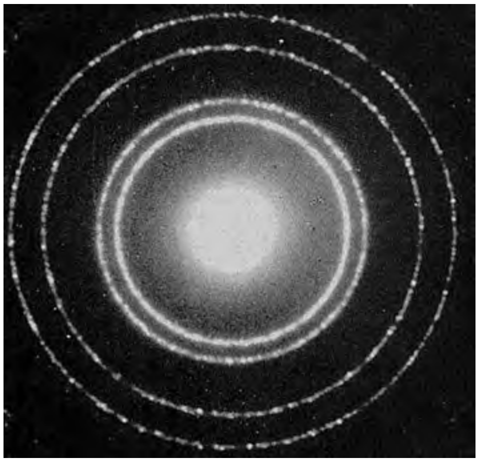
1 Crystal structure can be investigated using the diffraction of an electron beam.
A typical diffraction pattern is shown.



In a particular investigation the atomic spacing of the crystal is 2.3×10^{-11} m and the electrons are accelerated through 3000 V.

(a) Calculate the wavelength of these electrons.

(3)

Wavelength = m

(b) State with a reason whether these electrons will produce a suitable diffraction pattern.

(1)

(Total for Question = 4 marks)

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2 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)

p.d. =

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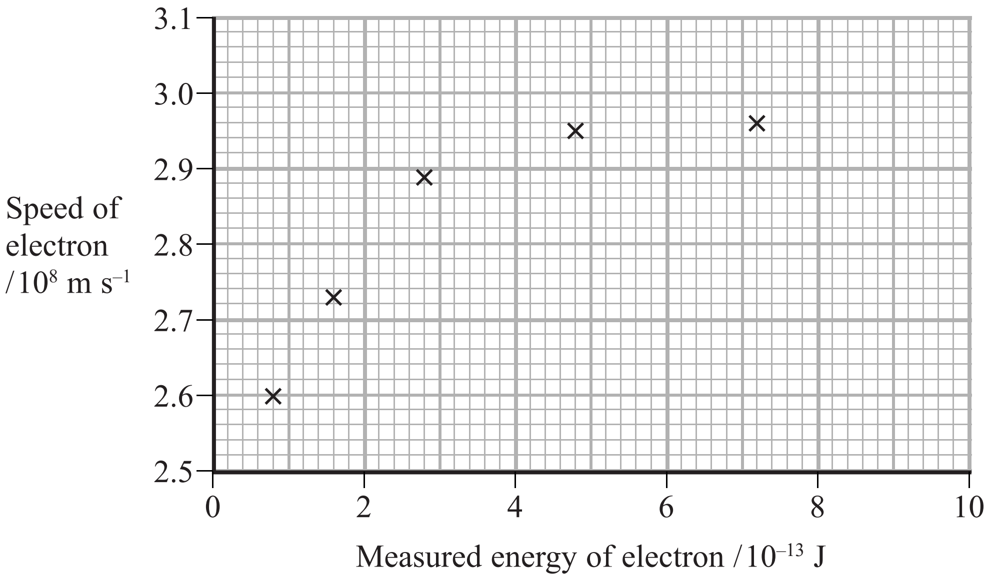
(b) The results are plotted on the graph below.



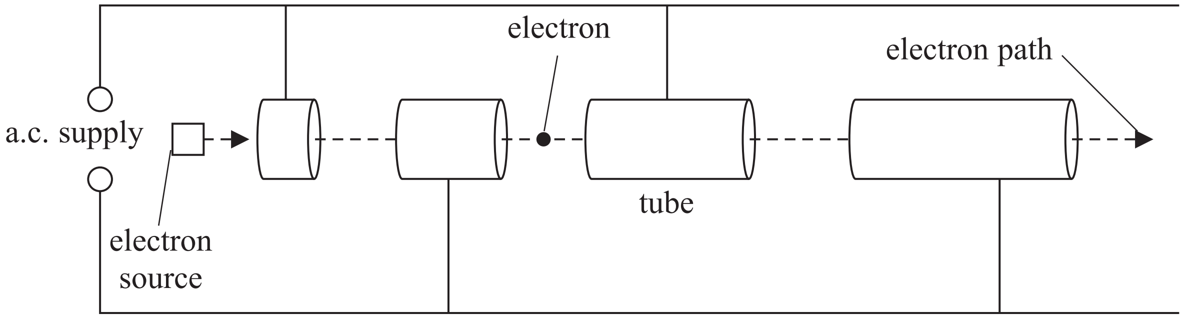
Use the graph to verify that Bertozzi's experiment supports Einstein's theory.

(2)

(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)

(d) 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)

(ii) State why the tubes are the same length at the end of the accelerator.
(1)

(Total for Question = 9 marks)

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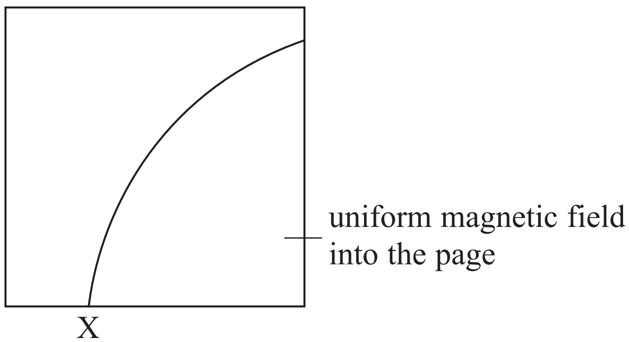
3 The photograph is an image of the paths of particles obtained from an early particle detector, the cloud chamber.

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)

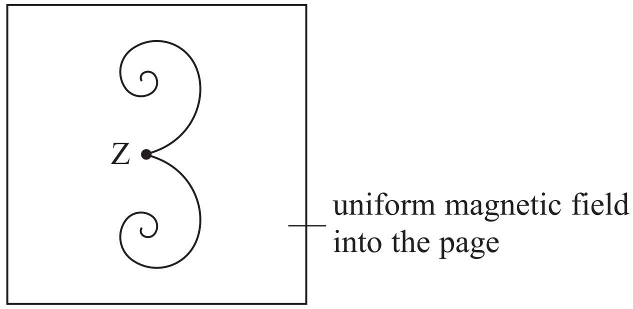
(b) The diagram below shows the ionisation path of a particle when it is in the region of a uniform magnetic field. The particle enters the field at X.



State how we know that the particle is negatively charged.

(1)

(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.

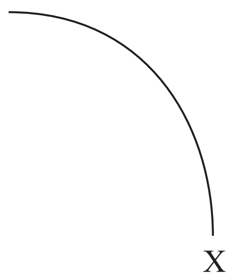
Describe, with reasons, what can be deduced about the photon and the two particles that are formed in this interaction.

(5)

(Total for Question = 7 marks)

4 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)

(t otal for Question = 5 marks)

5 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.

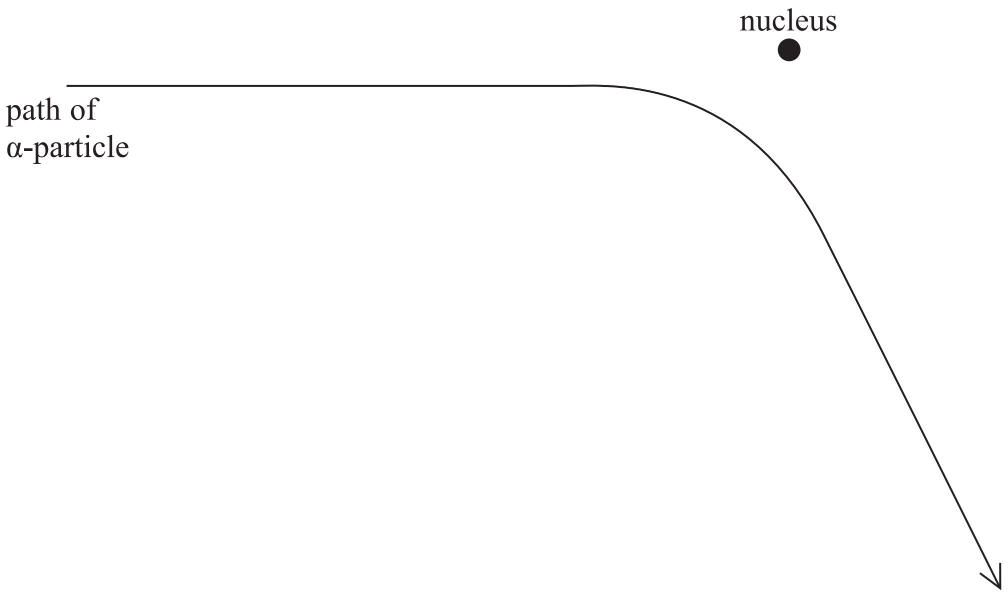
(1)

(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)

(t otal for Question = 9 marks)

6 A spacecraft called Deep Space 1, mass 486 kg, uses an "ion-drive" engine. This type of engine is designed to be used in deep space.

The following statement appeared in a web site.

> The ion propulsion system on Deep Space 1 expels 0.13 kg of xenon propellant each day. The xenon ions are expelled from the spacecraft at a speed of 30 km s^{-1}. The speed of the spacecraft is predicted to initially increase by about 8 m s^{-1} each day.

Use a calculation to comment on the prediction made in this statement.

(4)

(Total for Question = 4 marks)

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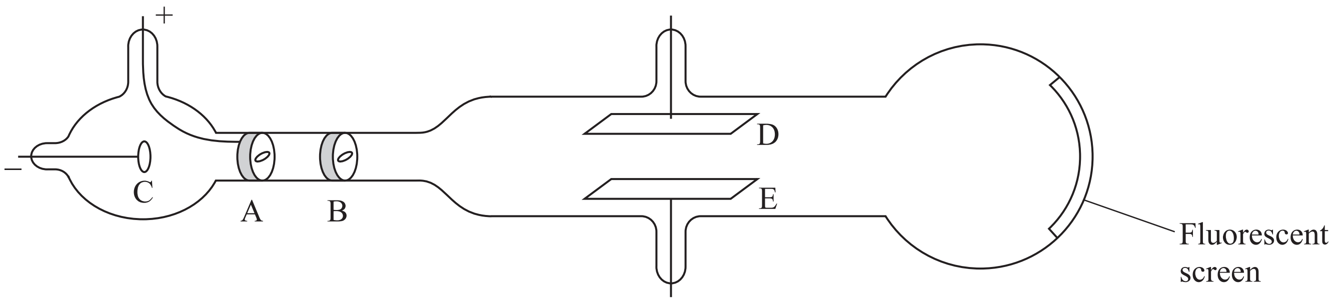
*7A bubble chamber is a particle detector which makes use of electric and magnetic fields.

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

(5)

(Total for Question = 5 marks)

8 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)

(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)

(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 = 13 marks)

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9 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 = 5 marks)