Answer ALL questions.

All multiple choice questions must be answered with a cross in the box ☒ for the correct answer from A to D. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

1 A particle has a mass of 1 u and a charge of -1.6×10^{-19} C.

Which of the following could be the particle?

☒ **A** antiproton

☒ **B** electron

☒ **C** neutron

☒ **D** positron

(Total for Question 1 = 1 mark)

2 The velocity v of a non-relativistic particle can be expressed in terms of combinations of the following quantities: kinetic energy E_k, momentum p and mass m.

Which of the following expressions is correct?

☒ **A** $v = \frac{p^2}{m}$

☒ **B** $v = \sqrt{\frac{2E_k}{m}}$

☒ **C** $v = \frac{E_k}{2p}$

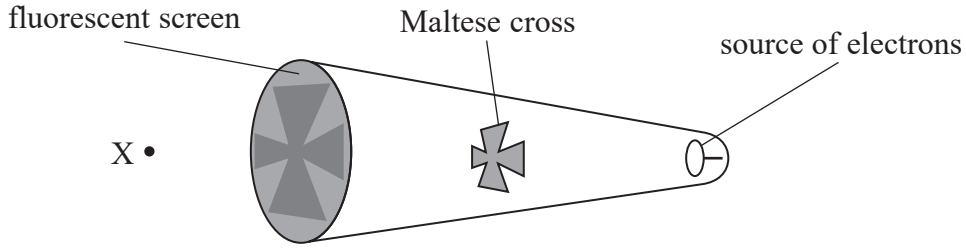
☒ **D** $v = \frac{2E_k}{pm}$

(Total for Question 2 = 1 mark)

Questions 4 and 5 refer to the information below.

A demonstration is carried out using a beam of electrons in an evacuated tube.

When electrons hit a fluorescent screen, light is emitted. A piece of metal, in the shape of a Maltese cross, stops electrons and produces a shadow on the screen as shown.



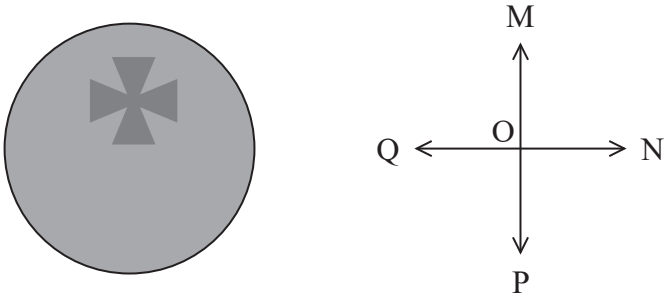
4 The electrons are produced by heating a metal filament.

Which of the following is the name of this process?

- ☒ **A** ionisation
- ☒ **B** scattering
- ☒ **C** the photoelectric effect
- ☒ **D** thermionic emission

(Total for Question 4 = 1 mark)

5 The screen is viewed by an observer at point X in the diagram above. A magnetic field is directed at the beam of electrons. This causes the shadow to move upwards on the screen in the direction OM.



In which of the following directions is the magnetic field acting as seen by this observer?

- ☒ **A** OM
- ☒ **B** ON
- ☒ **C** OP
- ☒ **D** OQ

(Total for Question 5 = 1 mark)

Questions 9 and 10 refer to the information below.

Alpha particle scattering investigations were first carried out in the early part of the 20th century.

9 An alpha particle with initial kinetic energy 8.8×10^{-13} J approaches a nucleus of a gold $\left({}^{197}_{79}\text{Au}\right)$ atom.

Which of the following is an equation for the closest distance r, in metres, between the alpha particle and the nucleus?

☒ **A** $r = 8.99 \times 10^{9} \left(\dfrac{2 \times 1.6 \times 10^{-19} \times 79 \times 1.6 \times 10^{-19}}{8.8 \times 10^{-13}} \right)$

☒ **B** $r = \dfrac{2 \times 1.6 \times 10^{-19} \times 197 \times 1.6 \times 10^{-19}}{8.99 \times 10^{9} \times 8.8 \times 10^{-13}}$

☒ **C** $r = 8.99 \times 10^{9} \left(\dfrac{8.8 \times 10^{-13}}{4 \times 1.6 \times 10^{-19} \times 79 \times 1.6 \times 10^{-19}} \right)$

☒ **D** $r = 8.99 \times 10^{9} \left(\dfrac{2 \times 79}{8.8 \times 10^{-13}} \right)$

(Total for Question 9 = 1 mark)

10 Which of the following conclusions could **not** be made as a result of these investigations?

☒ **A** The atom is mostly empty space.

☒ **B** The atom is neutral.

☒ **C** The nucleus is charged.

☒ **D** The nucleus is very small compared to the atom.

(Total for Question 10 = 1 mark)

15 A series of experiments was carried out in the 1970s to investigate the structure of protons using the linac at Stanford, USA.

*(a) Explain how an electron is accelerated in a linac.

(6)

(b) The electron leaves the accelerator with a high energy.

Explain why electrons need high energies to investigate the structure of a proton.

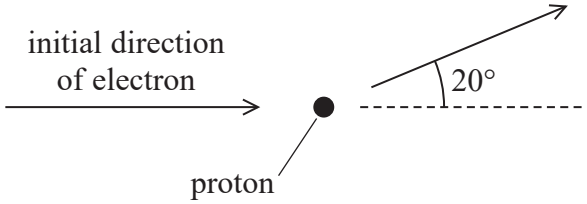
(2)

(c) An electron leaves the accelerator with a momentum of 20 GeV/c.

(i) Explain, with reference to base units, why GeV/c can be used as a unit of momentum.

(2)

(ii) An electron with initial momentum 20 GeV/c collides with a stationary proton. After the collision the electron is deflected by an angle of 20° as shown and its momentum is 9.1 GeV/c. The momentum of the proton after the collision is 11.9 GeV/c.



Deduce whether the law of conservation of momentum is obeyed.

(3)

(iii) The collisions between electrons and the protons in these experiments are sometimes inelastic.

State what is meant by an inelastic collision.

(1)

(Total for Question 15 = 14 marks)

17 A cosmic ray, consisting of a fast-moving proton, collides with a proton within the nucleus of an atom in the upper atmosphere. Three particles, a proton, a neutron and a pion result from the collision.

(a) Write a particle equation for this collision.

(2)

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(b) The table shows the properties of two quarks.

Quark	Charge / *e*
u	+2/3
d	−1/3

Give the quark structure for each of the particles produced by this collision.

(3)

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(c) The mass of a pion is 140 MeV/c^2.

Calculate the mass of the pion in kg.

(3)

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Mass = ... kg

(d) The mass of a neutron is about the same as the mass of a proton. A student suggests that the minimum kinetic energy the cosmic ray proton would need to create the pion in this collision is 140 MeV.

Discuss whether this suggestion is correct. Your answer should include reference to the laws of conservation of momentum and conservation of energy.

(4)

(Total for Question 17 = 12 marks)

(Total for Question 1 = 1 mark)

2 The π^- particle has a mass of 140 MeV / c^2.

Which row of the table is correct for the antiparticle of a π^-?

		Particle classification	Mass / MeV/c^2
☒	**A**	Baryon	+140
☒	**B**	Baryon	−140
☒	**C**	Meson	+140
☒	**D**	Meson	−140

(Total for Question 2 = 1 mark)

15 At the beginning of the 20th century, Rutherford carried out large-angle alpha particle scattering experiments using gold ($^{197}_{79}$Au) foil.

The vast majority of the alpha particles went straight through the foil whilst a few were deflected straight back.

(a) Describe how the model of the atom changed, as a consequence of these experiments.

(4)

(b) In one experiment the alpha particles had an initial energy of 7.7 MeV.

Calculate the distance of closest approach of the alpha particles to the nucleus of a gold atom. Assume that the gold nucleus remains at rest.

(4)

Distance of closest approach = ...

(c) Rutherford also carried out the experiment with aluminium ($^{27}_{13}$Al) foil.
The aluminium foil had the same thickness as the gold foil and the alpha particles had the same initial kinetic energy.

The following observations were made.

Observation 1:
The fraction of alpha particles scattered at any particular angle for aluminium foil was always much less than for gold foil.

Observation 2:
The alpha particles scattered from aluminium foil had less kinetic energy than the alpha particles scattered from gold foil.

Explain how these observations can be used to deduce how an aluminium nucleus compares to a gold nucleus.

(4)

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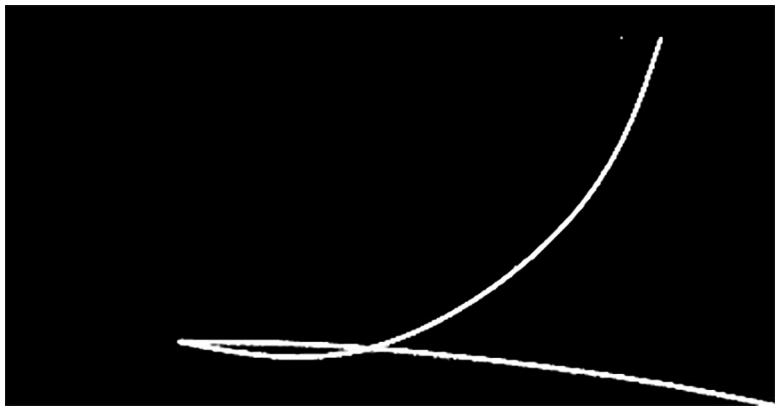
(Total for Question 15 = 12 marks)

16 The bubble chamber photograph shows tracks made by a proton and a pion. The proton and pion were both created by the decay of a lambda particle. No other particles were produced.



*(a) Explain how observations and measurements from the photograph can be used to establish information about the lambda particle.

(6)

(b) The lambda particle consists of up, down and strange quarks.

Explain how the conservation of charge, baryon number and lepton number apply to the decay of the lambda particle.

(3)

(c) Write an equation to represent the decay of the lambda (Λ) particle.

(1)

(d) The rest mass of the lambda particle is 1115 MeV / c^2.

(i) Calculate this mass in kg.

(3)

Mass = ... kg

(ii) The rest mass of a proton is 940 MeV / c^2. The rest mass of a pion is 140 MeV / c^2.

The kinetic energy of the lambda particle just before decay is 4.95 GeV.

Calculate the total kinetic energy of the proton and pion in MeV.

(3)

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Total kinetic energy = ... MeV

(Total for Question 16 = 16 marks)

(Total for Question 1 = 1 mark)

2 Which row of the table summarises the mass and charge of an antineutron?

	Mass / u	Charge / e
☒ **A**	0	0
☒ **B**	0	−1
☒ **C**	1	0
☒ **D**	1	+1

(Total for Question 2 = 1 mark)

(Total for Question 4 = 1 mark)

5 A high-energy proton can interact with a photon to produce two particles.

Which of the following could be the two particles produced?

☒ **A** $n + \pi^0$

☒ **B** $n + \pi^+$

☒ **C** $\pi^0 + \pi^+$

☒ **D** $\pi^- + \pi^+$

(Total for Question 5 = 1 mark)

(Total for Question 7 = 1 mark)

8 A proton has a mass of 1.67×10^{-27} kg.

Which of the following shows the conversion of this mass to GeV/c^2 ?

☒ **A** $\dfrac{1.67 \times 10^{-27} \times 1.60 \times 10^{-10}}{(3.00 \times 10^{8})^2}$

☒ **B** $\dfrac{1.67 \times 10^{-27} \times 1.60 \times 10^{-19}}{(3.00 \times 10^{8})^2}$

☒ **C** $\dfrac{1.67 \times 10^{-27} \times (3.00 \times 10^{8})^2}{1.60 \times 10^{-10}}$

☒ **D** $\dfrac{1.67 \times 10^{-27}}{1.60 \times 10^{-10} \times (3.00 \times 10^{8})^2}$

(Total for Question 8 = 1 mark)