Q1.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

When investigating the structure of the atom, alpha particles were directed at a thin gold foil. It was observed that most of the alpha particles passed straight through undeflected.

Which of the following is a valid conclusion from this observation?

☐ **A** A gold atom is mostly empty space.

☐ **B** A gold atom is neutral.

☐ **C** A gold nucleus is positively charged.

☐ **D** A gold nucleus has a large number of protons.

(Total for question = 1 mark)

Q2.

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.

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(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

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Force = ...

(Total for question = 6 marks)

Q3.

Answer the question with a cross in the box you think is correct (☒). If you change your mind about an answer, put a line through the box (☒) and then mark your new answer with a cross (☒).

Electrons can be used to investigate atomic nuclei.

Which of the following is **not** a reason why electrons can be used for such an investigation?

☐ **A** Electrons can be accelerated to very high speeds.

☐ **B** Electrons can have wavelengths similar to the size of atomic nuclei.

☐ **C** Electrons have negative charge.

☐ **D** Electrons undergo diffraction.

(Total for question = 1 mark)

Q4.

Which row of the table shows a possible arrangement of quarks in a baryon and a meson?

(1)

	baryon	meson
☐ **A**	$dd\bar{s}$	cd
☐ **B**	ddu	du
☐ **C**	$\bar{d}\bar{u}\bar{u}$	$c\bar{s}$
☐ **D**	$\bar{u}\bar{s}s$	$d\bar{d}$

(Total for question = 1 mark)

Q5.

A positron enters a particle accelerator. As it emerges from the accelerator its mass is measured to be 3.8×10^{-29} kg.

It can be concluded that the positron

☐ **A** has become a different particle.

☐ **B** is travelling in a circle.

☐ **C** is travelling at close to the speed of light.

☐ **D** is travelling at a non-relativistic speed.

(Total for question = 1 mark)

Q6.

The table compares the mass and charge of an electron with the mass and charge of a positron.

Select the line in the table that is correct.

	Mass	Type of charge
☐ **A**	equal	same
☐ **B**	equal	opposite
☐ **C**	unequal	same
☐ **D**	unequal	opposite

(Total for question = 1 mark)

Q7.

Which of the following is **not** a fundamental particle?

☐ **A** electron

☐ **B** neutrino

☐ **C** pion

☐ **D** quark

(Total for question = 1 mark)

Q8.

The equation for β^+ decay is

$$p \rightarrow n + e^+ + \nu_e$$

(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

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

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(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

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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 $E = pc$.

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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.

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(Total for question = 13 marks)

Q9.

Answer the question with a cross in the box you think is correct (☒). If you change your mind about an answer, put a line through the box (☒) and then mark your new answer with a cross (☒).

Which of the following decays for a pion would **not** be possible?

☒ **A** $\pi^0 \rightarrow 2\gamma$

☒ **B** $\pi^+ \rightarrow e^+ + \nu_e$

☒ **C** $\pi^0 \rightarrow e^+ + \bar{\nu}_e$

☒ **D** $\pi^0 \rightarrow e^+ + e^- + \gamma$

(Total for question = 1 mark)

Q10.

According to Einstein's theory of relativity, the total energy E of a particle with rest mass m and momentum p is given by the equation

$$E^2 = m^2c^4 + p^2c^2$$

where c is the speed of light in a vacuum.

(a) Show that the base units on both sides of the equation are the same.

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(b) Simplify the equation for particles with zero velocity.

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(c) For particles with relativistic velocities, m^2c^4 is negligible compared to E^2 so the equation simplifies to

$$E = pc$$

Show that this is correct and that the simplification is justified for an electron of energy 45 GeV.

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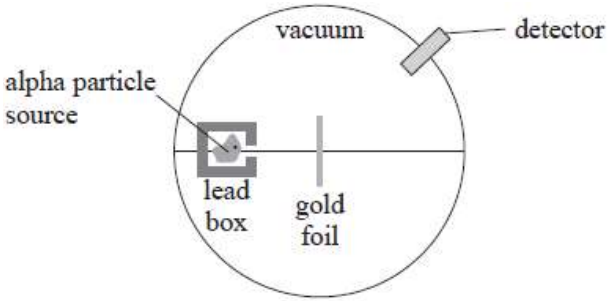
(Total for question = 9 marks)

Q11.

In the early 1900s Geiger and Marsden carried out experiments in which a beam of high speed alpha particles was directed at thin gold foil.
The apparatus used is represented in the diagram.



(a) Explain why the alpha source was placed in a lead box with a single small hole.

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* (b) The following conclusions about atoms were made after the experiments.

1. The atom is mostly empty space.

2. The atom contains a small region of highly concentrated charge.

3. Most of the mass of the atom is concentrated in a very small space relative to the size of the atom.

Explain how the observations from the experiments led to these conclusions.

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(c) The source of alpha particles in some experiments was radium.

Complete the nuclear equation to show alpha decay for radium.

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$$^{226}_{88}\text{Ra} \rightarrow \text{\_\_\_\_}\,\alpha + \text{\_\_\_\_}\,\text{Rn}$$

(d) An alpha particle has a speed of 1.50×10^7 m s^{-1}.

Determine the potential difference that would be required to bring it to rest. You may ignore relativistic effects at this speed.

mass of alpha particle = 4.00 *u*

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Potential difference = ...

(Total for question = 13 marks)

Q12.

There are two families of hadrons called mesons and baryons.

(a) State the structure of a meson.

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(b) The table shows the charge on up and down quarks.

Quark	Charge / *e*
up	+2/3
down	−1/3

Use the information in the table to state the quark composition of an antiproton and an antineutron.

(2)

Antiproton

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Antineutron

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(c) A proton has kinetic energy of 158 MeV. It annihilates with a stationary antiproton and two photons of equal energy are created.

Calculate the wavelength of the photons.

mass of stationary proton = 938 MeV/c^2

mass of stationary antiproton = 938 MeV/c^2

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Wavelength of the photons = ...

(Total for question = 7 marks)

Q13.

The existence of the Higgs boson was confirmed in 2012.

The Higgs boson has no charge and a mass of 126 MeV/c^2.

(a) Calculate the mass of the Higgs boson in kg.

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Mass = ... kg

(b) In a video about the Higgs boson the following statement is made:

"The Higgs boson can decay in many ways. Sometimes the Higgs boson decays into two high energy photons."

Calculate the frequency of the photons. Assume the photons are identical.

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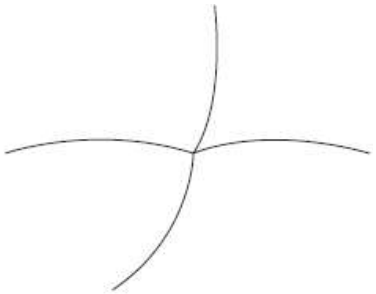
Frequency = ...

(c) The video shows the following diagram, which represents the decay of a Higgs boson.

The lines are tracks of decay particles moving in a magnetic field perpendicular to the diagram.



The video commentary includes the statement:

"Sometimes the Higgs boson decays into four electrons."

Discuss this statement.

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(Total for question = 9 marks)

Q14.

Which of the following particles is a lepton?

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☒ **A** muon

☒ **B** neutron

☒ **C** pion

☒ **D** proton

(Total for question = 1 mark)

Q15.

A kaon can decay in several different ways.
Which of the following decays is **not** possible?

(1)

☒ **A** $K^0 \rightarrow \pi^+ + e^- + \bar{\nu}_e$

☒ **B** $K^0 \rightarrow \pi^+ + \pi^0 + \pi^+$

☒ **C** $K^+ \rightarrow \pi^0 + e^+ + \nu_e$

☒ **D** $K^+ \rightarrow \mu^+ + \nu_\mu$

(Total for question = 1 mark)

Q16.

Which of the following is **not** a lepton?

☒ **A** electron

☒ **B** neutrino

☒ **C** pion

☒ **D** positron

(Total for question = 1 mark)

Q17.

Answer the question with a cross in the box you think is correct (☒). If you change your mind about an answer, put a line through the box (☒) and then mark your new answer with a cross (☒).

Which of the following is a lepton?

☒ **A** pion

☒ **B** photon

☒ **C** neutron

☒ **D** electron

(Total for question = 1 mark)

Q18.

Answer the question with a cross in the box you think is correct (☒). If you change your mind about an answer, put a line through the box (☒) and then mark your new answer with a cross (☒).

The isotope $^{209}_{84}Po$ decays by emitting an alpha particle.

Which of the following correctly shows the nucleons in the isotope produced?

☐ **A** 123 neutrons, 82 protons

☐ **B** 129 neutrons, 80 protons

☐ **C** 205 neutrons, 82 protons

☐ **D** 207 neutrons, 80 protons

(Total for question = 1 mark)

Q19.

Answer the question with a cross in the box you think is correct (☒). If you change your mind about an answer, put a line through the box (☒) and then mark your new answer with a cross (☒).

The Λ^0 particle is a baryon.

Which of the following products could **not** be produced by the decay of a Λ^0 particle?

☐ **A** $p + \pi^0$

☐ **B** $n + \pi^0$

☐ **C** $p + e^- + \bar{\nu}_e$

☐ **D** $p + \mu^- + \bar{\nu}_\mu$

(Total for question = 1 mark)

Q20.

Answer the question with a cross in the box you think is correct (☒). If you change your mind about an answer, put a line through the box (☒) and then mark your new answer with a cross (☒).

A particle has mass 4.8 MeV/c^2.

What is the mass of the particle in kilograms?

☐ **A** 8.5×10^{-36}

☐ **B** 8.5×10^{-30}

☐ **C** 2.6×10^{-21}

☐ **D** 5.3×10^{-11}

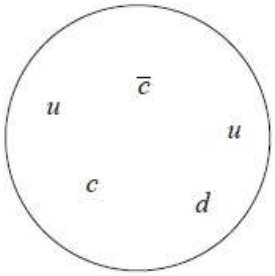
(Total for question = 1 mark)

Q21.

In 2015, scientists at CERN announced the discovery of a particle known as a pentaquark.

At this time the pentaquark structure had not been determined. It was suggested that it might be five quarks tightly bound as a single particle, or a 'meson-baryon molecule'.

The diagram illustrates the single particle model.

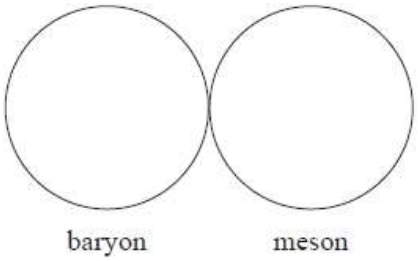


(a) The table shows the charges of the six types of quark.

Quark			Charge
u	c	t	$\frac{2}{3}e$
d	s	b	$-\frac{1}{3}e$

Complete the following diagram to show how the five quarks shown in the single particle model could be arranged in a 'meson-baryon molecule'. The meson should have charge zero and the baryon should have charge $+e$.

(3)



(b) The pentaquark has a mass of 4.38 GeV/c^2.

Calculate the mass of the pentaquark in kg.

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Mass = ... kg

(c) The pentaquark was produced in the decay of a lambda-zero particle which was created after a collision between high energy protons.

(i) In the experiment at CERN a lambda-zero particle was determined to have travelled 3.9 cm after its creation before decaying. The lambda-zero particle existed for 1.48×10^{-12} s.

Use these results to calculate a value of speed and comment on your answer.

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*(ii) The experiment at CERN involved colliding protons.

Explain why very high energies were required for the experiment.

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(Total for question = 13 marks)

Q22.

The table gives the quark structure of three particles.
The up quark has a charge of +2/3*e* and the down quark has a charge of −1/3*e*.

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)

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

(2)

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(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)

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Quark content of Δ^{++}.....

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Charge on pion .....

(Total for question = 5 marks)