Questions

Q1.

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

* Explain how an electron is accelerated in a linac.

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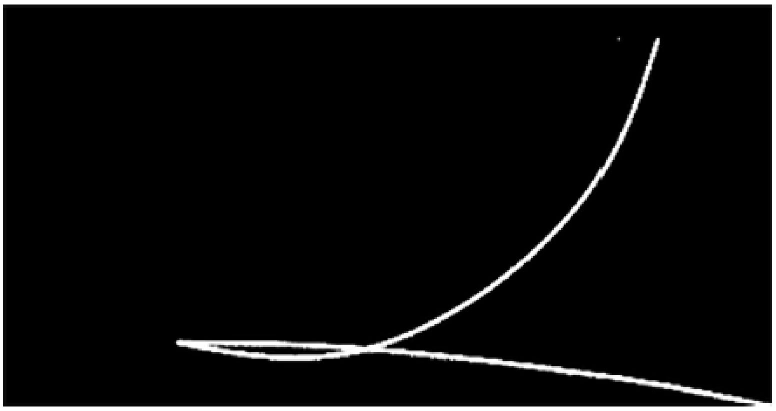
(Total for question = 6 marks)

Q2.

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.



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

(i) Calculate this mass in kg.

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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.

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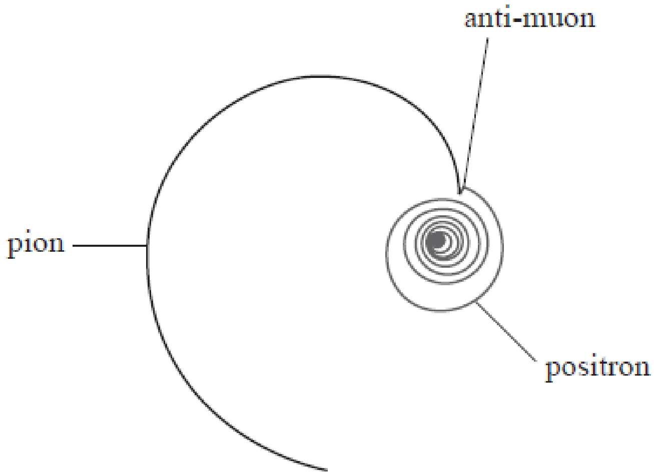
Total kinetic energy = ... MeV

(Total for question = 6 marks)

Q3.

Pions have a short half-life and decay into muons.
The diagram shows the tracks from the decay of a pion in a bubble chamber.



The pion decays into an anti-muon and muon neutrino.
The anti-muon then decays into a positron and an electron neutrino.
The magnetic field acts out of the page.

Use the diagram and the information given to explain what conclusions can be made about the particles in this interaction.

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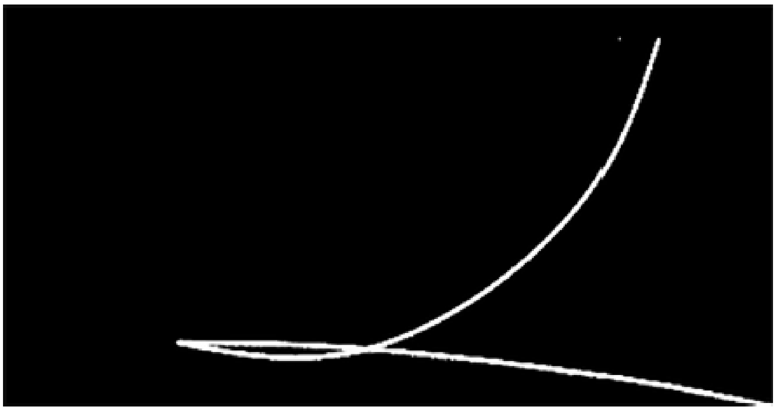
Q4.

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.



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

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(Total for question = 6 marks)

Q5.

The following extract is taken from a quote by Rutherford, speaking about the scattering of alpha particles by a thin gold foil.

> We knew the alpha particle was a very fast, massive particle with a great deal of energy, and the chance of an alpha particle being scattered backward was very small. Then I remember two or three days later Geiger coming to me in great excitement and saying "We have been able to get some of the alpha particles coming backward …" It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you.

(a) Rutherford compared the scattering of alpha particle through large angles to firing "a 15-inch shell at a piece of tissue paper and it came back and hit you."

Explain, with reference to the properties of the alpha particle, why a relatively large force is needed to deflect alpha particles through a large angle.

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(b) Before the alpha particle scattering experiment, scientists believed that the mass and charge of an atom were uniformly distributed throughout the atom in a radius of about 1.4×10^{-10} m. Following the scattering experiments, a model of the atom was developed in which there was a concentrated centre of charge called the nucleus.

Assess the validity of this model of the atom given that the magnitude of the force required to scatter these alpha particles by a large angle is about 2.0 N. You should include a calculation in your answer.

proton number of gold = 79

(5)

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Q6.

Pions (π^+, π^-, π^0) are created in the upper atmosphere when cosmic rays collide with protons. Pions are unstable and decay rapidly.

(a) Pions are the lightest of the hadrons. Charged pions (π^+ and π^-) decay to produce muons which then decay to positrons or electrons.

(i) A positive pion π^+ has a quark composition $u\bar{d}$.

State with a justification the possible quark compositions of a neutral pion π^0.

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(ii) Muons are examples of leptons whereas pions are examples of mesons.
State a structural difference between leptons and mesons.

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(b) Muons with a speed of 0.99*c* travel a distance of 15 km to reach the surface of the Earth from the upper atmosphere.

(i) Show that the time it takes a muon to travel this distance is about 51 μs.

(2)

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(ii) The muons are unstable particles.
Calculate the fraction of muons which would remain after a time of 51 μs.

half-life of muon = 2.2 μs

(4)

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Fraction = ...

(iii) In fact the fraction of muons reaching the surface of the Earth is about 0.1 Explain the discrepancy.

(4)

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(Total for question = 11 marks)

Q7.

A muon (μ) is a lepton with a mass of 106 MeV/c^2.

Muons are produced from the decay of pions in the upper atmosphere.

An example of this decay is given by the equation

$$\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$$

(i) Explain how this decay obeys the laws of conservation of charge, baryon number and lepton number.

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(ii) The masses of these three particles, in MeV/c^2, are given below.

π^-	μ^-	$\bar{\nu}_\mu$
140	106	≈0

Explain why the total kinetic energy of the products of this decay is approximately 34 MeV. Assume the π^- is stationary.

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(iii) State which two conservation laws could be used to calculate the kinetic energy of the μ– and the $\bar{\nu}_\mu$ just after the decay of the π^-.

(2)

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* (iv) The muons are produced at a height of 10 km in the atmosphere. The velocity of the muons is 0.99 *c*. The average lifetime for muons is normally 2.2 μs and yet muons produced in the upper atmosphere are found in significant numbers at sea level.

Discuss this apparent anomaly.

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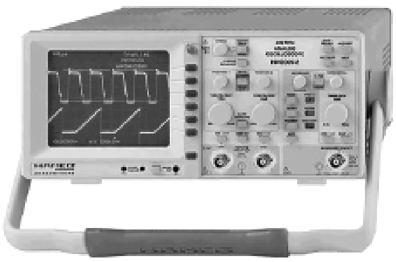
(Total for question = 13 marks)

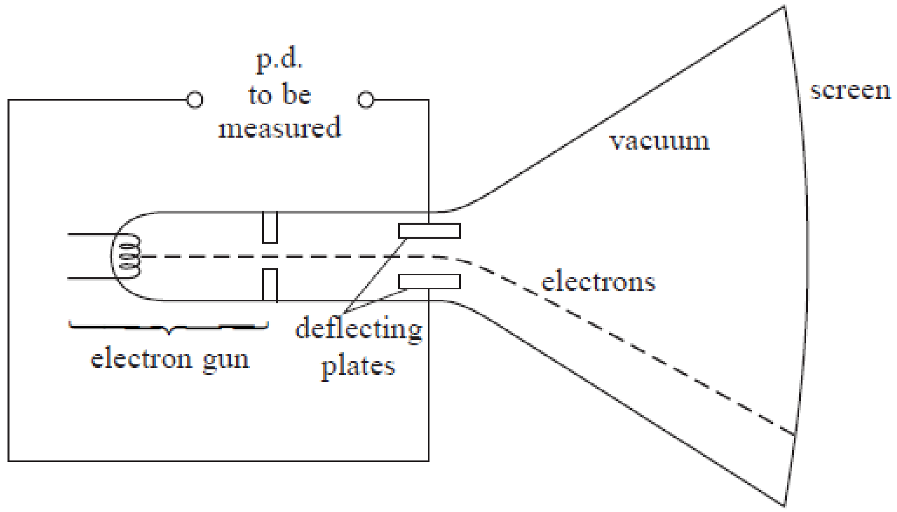
Q8.

Cathode ray tubes are used in oscilloscopes.



The diagram shows a simplified cathode ray tube that can be used to determine the magnitude and polarity of a potential difference (p.d.).

The cathode ray tube consists of an electron gun, a pair of deflecting plates and a fluorescent screen.



(a) The electron gun includes a filament. When this filament is heated, electrons are released and are accelerated by a p.d. of 1.5 kV to form an electron beam.

(i) Name the process by which electrons are released from the heated filament.

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(ii) Show that the maximum velocity of the electrons is about 2×10^7 m s^{-1}.

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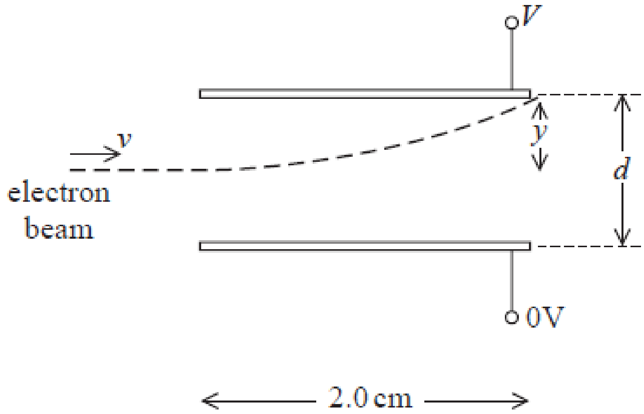
(b) The electron beam then enters a uniform electric field between the two parallel horizontal deflecting plates. The magnitude and direction of the deflection is determined by the p.d. *V* that is applied across the plates.

The diagram shows one possible path of the electron beam as it passes between the plates.



(i) Show that the acceleration of an electron, of mass *m* and charge *Q*, is given by

$\frac{VQ}{dm}$

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(ii) Calculate the magnitude of the vertical deflection y of the beam as it leaves the plates.

V = 50 V
d = 0.01 m

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y = ...

(c) A laboratory oscilloscope with the time base turned off operates in the same way as this simplified cathode ray tube. A student uses an oscilloscope in this way to monitor an alternating p.d. of 53 V_{rms}

On the grid, draw the trace that would be seen on the screen.

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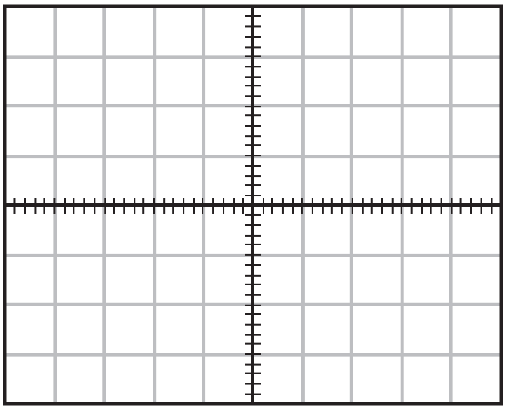

1 square = 25 V

(Total for question = 14 marks)

Q9.

The discovery of the Higgs particle was an important contribution to our understanding of particle physics.

(a) Describe the standard model for subatomic particles. You should identify the fundamental particles and the composition of the particles we can observe.

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(b) The mass of the Higgs particle is 2.2×10^{-25} kg.

Calculate this mass in GeV/c^2.

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Mass = ... GeV/c^2

(c) The Higgs particle was discovered using the Large Hadron Collider (LHC) in 2012. Two beams of very high energy protons, moving in opposite directions, were made to collide.

(i) Explain the need for such high energy collisions.

(3)

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(ii) The beams of protons are contained within a ring of superconducting magnets.

Calculate the momentum of a proton in a beam.

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magnetic field strength = 8.3 T
circumference of the ring = 27 km

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Momentum = ...

(iii) State the total momentum of the products of the collision between the two beams of protons.

(1)

Total momentum = ...

(d) A student used the equation $E_k = \frac{p^2}{2m}$ to predict the energy of a proton in the beam, using the momentum calculated in (c)(ii), but found the energy was far higher than 7 TeV.

Explain why.

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(Total for question = 17 marks)