Questions

Q1.

In the alpha particle scattering experiment a beam of alpha particles is directed at a thin metal foil.

(a) In 1911 Rutherford concluded that the atom has a central charge contained in a very small volume.

Explain how the results of the experiment led to this conclusion.

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(b) Rutherford wrote, "The main deductions from the theory are independent of whether the central charge is positive or negative."

Discuss why the observations did not allow Rutherford to conclude whether the central charge is positive or negative.

You may wish to use diagrams to illustrate your response.

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(c) We now know that the nucleus is positively charged.

An alpha particle with kinetic energy of 6.29 MeV approaches a platinum nucleus and is repelled. The proton number of platinum is 78.

Calculate the minimum distance of the alpha particle from the platinum nucleus.

Assume that the alpha particle and the nucleus are point charges.

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Distance = ...

(Total for question = 9 marks)

Q2.

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 SI unit of capacitance is the farad.

Which of the following gives the base units of the farad?

☒ **A** $C\ V^{-1}$

☒ **B** $C^2\ J^{-1}$

☒ **C** $kg^{-1}\ m^{-2}\ A^2\ s^4$

☒ **D** $kg^{-1}\ m^{-2}\ s^{-2}\ C^{-2}$

(Total for question = 1 mark)

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 ☒ .

A student writes the following equation for the decay of a neutron.

$$n \rightarrow p + e^{-} + \upsilon_e$$

Which of the following conservation laws is violated by the equation he has written?

☒ **A** baryon number

☒ **B** charge

☒ **C** energy

☒ **D** lepton number

(Total for question = 1 mark)

Q4.

A gamma photon of energy 18 MeV produces a particle and its antiparticle.

Which of the following will give the maximum possible mass of the particle in kg?

☒ **A** $\frac{9 \times 1.6 \times 10^{-19}}{3 \times 10^{8}}$

☒ **B** $\frac{9 \times 10^{6} \times 1.6 \times 10^{-19}}{3 \times 10^{8}}$

☒ **C** $\frac{9 \times 1.6 \times 10^{-19}}{(3 \times 10^{8})^{2}}$

☒ **D** $\frac{9 \times 10^{6} \times 1.6 \times 10^{-19}}{(3 \times 10^{8})^{2}}$

(Total for question = 1 mark)

Q5.

A neutron can decay to produce a proton.

Which of the following equations correctly shows neutron decay?

☒ **A** $n \rightarrow p + e^{+} + \overline{\nu}_e$

☒ **B** $n \rightarrow p + e^{+} + \nu_e$

☒ **C** $n \rightarrow p + e^{-} + \overline{\nu}_e$

☒ **D** $n \rightarrow p + e^{-} + \nu_e$

(Total for question = 1 mark)

Q6.

Positron emission tomography (PET) is a medical imaging technique used to create three-dimensional images of the body.

In PET, a low energy positron collides with an electron to produce a pair of gamma photons travelling in opposite directions. The gamma photons are detected and used to form the image.

(a) Name the process involved in producing the gamma photons.

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(b) Calculate the maximum wavelength of the gamma photons produced.

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Wavelength = ...

(Total for question = 5 marks)

Q7.

The following passage is taken from an article about the history of particle physics.

Mystery Particle

By 1932 scientists knew of the existence of the subatomic particles the electron, the proton and the neutron. These were believed to be the fundamental particles.

In 1936 scientists were using tracks of cosmic rays to identify a predicted particle known as a meson. Instead, another particle was discovered, the muon. This was so surprising that Nobel Prize winning physicist Isidor Rabi said "Who ordered that?"

Describe how the underlined particles fit into the standard model.

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(Total for question = 6 marks)

Q8.

In 1964 George Zweig proposed a model for matter.

Zweig suggested that mesons and baryons are made from a set of fundamental particles he called aces. In this model each ace carried baryon number 1/3 and was fractionally charged. Baryons were a combination of three aces and mesons were a combination of two aces. Zweig said that the number of aces should match the number of leptons, so there would be four types of ace.

Compare this model with the current standard model.

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(Total for question = 4 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 ☒.

Neutrinos can interact with protons to create neutrons.

Which of the following equations shows this process?

☒ **A** $\nu_e + p \rightarrow e^+ + n$

☒ **B** $\nu_e + p \rightarrow e^- + n$

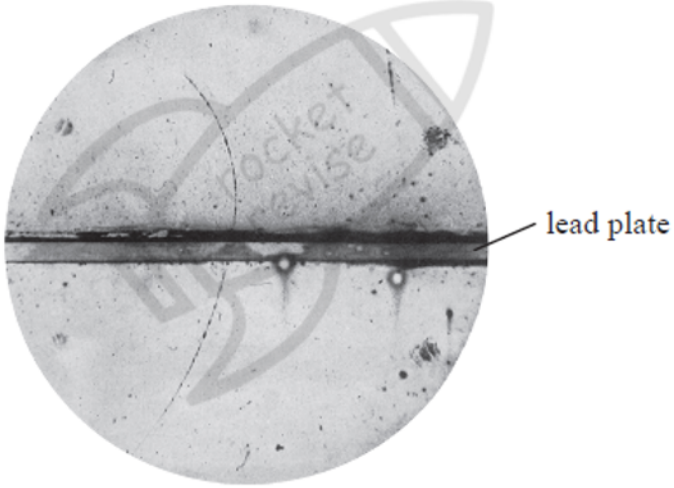
☒ **C** $\bar{\nu}_e + p \rightarrow e^+ + n$

☒ **D** $\bar{\nu}_e + p \rightarrow e^- + n$

(Total for question = 1 mark)

Q10.

In 1932, Carl Anderson published this photograph of a track in a cloud chamber. The cloud chamber contained a lead plate. There was a magnetic field perpendicular to the plane of the track.



(Source: Anderson, Carl D. (1933). "The Positive Electron". Physical Review 43 (6): 491–494. DOI:10.1103/PhysRev.43.491.)

The photograph shows the track of a positron from cosmic rays and is the first photographic record of the existence of an antiparticle.

(a) State the properties of a positron that show it is the antiparticle to the electron.

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(b) Deduce the direction of the magnetic field.

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Direction of magnetic field = ...

(c) In the upper part of the photograph the positron had an energy of 23 MeV.

(i) Show that the positron must have been travelling at a relativistic speed.
Assume that all of its energy is kinetic energy.

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(ii) For relativistic particles such as this positron, momentum obeys the relationship

$$E = pc$$

where E = particle energy, p = particle momentum and c = speed of light.

Determine the magnetic flux density of the magnetic field.

radius of curvature of path = 3.7 cm

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Magnetic flux density = ...

(d) A positron travelling at a non-relativistic speed of 1.5×10^7 m s^{-1} collides with an electron travelling at the same speed
in the opposite direction. This collision results in the production of gamma radiation.

Calculate the frequency of the gamma radiation produced.

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Frequency = ...

(Total for question = 16 marks)

Q11.

A stationary anti-neutron decays by emitting a positron.

(a) Explain how energy is conserved in this decay.

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(b) The equation shows the decay of an anti-neutron.

$$^{1}_{0}\overline{n} \rightarrow {}^{1}_{-1}\overline{p} + {}^{0}_{1}\overline{e} + \nu_e$$

Explain how this equation shows that the decay obeys three conservation laws.

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(Total for question = 8 marks)

Q12.

Muons are produced by cosmic rays in the Earth's upper atmosphere.

In 1940, Bruno Rossi and David Hall made observations of the decay of these muons.

They measured the number of muons reaching the bottom of a mountain and the number reaching a position 1600 m higher up the mountain.

The muons were travelling at a speed of 0.994 *c*.

Rossi and Hall found that 74% of the muons detected at 1600 m reached the bottom of the mountain. The average lifetime of muons at rest is only 2.2×10^{-6} s, so they suggested that their observations could be explained using ideas from relativity.

(a) Explain whether these observations are consistent with ideas from relativity.

Your answer should include a calculation.

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(b) After muons were discovered in 1936 they were known for many years as mu mesons.

Explain why muons are not described as mesons in the standard model.

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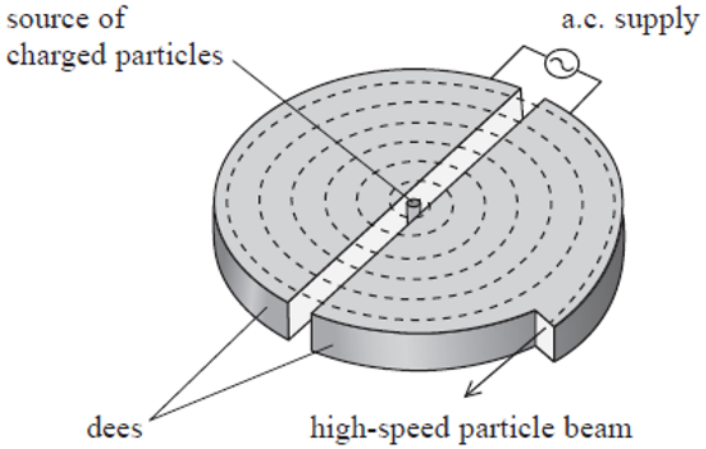
(Total for question = 7 marks)

Q13.

In 1937 scientists at the University of California used high-speed particles from a cyclotron to produce an isotope of phosphorus. This isotope can be used in a treatment for cancer.



* (a) Explain the role of electric and magnetic fields in the production of high-speed charged particles by a cyclotron.

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(b) The cyclotron could produce beams of alpha particles with kinetic energy up to 16 MeV.

Calculate the magnetic flux density required by the cyclotron when alpha particles with kinetic energy of 16 MeV are produced.

diameter of cyclotron = 0.94 m

mass of alpha particle = 6.6×10^{-27} kg

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Magnetic flux density = ...

(Total for question = 10 marks)

Q14.

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 the quark structure for a π^- particle?

☐ **A** d d d

☐ **B** $\bar{u}\,\bar{u}\,\bar{d}$

☐ **C** $\bar{u}$ d

☐ **D** u d

(Total for question = 1 mark)

Q15.

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 ☒.

In 2015, a pentaquark was discovered.

The pentaquark was made of 5 quarks, $c, \bar{c}, d, u, u$.

The pentaquark can form a baryon-meson combination.

Which row of the table shows a possible arrangement of the quarks?

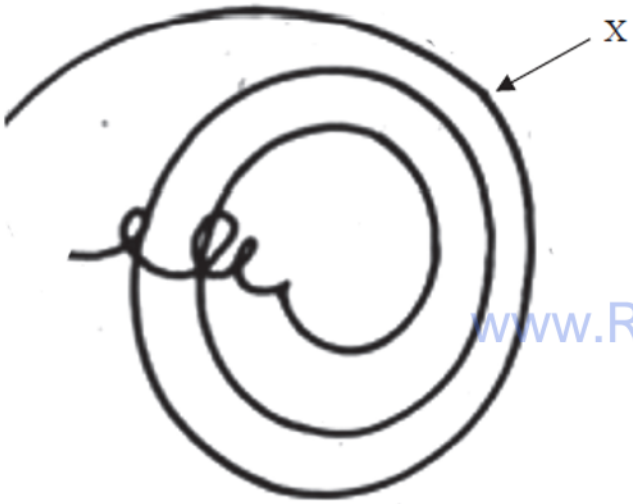
	Quarks in baryon	Quarks in meson
☒ **A**	d u u	c $\bar{c}$
☒ **B**	u $\bar{c}$ u	d c
☒ **C**	$\bar{c}$ u	d u c
☒ **D**	u d	c $\bar{c}$ u

(Total for question = 1 mark)

Q16.

The diagram shows particle tracks in a detector.

A positive pion decays into an anti-muon at point X.



(a) State two ways in which the diagram shows that an anti-muon must also have a positive charge.

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(b) Explain how the diagram shows that the anti-muon is travelling in a clockwise path.

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(c) State the direction of the magnetic field acting in the detector.

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(d) The momentum of the pion is 1.2×10^{-19} N s.

Calculate the radius of the path of the pion.

magnetic flux density = 3.5 T

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Radius = ...

(e) A neutrino is also produced at X.

(i) Write an equation for this decay process.

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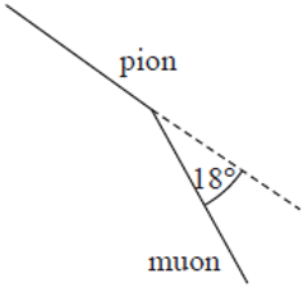
(ii) The initial path of the muon is at an angle of 18° to the direction of the pion, as shown. Data for the momentum of each particle at point X is listed below.

momentum of pion = 1.2×10^{-19} N s
momentum of muon = 0.75×10^{-19} N s
momentum of neutrino = 0.54×10^{-19} N s



Deduce whether this data is consistent with the law of conservation of momentum. You should include a scaled vector diagram in the space below.

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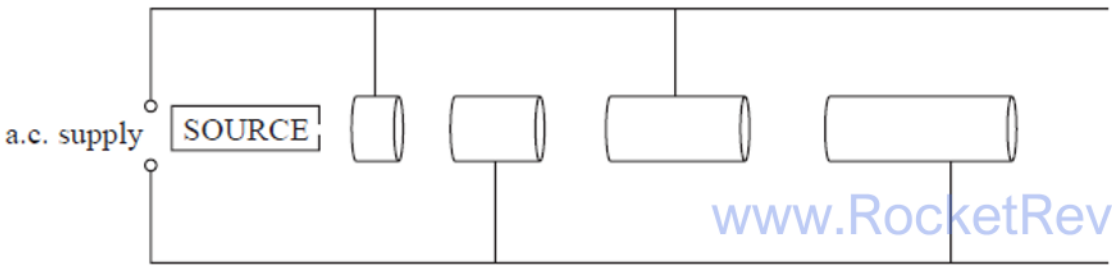
(Total for question = 15 marks)

Q17.

A particle collider can include a LINAC.

(a) The diagram represents a LINAC.



Explain why this arrangement works with a constant frequency a.c. supply.

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(b) In a particle collider, a positron and an electron collided. Each particle had an energy of 14.5 GeV. The collision produced two particles of a type called omega baryons.

(i) An omega baryon has a mass equivalent to 3272 times the mass of an electron.

Show that the mass of an omega baryon is about 1700 MeV/c^2.

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(ii) Calculate the kinetic energy of one of the omega baryons.

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Kinetic energy = ...

(c) A student correctly suggests that this collision cannot lead to both particles being omega baryons, as this breaks a conservation law.

Discuss the student's suggestion.

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(Total for question = 14 marks)

Q18.

A particle has a mass of 3.17×10^{-27} kg.

Which of the following gives the mass in GeV/c^2?

☒ **A** $\dfrac{3.17 \times 10^{-27} \times 10^{9} \times 1.6 \times 10^{-19}}{3.00 \times 10^{8}}$

☒ **B** $\dfrac{3.17 \times 10^{-27} \times 10^{9} \times 1.6 \times 10^{-19}}{(3.00 \times 10^{8})^{2}}$

☒ **C** $\dfrac{3.17 \times 10^{-27} \times (3.00 \times 10^{8})^{2}}{1.6 \times 10^{-19}}$

☒ **D** $\dfrac{3.17 \times 10^{-27} \times (3.00 \times 10^{8})^{2}}{10^{9} \times 1.6 \times 10^{-19}}$

(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 ☒.

Which of the following is a fundamental particle?

☒ **A** atom

☒ **B** baryon

☒ **C** neutrino

☒ **D** pion

(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 ☒.

Which of the following is a fundamental particle?

☒ **A** antiproton

☒ **B** muon

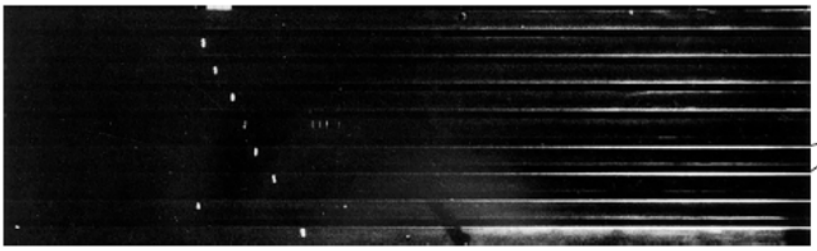
☒ **C** neutron

☒ **D** pion

(Total for question = 1 mark)

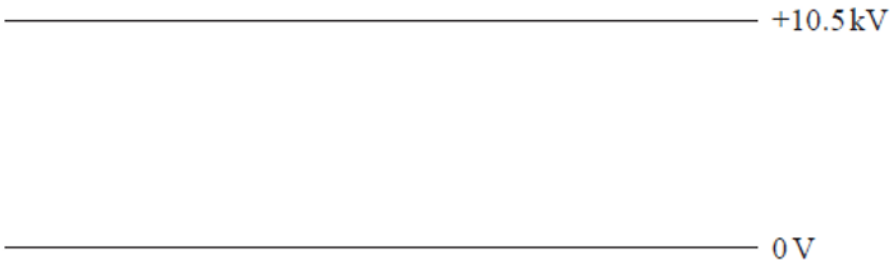
Q21.

A spark chamber consists of a set of parallel metal plates. It can reveal the path of a high energy particle as shown.



(Source: © Smith Collection/Gado/Contributor/Getty Image)

A potential difference of 10.5 kV is applied across two adjacent plates as shown below.



(a) Sketch lines to represent the electric field between the plates.

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(b) A high energy particle causes ionisation of the atoms in the space between the plates.

(i) Show that the force on an ionised atom due to the electric field is about 2.6×10^{-13} N.

charge on ionised atom = 1.60×10^{-19} C
distance between plates = 6.40 mm

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(ii) The ionised atom travels 0.2 μm in the direction perpendicular to the plates before colliding with another atom.

Deduce whether the collision could lead to further ionisation.

ionisation energy of atoms = 3.9×10^{-19} J

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(c) Most of the particles detected in the spark chamber are muons. The muons were created in the upper atmosphere. Muons normally have a very short lifetime and should have decayed before they reach the surface of the Earth.

Explain why these muons reach the surface of the Earth.

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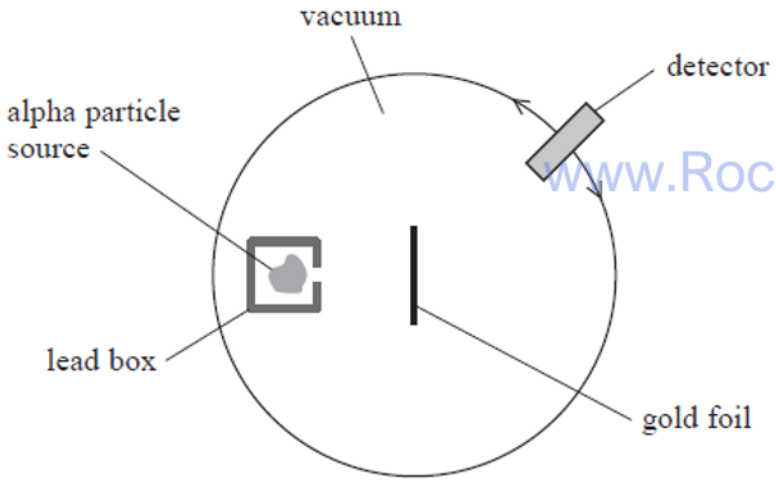
(Total for question = 11 marks)

Q22.

In the early 20th century, experiments were carried out in which alpha particles were directed towards thin gold foil.

A simplified diagram of the apparatus used is shown.



(a) State three observations and the corresponding conclusions made from the alpha particle scattering experiment.

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(b) One experiment used gold foil made from the gold isotope $^{197}_{79}Au$. The alpha particles had an initial
kinetic energy of 4.7 MeV.

(i) Show that the closest distance these alpha particles can get to a gold nucleus is about 5×10^{-14} m.

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(ii) Calculate the strength of the electric field due to the gold nucleus at this distance.

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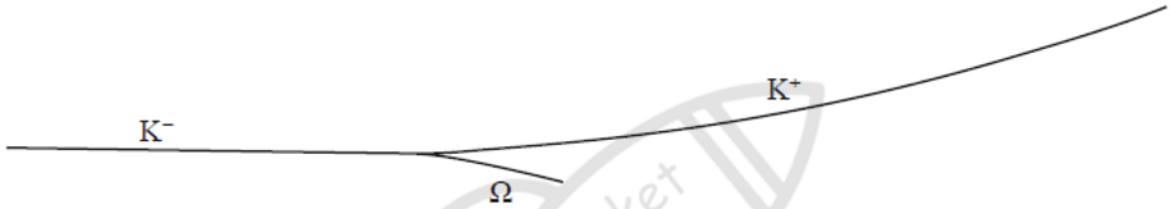
Strength of electric field = ...

(Total for question = 13 marks)

Q23.

The diagram shows particle tracks in a detector. A negative K meson collided with a stationary proton. An omega baryon and a positive K meson were produced after the impact.



(a) Explain the process that enables a particle detector to detect charged particles.

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(b) (i) Describe the structure of a baryon and a meson.

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(ii) A magnetic field acts in the detector.

State the direction of the magnetic field.

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(iii) Deduce the charge and baryon number for the omega particle.

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* (c) The rest mass of the omega baryon is significantly larger than the rest mass of the proton.

Discuss how energy and momentum are conserved during this collision.

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(Total for question = 14 marks)

Q24.

Experiments with muons are taking place at Fermilab in the USA to improve our understanding of the standard model.

(a) The muon belongs to the same family of particles as the electron.

State how the muon is classified in the standard model.

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(b) A muon (μ) can be produced by the decay shown in this nuclear equation.

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

State the names of the two other particles involved.

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(c) A website states: "The rest mass of a muon is 106 MeV / c^2, which is a little over 200 times that of an electron."

Deduce whether this statement is correct.

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(d) Muons are stored in a 'storage ring' at Fermilab. The website describes the ring as having a circumference of 44.7 m and using a magnetic field of flux density 1.45 T.

The website claims that this enables the storage ring to confine muons with a momentum of 3.10 GeV / c.

(i) Explain why the unit GeV / c is a valid unit for momentum.

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(ii) Deduce whether the website's claim is correct.

muon charge = -1.6×10^{-19} C
3.10 GeV/c = 1.65×10^{-18} N s

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(iii) Stationary muons are unstable and have a mean lifetime of a few microseconds.

Explain why muons in the ring are observed to have a much greater mean lifetime.

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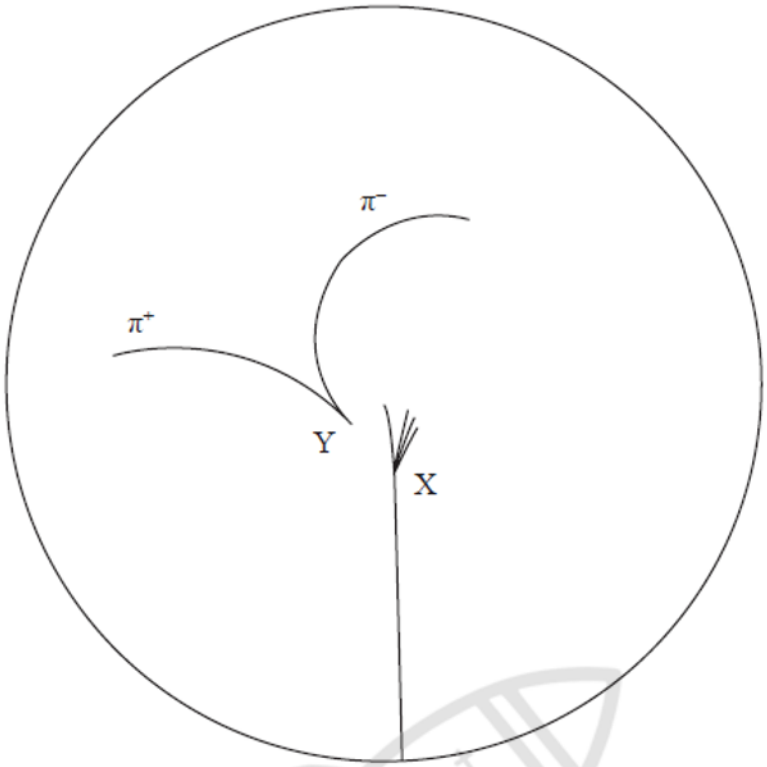
(Total for question = 14 marks)

Q25.

The diagram shows the paths of particles in a circular particle detector. There is a magnetic field acting at right angles to the plane of the paper. The diagram is drawn to scale. 1 cm on the

diagram represents 10 cm in the particle detector.

An antiproton enters the detector and collides with a stationary proton at X. Several particles are produced. One particle is a kaon (K^0). The kaon then decays into two pions (π^+ and π^-) at Y.



(a) Determine the momentum of the negative pion.

magnetic flux density of field in the detector = 7.0T

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Momentum = ...

(b) State two ways that the diagram shows the kaon is neutral.

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(c) The table shows the charge for the up quark and the down quark as a fraction of the charge on the proton.

Quark	Charge
u	+2/3
d	−1/3

Deduce the quark structure of the antiproton and the negative pion.

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Quark structure of the antiproton .....

Quark structure of the negative pion .....

(d) Calculate the mass of a proton in GeV/c^2.

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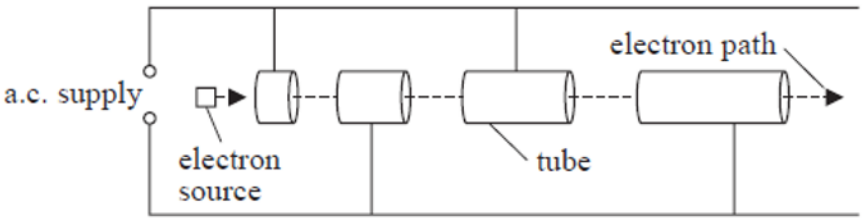
Mass = ... GeV/c^2

(Total for question = 11 marks)

Q26.

Some particle physics experiments use electrons which are accelerated to very high energies by a linac. The diagram shows the first section of the linac.



*(a) Explain why the distances between consecutive tubes increase in the first section of the linac but are almost equally spaced in the last section of the linac.

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(b) In some experiments, a high-energy electron collides with a stationary atom. In other experiments beams of high-energy electrons, travelling in opposite directions, collide head-on. New particles can be created from collisions.

Deduce which type of collision is more likely to produce new particles with the largest mass.

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(Total for question = 9 marks)

Q27.

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 ☒.

Muons can travel at speeds close to the speed of light. At these speeds the lifetime and mass of a muon are different from those of a stationary muon.

Which row of the table describes the lifetime and the mass of a high-speed muon compared to a stationary muon?

		Lifetime	Mass
☒	**A**	shorter	smaller
☒	**B**	shorter	larger
☒	**C**	longer	smaller
☒	**D**	longer	larger

(Total for question = 1 mark)

Q28.

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 fundamental particle?

☒ **A** pion

☒ **B** proton

☒ **C** neutrino

☒ **D** neutron

(Total for question = 1 mark)

Q29.

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 proton collides with an antiproton.

Which of the following could be produced by this collision?

☒ **A** $\pi^+ + n$

☒ **B** $\pi^- + p^+$

☒ **C** $\pi^+ + e^-$

☒ **D** $\pi^+ + \pi^-$

(Total for question = 1 mark)

Q30.

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 row of the table describes the mass and charge of an anti-proton?

		Mass / kg	Charge / C
☒	**A**	1.67×10^{-27}	1.6×10^{-19}
☒	**B**	1.67×10^{-27}	-1.6×10^{-19}
☒	**C**	-1.67×10^{-27}	1.6×10^{-19}
☒	**D**	-1.67×10^{-27}	-1.6×10^{-19}

(Total for question = 1 mark)

Q31.

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 table shows the relative charges on up and down quarks.

u	$\frac{2}{3}e$
d	$-\frac{1}{3}e$

Which of the following could be the quark composition for a baryon with a charge of +2*e*?

☒ **A** ddd

☒ **B** $u\bar{d}$

☒ **C** $u\bar{u}$

☒ **D** uuu

(Total for question = 1 mark)

Q32.

(a) Pions belong to a group of particles known as mesons.

State the quark structure of mesons.

(1)

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(b) Muons belong to a family of particles known as leptons.

State one property of leptons.

(1)

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(c) Charged pions usually decay into a muon (μ) and another particle X, as shown by the decay equation:

$$\pi^- \rightarrow \mu^- + X$$

A student suggests that X is an anti-neutrino due to particle conservation laws.

Deduce whether the student is correct.

(4)

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(Total for question = 6 marks)

Q33.

The Proton-Antiproton Collider ($S\bar{p}pS$) was a large particle accelerator. An experiment using the $S\bar{p}pS$ proved the existence of a particle called a Z boson.

(a) The mass of the Z boson is 91 GeV/c^2.

Show that the mass of the Z boson is nearly 100 times greater than the mass of a proton.

(4)

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(b) Protons and anti-protons were accelerated in the $Sp\bar{p}S$ to very high energies before they collided.

Explain why the protons and anti-protons needed high energies to produce the Z boson.

(3)

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(c) Z bosons produced by high energy collisions can have a range of lifetimes.

The Z bosons with the longest lifetimes are those that were moving very fast.

Explain this observation.

(2)

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(Total for question = 9 marks)

Q34.

Select one answer from A to D and put a cross in the box ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

Which row in the table gives the charge and mass of an antiproton?

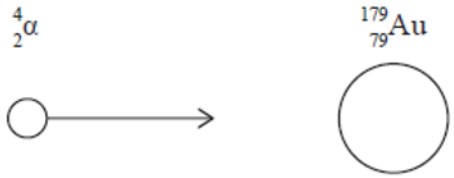
		Charge / C	Mass / kg
☒	**A**	1.6×10^{-19}	-9.11×10^{-31}
☒	**B**	-1.6×10^{-19}	9.11×10^{-31}
☒	**C**	1.6×10^{-19}	-1.67×10^{-27}
☒	**D**	-1.6×10^{-19}	1.67×10^{-27}

(Total for question = 1 mark)

Q35.

The nuclear model of the atom was developed after a series of experiments in which alpha particles were directed at thin gold foil.

An alpha particle $\left({}^{4}_{2}\alpha\right)$ with kinetic energy 5.52 MeV approaches a gold nucleus $\left({}^{179}_{79}\text{Au}\right)$ head-on, as shown.



The alpha particle is brought to rest and then returns along its original path.

(a) Calculate the minimum distance between the alpha particle and the gold nucleus.

(4)

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Minimum distance = ...

(b) An alpha particle with a different energy approaches the gold nucleus. The minimum distance between this alpha particle and the gold nucleus is 5.68×10^{-14} m.

Calculate the maximum electrostatic force F that acts between this alpha particle and the gold nucleus.

(2)

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F = ...

(Total for question = 6 marks)

Q36.

In 1977 a fifth quark, named the bottom quark, was discovered by particle physicists.

The table shows the particles in the standard model known at that time.

Quarks		Leptons	
up	down	electron	electron neutrino
strange	charm	muon	muon neutrino
bottom		tau	

(a) (i) Explain why the existence of a sixth quark was predicted.

(3)

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(ii) A short time after formation, most quarks combine to make particles known as hadrons. There are two categories of hadron.

Name the two categories of hadron.

(1)

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(b) In 1995 the sixth quark, known as the top quark, was discovered using the Tevatron collider at Fermilab. A collision of a proton with an anti-proton produced a top quark and a top anti-quark.

Particle experiments may direct beams of particles at stationary targets or collide beams of particles travelling in opposite directions.

(i) Explain the advantage of colliding beams of particles.

(4)

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(ii) In the collider experiment, the protons and anti-protons each had total energy 900 GeV.

Calculate the maximum kinetic energy, in joules, of a top quark produced in this experiment.

rest energy of top quark = 173 GeV

(3)

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Maximum kinetic energy = ... J

(iii) Deduce whether a top quark with kinetic energy 1.2×10^{-7} J is travelling at a relativistic speed.

rest mass of top quark = 173 GeV/c^2

(3)

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(c) Most types of quark form hadrons on a timescale of 10^{-23} s. The top quark does not form hadrons because its lifetime is only 10^{-25} s.

A student suggests that, if the top quarks travelled at relativistic speeds, it could be possible for them to form hadrons.

Assess this suggestion.

(2)

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(Total for question = 16 marks)

Q37.

A particle with charge Q and momentum p follows a circular path of radius r. The path is at right angles to a magnetic field of magnetic flux density B.

(a) Derive the following equation for the particle.

$$r = \frac{p}{BQ}$$

(2)

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(b) The particle is an alpha particle of energy 5.4 MeV.

Calculate B.

mass of alpha particle = 6.64×10^{-27} kg
r = 0.096 m

(4)

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B = ...

(Total for question = 6 marks)

Q38.

In 2022, CERN announced the discovery of a new particle known as a pentaquark which is made of five quarks.

The table shows the charges on some quarks.

Quark	Charge / e
u	+2/3
d	−1/3
s	−1/3
c	+2/3

The five quarks in the pentaquark are c, $\bar{c}$, d, s and u.

Some scientists said the pentaquark is made of a meson and a baryon, held together by the attraction of their equal and opposite charges.

Determine the quark combination and charge of a meson and of a baryon that could make up the pentaquark.

Meson

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Quark combination = ...

Charge = ...

Baryon

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Quark combination = ...

Charge = ...

(Total for question = 5 marks)

Q39.

A muon will decay into a neutrino, an antineutrino and an electron or a positron.
A positron is the antiparticle of an electron.

(a) State one difference between a positron and an electron.

(1)

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(b) Explain whether the following decay would be possible.

You should consider conservation of charge and lepton number.

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

(3)

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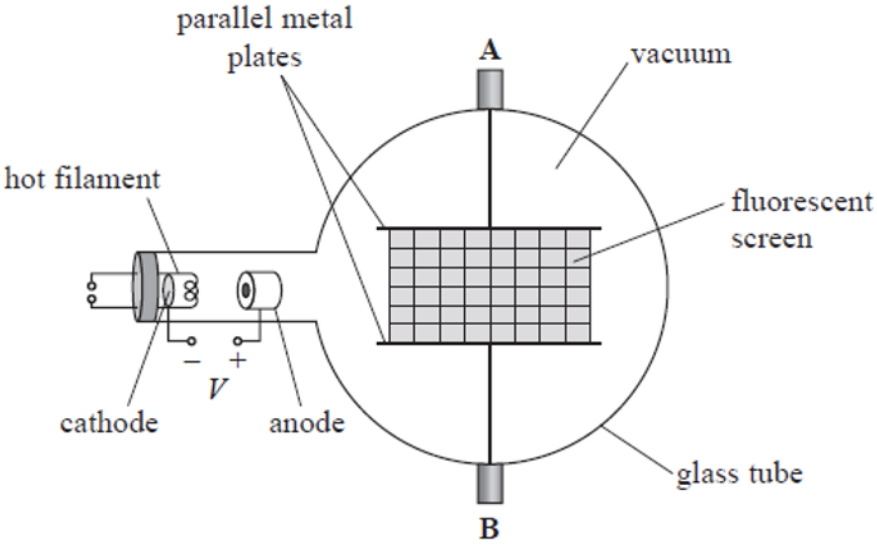
(Total for question = 4 marks)

Q40.

The electron beam tube can be used to determine the specific charge $\frac{e}{m}$ of an electron.

A potential difference *V* is applied between the cathode and the anode to produce a beam of electrons.



The beam is aimed at a fluorescent screen inside the tube and the path of the electrons is seen on the screen.

There are two parallel metal plates above and below the screen. A and B are connected to these plates and allow a potential difference to be applied across the plates.

(a) Explain why electrons are deflected into a parabolic path when a potential difference is applied between A and B.

(3)

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(b) A potential difference V of 850 V is applied between the cathode and the anode.

(i) Show that the maximum speed of the electrons as they emerge from the anode is about 1.7×10^7 m s^{-1}.

(3)

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(ii) The electric field strength between the parallel metal plates is 1.7×10^4 V m^{-1}.

The length of each plate is 7.5 cm. The electrons pass through the region between the parallel metal plates.

Calculate the vertical deflection of the electron beam.

You should ignore the weight of the electrons.

(5)

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Vertical deflection of electron beam = ...

(iii) The electric field between the parallel metal plates is removed. A uniform magnetic field is applied to deflect the electron beam into a circular path of radius 3.5 cm.

Assess whether this gives a value for $\frac{e}{m}$ in agreement with the standard value.

magnetic flux density = 3.0 mT

(4)

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(Total for question = 15 marks)

Q41.

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 fundamental particle?

☒ **A** neutrino

☒ **B** neutron

☒ **C** pion

☒ **D** proton

(Total for question = 1 mark)

Q42.

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 6.5 MeV / c^2.

Which of the following gives the mass, in kg, of the particle?

☒ **A** $\frac{6.5 \times 1.6 \times 10^{-19}}{(3 \times 10^{8})^{2}}$

☒ **B** $\frac{6.5 \times 1.6 \times 10^{-13}}{(3 \times 10^{8})^{2}}$

☒ **C** $\frac{6.5 \times (3 \times 10^{8})^{2}}{1.6 \times 10^{-19}}$

☒ **D** $\frac{6.5 \times (3 \times 10^{8})^{2}}{1.6 \times 10^{-13}}$

(Total for question = 1 mark)

Q43.

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 shows the β^- decay of a nucleon?

☒ **A** $n \rightarrow p + \beta^- + \nu_e$

☒ **B** $n \rightarrow p + \beta^- + \bar{\nu}_e$

☒ **C** $p \rightarrow n + \beta^- + \nu_e$

☒ **D** $p \rightarrow n + \beta^- + \bar{\nu}_e$

(Total for question = 1 mark)

Q44.

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 table shows the charges on up quarks and down quarks.

Quark	Charge / e
u	$+\frac{2}{3}$
d	$-\frac{1}{3}$

Which row of the table shows the quark structure of protons and neutrons?

		Proton	Neutron
☒	**A**	ddd	uuu
☒	**B**	ddu	uud
☒	**C**	duu	ddu
☒	**D**	uuu	ddd

(Total for question = 1 mark)

Q45.

Pions are created in the upper atmosphere when high-energy cosmic rays interact with nuclei. Pions are mesons and they quickly decay to muons. Muons are leptons with a mass of 106 MeV/c^2.

(a) Give a possible quark structure of a pion.

(1)

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(b) The equation shows a pion decaying into a muon and an antineutrino.

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

Energy and momentum must be conserved in this decay.

Explain two other conservation laws that apply to this decay.

(4)

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(c) Calculate the mass, in kg, of a muon.

(3)

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Mass of muon = ... kg

(d) When at rest, pions have an average lifetime of 26 ns. When produced in the upper atmosphere, high-energy pions have a speed of up to 0.99 *c*.

Explain how the average lifetime of these high-energy pions compares with the lifetime of pions at rest.

You do not need to carry out any calculations.

(2)

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(Total for question = 10 marks)