PEARSON EDEXCEL A-LEVEL PHYSICS · 9PH0

PHYSICS



EXAM QUESTION PACK

TOPIC 8: NUCLEAR AND PARTICLE PHYSICS

PARTICLE PHYSICS AND THE STANDARD MODEL

SCORE	PERCENTAGE
/431	%

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Q1.

The equation $\Delta E = c^2 \Delta m$ can be used with data at the back of this paper to calculate

☒ **A** the kinetic energy of an electron.

☒ **B** the energy produced when a lambda particle decays.

☒ **C** the energy of the photons produced when a proton and an antiproton annihilate.

☒ **D** the mass of uranium that produces 50 MJ of energy in a nuclear reactor.

(Total for question = 1 mark)

Q2.

The neutral lambda Λ^0 particle is a baryon of mass 1116 MeV/c^2 and contains one strange quark.

The table shows quarks and their relative charge.

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

Calculate the mass of the Λ^0 particle in kg.

(3)

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Mass of Λ^0 particle = ... kg

(Total for question = 3 marks)

Q3.

* Particle accelerators accelerate particles to very high speeds before collisions occur. New particles are created during the collisions.

Two particles of the same type can undergo two kinds of collision.

Fixed target: a high speed particle hits a stationary particle.

Colliding beams: two particles travelling at high speeds, in opposite directions, collide head-on.

By considering the conservation of energy and momentum, explain which type of collision is able to create a new particle with the largest mass.

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(Total for question = 6 marks)

Q4.

A high energy proton collides with a stationary proton and a π^0 particle is produced.
The equation for the reaction is

$$p + p \rightarrow p + p + \pi^0$$

(i) Explain why the proton must have a high energy in order for this reaction to occur.

(2)

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(ii) The rest mass of the π^0 is $\frac{1}{7}$ of the rest mass of a proton.

In this reaction the total kinetic energy of the particles decreases.

Calculate the minimum decrease in kinetic energy if the reaction is to occur.

rest mass of proton = 938 GeV/c^2

(2)

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Minimum decrease in kinetic energy = ...

Q5.

The neutral lambda Λ^0 particle is a baryon of mass 1116 MeV/c^2 and contains one strange quark.

The table shows quarks and their relative charge.

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

Lambda particles were first detected in experiments which made use of cosmic rays entering the atmosphere. Cosmic rays are mainly high-energy protons which have a mass less than that of a lambda particle.

Explain why a cosmic ray could lead to the creation of a lambda particle.

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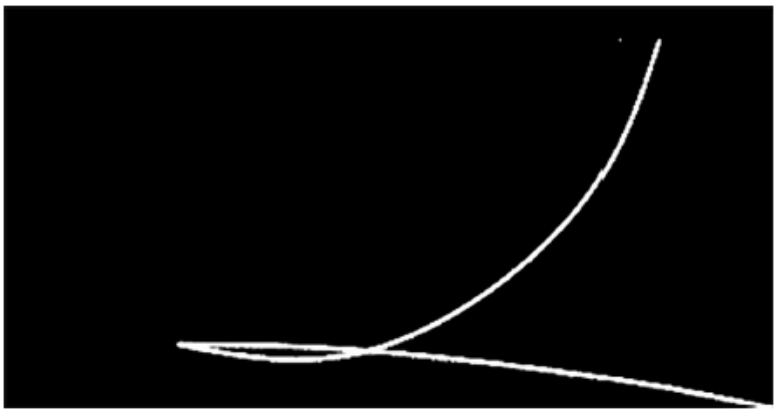
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(Total for question = 2 marks)

Q6.

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.

(3)

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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.

(3)

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Total kinetic energy = ... MeV

(Total for question = 6 marks)

Q7.

A treatment for brain tumours involves firing a beam of pions at the tumour. Pions exist for a very short time. During treatment many pions hit the tumour just as they decay.

This causes the cells in the tumour to fragment, which kills them with no harmful effect to the surrounding tissue.

Pions belong to a group of sub-atomic particles called mesons. There are three types of pion: π^- π^+ π^0.

(a) The following table lists some quarks and their charge.

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

State a possible quark combination for a π^-

(1)

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(b) Pions are produced when protons, accelerated in a cyclotron, are aimed at a target of beryllium and interact with protons in the beryllium.

Identify the type of pion produced in the following interaction.

$$p + p \rightarrow p + p + \pi$$

(1)

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(c) The π^- mesons used for a treatment have a speed of 2.3×10^8 m s^{-1} and a range in air of 5.9 m.

Calculate the time for which these π^- mesons exist.

(2)

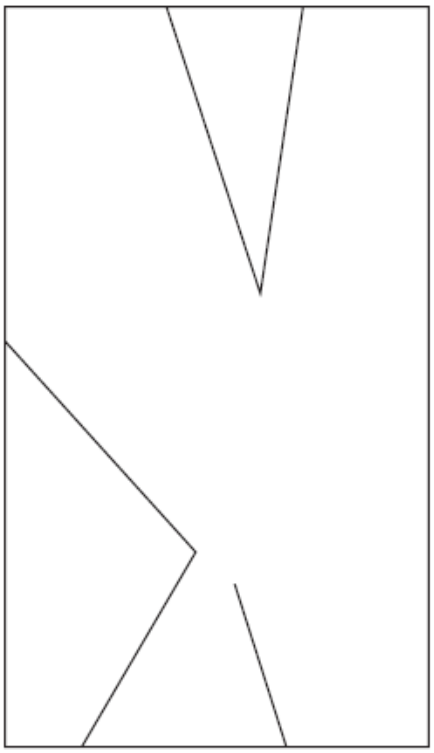
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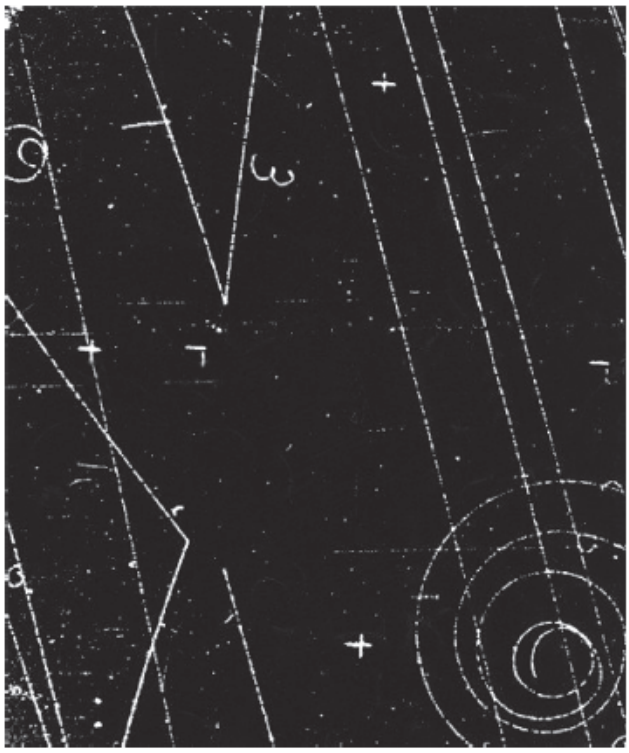
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Time = ...

*(d) The photograph shows what happens in a Bubble Chamber when some pions enter at the bottom and travel upwards. One pion has been identified by X in the photograph and the simplified line diagram shows the visible tracks of the pion and subsequent decay products.



X



X

Explain what can be deduced about the sequence of the events shown in the line diagram.

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(e) If very high speed protons are fired at beryllium, the following interaction occurs

$$p + p = p + p + p + \overline{p}$$

(i) State the name of the particle $\overline{p}$ and give its properties.

(2)

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(ii) State what is likely to happen to the $\overline{\mathrm{p}}$ particle.

(1)

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(Total for question = 13 marks)

Q8.

Subatomic particles such as pions are produced after collisions between protons that have been accelerated in a cyclotron.

*(a) Explain briefly the role of electric and magnetic fields in the cyclotron.

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(b) The mass of a pion is 2.5×10^{-28} kg.

Calculate the mass of a pion in GeV/c^2.

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Mass = ... GeV/c^2

(c) The table shows the charge of some quarks.

Type of quark	Charge/*e*
u	+2/3
d	−1/3
s	−1/3

Explain what is meant by a charge of +2/3

(1)

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(d) The omega (Ω) minus particle consists of three strange quarks and is produced by the following interaction.

$$K^- + p \rightarrow K^+ + K^0 + \Omega^-$$

Kaons are mesons and consist of a strange quark and either an up or a down quark.

(i) Complete the table to show a possible quark combination for each kaon.

(3)

Particle	Quark combination
K^-	
K^+	
K^0	

(ii) The total mass of the particles produced in this interaction is greater than the total mass of the two particles that collided.

Explain this increase in mass.

(3)

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(Total for question = 15 marks)

Q9.

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.

(3)

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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.

(2)

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(iii) State which two conservation laws could be used to calculate the kinetic energy of the μ– and the $\overline{\nu}_{\mu}$ 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)

Q10.

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.

(5)

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

Calculate this mass in GeV/c^2.

(3)

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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.

(3)

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.

(2)

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(Total for question = 17 marks)

Q1.

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.

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)

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Distance of closest approach = ...

(Total for question = 4 marks)

Q2.

The neutral lambda Λ^0 particle is a baryon of mass 1116 MeV/c^2 and contains one strange quark.

The table shows quarks and their relative charge.

Quark	Charge / e
u	+2/3
d	−1/3
s	−1/3

Calculate the mass of the Λ^0 particle in kg.

(3)

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Mass of Λ^0 particle = ... kg

(Total for question = 3 marks)

Q3.

Pions belong to a group of particles called mesons. Pions can be used in a form of radiotherapy to treat brain tumours.

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

Calculate the mass of a pion in kg.

(3)

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Mass = ...

Q4.

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 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 = 1 mark)

Q5.

A high energy proton collides with a stationary proton and a π^0 particle is produced.
The equation for the reaction is

$$p + p \rightarrow p + p + \pi^0$$

(i) Explain why the proton must have a high energy in order for this reaction to occur.

(2)

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(ii) The rest mass of the π^0 is $\frac{1}{7}$ of the rest mass of a proton.

In this reaction the total kinetic energy of the particles decreases.

Calculate the minimum decrease in kinetic energy if the reaction is to occur.

rest mass of proton = 938 GeV/c^2

(2)

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Minimum decrease in kinetic energy = ...

Q6.

Phosphogypsum is a by-product in the manufacture of fertiliser. It is slightly radioactive because of the presence of radium-226, a radioisotope with a half-life of 1600 years.

It must be stored securely as long as the activity of the radium-226 it contains is greater than 0.4 Bq per gram of phosphogypsum.

Radium-226 decays to radon-222 by alpha emission.

Determine the energy released in MeV in the decay of a single nucleus of radium-226.

(5)

mass of radium-226 nucleus = 225.97713 u
mass of radon-222 nucleus = 221.97040 u
mass of α particle = 4.00151 u

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Energy released = ... MeV

(Total for question = 5 marks)

Q7.

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

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)

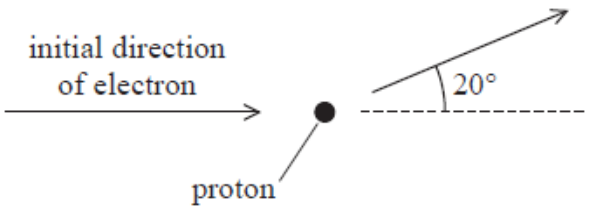
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(ii) An electron with initial momentum 20 GeV / c collides with a stationary proton. After the collision the electron is deflected by an angle of 20° as shown and its momentum is 9.1 GeV / c. The momentum of the proton after the collision is 11.9 GeV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



Deduce whether the law of conservation of momentum is obeyed.

(3)

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

State what is meant by an inelastic collision.

(1)

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(Total for question = 6 marks)

Q8.

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.

(3)

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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.

(3)

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Total kinetic energy = ... MeV

(Total for question = 6 marks)

Q9. The magnetic force *F* that acts on a current-carrying conductor in a magnetic field is given by the equation

$$F = BIl.$$

(a) State the condition under which this equation applies.

(1)

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(b) The unit for magnetic flux density *B* is the tesla.

Express the tesla in base units.

(2)

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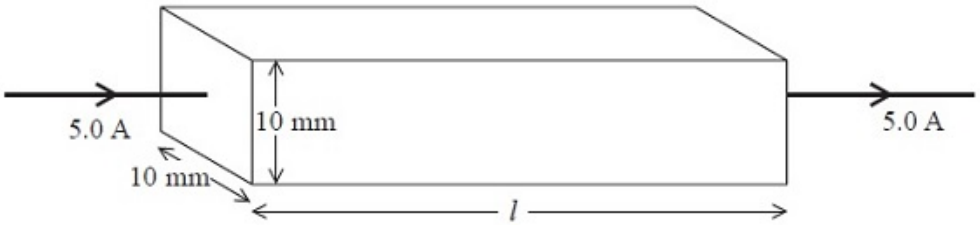
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(c) The diagram shows a rectangular bar of aluminium which has a current of 5.0 A through it.



The bar is placed in a magnetic field so that its weight is supported by the magnetic field.

Calculate the minimum value of the magnetic flux density *B* needed for this to occur.

density of aluminium = 2.7×10^3 kg m^{-3}

(3)

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Minimum *B* = ...

(d) State the direction of the magnetic field.

(1)

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(Total for Question = 7 marks)

Q10.

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

Calculate the mass of a muon in kg.

(3)

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Mass of muon = ... kg

(Total for question = 3 marks)

Q11. Hadrons are a group of particles composed of quarks. Hadrons can be either baryons or mesons.

(a) (i) State the quark structure of a baryon.

(1)

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(ii) State the quark structure of a meson.

(1)

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(b) State **one** similarity and **one** difference between a particle and its antiparticle.

(2)

Similarity

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Difference

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(c) (i) The table gives some of the properties of up, down and strange quarks.

Type of quark	Charge/e	Strangeness
u	+2/3	0
d	−1/3	0
s	−1/3	−1

One or more of these quarks combine to form a K^+, a meson with a strangeness of +1.

Write down the quark combination of the K^+.

(1)

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(ii) The K^+ can decay in the following way

$$K^+ \rightarrow \mu^+ + \nu_\mu$$

K^- is the antiparticle of the K^+.

Complete the equation below by changing each particle to its corresponding antiparticle in order to show an allowed decay for the K^- meson.

(2)

$$K^- \rightarrow$$

(iii) The rest mass of the K^+ is 494 MeV/c^2.

Calculate, in joules, how much energy is released if a K^+ meets and annihilates a K^-.

(3)

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Energy = ... J

(Total for Question = 10 marks)

Q12.

Subatomic particles such as pions are produced after collisions between protons that have been accelerated in a cyclotron.

*(a) Explain briefly the role of electric and magnetic fields in the cyclotron.

(5)

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(b) The mass of a pion is 2.5×10^{-28} kg.

Calculate the mass of a pion in GeV/c^2.

(3)

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Mass = ... GeV/c^2

(c) The table shows the charge of some quarks.

Type of quark	Charge/*e*
u	+2/3
d	−1/3
s	−1/3

Explain what is meant by a charge of +2/3

(1)

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(d) The omega (Ω) minus particle consists of three strange quarks and is produced by the following interaction.

$$K^- + p \rightarrow K^+ + K^0 + \Omega^-$$

Kaons are mesons and consist of a strange quark and either an up or a down quark.

(i) Complete the table to show a possible quark combination for each kaon.

(3)

Particle	Quark combination
K^-	
K^+	
K^0	

(ii) The total mass of the particles produced in this interaction is greater than the total mass of the two particles that collided.
Explain this increase in mass.

(3)

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(Total for question = 15 marks)

Q13. A muon has a mass of 106 MeV/c^2.

The mass of a muon, to two significant figures, is

☒ **A** 1.7×10^{-11} kg

☒ **B** 5.7×10^{-20} kg

☒ **C** 1.9×10^{-28} kg

☒ **D** 1.9×10^{-34} kg

(Total for Question = 1 mark)

Q14.

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.

(3)

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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.

(2)

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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)

Q15.

In 2011 physicists at the Relativistic Heavy Ion Collider (RHIC) announced the creation of nuclei of anti-helium-4 which consists of anti-protons and anti-neutrons instead of protons and neutrons.

(a) 'Ordinary' helium-4 is written as $^{4}_{2}\mathrm{He}$

What do the numbers 4 and 2 represent?

(2)

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(b) In the RHIC experiment, nuclei of gold $^{197}_{79}\mathrm{Au}$ travelling at speeds greater than 2.99×10^{8} m s^{-1}, in opposite directions, collided, releasing energies of up to 200 GeV. After billions of collisions, 18 anti-helium nuclei had been detected.

(i) What is meant by 'relativistic' in the collider's name?

(1)

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(ii) State why it is necessary to use very high energies in experiments such as these.

(1)

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(iii) Show that the mass of a stationary anti-helium nucleus is about 4 GeV/c^2.

(4)

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(iv) State why the small number of anti-helium nuclei produced only survive for a fraction of a second.

(1)

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(v) A slow moving anti-helium nucleus meets a slow moving helium nucleus. If they were to combine to produce 2 high energy gamma rays, calculate the frequency of each gamma ray.

(2)

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Frequency = ...

(c) There are two families of hadrons, called baryons and mesons. Baryons such as protons are made of three quarks.

(i) Describe the structure of a meson.

(1)

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(ii) Up quarks have a charge of +2/3e and down quarks a charge of −1/3e. Describe the quark composition of anti-protons and anti-neutrons and use this to deduce the charge on each of these particles.

(4)

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(Total for question = 16 marks)

Q16.

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.

(3)

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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.

(3)

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.

(2)

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(Total for question = 17 marks)

Q17.

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.

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.

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(Total for question = 4 marks)

Q18.

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.

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

(Total for question = 3 marks)

Q19.

The SI unit for mass is the kilogram. However, particle physicists often use the alternative unit

☒ **A** MeV

☒ **B** MeV/c

☒ **C** MeV/c^2

☒ **D** MeV^2/c^2

(Total for question = 1 mark)

Q20.

Pions are the lightest mesons. A negative pion (π^-) has a mass of 2.48×10^{-28} kg.

Which of the following is the mass of the π^- in in MeV/c^2?

☒ **A** 1.4×10^8

☒ **B** 1.4×10^2

☒ **C** 4.7×10^{-7}

☒ **D** 3.6×10^{-24}

(Total for question = 1 mark)

Q1.

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.

(2)

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

(1)

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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)

Q2.

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.

(3)

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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.

(2)

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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)

Q3.

In 2011 physicists at the Relativistic Heavy Ion Collider (RHIC) announced the creation of nuclei of anti-helium-4 which consists of anti-protons and anti-neutrons instead of protons and neutrons.

(a) 'Ordinary' helium-4 is written as $^{4}_{2}\mathrm{He}$

What do the numbers 4 and 2 represent?

(2)

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(b) In the RHIC experiment, nuclei of gold $^{197}_{79}\mathrm{Au}$ travelling at speeds greater than 2.99×10^{8} m s^{-1}, in opposite directions, collided, releasing energies of up to 200 GeV. After billions of collisions, 18 anti-helium nuclei had been detected.

(i) What is meant by 'relativistic' in the collider's name?

(1)

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(ii) State why it is necessary to use very high energies in experiments such as these.

(1)

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(iii) Show that the mass of a stationary anti-helium nucleus is about 4 GeV/c^2.

(4)

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(iv) State why the small number of anti-helium nuclei produced only survive for a fraction of a second.

(1)

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(v) A slow moving anti-helium nucleus meets a slow moving helium nucleus. If they were to combine to produce 2 high energy gamma rays, calculate the frequency of each gamma ray.

(2)

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Frequency = ...

(c) There are two families of hadrons, called baryons and mesons. Baryons such as protons are made of three quarks.

(i) Describe the structure of a meson.

(1)

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(ii) Up quarks have a charge of +2/3e and down quarks a charge of −1/3e. Describe the quark composition of anti-protons and anti-neutrons and use this to deduce the charge on each of these particles.

(4)

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(Total for question = 16 marks)

Q1.

Which of the following particles is an example of a fundamental particle?

☒ **A** nucleus

☒ **B** neutrino

☒ **C** pion

☒ **D** proton

(Total for question = 1 mark)

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

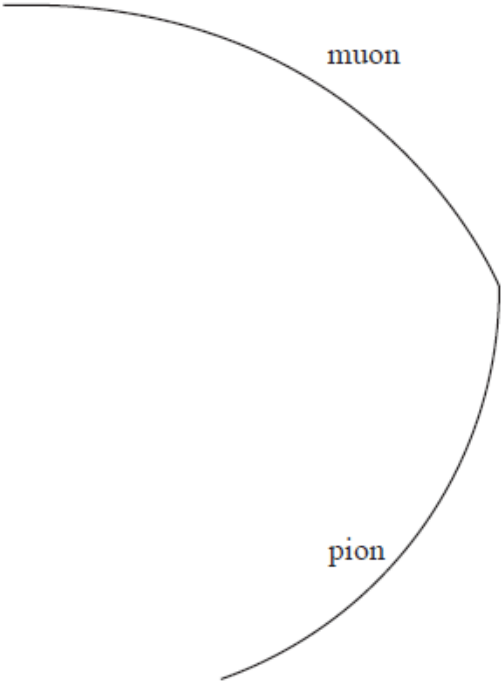
Which row of the table is correct for the antiparticle of a π^- ?

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

(Total for question = 1 mark)

Q3.

A negatively charged pion decays into a muon and an antineutrino. The diagram shows tracks in a particle detector formed in such an event.



According to the standard model, the pion and muon are classified within two different groups of particles.

State which group each particle belongs to and describe the two groups.

(4)

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(Total for question = 4 marks)

Q4.

A treatment for brain tumours involves firing a beam of pions at the tumour. Pions exist for a very short time. During treatment many pions hit the tumour just as they decay.

This causes the cells in the tumour to fragment, which kills them with no harmful effect to the surrounding tissue.

Pions belong to a group of sub-atomic particles called mesons. There are three types of pion: π^- π^+ π^0.

(a) The following table lists some quarks and their charge.

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

State a possible quark combination for a π^-

(1)

.....

(b) Pions are produced when protons, accelerated in a cyclotron, are aimed at a target of beryllium and interact with protons in the beryllium.

Identify the type of pion produced in the following interaction.

$$p + p \rightarrow p + p + \pi$$

(1)

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(c) The π^- mesons used for a treatment have a speed of 2.3×10^8 m s^{-1} and a range in air of 5.9 m.

Calculate the time for which these π^- mesons exist.

(2)

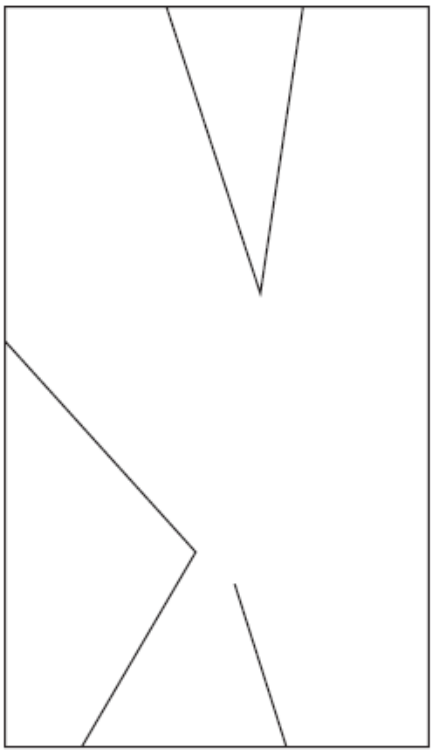
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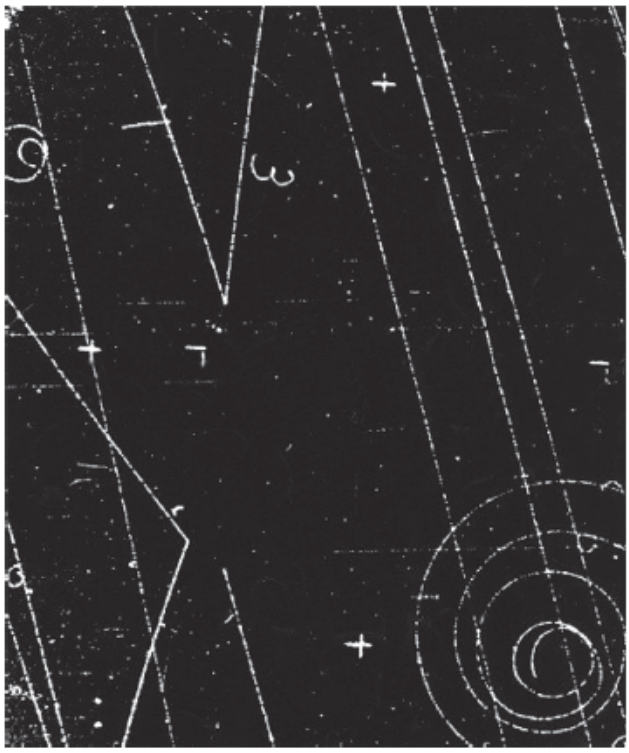
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Time = ...

*(d) The photograph shows what happens in a Bubble Chamber when some pions enter at the bottom and travel upwards. One pion has been identified by X in the photograph and the simplified line diagram shows the visible tracks of the pion and subsequent decay products.



X



X

Explain what can be deduced about the sequence of the events shown in the line diagram.

(6)

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(e) If very high speed protons are fired at beryllium, the following interaction occurs

$$p + p = p + p + p + \overline{p}$$

(i) State the name of the particle $\overline{p}$ and give its properties.

(2)

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(ii) State what is likely to happen to the $\bar{p}$ particle.

(1)

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(Total for question = 13 marks)

Q5. The table gives some of the properties of the up, down and strange quarks.

Type of quark	Charge/*e*	Strangeness
u	+2/3	0
d	−1/3	0
s	−1/3	−1

There are nine possible ways of combining u, d and s quarks and their antiquarks to make nine different mesons. These are listed below

$u\bar{u}$ $u\bar{d}$ $u\bar{s}$ $d\bar{d}$ $d\bar{u}$ $d\bar{s}$ $s\bar{s}$ $s\bar{u}$ $s\bar{d}$

(a) From the list select the four strange mesons and state the charge and strangeness of each of them.

(4)

Meson	Charge/*e*	Strangeness

(b) Some of the mesons in the list have zero charge and zero strangeness.

Suggest what might distinguish these mesons from each other.

(1)

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(Total for Question = 5 marks)

Q6. Hadrons are a group of particles composed of quarks. Hadrons can be either baryons or mesons.

(a) (i) State the quark structure of a baryon.

(1)

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(ii) State the quark structure of a meson.

(1)

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(b) State **one** similarity and **one** difference between a particle and its antiparticle.

(2)

Similarity

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Difference

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(c) (i) The table gives some of the properties of up, down and strange quarks.

Type of quark	Charge/*e*	Strangeness
u	+2/3	0
d	−1/3	0
s	−1/3	−1

One or more of these quarks combine to form a K^+, a meson with a strangeness of +1.

Write down the quark combination of the K^+.

(1)

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(ii) The K^+ can decay in the following way

$$K^+ \rightarrow \mu^+ + \nu_\mu$$

K^- is the antiparticle of the K^+.

Complete the equation below by changing each particle to its corresponding antiparticle in order to show an allowed decay for the K^- meson.

(2)

$$K^- \rightarrow$$

(iii) The rest mass of the K^+ is 494 MeV/c^2.

Calculate, in joules, how much energy is released if a K^+ meets and annihilates a K^-.

(3)

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Energy = ... J

(Total for Question = 10 marks)

Q7.

Subatomic particles such as pions are produced after collisions between protons that have been accelerated in a cyclotron.

*(a) Explain briefly the role of electric and magnetic fields in the cyclotron.

(5)

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(b) The mass of a pion is 2.5×10^{-28} kg.

Calculate the mass of a pion in GeV/c^2.

(3)

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Mass = ... GeV/c^2

(c) The table shows the charge of some quarks.

Type of quark	Charge/*e*
u	+2/3
d	−1/3
s	−1/3

Explain what is meant by a charge of +2/3

(1)

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(d) The omega (Ω) minus particle consists of three strange quarks and is produced by the following interaction.

$$K^- + p \rightarrow K^+ + K^0 + \Omega^-$$

Kaons are mesons and consist of a strange quark and either an up or a down quark.

(i) Complete the table to show a possible quark combination for each kaon.

(3)

Particle	Quark combination
K^-	
K^+	
K^0	

(ii) The total mass of the particles produced in this interaction is greater than the total mass of the two particles that collided.
Explain this increase in mass.

(3)

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(Total for question = 15 marks)

Q8.

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.

(2)

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

(1)

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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)

Q9.

Pions belong to a group of particles called mesons. Pions can be used in a form of radiotherapy to treat brain tumours.

The table lists some quarks and their charges.

Quark	Charge/*e*
u	+2/3
d	−1/3
s	−1/3

From the list below circle the quark combination which could correspond to a π^- pion.

(1)

dds $\quad \bar{u}d \quad \bar{u}\bar{u}\bar{d} \quad \bar{s}u$

Q10.

Which of these is **not** made from quarks?

☒ **A** proton

☒ **B** neutron

☒ **C** lepton

☒ **D** meson

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 ☒.

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 mark)

Q2.

The equation $\Delta E = c^2 \Delta m$ can be used with data at the back of this paper to calculate

☒ **A** the kinetic energy of an electron.

☒ **B** the energy produced when a lambda particle decays.

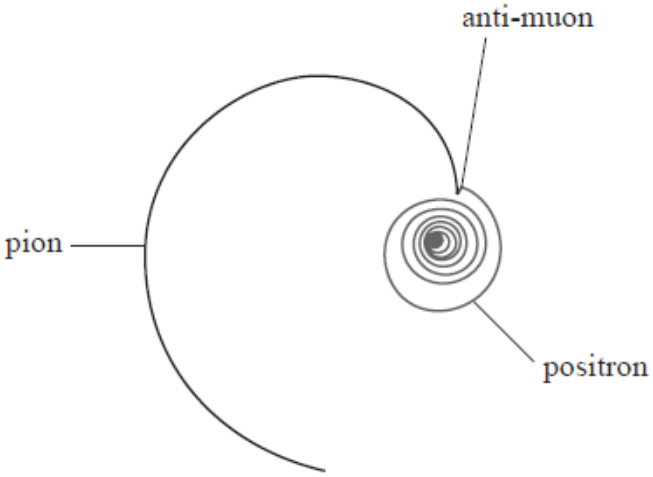
☒ **C** the energy of the photons produced when a proton and an antiproton annihilate.

☒ **D** the mass of uranium that produces 50 MJ of energy in a nuclear reactor.

(Total for question = 1 mark)

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.

(6)

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Q4.

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 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 = 1 mark)

Q5.

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 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 = 1 mark)

Q6.

A treatment for brain tumours involves firing a beam of pions at the tumour. Pions exist for a very short time. During treatment many pions hit the tumour just as they decay.

This causes the cells in the tumour to fragment, which kills them with no harmful effect to the surrounding tissue.

Pions belong to a group of sub-atomic particles called mesons. There are three types of pion: π^- π^+ π^0.

(a) The following table lists some quarks and their charge.

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

State a possible quark combination for a π^-

(1)

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(b) Pions are produced when protons, accelerated in a cyclotron, are aimed at a target of beryllium and interact with protons in the beryllium.

Identify the type of pion produced in the following interaction.

$$p + p \rightarrow p + p + \pi$$

(1)

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(c) The π^- mesons used for a treatment have a speed of 2.3×10^8 m s^{-1} and a range in air of 5.9 m.

Calculate the time for which these π^- mesons exist.

(2)

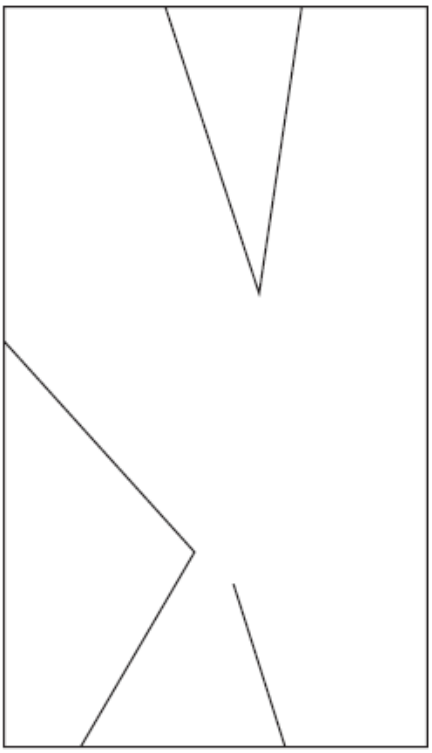
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Time = ...

*(d) The photograph shows what happens in a Bubble Chamber when some pions enter at the bottom and travel upwards. One pion has been identified by X in the photograph and the simplified line diagram shows the visible tracks of the pion and subsequent decay products.



X



X

Explain what can be deduced about the sequence of the events shown in the line diagram.

(6)

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(e) If very high speed protons are fired at beryllium, the following interaction occurs

$$p + p = p + p + p + \overline{p}$$

(i) State the name of the particle $\overline{p}$ and give its properties.

(2)

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(ii) State what is likely to happen to the $\bar{p}$ particle.

(1)

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(Total for question = 13 marks)

Q7.

The neutral lambda Λ^0 particle is a baryon of mass 1116 MeV/c^2 and contains one strange quark.

The table shows quarks and their relative charge.

Quark	Charge / *e*
u	+2/3
d	–1/3
s	–1/3

A student suggests five ways a Λ^0 particle might decay. These are

$$\Lambda^0 \rightarrow p + \pi^-$$
$$\Lambda^0 \rightarrow e^+ + e^-$$
$$\Lambda^0 \rightarrow n + \pi^0$$
$$\Lambda^0 \rightarrow n$$
$$\Lambda^0 \rightarrow p + \pi^0$$

Deduce which of these decay processes are **not** possible.

(6)

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(Total for question = 6 marks)

Q8.

A physicist investigates how light intensity varies with distance from a light bulb. She sets up the apparatus as shown.



Explain why the resistance *R* of the LDR will increase as it gets further away from the bulb.

(2)

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(Total for question = 2 marks)

Q9.

The Large Hadron Collider is designed to accelerate protons to very high energies for particle

physics experiments.

Very high energies are required to

☒ **A** annihilate protons and antiprotons.

☒ **B** allow protons to collide with other protons.

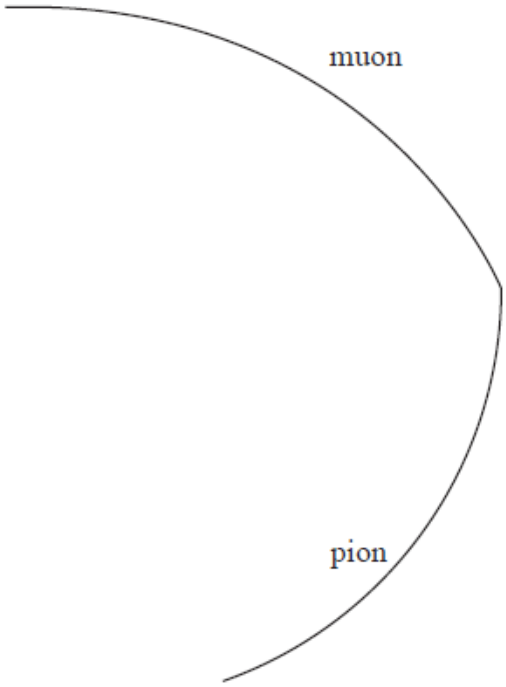
☒ **C** create particles with large mass.

☒ **D** to produce individual quarks.

(Total for question = 1 mark)

Q1.

A negatively charged pion decays into a muon and an antineutrino. The diagram shows tracks in a particle detector formed in such an event.



Deduce whether the antineutrino is charged, giving two reasons for your decision.

(2)

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(Total for question = 2 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 (☒).

Which of the following particle equations is correct for the decay of a proton within a nucleus?

☒ **A** $p \rightarrow n + \beta^{+}$

☒ **B** $p \rightarrow p + \beta^+$

☒ **C** $p \rightarrow n + \beta^+ + \nu$

☒ **D** $p \rightarrow p + \beta^+ + \nu$

(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 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 = 1 mark)

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.



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)

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(Total for question = 3 marks)

Q5.

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.

(3)

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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.

(2)

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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.

(6)

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(Total for question = 13 marks)

Q6.

Protons interact with particles in the upper atmosphere and create new particles. Pions can be produced from high energy proton collisions.

(i) State why the following reaction is not possible.

$$p + p \rightarrow p + p + \pi^-$$

(1)

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(ii) State one similarity and one difference between the electric field of a proton and the electric field of a π^-.

(2)

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Q7.

The neutral lambda Λ^0 particle is a baryon of mass 1116 MeV/c^2 and contains one strange quark.

The table shows quarks and their relative charge.

Quark	Charge / *e*
u	+2/3
d	–1/3
s	–1/3

A student suggests five ways a Λ^0 particle might decay. These are

$$\Lambda^0 \rightarrow p + \pi^-$$
$$\Lambda^0 \rightarrow e^+ + e^-$$
$$\Lambda^0 \rightarrow n + \pi^0$$
$$\Lambda^0 \rightarrow n$$
$$\Lambda^0 \rightarrow p + \pi^0$$

Deduce which of these decay processes are **not** possible.

(6)

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(Total for question = 6 marks)

Q1.

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.

Write a particle equation for this collision.

(2)

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(Total for question = 2 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 (☒).

Which of the following particle equations is correct for the decay of a proton within a nucleus?

☒ **A** $p \rightarrow n + \beta^+$

☒ **B** $p \rightarrow p + \beta^+$

☒ **C** $p \rightarrow n + \beta^+ + v$

☒ **D** $p \rightarrow p + \beta^+ + v$

(Total for question = 1 mark)

Q3.

Tomatoes can be made into a puree.

The tomato puree has a mass of 0.444 kg and boils at 101°C. 175kJ of energy are supplied to bring it to its boiling point from a temperature of 21°C.

Determine the specific heat capacity of the puree.

(2)

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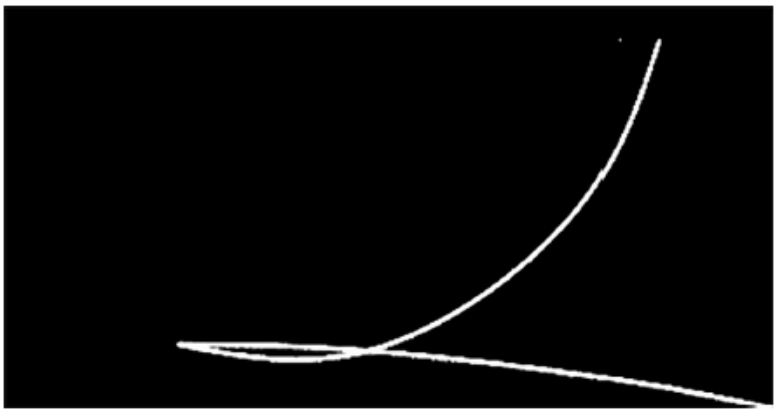
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Specific heat capacity = ...

(Total for question = 2 marks)

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.



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

(1)

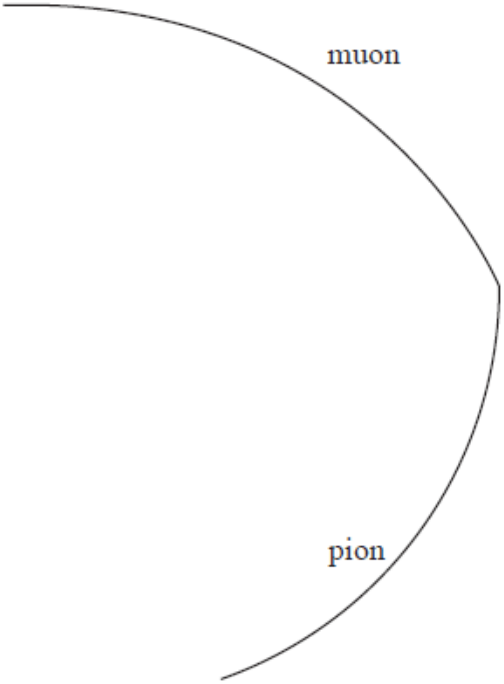
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(Total for question = 1 mark)

Q5.

A negatively charged pion decays into a muon and an antineutrino. The diagram shows tracks in a particle detector formed in such an event.



Write a particle equation to represent this decay.

(1)

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(Total for question = 1 mark)

Q6.

A treatment for brain tumours involves firing a beam of pions at the tumour. Pions exist for a very short time. During treatment many pions hit the tumour just as they decay.

This causes the cells in the tumour to fragment, which kills them with no harmful effect to the surrounding tissue.

Pions belong to a group of sub-atomic particles called mesons. There are three types of pion: π^- π^+ π^0.

(a) The following table lists some quarks and their charge.

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

State a possible quark combination for a π^-

(1)

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(b) Pions are produced when protons, accelerated in a cyclotron, are aimed at a target of beryllium and interact with protons in the beryllium.

Identify the type of pion produced in the following interaction.

$$p + p \rightarrow p + p + \pi$$

(1)

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(c) The π^- mesons used for a treatment have a speed of 2.3×10^8 m s^{-1} and a range in air of 5.9 m.

Calculate the time for which these π^- mesons exist.

(2)

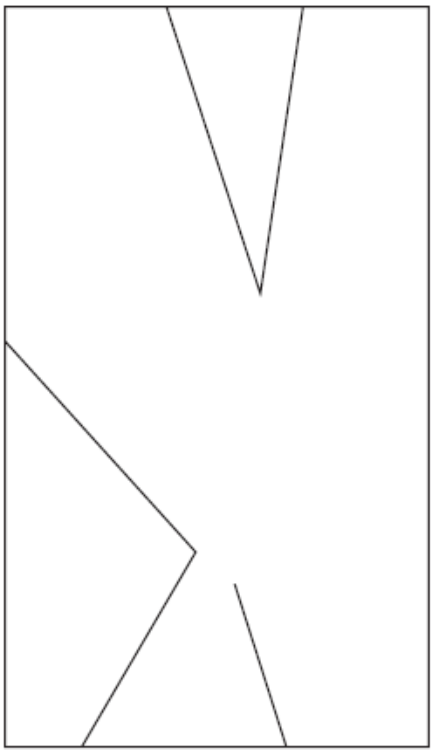
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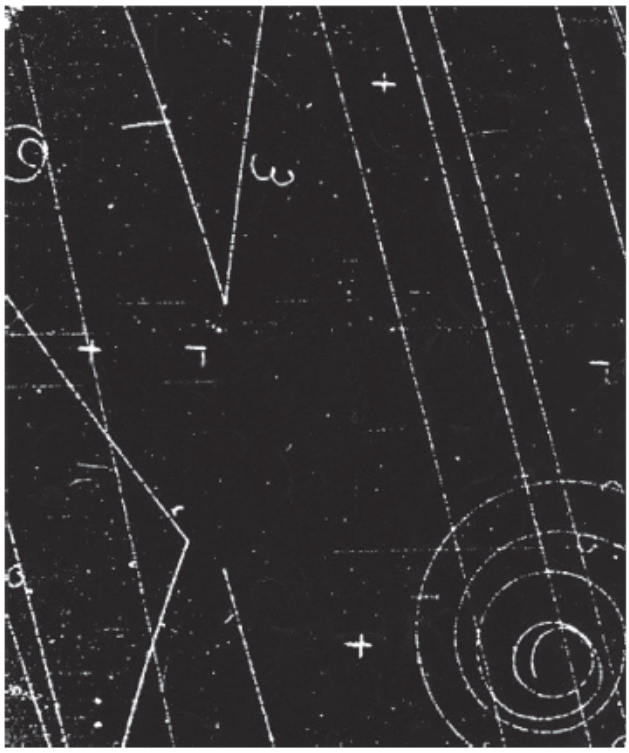
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Time = ...

*(d) The photograph shows what happens in a Bubble Chamber when some pions enter at the bottom and travel upwards. One pion has been identified by X in the photograph and the simplified line diagram shows the visible tracks of the pion and subsequent decay products.



X



X

Explain what can be deduced about the sequence of the events shown in the line diagram.

(6)

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(e) If very high speed protons are fired at beryllium, the following interaction occurs

$$p + p = p + p + p + \overline{p}$$

(i) State the name of the particle $\overline{p}$ and give its properties.

(2)

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(ii) State what is likely to happen to the $\overline{\mathrm{p}}$ particle.

(1)

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(Total for question = 13 marks)

Q7. Hadrons are a group of particles composed of quarks. Hadrons can be either baryons or mesons.

(a) (i) State the quark structure of a baryon.

(1)

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(ii) State the quark structure of a meson.

(1)

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(b) State **one** similarity and **one** difference between a particle and its antiparticle.

(2)

Similarity

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Difference

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(c) (i) The table gives some of the properties of up, down and strange quarks.

Type of quark	Charge/e	Strangeness
u	+2/3	0
d	−1/3	0
s	−1/3	−1

One or more of these quarks combine to form a K^+, a meson with a strangeness of +1.

Write down the quark combination of the K^+.

(1)

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(ii) The K^+ can decay in the following way

$$K^+ \rightarrow \mu^+ + \nu_\mu$$

K^- is the antiparticle of the K^+.

Complete the equation below by changing each particle to its corresponding antiparticle in order to show an allowed decay for the K^- meson.

(2)

$$K^- \rightarrow$$

(iii) The rest mass of the K^+ is 494 MeV/c^2.

Calculate, in joules, how much energy is released if a K^+ meets and annihilates a K^-.

(3)

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Energy = ... J

(Total for Question = 10 marks)

Q8.

Subatomic particles such as pions are produced after collisions between protons that have been accelerated in a cyclotron.

*(a) Explain briefly the role of electric and magnetic fields in the cyclotron.

(5)

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(b) The mass of a pion is 2.5×10^{-28} kg.

Calculate the mass of a pion in GeV/c^2.

(3)

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Mass = ... GeV/c^2

(c) The table shows the charge of some quarks.

Type of quark	Charge/*e*
u	+2/3
d	−1/3
s	−1/3

Explain what is meant by a charge of +2/3

(1)

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(d) The omega (Ω) minus particle consists of three strange quarks and is produced by the following interaction.

$$K^- + p \rightarrow K^+ + K^0 + \Omega^-$$

Kaons are mesons and consist of a strange quark and either an up or a down quark.

(i) Complete the table to show a possible quark combination for each kaon.

(3)

Particle	Quark combination
K^-	
K^+	
K^0	

(ii) The total mass of the particles produced in this interaction is greater than the total mass of the two particles that collided.
Explain this increase in mass.

(3)

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(Total for question = 15 marks)

Q9.

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.

(3)

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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.

(2)

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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.

(6)

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(Total for question = 13 marks)

Q10.

The neutral lambda Λ^0 particle is a baryon of mass 1116 MeV/c^2 and contains one strange quark.

The table shows quarks and their relative charge.

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

A student suggests five ways a Λ^0 particle might decay. These are

$$\Lambda^0 \rightarrow p + \pi^-$$
$$\Lambda^0 \rightarrow e^+ + e^-$$
$$\Lambda^0 \rightarrow n + \pi^0$$
$$\Lambda^0 \rightarrow n$$
$$\Lambda^0 \rightarrow p + \pi^0$$

Deduce which of these decay processes are **not** possible.

(6)

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(Total for question = 6 marks)