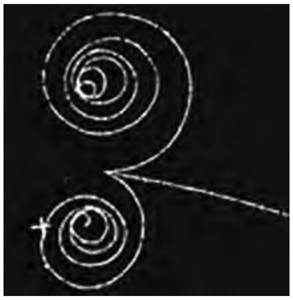
1 The picture shows the tracks in a bubble chamber after an interaction. A photon enters from the left and collides with a stationary neutral hydrogen atom. An electron is ejected from the hydrogen atom and moves at high speed. An electron-positron pair is also created.



(a) State why the photon leaves no track.

(1)

(b) Explain why the ejected electron undergoes less deflection than the electron-positron pair.

(2)

(c) Show that charge is conserved in the interaction.

(2)

(d) Explain why there is no track from the ionised hydrogen atom after the collision.

(2)

(Total for Question = 7 marks)

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

(a) 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 $\quad$ $\bar{u}d$ $\quad$ $\bar{u}\bar{u}\bar{d}$ $\quad$ $\bar{s}u$

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

Calculate the mass of a pion in kg.

(3)

Mass =

(Total for Question = 4 marks)

3 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)

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

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

(3)

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)

(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)

(Total for Question = 15 marks)

4 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)

(Total for Question = 5 marks)

5 An electron and a positron annihilate with the emission of two photons of equal energy.

Calculate the wavelength of the photons.

(5)

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Wavelength ....

(Total for Question 5 marks)

6 (a) Physicists were able to confidently predict the existence of a sixth quark. State why.

(1)

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(b) The mass of the top quark was determined by an experiment. Collisions between protons and anti-protons occasionally produce two top quarks.

(i) How do the properties of a proton and an anti-proton compare?

(2)

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(ii) After the collision the two top quarks move in opposite directions with the same speed.

Explain why.

(2)

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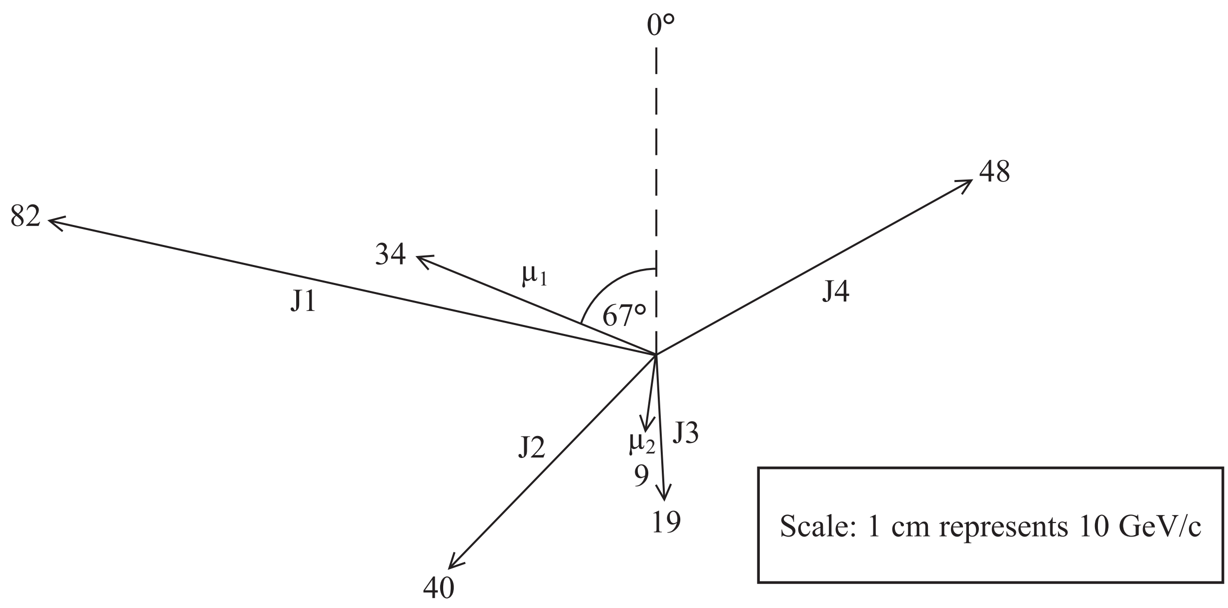
(c) The two top quarks decay rapidly into two muons and four jets of particles. These can be detected and their momenta measured.

The diagram shows an end-on view of the directions of the four jets (J1 to J4) of particles. The two muons are shown as μ_1 and μ_2. A muon neutrino is also produced but cannot be detected, so is **not** shown. Each momentum is measured in GeV/c.

The magnitude of the momentum for each particle or 'jet' is shown by the number printed at the end of each arrow.



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

(2)

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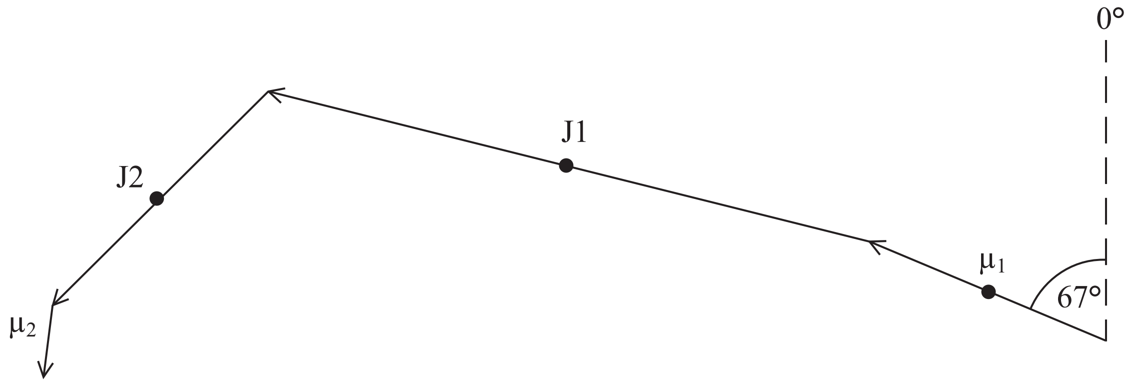
(ii) The vector diagram shown below is **not** complete. Add to the diagram arrows to represent the momenta of J3 and J4.

(2)



Scale: 1 cm represents 10 GeV/c

(iii) Complete the diagram to determine the magnitude of the momentum of the muon neutrino.

(1)

Momentum .... GeV/c.

(iv) Show that the total energy of all the products of this event is about 300 GeV.

(1)

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(v) Deduce the mass of a top quark in GeV/c^2.

(1)

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(vi) Suggest why it took a long time to find experimental evidence for the top quark.

(2)

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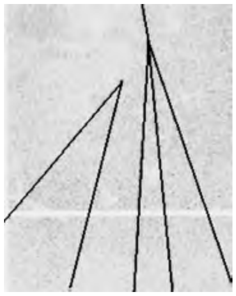
(Total for Question 14 marks)

7 Evidence for a charm quark was discovered in 1974 at the linear accelerator (linac) at Stanford University.

(a) Why do the tubes of a linac become progressively longer down its length?

(1)

(b) This image shows the decay of a D^0 meson into a positively charged kaon and a negatively charged pion.



(i) Mark on the image the point P at which this decay occurs.

(1)

(ii) Give **two** reasons for choosing this point.

(2)

(iii) Write an equation for this decay event.

(2)

*(iv) State and discuss how three conservation laws apply to this decay event.

(6)

(c) The table below shows some quarks and their properties.

Quark	**Charge / *e***
Up (u)	$+\frac{2}{3}$
Down (d)	$-\frac{1}{3}$
Strange (s)	$-\frac{1}{3}$
Charm (c)	$+\frac{2}{3}$

(i) Circle the correct combination of quarks in the list below which corresponds to a D^0 meson.

(1)

$c\bar{u}$ cds $c\bar{s}$ cud

(ii) Suggest a possible quark combination of the positively charged kaon.

(1)

(Total for Question = 14 marks)