Particle Physics

1. The number of neutrons in a nucleus of ${}^{197}_{79}\text{Au}$ is

A 79

B 118

C 197

D 276

(Total 1 mark)

2. The derivation of the formula $E_k = \frac{p^2}{2m}$ could include the expression

A $\frac{1}{2}mv^2 = p^2$

B $\frac{1}{2}m^2 v^2 = p^2$

C $m^2 v^2 = \frac{p^2}{m}$

D $m v^2 = \frac{p^2}{m}$

(Total 1 mark)

3. Which of the following is **not** a valid conclusion from Rutherford's alpha particle scattering experiments?

A The atom is mainly empty space.

B The nucleus contains protons and neutrons.

C The nucleus must be charged.

D The nucleus must be very small compared to the atom.

(Total 1 mark)

4. The diagram shows the path of an electron in a bubble chamber.

Which of the following can you deduce from the diagram?

A The electron is moving anti-clockwise.

B The electron is moving clockwise.

C The magnetic field is acting out of the page.

D The speed of the electron is increasing.

(Total 1 mark)

5. Which one of the following quantities would the de Broglie equation be used to calculate?

A The momentum of a moving particle.

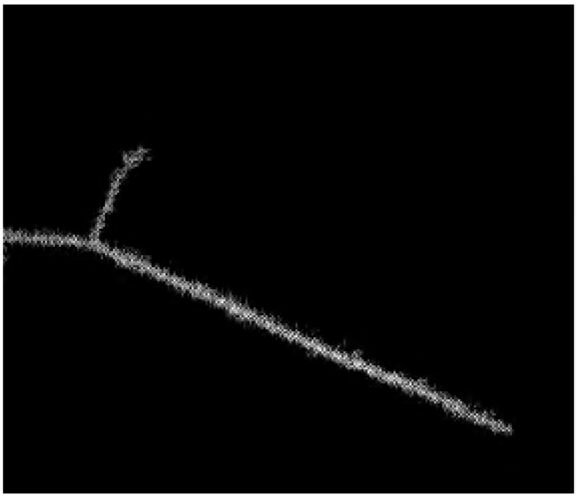
B The value of the Planck constant.

C The wavelength of a moving electron.

D The wavelength of a photon of light.

(Total 1 mark)

6. A low-energy particle collides elastically with a stationary particle of the same mass. The particle enters from the left of the photograph.



(a) State what is meant by collides *elastically*.

....

.... **(1)**

(b) Sketch a labelled vector diagram to show how the momentum of the initial moving particle relates to the momenta of the two particles after the collision.

(2)

(c) Use your answers to (a) and (b) to confirm that the angle between the subsequent paths of both particles must be 90°.

....

....

.... **(2)**

(d) (i) Explain the process by which a proton is given energy in a particle accelerator.

....

....

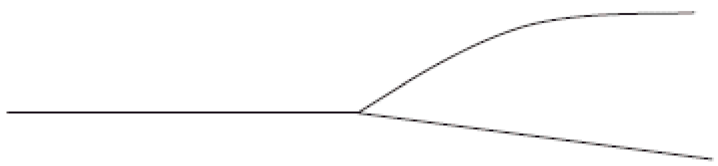
....

....

....

....

The diagram shows a collision between a high-energy proton (track from the left) and a stationary proton in a particle accelerator experiment.



(3)

(ii) Explain why the angle between the two paths is not 90°.

....

....

....

....

(2)

(e) Deduce the direction of the magnetic field in this particle accelerator experiment. Circle the correct direction from those given below.

left to right across the paper   out of the plane of the paper   into the plane of the paper

(1)
(Total 11 marks)

7. In 1961 Murray Gell-Mann predicted the existence of a new particle called an omega (Ω) minus. It was subsequently discovered in 1964.

At this time the quark model consisted of three particles, the properties of which are given in the table.

Quark	**Charge**	**Predicted mass in MeV/c^2**
Up (u)	$+\frac{2}{3}$	4
Down (d)	$-\frac{1}{3}$	4
Strange (s)	$-\frac{1}{3}$	80

(a) Explain what a charge of $+\frac{2}{3}$ means.

....

....
(1)

(b) State the predicted mass of, and the charge on a $\bar{s}$.

....

....
(2)

(c) Convert 4 MeV/c^2 to kg.

....

....

....

....

....

....

Mass = ... kg

(3)

(d) The event which led to the discovery of the omega minus particle can be summarised as follows. A negative kaon collided with a stationary proton and produced a positive kaon, a neutral kaon and the omega minus.

(i) Kaons K consist of combinations of either an up or down quark plus a strange quark. The omega minus consists of three strange quarks.

Complete the following table by ticking the appropriate boxes.

	Meson	Baryon	Nucleon	Lepton
Negative kaon				
Omega minus				

(2)

(ii) Write an equation using standard particle symbols to summarise this event.

....

....

....

....

(2)

(iii) The negative kaon consists of $\bar{u}s$. Deduce the quark structure of the other two kaons involved in this event.

....

....

....

....

(2)

(iv) The total mass of the three particles created after this event is larger than the total mass of the two particles before. Discuss the quantities that must be conserved in interactions between particles and use an appropriate conservation law to explain this increase in mass.

....

....

....

....

....

....

....

....

....

....

(5)

(Total 17 marks)

8. An electron gun uses a potential difference to accelerate electrons from rest to a speed of 2.00×10^7 m s^{-1}.

The de Broglie wavelength associated with electrons moving at 2.00×10^7 m s^{-1} is

A 3.3×10^{-41} m

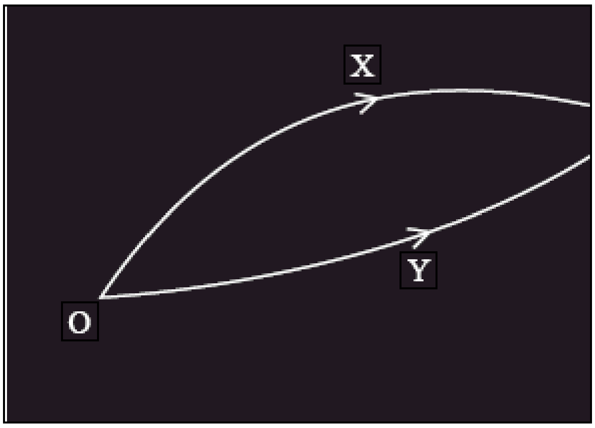
B 5.0×10^{-14} m

C 3.6×10^{-11} m

D 5.0×10^{-8} m

(Total 1 mark)

9. A particle detector shows tracks produced by two particles X and Y that were created by the decay of a lambda particle at O.



Which of the following is a valid conclusion from these facts?

A X is a negatively charged particle.

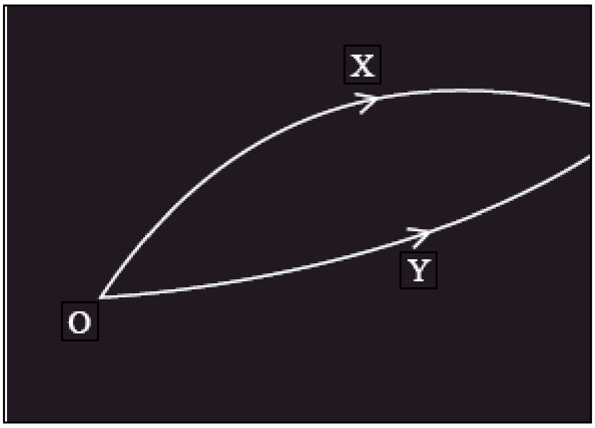
B Y is a positively charged particle.

C The lambda particle is neutral.

D The magnetic field is acting into the plane of the paper.

(Total 1 mark)

10. A particle detector shows tracks produced by two particles X and Y that were created by the decay of a lambda particle at O.



Which of the following is a correct statement about energy at the decay?

A The energy of X must be greater than that of Y.

B The combined energy of X and Y must be more than the energy of the lambda particle.

C The mass of the lambda particle must equal the combined energy of X and Y.

D The mass energy of the lambda particle must equal the total energy of X and Y.

(Total 1 mark)

11. Rutherford designed an experiment to see what happened when alpha particles were directed at a piece of gold foil. Summarise the observations and state the conclusions Rutherford reached about the structure of gold atoms.

....

....

....

....

....

....

....

....

....

....

....

(Total 5 marks)

12. Pion radiotherapy is a new form of cancer treatment that has been extensively investigated for tumours of the brain. Pions are short lived sub-atomic particles and belong to a group called mesons.

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

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

On the list below circle the combination which could correspond to a π^+ pion.

uud $\overline{ddd}$ $u\bar{d}$ $s\bar{c}$

(1)

(b) The mass of a pion is 0.14 GeV/c^2. Calculate the mass of a pion in kg.

....

....

....

....

....

....

Mass = ... kg

(3)

(c) Pions can be produced by accelerating protons using a cyclotron. Briefly explain the role of electric and magnetic fields within a cyclotron.

....

....

....

....

....

....

....

....

....

....

(5)

(d) When pions are used to treat brain tumours they are slowed by the tissue in the brain and cause little damage. When a pion is moving very slowly it may be absorbed by the nucleus of an atom. The atom nucleus then becomes unstable and breaks up into several fragments.

Explain why these fragments shoot out in all directions.

....

....

....

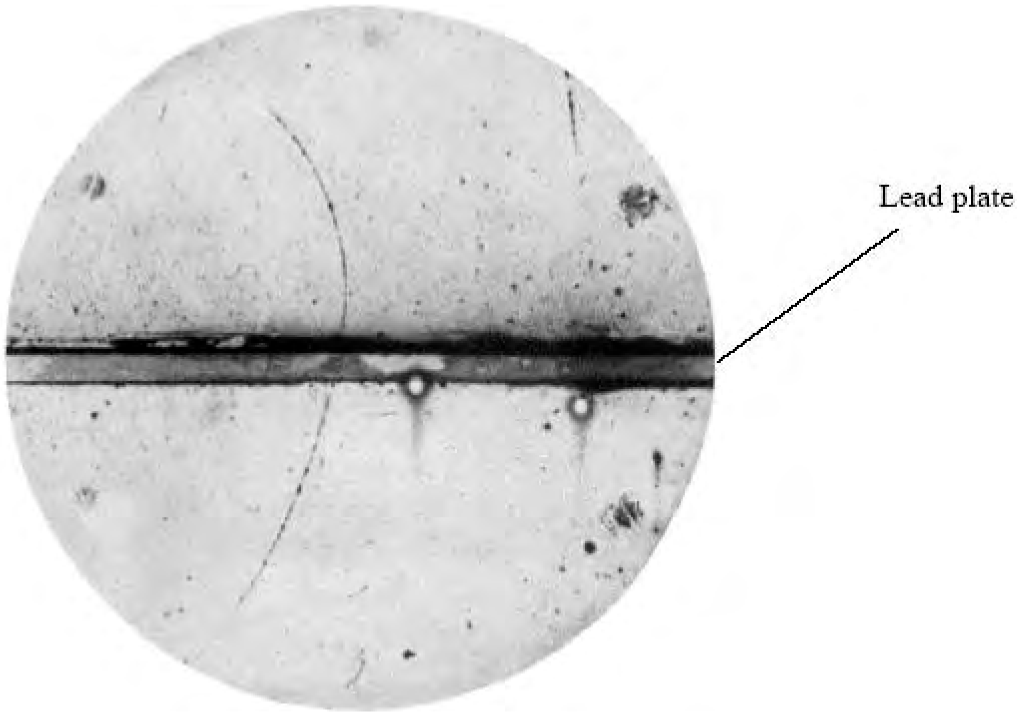
....

....

....

(3)
(Total 12 marks)

13. The photograph shows the track of a positively charged particle either side of a lead plate.



The particle was deflected by a magnetic field of magnetic flux density 1.5 T. The field is perpendicular to the plane of the photograph.

(a) (i) Estimate the actual radius of the track above the lead plate.

The lead plate is 6 mm thick.

....

....

....

....

....

....

Radius = ...

(3)

(ii) Calculate the momentum of this particle above the lead plate.
Particle charge = 1.6×10^{-19} C

....

....

....

....

Momentum = ...

(2)

(b) Explain whether this particle was moving up or down through the lead plate.

....

....

....

....

....

....

(3)

(c) On the list below circle the correct direction of the magnetic field.

Into the page   from left to right   down the page   out of the page   up the page

(1)

(d) This particle was identified as a positron.

(i) Calculate the speed of the positron while it is moving above the lead plate.

....

....

....

Speed = ...

(2)

(ii) Comment on your answer.

....

....

....

....

(2)
(Total 13 marks)

14. A top quark has a mass of 171 $\frac{\text{GeV}}{\text{c}^2}$. Its mass in kilograms is about

A 3×10^{-31}

B 3×10^{-28}

C 3×10^{-25}

D 3×10^{-19}

(Total 1 mark)

15. A π^+ pion is composed of which combination of quarks?

A ud

B $\bar{u}d$

C $u\bar{d}$

D $\bar{u}\bar{d}$

(Total 1 mark)

16. (a) State what is meant by the term **baryon**.

....

....

(1)

(b) In β^- decay a neutron decays into a proton.

Explain how the quark structure of the baryon changes in this process.

....

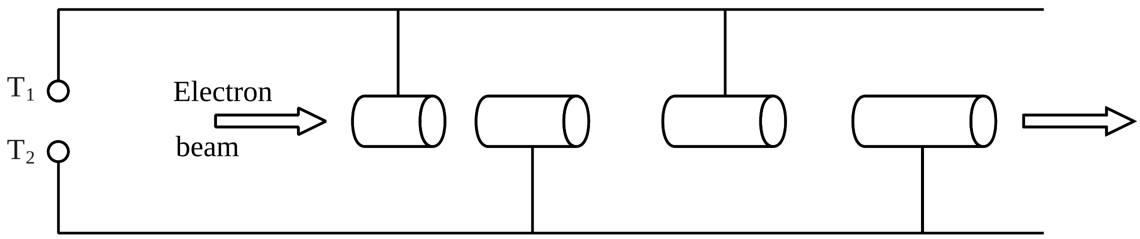
....

....

....

(2)
(Total 3 marks)

17. Quarks were discovered using the Stanford Linear Accelerator (SLAC). The diagram below shows the principle of a linear accelerator (LINAC).



(a) State what is connected between terminals T_1 and T_2.

....

....

(2)

(b) Explain why the electrons travel with constant velocity whilst in the cylinders.

....

....

(2)

(c) Explain why the cylinders gradually increase in length along the accelerator.

....

....

....

....

(2)
(Total 6 marks)

18. At the start of the 20th century it was thought that the atom contained an even distribution of positive charge with electrons embedded in it. Rutherford directed a series of experiments using α-particles to investigate the structure of the atom.

In 1913 Rutherford wrote that “the observations on the scattering of α-particles by matter afford strong experimental evidence for the theory that the atom consists of a positively charged nucleus of minute dimensions surrounded by a compensating distribution of negative electrons”.

Outline the experimental observations to which Rutherford is referring and explain how they led him to this deduction.

....

....

....

....

....

....

....

....

....

....

....

....

....

(Total 5 marks)

19. (a) In their famous experiment conducted in 1932, Cockcroft and Walton accelerated protons through a potential difference of 300 kV and used them to bombard a lithium ($^{7}_{3}\text{Li}$) target. They found that two alpha particles were produced. The energy of the alpha particles was subsequently calculated from the tracks they made in a cloud chamber.

Complete the nuclear equation for this event.

$$^{7}_{3}\text{Li} + \qquad \longrightarrow$$

(2)

(b) Cockcroft and Walton reported to the Royal Society that "if momentum is conserved in the process, then each of the α-particles must take up equal amounts of energy, and from the observed range of the α-particles we conclude that an energy of 17.2 million electron-volts [MeV] would be liberated in this disintegration process".

(i) State **two** other properties, in addition to momentum, that are conserved in such a process.

....

....

....

(2)

(ii) Use the data below to show that the energy released in this process is approximately 2.8×10^{-12} J.

Mass of lithium nucleus	= 7.0143 u
Mass of proton	= 1.0073 u
Mass of α-particle	= 4.0015 u

....

....

....

....

....

....

....

....

(4)

(iii) Hence discuss the extent to which Cockcroft and Walton's results confirm Einstein's prediction that E is equal to mc^2.

....

....

....

....

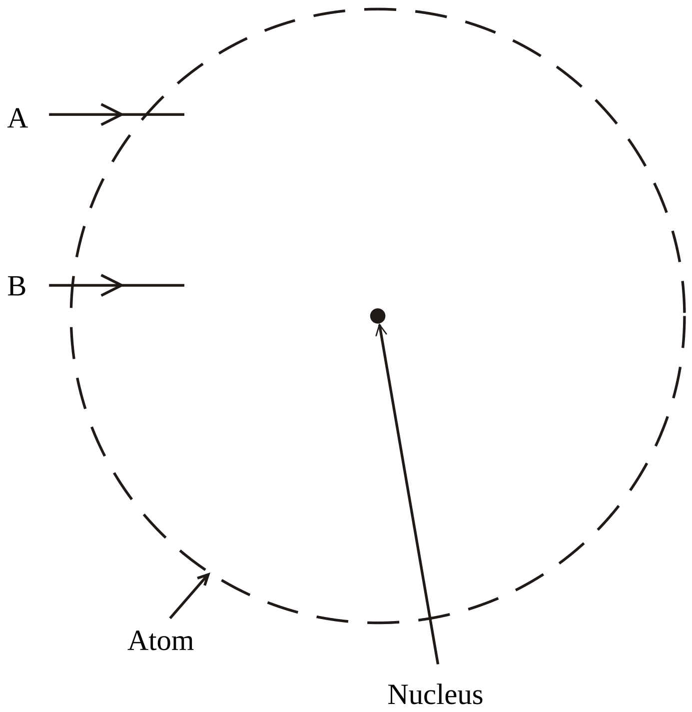
....

....

....

(5)
(Total 13 marks)

20. (a) The lines A and B show part of the paths of two alpha particles as they travel through an atom.



Add to the diagram the subsequent paths of each alpha particle as they travel through and out of the atom.

(2)

(b) Rutherford investigated the scattering of alpha particles by gold foil in an evacuated container. The evidence from his investigations led to the nuclear model of the atom.

Why was it important for this investigation that

(i) the alpha source was inside the container,

....

....

....

(1)

(ii) the alpha particles had the same initial kinetic energy,

....

....

....

(1)

(iii) the container was evacuated?

....

....

....

(1)
(Total 5 marks)

21. Classify each of the following particles by ticking **all** the appropriate boxes in the table.

Particle	Lepton	Baryon	Hadron	Meson
Neutron, n				
Neutrino, υ				
Muon, μ				

(Total 3 marks)

22. (i) Two particle reactions are shown. Use appropriate conservation laws to show whether these reactions are possible.

$$\underset{(udd)}{\Delta^0} + \underset{(d\bar{s})}{K^0} \rightarrow \underset{(u\bar{s})}{K^+} + \underset{(uus)}{\Sigma^+} \qquad \underset{(sss)}{\Omega^-} \rightarrow \underset{(ssd)}{\Xi^-} + \underset{(s\bar{d})}{\overline{K}^0}$$

....

....

....

....

....

....

(3)

(ii) Using **only** the information given above deduce the charges on each of the strange, up and down quarks. Justify your answers.

....

....

....

....

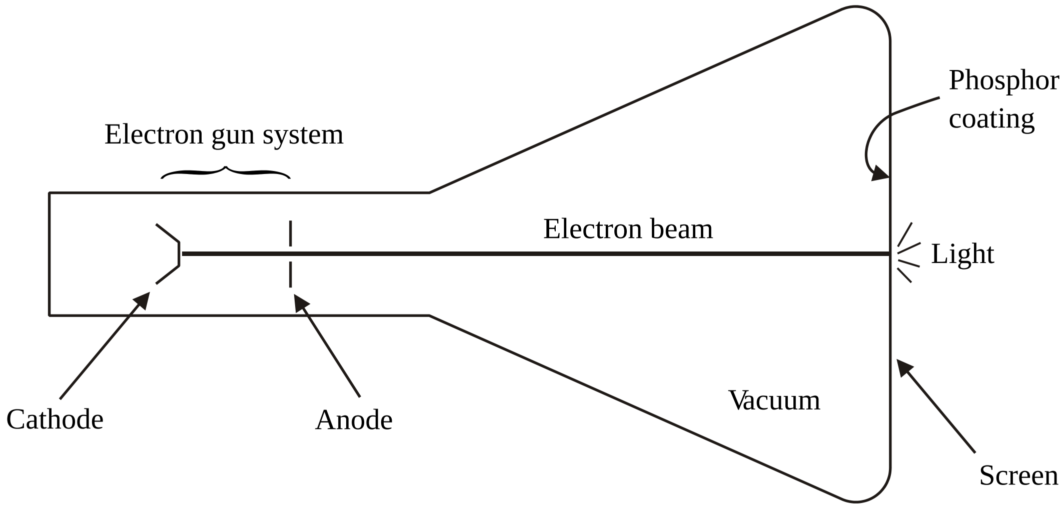
....

....

....

(2)
(Total 5 marks)

23. A simplified diagram of a cathode ray oscilloscope is shown.



(a) Electrons liberated from the cathode are accelerated to the anode through a large potential difference, giving each electron in the beam an energy of 1.2 keV.

(i) Calculate the velocity of electrons in the beam.

....

....

....

....

Velocity = ...

(3)

(ii) The phosphor coating produces green light, each photon of which has an energy of 2.4 eV. The efficiency of the conversion of electron kinetic energy to light in the phosphor is 8.0%. Calculate the number of photons that will be liberated from the phosphor coating by the arrival of one electron in the beam.

....

....

....

....

Number of photons = ...

(2)

(b) In a badly-designed cathode ray tube, electrons arriving at the screen are not conducted away but build up in the area where the beam hits it. Explain how this will have an adverse effect on the amount of light emitted by the phosphor. You may be awarded a mark for the clarity of your answer.

....

....

....

....

....

....

....

....

....

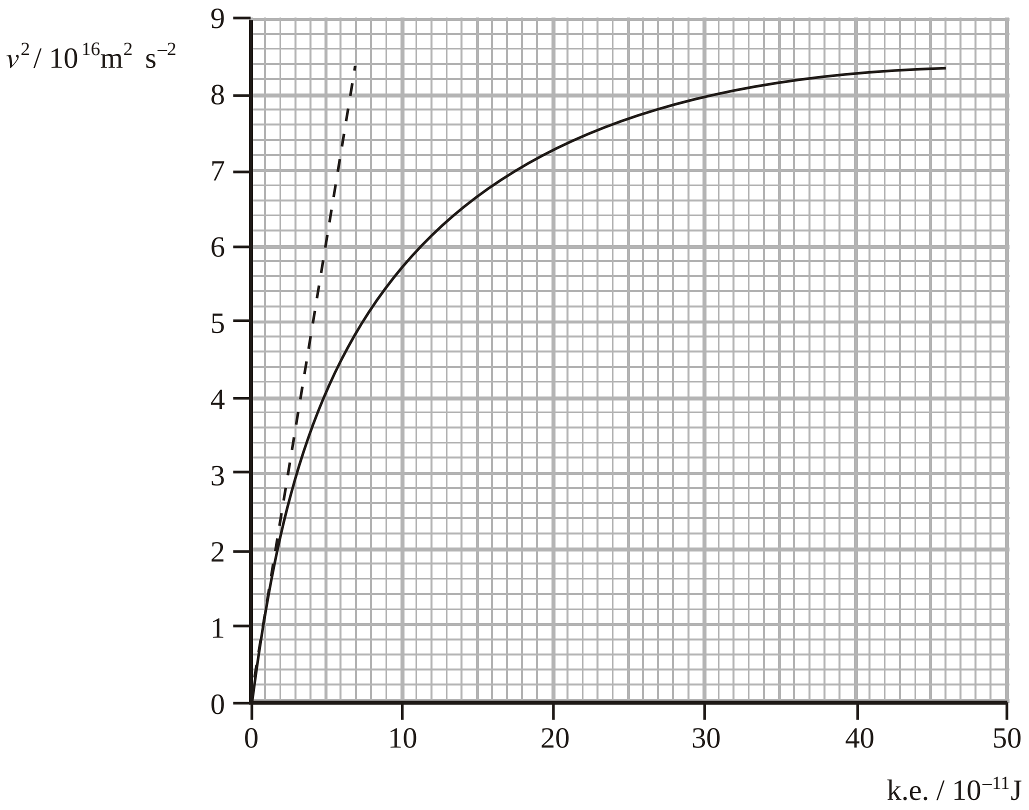
....

(4)
(Total 9 marks)

24. (a) The dashed line on the graph below shows how the kinetic energy of a proton would vary with the square of its speed if the relationship

$$\text{k.e.} = \tfrac{1}{2}mv^2$$

were to hold for all values of v, no matter how high.



Use data from the graph to show that the rest mass of the proton is about 1.7×10^{-27} kg.

....

....

....

....

....

....

....

(3)

(b) The curved line on the graph shows how the kinetic energy of a high-energy proton actually varies with the square of its speed. This is greater than that predicted by the $\frac{1}{2}mv^2$ expression because of relativistic effects.

(i) Complete the table below to show the extra energy ΔE, caused by relativistic effects, for protons accelerated to the three speeds v shown in the left column.

$v/10^8$ m s^{-1}	$v^2/10^{16}$ m^2 s^{-2}	$\Delta E/10^{-11}$ J
2.00	4.0	
2.24	5.0	
2.45	6.0	

(ii) For any **one** of your values for ΔE, calculate the equivalent mass increase Δm of a proton moving at that speed and express this mass increase as a percentage of the rest mass of a proton.

....

....

....

....

....

(5)
(Total 8 marks)

25. In 2002 the Jefferson Laboratory released the results of an experiment involving collisions of high speed electrons with protons. The results suggested that protons are not spherical, but have a bulging shape. In a subsequent paper some of these results were explained by modelling a nucleon as ‘a relativistic system of three bound quarks surrounded by a cloud of pions.’

Protons and neutrons are the two types of nucleon and both consist of up and down quarks.

Nucleon	**Quark composition**
proton	uud
neutron	udd

Quark	Charge
up quark	+2/3 *e*
down quark	–1/3 *e*

(a) Use the information in the tables to show how the charge of the proton and the charge of the neutron are arrived at.

proton ....

neutron ....

(2)

(b) Protons, neutrons and pions are all hadrons. There are two types of hadron, with different quark combinations.

(i) Complete the table below to name the two types of hadron.

Particles	**Hadron type**
proton, neutron	
pion	

(ii) State the differences in quark composition between these two types of hadron.

....

....

....

(4)

(c) Explain why high speed particles are used to examine the internal structure of other particles.

....

....

....

....

....

....

....

....

(4)

(d) The model mentions a 'relativistic system'. State the condition needed for relativistic effects to be significant.

....

....

....

(1)
(Total 11 marks)

26. A student is researching information about CERN, the particle research centre near Geneva. He finds the following statement on a web site:

"The circular tunnel is eight kilometres in diameter … fully accelerated particles circle the tube twenty thousand times in one second …"

Calculate the speed of the particles, and comment on the likely accuracy of the statement.

....

....

....

....

....

....

....

....

....

....

....

(Total 4 marks)

27. PET (positron emission tomography) scanning is often used to see how cancers are responding to therapy. It requires a radioactive isotope which emits positrons. A positron soon meets an electron and annihilates. The resulting photons can be detected and an image produced. An isotope of fluorine $^{18}_{9}F$ can be used as it can be added to a glucose molecule. The patient is given a glucose drink containing this fluorine isotope which will then be absorbed by the cancer.

(a) The fluorine isotope is produced by bombarding an isotope of oxygen $^{18}_{8}O$ with a high energy proton. Write a nuclear equation for this process.

.... $\longrightarrow$ ....

(3)

(b) The protons are typically given an energy of 19 MeV. Briefly suggest how this might be achieved.

....

....

....

....

....

....

(2)

(c) Fluorine ^{18}F emits positrons and has a half-life of 110 minutes. Explain the meaning of half-life and suggest why 110 minutes is suitable for this application.

....

....

....

....

....

....

(3)

(d) Two identical photons are produced when an electron meets a positron. Calculate the wavelength of each photon.

....

....

....

....

....

....

....

....

....

....

(4)

(e) Detectors placed on opposite sides of the patient detect these photons and can then accurately predict the precise location of the positron annihilation within the patient.

Explain why the two photons must be emitted in opposite directions.

....

....

....

....

....

....

(2)
(Total 14 marks)

28. (a) The ratio $\frac{\text{radius of atom}}{\text{radius of nucleus}}$ for a given atom is about 10^5.

Use this value to calculate the ratio $\frac{\text{density of atom}}{\text{density of nucleus}}$.

State the assumption you have made.

....

....

....

....

....

Assumption ....

....

(4)

(b) What observation is made in the alpha particle scattering experiment that supports your assumption?

....

....

(1)
(Total 5 marks)

29. In 2007 the Large Hadron Collider (LHC) was opened at CERN. The circular accelerator is 27 km in circumference and has five thousand superconducting magnets. The LHC can give a proton an energy of up to 7 TeV.

$$1 \text{ TeV} = 1 \times 1012\text{eV}$$

(a) One of the experiments on the LHC will attempt to create the Higgs particle, which has not been created by any of the existing, lower energy accelerators. The theoretical upper limit for the rest mass of the Higgs particle is 251 GeV/c^2.

Explain why the LHC should be able to create the Higgs particle.

....

....

....

....

(2)

(b) Provided the energy of an accelerated particle is much greater than its rest-mass energy, its momentum may be calculated using

$$\text{momentum} = \frac{\text{particle energy}}{c}$$

(i) Show that a 7 TeV proton has energy much greater than its rest-mass energy.

....

....

....

....

....

(2)

(ii) Show that the momentum of a 7 TeV proton is about 4×10^{-15} kg m s^{-1}.

....

....

....

....

(2)

(iii) Calculate the magnetic flux density provided by the superconducting magnets.

....

....

....

....

....

....

Magnetic flux density = ...

(4)

(iv) A student says "The magnetic field needs to be in the vertical direction to cause the protons to travel in a horizontal circle". Comment on this statement.

....

....

....

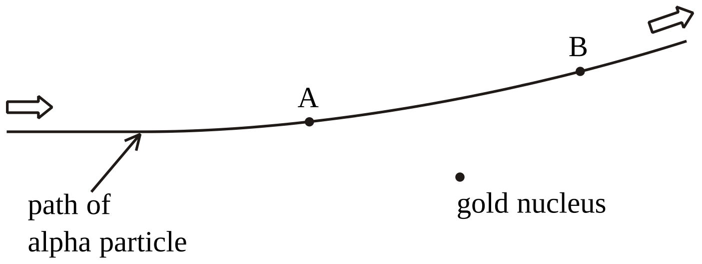
....

....

....

(2)
(Total 12 marks)

30. The diagram shows the path of an alpha particle, ${}^{4}_{2}\text{He}$, as it closely approaches and then moves away from a gold nucleus, ${}^{197}_{79}\text{Au}$.



(i) Add to the diagram the direction of the electric force acting on the alpha particle at each of the points A and B.

(1)

(ii) At point A the distance of the alpha particle from the nucleus is 1.5×10^{-13} m. Calculate the magnitude of the force acting on the alpha particle at this point.

....

....

....

....

....

....

Magnitude of force = ...

(3)

(iii) How does the speed of the alpha particle vary as it moves from A to B?

....

....

(1)
(Total 5 marks)

31. Below are some extracts from the novel "Angels and Demons" by Dan Brown. A discussion about antimatter is taking place between two characters.

(a) Extract 1

A: "So antimatter is real?"

B: "A fact of nature. Everything has its opposite. **Protons have electrons. Up quarks have down quarks.** There is a cosmic symmetry at the subatomic level."

In the context of antimatter, comment on the scientific accuracy of the two statements in bold type.

Protons have electrons. ....

....

....

....

....

Up quarks have down quarks. ....

....

....

....

....

(5)

(b) Extract 2

A: "There would be no way to separate the particles from their antiparticles."

B: "He applied a magnetic field. Matter arced right, and antimatter arced left."

Comment on the physics of this method for separating particles from their antiparticles.

....

....

....

....

(2)

(c) Extract 3

A: “You collected visible amounts of antimatter?”

B: “Five thousand nanograms ... a plasma containing millions of positrons.”

Calculate how many positrons there would be in a sample of five thousand nanograms.

....

....

Number of positrons = ...

(1)

(d) Extract 4

B: “Antimatter releases pure energy. A one hundred per cent conversion of mass to photons. **So don’t look directly at the sample. Shield your eyes.**”

(i) A positron annihilates with an electron to produce two identical photons. Calculate the wavelength of each photon.

....

....

....

....

....

Wavelength = ...

(3)

(ii) Comment on the two sentences in bold type in relation to the wavelength you have calculated.

....

....

(1)
(Total 12 marks)

32. Explain the role of magnetic fields in particle accelerators and detectors.

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

(Total 5 marks)

33. The scattering of alpha particles by thin films of metal, such as gold, reveals details about the structure of an atom.

(a) For each of the two observations below give one clear deduction that can be made concerning atomic structure.

(i) Most alpha particles pass through the metal film without being deflected.

....

....

(ii) Some alpha particles are deflected by angles greater than 90° from their original direction.

....

....

(2)

(b) Of the alpha particles that are deflected most are deflected through angles much less than 90° from their original direction.

Explain why, from this observation alone, it is impossible to deduce the sign of the charge on the nucleus. You may use a diagram to illustrate your explanation.

....

....

....

....

....

....

(2)

(c) The ratio of atomic diameter to nuclear diameter can be expressed in the form 10^n. Suggest an appropriate value for n.

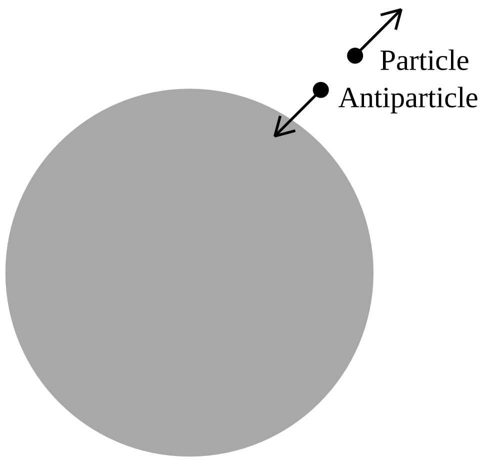
Value for n = ...

(1)
(Total 5 marks)

34. Black holes are formed when stars collapse into a state of extremely high density. The gravitational field strength is so great that nothing can escape from within the black hole – not even light.

Even so, Professor Stephen Hawking suggested a way in which black holes might 'evaporate' over time.

Spontaneous production of particle-antiparticle pairs close to the black hole can enable it to lose mass. If one particle falls into the black hole and the other escapes, the mass and energy of the escaping particle are lost by the black hole.



(a) Explain why you would expect the initial motion of the particle and antiparticle to be in opposite directions at the instant at which they are produced.

....

....

....

(2)

(b) In a particular event, a particle (π^+) and its antiparticle (π^-) are produced. Complete the table of their properties.

Particle name	π^+	π^-
mass	0.140 GeV/c^2	
charge	$+1.6 \times 10^{-19}$ C	
quark composition	$u\bar{d}$	

(3)

(c) Circle the word below which correctly describes a π^+ particle.

meson baryon lepton

(1)

In the event described, the π^+ escapes.

(d) State the minimum energy in eV lost by the black hole.

....

....

Minimum energy = ... eV

(2)

(e) Explain why this energy is a minimum.

....

....

(1)

(f) Calculate the minimum mass in kg lost by the black hole in this event.

....

....

....

Mass loss = ... kg

(2)

(Total 11 marks)

35. The equation for β^- decay can be written as:

$$n \rightarrow p + \beta^- + \bar{\nu}$$

(i) For each particle, either give its quark composition or state that fundamental particle.

n ....

p ....

β ....

$\bar{\nu}$ ....

(2)

(ii) Write a similar equation for β^+ decay.

(2)

(Total 4 marks)

36. In 1995 scientists at CERN created atoms of antihydrogen.

(i) Name the particles that make up antihydrogen.

....

....

(1)

(ii) Describe these particles in terms of charge and quark structure where relevant.

....

....

(2)

(iii) State the charge of an atom of antihydrogen.

....

(1)

(iv) Explain why it is not possible to store atoms of antihydrogen.

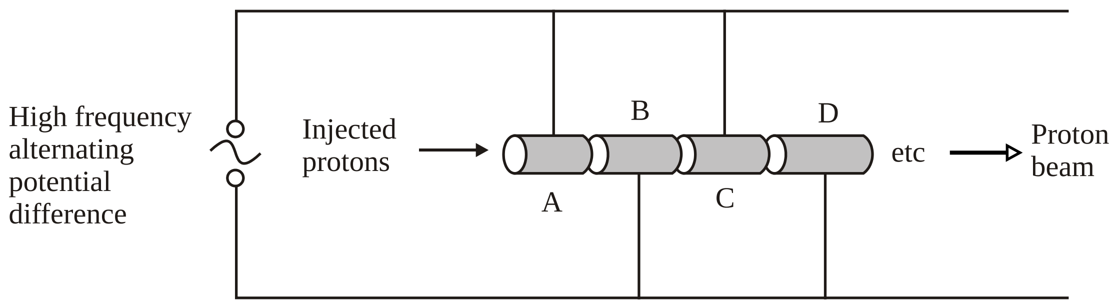
....

....

....

(2)
(Total 6 marks)

37. The diagram shows part of a linear accelerator - a linac. Alternate metal tubes are connected together and to opposite terminals of a high-frequency alternating potential difference of fixed frequency.



(a) Describe how the protons are accelerated as they move along the linac and explain why the tubes get longer towards the right. You may be awarded a mark for the clarity of your answer.

....

....

....

....

....

....

....

....

....

....

(5)

(b) A particular linac has 420 metal tubes and the peak voltage of the alternating supply is 800 kV.

(i) Show that the emerging protons have gained a kinetic energy of about 5×10^{-11} J and express the mass equivalent of this energy as a fraction of the mass of a stationary proton. Take the mass of a proton m_p as 1.01 u.

....

....

....

....

....

....

....

....

....

(6)

(ii) The frequency of the alternating supply is 390 MHz. Calculate how long it takes a proton to travel along the linac.

....

....

....

....

....

Time = ...

(2)

(c) The emerging protons can be made to collide with

(i) a target of fixed protons, e.g. liquid hydrogen, or

(ii) a similar beam of protons travelling in the opposite direction.

State some advantages of either or both experimental arrangement(s).

....

....

....

....

....

....

(2)
(Total 15 marks)

38. The table below summarises some properties of some particles in the standard quark-lepton model.

Quarks			Leptons		
Name	Symbol	Charge	Name	Symbol	Charge
up	u	+2/3	electron	e^-	–1
down	d	–1/3	electron-neutrino	ν_e	0

Write bullet points to explain the composition of everyday matter using the information in the table.

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

(Total 6 marks)

39. The following extract is taken from an article about the Continuous Electron Beam Accelerator Facility (CEBAF), which produces high-energy electrons for particle experiments.

> The sheer size of the magnets reflects a bizarre phenomenon at work within CEBAF. At speeds close to the speed of light, Einstein's special theory of relativity predicts that objects appear to gain mass. The electrons in CEBAF move so fast that they act as if they have gained 8000 times their normal mass, making them far more reluctant to change course – hence the need for powerful magnets.

The gain in mass of an electron is another way of saying that it has gained energy equivalent to 8000 electron masses. Calculate the voltage through which an electron has to be accelerated from rest to gain this energy.

....

....

....

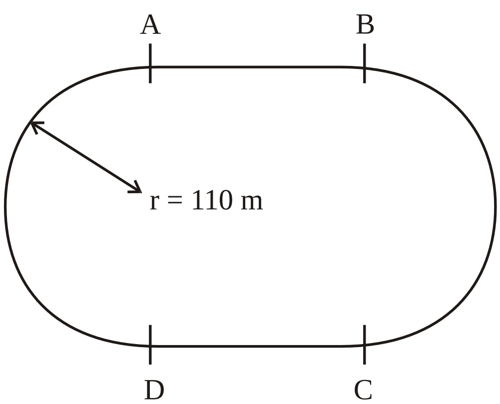
....

....

Voltage = ...

(3)

The electrons are guided along a path which has two straight sections with two semicircular sections at each end, as shown.



Explain the role of the magnets in this particle accelerator, including an approximate calculation of field strength. You may wish to refer to the various sections AB, BC, CD and DA along the path.

Assume that the electrons are travelling close to the speed of light so that they have a mass of 8000 times their normal mass.

....

....

....

....

....

....

....

....

....

....

....

(7)
(Total 10 marks)

40. In 1964 the following reaction was observed for the first time. The K particles are kaons (a type of meson) and X was a new particle.

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

Use conservation laws to deduce the nature of particle X in order to underline the correct words in the sentence below. Show all your working.

Particle X is a meson/baryon/lepton with a charge of –1 / 0 / +1

....

....

....

....

(4)

Add the quark content of the proton and the K^+ to the table.

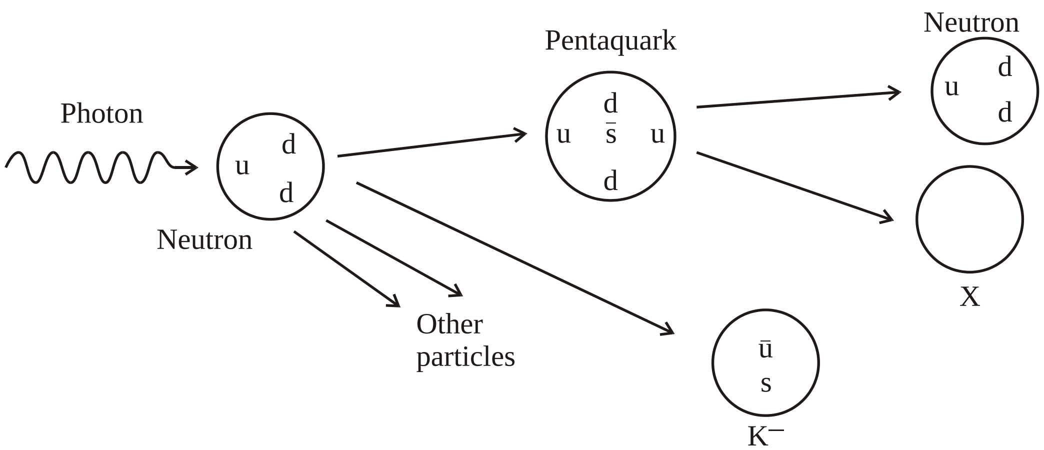
Particle	Quark content
K^-	$s\bar{u}$
P	
K^0	$d\bar{s}$
K^+	

(2)
(Total 6 marks)

41. In July 2003 scientists at the SPring-8 synchrotron in Japan announced the discovery of a pentaquark – a particle made up of 5 quarks.

The pentaquark was produced by firing gamma photons at a target. It decayed very rapidly into other products.

The diagram shows some of the particles involved in the production and decay of the pentaquark, including the quark composition for several of them.



Name three quantities conserved during the decay of the pentaquark.

....

....

(2)

The table shows the charges of the six types of quarks as a fraction of the charge on a proton.

Quark type			Charge
up	charm	top	2/3 *e*
down	strange	bottom	–1/3 *e*

Find the charge of the pentaquark. Express your answer as a fraction of the charge on a proton.

....

....

Charge = ...

(1)

Explain whether particle X must be positive, negative or neutral.

....

....

....

(1)

Suggest a possible quark composition for particle X. Explain your choice of quarks.

....

....

....

(2)

The pentaquark had a mass of 1.54 GeV/c^2. Find its mass in kg.

....

....

....

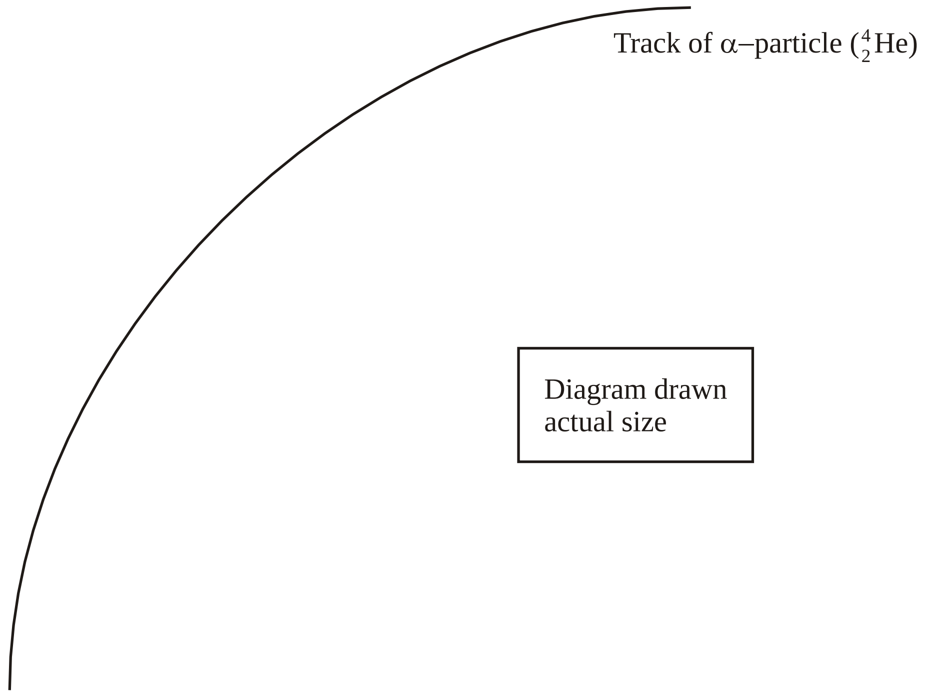
....

Mass = ...kg

(2)

(Total 8 marks)

42. A particle experiment shows the track of an alpha particle (a helium nucleus ${}^{4}_{2}\text{He}$) travelling at right angles to a magnetic field of magnetic flux density 3.7 T. Make an appropriate measurement and hence find the approximate energy of the alpha particle.



....

....

....

....

....

....

....

....

....

....

....

....

....

Energy = ...

(Total 7 marks)

43. (i) Particle energies are often quoted in units of mega-electronvolts (MeV). Show that the base units of the electronvolt can be expressed as kg m^2 s^{-2}.

....

....

....

(3)

(ii) Calculate the theoretical energy released when a $^{238}_{92}U$ nucleus is formed from individual protons and neutrons. Give your answer in MeV.

Data (masses):

$^{238}_{92}U$	= 238.0003 u
proton	= 1.0073 u
neutron	= 1.0087 u

....

....

....

....

....

....

(4)
(Total 7 marks)

44. (i) In the Sun, fusion reactions convert hydrogen nuclei into helium nuclei. One step of this process involves a β^+ decay. Complete a full nuclear equation for this part of the reaction by adding nucleon and proton numbers to each particle.

$$p \rightarrow n + \beta^+ + \nu$$

(2)

(ii) Tick the appropriate boxes to indicate which particles fit which classification.

	baryon	hadron	meson	lepton	antimatter
proton					
neutron					
β^+					
ν					

(4)
(Total 6 marks)

45. In 1989 the Large Electron Positron collider (LEP) at CERN was opened. It was used until 2000, when it was shut down to allow the construction of a new accelerator. At LEP, beams of electrons and positrons were accelerated to energies of 100 GeV in a huge ring with a circumference of 27 km before being made to collide with each other.

Just before LEP closed, scientists using it found some evidence for the proposed Higgs boson at a mass of 115 GeV/c^2.

Explain why 1 eV is equal to 1.6×10^{-19} J.

....

....

....

....

(2)

Show how GeV/c^2 can be used as a unit of mass.

....

....

....

(2)

If the Higgs boson has a mass of 115 GeV/c^2, find its mass in kg.

....

....

....

....

Mass = ... kg

(2)

The positron is the antiparticle to the electron. What is an **antiparticle**?

....

....

(1)

A description of LEP refers to '....the relatively small magnetic field required for LEP's gentle curvature....'.

Explain the need for a magnetic field and why it can be 'relatively small' in this case.

....

....

....

....

....

....

....

(4)
(Total 11 marks)

46. The following strong interaction has been observed.

$$\underset{(dds)}{\Sigma^-} + p \rightarrow X + \underset{(\bar{u}s)}{K^-} + n$$

Is particle X positive, negative or neutral?

....

(1)

Is particle X a baryon, a meson or a lepton?

....

(1)

State the quark composition of the proton and the neutron.

....

proton .... neutron ....

(1)

Explain why particle X cannot contain a strange quark, and deduce the identity of particle X. You may be awarded a mark for the clarity of your answer.

....

....

....

....

....

....

(4)
(Total 7 marks)

47. Experiments supervised by Rutherford about 100 years ago involved firing alpha particles at thin gold foils. Outline the results of these experiments, and the conclusions scientists drew from them.

....

....

....

....

....

....

....

....

....

....

(4)

The relationship between the rate of alpha detection (N) and the angle of scatter (θ) is predicted to be of the form

$$N \propto (\sin \theta/2)^{x}$$

Explain how you would determine x graphically from a set of experimental results for N and θ.

....

....

....

....

....

....

(2)

The symbols for an alpha particle and a gold nucleus are given below.

$^{4}_{2}\text{He}$ alpha particle

$^{197}_{79}\text{Au}$ gold nucleus

Explain the meaning of the numbers in the symbol for the gold nucleus.

....

....

....

....

(2)

Show that the mass of an alpha particle is about 7×10^{-27} kg.

....

....

(1)

In these experiments, an alpha particle may approach a gold nucleus to within a distance of 5×10^{-14} m. Calculate the electric force between them at this separation.

....

....

....

....

....

....

....

....

Force = ...

(3)
(Total 12 marks)

48. In 1995 scientists at CERN created, for the first time, anti-atoms of hydrogen. Each of these consisted of an anti-electron (a positron) in orbit around an antiproton. Each anti-atom produced survived for only about forty nanoseconds.

How do the properties of particles and antiparticles compare?

....

....

....

(1)

Show that the energy required to produce an antiproton is about 1 GeV.

....

....

....

....

....

(3)

Why did each anti-atom produced survive for only about forty nanoseconds?

....

....

....

....

(2)

Tick appropriate boxes in the table below to show the nature of each of the named particles.

	Meson	Baryon	Lepton
proton			
antiproton			
electron			
positron			

(2)

A proton consists of two up quarks and a down quark. Describe the quark structure of an antiproton and show how this structure provides the correct charge.

(Charge of up quark = $+\frac{2}{3}e$)

(Charge of down quark = $-\frac{1}{3}e$)

....

....

....

....

(2)
(Total 10 marks)

49. In the Rutherford scattering experiment, fast-moving alpha particles were fired at a thin gold foil. What observations from this experiment suggested that the atom has a small, massive nucleus?

....

....

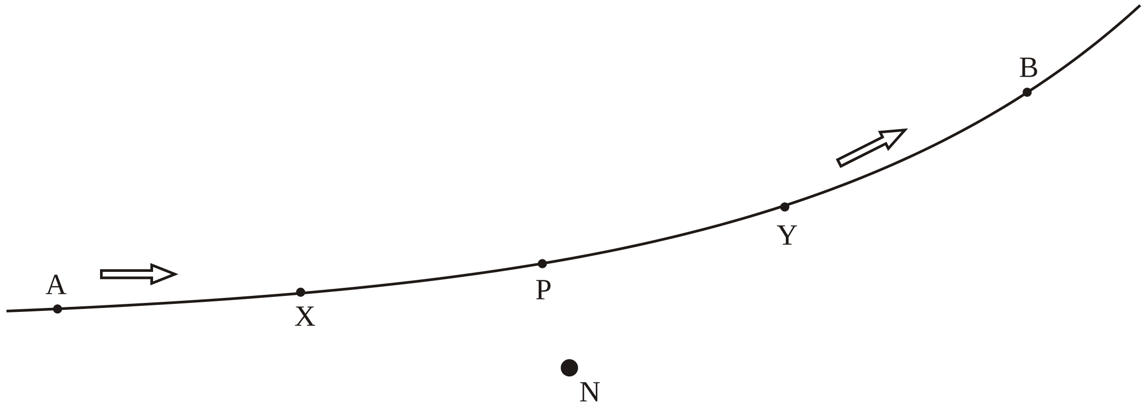
....

....

....

(2)

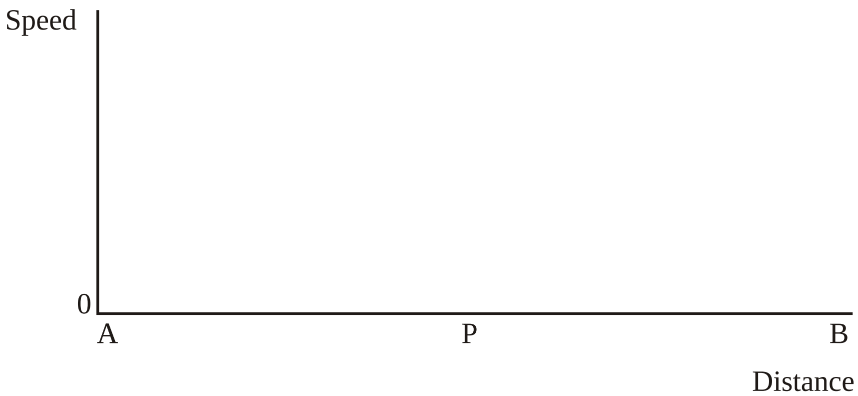
The diagram shows the path followed by one alpha particle which passes close to a gold nucleus N.



Add arrows to the diagram at points X and Y to show the direction of the force on the alpha particle when it is at each of these points.

(1)

The speed of the alpha particle was the same at points A and B. On the axes below, sketch a graph showing how the speed would vary with distance along the path from A to B.



(2)

With reference to the forces you added to the previous diagram, explain the shape of the graph.

....

....

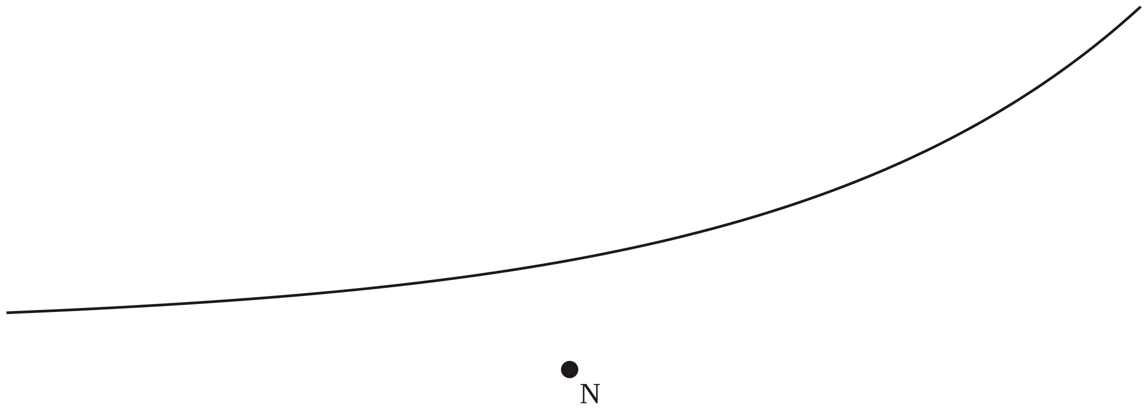
....

....

....

(2)

The diagram below shows the path of the alpha particle again.



Add a line to this diagram to show the path which would be followed by an alpha particle which was travelling initially along the same line as before, but more slowly.

(1)

The evidence for a small, massive nucleus from Rutherford scattering might have been less convincing if the alpha particles used had been of lower energy. Suggest how the observations would have changed if lower energy alpha particles had been used.

....

....

....

(1)
(Total 9 marks)

50. Give one similarity and one difference between an antiparticle and its particle pair.

Similarity: ....

Difference: ....

(2)

What is the quark composition of an antiproton?

....

(1)

State the baryon number of the antiproton.

....

(1)

At CERN protons and antiprotons, each of energy 45 GeV, were collided when trying to create W and Z particles. The antiprotons had to be stored until enough of them were available to be accelerated to the required energy.

Explain why it is difficult to store antiprotons.

....

....

....

(2)

What is the maximum possible mass which can be created from such a collision? Give your answer in u.

....

....

....

(3)

Give two reasons why the following interaction cannot take place.

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

....

....

....

....

(2)
(Total 11 marks)

51. Neutrons, like electrons, are often used to study crystal structure. A suitable de Broglie wavelength for the neutrons would be about 1 nm.

Explain why the neutrons must have a de Broglie wavelength of this order of magnitude.

....

....

....

(2)

Given the mass of a neutron as 1.67×10^{-27} kg, calculate the kinetic energy of a neutron which has a de Broglie wavelength of 1.20 nm.

....

....

....

....

....

Kinetic energy = ...

(3)
(Total 5 marks)

52. High energy X-rays can be used for radiation therapy for cancers.

An X-ray photon interacts with an atom to produce an electron-positron pair. The positron soon meets an electron and the energy is released, helping to destroy the cancer cells.

How do the properties of a positron compare with those of an electron?

....

....

....

(2)

Calculate the minimum energy of the X-ray photon in MeV.

....

....

....

....

....

....

Energy = ... MeV

(3)

Name the process that occurs when a positron meets an electron, and describe how this energy is released.

....

....

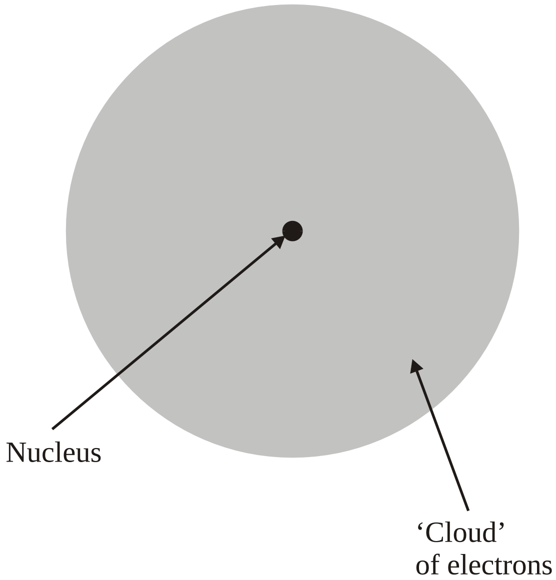
....

....

....

(3)
(Total 8 marks)

53. The nuclear atom may be represented as in the diagram.



Explain how the results of the alpha particle scattering experiment verify the nuclear model of the atom. You may be awarded a mark for the clarify of your answer.

....

....

....

....

....

....

....

....

....

....

(Total 5 marks)

54. A xi minus particle Ξ^- decays to a lambda particle Λ and a pi meson π as shown below.

$$\underset{(dss)}{\Xi^-} \rightarrow \underset{(uds)}{\Lambda} + \underset{(ud)}{\pi^-}$$

Classify each particle as either a baryon, a meson or a lepton.

Ξ^- ....

Λ ....

π^- ....

(3)

By considering the quark composition of the Ξ^- show that the strange quark has charge of $-\frac{1}{3}$.

....

....

(1)

Is the Λ particle positive, negative or neutral? Justify your answer.

....

....

....

(2)
(Total 6 marks)

55. A student hastily writes out some notes about particle physics. Some of the notes (shown below) contain errors.

Identify **three** of these errors. Draw a ring carefully round only the word or phrase that contains the error, and write below it a correct word, phrase or statement which could take the place of the wrong word or phrase you have ringed. An example has been given to show you what to do.

An electron, which is a lepton, has no antiparticle

an antiparticle

To every quark there is a corresponding antiquark.

Leptons are made from a quark and an antiquark.

A meson is nor made up from any smaller particles.

A proton is made from three quarks.

A neutron is made from a quark and an antiquark.

For the event: electron + positron → photons

- *a process called annihilation occurs*
- *momentum is conserved*
- *the equation $\Delta E = c^2 \Delta m$ can be used to calculate the total momentum of the photons*

(Total 6 marks)

56. Add the quark content of the proton to column (ii) of the table below.

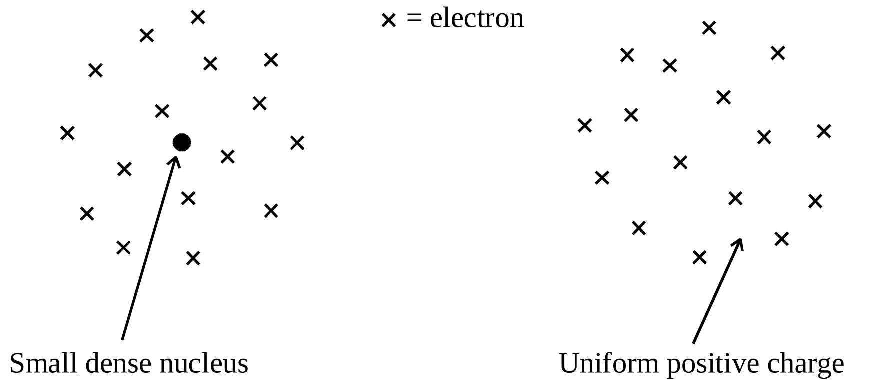
(i) particle	(ii) quark content	(iii) antiparticle	(iv) quark content
proton			
π^-	$d\bar{u}$		
K^0	$d\bar{s}$		

Complete column (iii) to give the antiparticles of the particles in column (i).

Complete column (iv) to show the quark content of the antiparticles.

(Total 5 marks)

57. Two possible structures of the atom were proposed in the early 1900s.They were the Rutherford and “plum pudding” models, as shown.



Rutherford model: a small dense nucleus surrounded by electrons

Plum pudding model: electrons embedded in a region of uniform positive charge

Geiger and Marsden scattered alpha particles off gold atoms. Outline the evidence from this experiment that supported Rutherford’s model.

....

....

....

....

....

....

(3)

Suggest what Geiger and Marsden would have observed if the “plum pudding” model had been correct.

....

....

Explain your answer.

....

....
(2)
(Total 5 marks)

58. State what is meant by a fundamental particle.

....

....

Circle any fundamental particles in the following list.

positron; neutron; muon; K^0 meson.
(3)

Explain why it is not possible to have a meson with a charge of +2. You may be awarded a mark for the clarity of your answer.

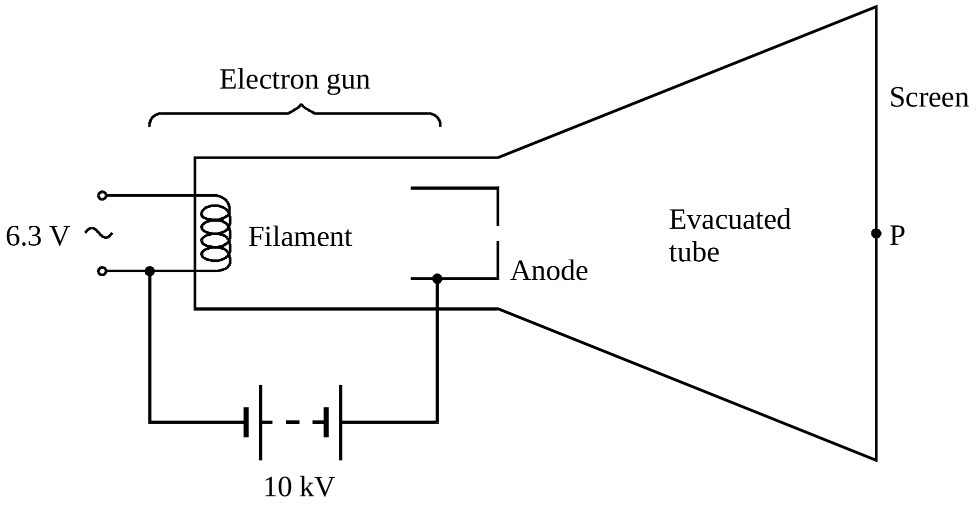
....

....

....

....
(3)
(Total 6 marks)

59. The diagram is of a simplified cathode ray tube.



An electron beam is produced by the electron gun in the tube. A beam of electrons emerges from the hole in the anode and strikes the screen at point P.

Explain why electrons are emitted from the surface of the filament.

....

....

(2)

Explain why the electrons move from the filament towards the anode.

....

....

(1)

The potential difference between the filament and the anode is 10 kV. Calculate the energy in joules of an electron emerging from the hole in the anode.

....

....

....

Energy = ... H

(2)

The electron beam forms a current of 1.5 mA. Show that the number of electrons passing through the hole in the anode is about 9×10^{15} per second.

....

....

....

(2)

Hence calculate the rate at which energy is being delivered to the screen by the beam of electrons.

....

....

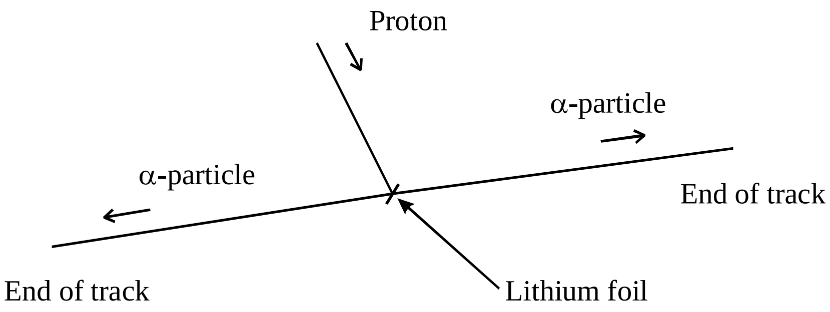
....

Rate = ...

(2)

(Total 9 marks)

60. In 1932 Cockroft and Walton accelerated protons through a few hundred kilovolts and directed them at a lithium-7 target placed in a cloud chamber. The diagram illustrates the outcome of the experiment.



(a) (i) What evidence is there in the diagram that the two α-particles have the same initial energy?

(ii) Write a nuclear equation for this event.

(4)

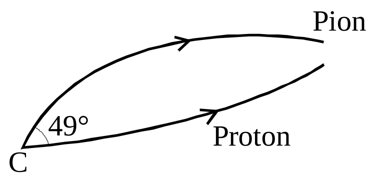
(iii) Calculate the kinetic energy of the pair of α-particles in joules, given

mass of proton = 1.007 28 u
mass of lithium nucleus = 7.014 37 u
mass of α-particle = 4.001 50 u

State any assumption you make.

(4)
(Total 8 marks)

61. A lambda particle enters a detection chamber, and decays, at point C, into a pion (which has charge –1) and a proton. The lambda particle itself leaves no visible track. A magnetic field acts at right angles to the plane of the diagram.



Explain how the diagram confirms that the pion is negatively charged.

....

....

....

....

(2)

State the charge carried by the lambda particle, explaining your reasoning.

....

....

....

....

(2)

Explain how you can deduce from the diagram that the proton has more momentum than the pion.

....

....

....

....

(2)

The angle between the proton and the pion tracks at point C is 49°. The momentum of the proton is 6.0×10^{-18} kg m s^{-1}, and the momentum of the pion is 5.0×10^{-18} kg m s^{-1}. Use a scale drawing to find the magnitude of the momentum of the lambda particle.

(3)

The quark composition of two of the three particles is as follows:

pion	$u\bar{d}$	lambda	uds

Particles composed of quarks are classified as either baryons or mesons. Tick the correct classification for each of these two particles.

	baryon	meson
pion	....	....
lambda	....	....

(2)

The charge of an up quark (u) is $+\frac{2}{3}e$.

Deduce the charge of a down quark (d).

....

(1)
(Total 12 marks)

62. State one similarity and one difference between a proton and an antiproton.

Similarity ....

Difference ....

....

(2)

Write down two particle-antiparticle pairs of leptons.

....

....

(2)

What happens when a particle and its antiparticle collide?

....

....

(1)
(Total 5 marks)

63. The electron in a hydrogen atom can be described by a stationary wave which is confined within the atom. This means that its de Broglie wavelength must be similar to the size of the atom, of the order of 10^{-10} m.

Calculate the speed of an electron whose de Broglie wavelength is 1.0×10^{-10} m.

....

....

....

Speed = ...

Calculate the kinetic energy of this electron, in electron volts.

....

....

....

....

Kinetic energy = ... eV

(5)

When β radiation was first discovered, it was suggested that the atomic nucleus must contain electrons. However, it was soon realised that this was impossible because such electrons would possess far too much energy to be bound within the nucleus. Using the ideas of the earlier parts of this question, suggest why an electron confined within the nucleus would have a very high energy.

....

....

....

....

....

....

(2)
(Total 7 marks)

64. The family of quarks is shown below, together with the charge and mass of each.

quark	**charge**	**mass (GeV/c^2)**
up	$+\frac{2}{3}$	0.005
down	$-\frac{1}{3}$	0.01
strange	$+\frac{2}{3}$	0.2
charm	$+\frac{2}{3}$	1.3
bottom	$-\frac{1}{3}$	4.3
top	$+\frac{2}{3}$	180

What is meant by "charge = $+\frac{2}{3}$"?

....

....
(2)

Calculate the mass of the strange quark in kilograms.

....

....

....

....

Mass = ... kg
(2)

What would be the charge and mass of the anti-particle to the charm quark? (Use the same units as in the table above.)

....

....
(2)

The top quark was predicted by theoretical physicists several years before it was actually found experimentally in 1994. What made them confident that the top quark existed?

....

....

(1)

Give one reason why it took such a long time to find experimental evidence for the top quark.

....

....

(1)

In their search for the top quark, physicists thought that another particle called the W might decay while stationary into one top and one bottom quark.

They predicted *"The resulting top quark moves off relatively sluggishly on one side while the lighter bottom quark travels more rapidly in the opposite direction".*

Using an appropriate conservation law, explain why the top quark moves off more sluggishly than the bottom quark.

....

....

....

....

(3)
(Total 11 marks)

65. An atom of antihydrogen (a positron orbiting around an antiproton) has been produced.

Is an atom of antihydrogen positive, negative or neutral?

....

(1)

State the quark composition of an antiproton.

....

(1)

Show that an antiproton has a charge of –1.

....

....

(1)

Explain why it is extremely difficult to store antimatter.

....

....

....

....

(2)

Complete the following quark table.

Quarks			Charge
up	charm		+2/3
down	strange		–1/3

(1)

Selecting from the shaded boxes only, use the table to deduce the quark composition of the following particles.

(i) A neutral strange meson

....

(ii) A positive charmed meson

....

(iii) A neutral strange baryon

....

(3)
(Total 9 marks)

66. Use the laws of conservation of charge and baryon number to decide whether the following reactions are possible or not possible. In each case show how you applied the laws. Pions (π^+, π^- and π^0) are mesons.

(i) $\pi^- + p \rightarrow n + \pi^- + \pi^+ + \pi^0$

....

....

....

(ii) $p + p \rightarrow p + p + p + \overline{p}$

....

....

....

(Total 4 marks)

67. In February 2000 scientists at CERN announced that they had made some “quark-gluon plasma” (QGP) - the extremely dense energetic matter that was present throughout the universe about 1 μs after the Big Bang. They did this by colliding lead ions in the accelerator.

A particular isotope of lead (symbol Pb) has 82 protons and 124 neutrons in its nucleus.

Complete the symbol for this particular nucleus.

$$^{\cdots\cdots}_{\cdots\cdots}\mathbf{Pb}$$

What other particles are present in a neutral atom of this lead isotopes

....

(1)

When QGP existed in the early universe, all the particles listed in the table below were present.

Quarks			Leptons		
Name	Symbol	Charge	Name	Symbol	Charge
up	u	+2/3	electron	e^-	–1
down	d	–1/3	electron-neutrino	ν_e	0
charm	c	+2/3	muon	μ	–1
strange	s	–1/3	muon-neutrino	ν_μ	0
top	t	+2/3	tau	τ^-	–1
bottom	b	–1/3	tau-neutrino	ν_τ	0

Protons and neutrons are made entirely of up and down quarks. Show how an appropriate number of quarks can combine to give the correct charge for a proton.

....

....

....

(2)

Explain briefly what circumstances are required for the remaining quarks in the table to be created.

....

....

....

....

(2)

The early universe also contained positrons. Describe how the positron relates to one of the particles in the table.

....

....

....

....

(2)
(Total 8 marks)

68. The following strong interaction has been observed.

$$K^- + p \rightarrow n + X$$

The K^- is a strange meson of quark composition $\bar{u}s$.

The u quark has a charge of +2/3.

The d quark has a charge of –1/3.

Deduce the charge of the strange quark.

....

(1)

Use the appropriate conservation law to decide whether particle X is positive, negative or neutral.

....

....

(2)

Is particle X a baryon or a meson? Show how you obtained your answer.

....

....

(2)

State the quark composition of X. Justify your answer.

....

....

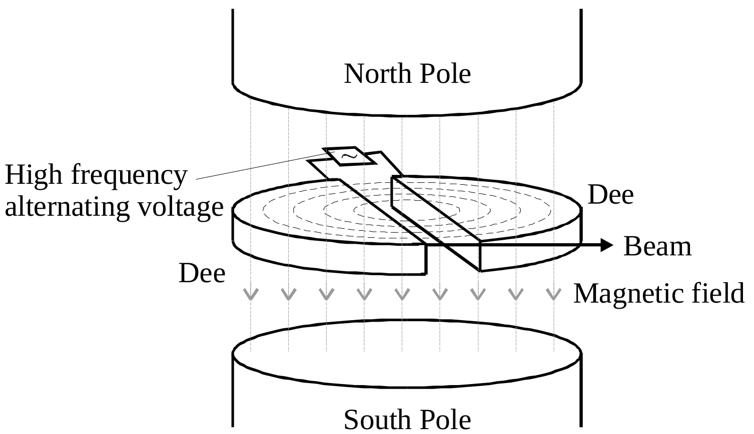
....

....

....

(3)
(Total 8 marks)

69. Some radioisotopes for use in hospital treatments have short half-lives. These radioisotopes are manufactured in the hospital where they will be used. Some hospitals use a relatively cheap machine such as a cyclotron to produce a beam of high energy protons. This beam is allowed to collide with the target material to produce the radioisotope.



In a cyclotron. the protons are accelerated by a high frequency alternating voltage. A uniform magnetic field. of strength 200 mT. causes the protons to follow a circular path which increases in radius as the protons gain kinetic energy.

Immediately before the protons leave the cyclotron they are moving in a circular arc of radius 1.5 m.

Show that the speed of these protons is about 10% of the speed of light.

....

....

....

....

(3)

Calculate the approximate time taken for the proton to complete the last semi-circle of its orbit.

....

Time =...

(2)

Hence calculate the frequency of the accelerating p.d.

....

Frequency =...

(1)
(Total 6 marks)

70. The results of particle collisions are observed using particle detectors. Sometimes the products of these collisions are themselves unstable and decay to give further particles; the products of decay can be photons.

In one collision, a stationary π^o meson is produced which then decays to give two gamma ray photons. The rest mass of the meson is 135 MeV/c^2.

$$\pi^o \rightarrow \gamma + \gamma$$

Calculate the wavelength of each photon.

....

....

....

....

....

....

....

....

....

Wavelength =..

(5)

(Total 5 marks)

71. One way of producing neutrons for experiments is to fire a beam of protons at a target of lithium metal. The interaction between a proton and a lithium nucleus produces a beryllium nucleus.

Complete the nuclear equation shown below which describes this reaction.

$${}^{7}_{3}\text{Li} \quad + \quad \text{p} \quad \rightarrow \quad \text{Be} \; + \quad \text{n}$$

(2)

Useful data:

Accelerating voltage for protons	= 2.8 MV
Beam current	= 2.0 mA
Area of lithium target	= $1.2 \times 10^{-3} m^2$

All protons are stopped within 280 μm of the target surface.

Calculate the rate at which energy is transferred by the beam of protons to the target.

....

....

Rate of energy transfer = ...

(2)

Show that energy is absorbed in the surface layer at the rate of 17 GW per cubic metre.

....

....

....

....

(2)

Suggest a problem this may cause.

....

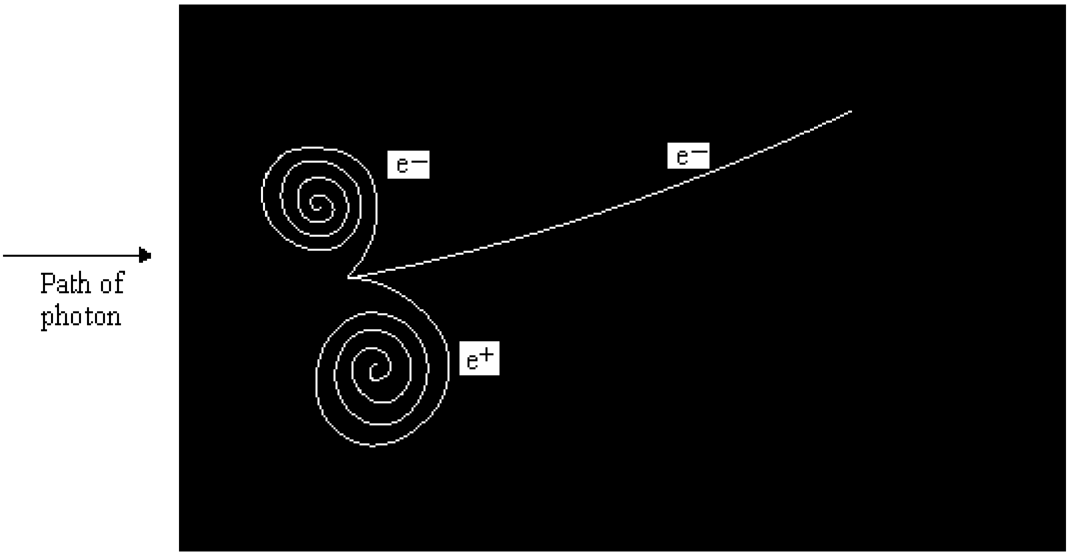
....

(1)

(Total 7 marks)

72. Collisions between sub-atomic particles can be observed using a bubble chamber by taking a photograph of the tracks left by the particles as they move through the magnetic field in the chamber. Photons produce very few ions and so they cannot be seen in bubble chamber photographs.

This question is about the interaction between an atomic electron and a photon which has entered the chamber from the left in the direction shown. The photograph shows the result of this interaction.



The interaction has caused the release of the atomic electron and the creation of an electron-positron pair. The tracks of these three particles can be seen.

Explain how you can deduce that the magnetic field acts out of the plane of the photograph.

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

(2)

Explain which e^- moves faster.

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

(1)

Measurements from the photograph show the initial radius of curvature of the positron to be r = 0.048 m. Calculate the momentum of the positron if the magnetic field strength is B = 5.4×10^{-3}T.

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

Momentum = ………………………..

(2)

Explain why the path of the positron is a spiral.

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

(1)

In interactions such as these, charge, energy and momentum are always conserved. For the interaction shown in the photograph, discuss the conservation of any *two* of these properties.

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

(5)

(Total 11 marks)

73. Read the following paragraph carefully and CIRCLE the correct response to the choices in the brackets.

Geiger and Marsden carried out an experiment to investigate the structure of the atom.

In this experiment $\begin{Bmatrix}\text{Alpha particles}\\ \text{Beta particles}\\ \text{Gamma rays}\end{Bmatrix}$ were $\begin{Bmatrix}\text{diffracted}\\ \text{refracted}\\ \text{scattered}\end{Bmatrix}$ by thin films of metals such as gold.

The experiment led to the conclusion that the atom had an $\begin{Bmatrix}\text{uncharged}\\ \text{negatively charged}\\ \text{positively charged}\end{Bmatrix}$ nucleus of

diameter approximately $\begin{Bmatrix}10^{-15}\text{ m}\\ 10^{-10}\text{ m}\end{Bmatrix}$ and containing $\begin{Bmatrix}\text{all the mass}\\ \text{most of the mass}\\ \frac{1}{2000}\text{ of the mass}\end{Bmatrix}$ of the atom.

(Total 5 marks)