Particles

Q1.

(a) Describe the interaction that is responsible for keeping protons and neutrons together in a stable nucleus.
You should include details of the properties of the interaction in your answer.

(3)

(b) Nuclei can decay by alpha decay and by beta decay.

In alpha decay only one particle is emitted but in beta decay there are two emitted particles.

Explain how baryon number is conserved in alpha and beta decay.

(3)

(c) Kaons are mesons that can be produced by the strong interaction between pions and protons.

The equation shows a reaction in which a kaon and a lambda particle are produced.

$$\pi^{-} + p \rightarrow K^{0} + \Lambda^{0}$$

Deduce the quark structure of the Λ^0

quark structure = ____________________

(2)

(d) The kaon decays by the weak interaction.

The equation shows an example of kaon decay.

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

State **one** feature of this decay that shows it is an example of the weak interaction.

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(1)

(e) There have been considerable advances in our understanding of particle physics over the past 100 years.

Explain why it is necessary for many teams of scientists and engineers to collaborate in order for these advances to be made.

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(2)

(Total 11 marks)

Q2.

A radioactive source emits alpha particles each with 8.1×10^{-13} J of kinetic energy.

(a) Show that the velocity of an alpha particle with kinetic energy 8.1×10^{-13} J is approximately 2×10^7 m s^{-1}

specific charge of an alpha particle = 4.81×10^7 C kg^{-1}

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(2)

(b) The alpha particles travel through air in straight lines with a range of 3.5 cm

Calculate the average force exerted on an alpha particle as it is stopped by the air.

average force = ____________________ N

(2)

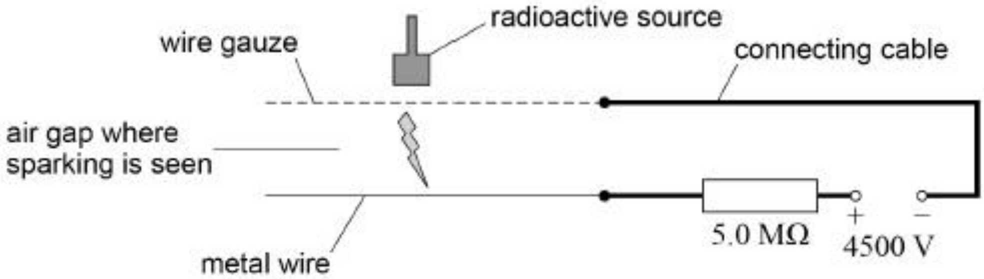
(c) An alpha particle transfers all its kinetic energy to air molecules and produces 5.1×10^4 ions per centimetre over its range of 3.5 cm

Calculate the average ionisation energy, in eV, of a molecule of air.

ionisation energy = ____________________ eV

(3)

(d) A spark counter consists of a wire gauze separated from a metal wire by a small air gap. A power supply with an output of 4500 V is connected in series with a 5.0 MΩ resistor and the spark counter as shown in the diagram. When the radioactive source is moved close to the wire gauze, sparking is seen in the air gap.



Sparks are produced when alpha particles produce ionisation in the air gap.

One ionisation event produces a current of 0.85 mA for a time of 1.2 ns

Calculate the number of charge carriers that pass a point in the connecting cable during this ionisation event.

number of charge carriers = ____________________

(2)

(e) The radioactive source was positioned 10 cm above the wire gauze before being moved slowly towards the wire gauze leading to the ionisation event in part **(d)**.

Discuss how the potential difference across the air gap varied as the radioactive source was moved over this distance.

Assume the power supply has negligible internal resistance.

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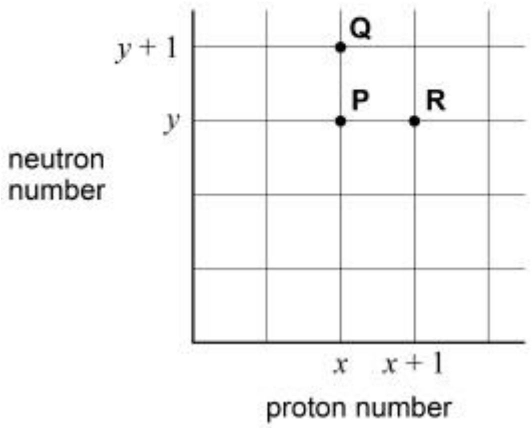
(3)
(Total 12 marks)

Q3.

The graph of neutron number against proton number shows three nuclei **P**, **Q** and **R**.



Which row identifies an isotope of **P** and the nucleon number of this isotope of **P**?

	Isotope of P	Nucleon number of isotope of P	
A	**Q**	$y + 1$	⬭
B	**Q**	$x + y + 1$	⬭
C	**R**	$x + y + 1$	⬭
D	**R**	$x + 1$	⬭

(Total 1 mark)

Q4.

$^{236}_{92}U$ undergoes a series of decays to produce $^{204}_{82}Pb$.

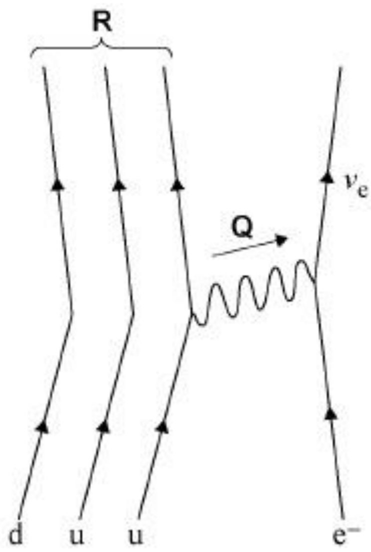
How many alpha decays are involved in this decay series?

A	5	○
B	6	○
C	8	○
D	10	○

(Total 1 mark)

Q5.

The partially completed diagram represents electron capture.



Which row identifies the exchange particle **Q** and the quark structure of particle **R**?

	Particle Q	Quark structure of particle R	
A	W^-	uuu	○
B	W^+	dud	○
C	W^+	uuu	○
D	W^-	dud	○

(Total 1 mark)

Q6.

The decay of a neutral kaon K^0 is given by the equation

$$K^0 \rightarrow X + Y + \overline{\nu}_e$$

What are X and Y?

	X and Y	
A	e^+ and e^-	⬭
B	μ^+ and e^-	⬭
C	π^+ and e^-	⬭
D	π^- and e^+	⬭

(Total 1 mark)

Q7.

Fluoride ions are produced by the addition of a single electron to an atom of fluorine $^{19}_{9}F$.

What is the magnitude of specific charge of the fluoride ion?

A 3.2×10^{-26} C kg^{-1} ⬭

B 8.4×10^{-21} C kg^{-1} ⬭

C 5.0×10^{6} C kg^{-1} ⬭

D 4.5×10^{7} C kg^{-1} ⬭

(Total 1 mark)

Q8.

Two gamma photons are produced when a muon and an antimuon annihilate each other.

What is the minimum frequency of the gamma radiation that could be produced?

A 2.55×10^{16} Hz ⬭

B 5.10×10^{16} Hz ⬭

C 2.55×10^{22} Hz ⬭

D 5.10×10^{22} Hz ⬭

(Total 1 mark)

Q9.

The Σ^0 baryon, composed of the quark combination uds, is produced through the strong interaction between a π^+ meson and a neutron.

$$\pi^+ + n \rightarrow \Sigma^0 + X$$

What is the quark composition of X?

A $u\bar{s}$ ○

B ud ○

C $u\bar{d}$ ○

D $ud\bar{s}$ ○

(Total 1 mark)

Q10.

An iodine nucleus decays into a nucleus of Xe−131, a beta-minus particle and particle Y.

$$^{131}_{53}\mathrm{I} \rightarrow {}^{131}_{54}\mathrm{Xe} + {}^{0}_{-1}\mathrm{e} + \mathrm{Y}$$

Which is a property of particle Y?

A It has a lepton number of +1 ○

B It is an antiparticle ○

C It is negatively charged ○

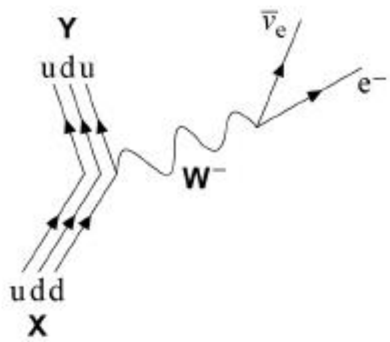
D It experiences the strong interaction ○

(Total 1 mark)

Q11.

The diagram below represents the decay of a particle **X** into a particle **Y** and two other particles.

The quark structure of particles **X** and **Y** are shown in the diagram.



(a) Deduce the name of particle **X**.

____ **(1)**

(b) State the type of interaction that occurs in this decay.

____ **(1)**

(c) State the class of particles to which the **W**$^-$ belongs.

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(1)

(d) Show clearly how charge and baryon number are conserved in this interaction.

You should include reference to all the particles, including the quarks, in your answer.

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(2)

(e) Name the only stable baryon.

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(1)

(f) A muon is an unstable particle.

State the names of the particles that are produced when a muon decays.

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(1)
(Total 7 marks)

Q12.

Which row shows the correct interactions experienced by a hadron or a lepton?

	Particle	Strong interaction	Weak interaction	
A	Hadron	Yes	Yes	☐
B	Lepton	Yes	Yes	☐
C	Hadron	Yes	No	☐
D	Lepton	Yes	No	☐

(Total 1 mark)

Q13.

When a nucleus of the radioactive isotope $^{65}_{28}Ni$ decays, a β$^-$ particle and an electron antineutrino are emitted.

How many protons and neutrons are there in the resulting daughter nucleus?

	Number of protons	Number of neutons	
A	28	65	⬭
B	29	65	⬭
C	29	36	⬭
D	30	35	⬭

(Total 1 mark)

Q14.

What interactions are involved in the production of a strange particle and its decay into non-strange particles?

	Production	Decay	
A	strong	weak	⬭
B	strong	strong	⬭
C	weak	strong	⬭
D	weak	weak	⬭

(Total 1 mark)

Q15.

An isotope of potassium $^{40}_{19}K$ is used to date rocks. The isotope decays into an isotope of argon (Ar) mainly by electron capture.

(a) The decay is represented by this equation:

$$^{40}_{19}K + {}^{0}_{-1}e \rightarrow {}^{\_}_{\_}Ar + \_\_\_\_\_$$

Complete the equation to show the decay by filling in the gaps.

(2)

(b) Explain which fundamental interaction is responsible for the decay in question (a).

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(2)

(c) One decay mechanism for the decay of $^{40}_{19}K$ results in the argon nucleus having an excess energy of 1.46 MeV. It loses this energy by emitting a single gamma photon.

Calculate the wavelength of the photon released by the argon nucleus.

wavelength = ____________________ m

(3)

(d) The potassium isotope can also decay by a second decay process to form a calcium-40 nuclide ($^{40}_{20}Ca$).

Suggest how the emissions from a nucleus of decaying potassium can be used to confirm which decay process is occurring.

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(3)

(Total 10 marks)

Q16.

An atom of $^{16}_{7}N$ gains 3 electrons.

What is the specific charge of the ion?

A 1.80×10^{7} C kg^{-1} ☐

B -1.80×10^{7} C kg^{-1} ☐

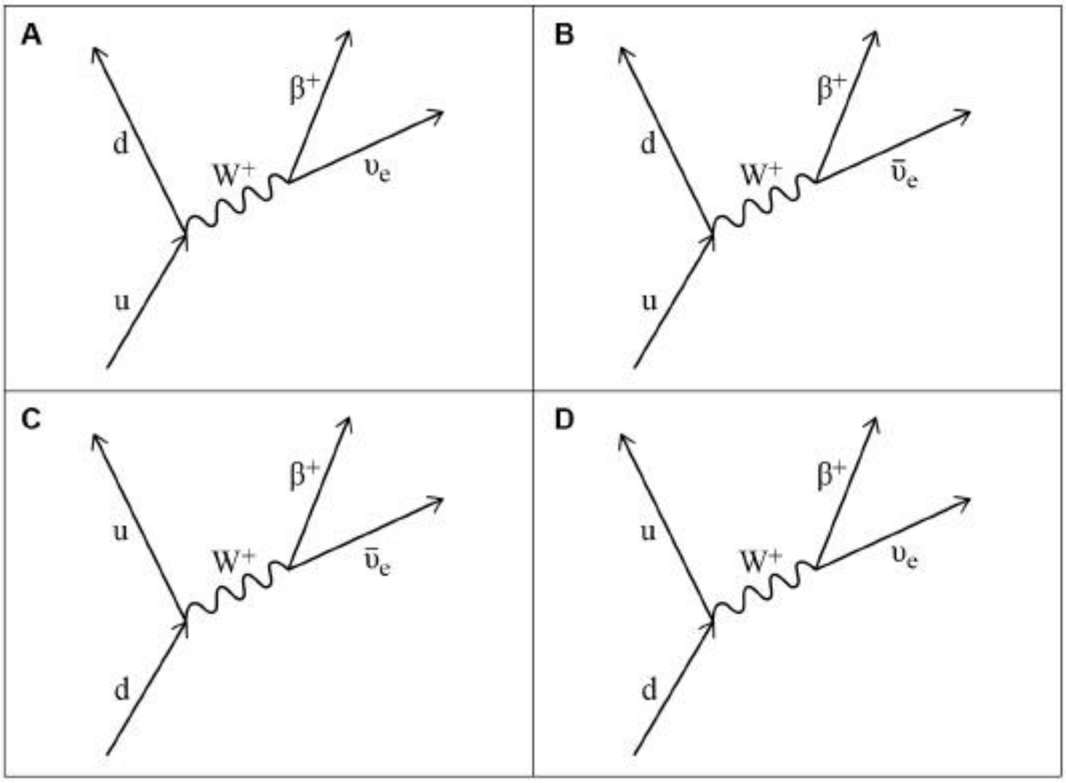
C 4.19×10^{7} C kg^{-1} ☐

D -4.19×10^{7} C kg^{-1} ☐

(Total 1 mark)

Q17.

Which diagram represents the process of beta-plus decay?



A ☐

B ☐

C ☐

D ☐

(Total 1 mark)

Q18.

A beam of light of wavelength λ is incident on a clean metal surface and photoelectrons are emitted. The wavelength of the light is halved but energy incident per second is kept the same.

Which row in the table is correct?

	Maximum kinetic energy of the emitted photoelectrons	Number of photoelectrons emitted per second	
A	Increases	Unchanged	☐
B	Decreases	Increases	☐
C	Increases	Decreases	☐
D	Decreases	Unchanged	☐

(Total 1 mark)

Q19.

Electrons moving in a beam have the same de Broglie wavelength as protons in a separate beam moving at a speed of 2.8×10^4 m s^{-1}.

What is the speed of the electrons?

A 1.5×10^1 m s^{-1}

B 2.8×10^4 m s^{-1}

C 1.2×10^6 m s^{-1}

D 5.1×10^7 m s^{-1}

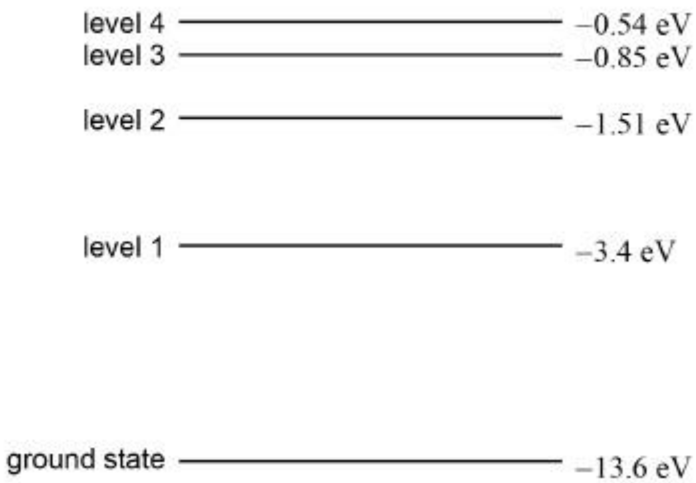
(Total 1 mark)

Q20.

The diagram shows an energy level diagram for a hydrogen atom.

Electrons with energy 13.0 eV collide with atoms of hydrogen in their ground state.

What is the number of different wavelengths of electromagnetic radiation that could be emitted when the atoms de-excite?



A 0

B 3

C 6

D 7

(Total 1 mark)

Q21.

The Rutherford scattering experiment led to

A the discovery of the electron.

B the quark model of hadrons. ○

C the discovery of the nucleus. ○

D evidence for wave-particle duality. ○

(Total 1 mark)

Q22.

A Geiger counter is placed near a radioactive source and different materials are placed between the source and the Geiger counter.

The results of the tests are shown in the table.

Material	Count rate of Geiger counter / s^{-1}
None	1000
Paper	1000
Aluminium foil	250
Thick steel	50

What is the radiation emitted by the source?

A α only ○

B α and γ ○

C α and β ○

D β and γ ○

(Total 1 mark)

Q23.

Nobelium-259 has a half-life of 3500 s.

What is the decay constant of nobelium-259?

A $8.7 \times 10^{-5}\ s^{-1}$ ○

B $2.0 \times 10^{-4}\ s^{-1}$ ○

C $1.7 \times 10^{-2}\ s^{-1}$ ○

D $1.2 \times 10^{-2}\ s^{-1}$ ○

(Total 1 mark)

Q24.

Cosmic rays are high-energy particles coming from Space. They collide with the air molecules in the Earth's atmosphere to produce pions and kaons.

(a) Pions and kaons are mesons. Identify the quark–antiquark composition for a meson.

Tick (✓) the correct answer in the right-hand column.

	✓ if correct
qqq	
$q\bar{q}\bar{q}$	
$q\bar{q}$	
qq	

(1)

(b) A positron with a kinetic energy of 2.0 keV collides with an electron at rest, creating two photons that have equal energy.

Show that the energy of each photon is 8.2×10^{-14} J.

(3)

(c) Calculate the wavelength of a photon of energy 8.2×10^{-14} J.

wavelength = ________________________ m

(2)

(d) Show that the speed of the positron before the collision was about 2.7×10^{7} m s^{-1}.

(3)

(e) Calculate the de Broglie wavelength of the positron travelling at a speed of 2.7×10^{7} m s^{-1}.

wavelength = ______________________ m

(2)

(f) The separation between the carbon atoms in graphite is about 0.15 nm.

Discuss whether electrons travelling at 2.7×10^7 m s^{-1} can be can be used to demonstrate diffraction as they pass through a sample of graphite.

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(4)

(Total 15 marks)

Q25.

Which of the following nuclei has the smallest specific charge?

A $^{1}_{1}H$ ☐

B $^{12}_{6}C$ ☐

C $^{14}_{6}C$ ☐

D $^{235}_{92}U$ ☐

(Total 1 mark)

Q26.

$^{232}_{90}Th$ is an unstable nuclide in a radioactive decay series. It decays by emitting an α particle. The next two nuclides in the series emit β^- particles.

What nuclide is formed after these three decays have taken place?

A $^{230}_{90}Th$ ☐

B $^{228}_{92}U$ ☐

C $^{228}_{88}Ra$ ☐

D $^{228}_{90}Th$ ☐

(Total 1 mark)

Q27.

Which line does **not** give the correct exchange particle for the process?

	Process	Exchange particle	
A	gravitational attraction	W boson	☐
B	electrostatic repulsion of electrons	virtual photon	☐
C	strong interaction	pion	☐
D	β^- decay	W boson	☐

(Total 1 mark)

Q28.

Which line correctly classifies the particle shown?

	Particle	Category	Quark combination	
A	neutron	baryon	$\bar{u}d$	☐
B	neutron	meson	udd	☐
C	proton	baryon	uud	☐
D	positive pion	meson	$\bar{u}d$	☐

(Total 1 mark)

Q29.

Which of the following statements about muons is **incorrect**?

A A muon is a lepton. ☐

B A muon has a greater mass than an electron. ☐

C If a muon and an electron each have the same de Broglie wavelength then they each have the same momentum. ☐

D A muon with the same momentum as an electron has a larger kinetic energy than the electron. ☐

(Total 1 mark)

Q30.

What is the best estimate for the order of magnitude for the diameter of an atom?

A 10^{-14} m ☐

B 10^{-12} m ☐

C 10^{-11} m ☐

D 10^{-8} m ☐

(Total 1 mark)

Q31.

More than 200 subatomic particles have been discovered so far. However, most are not fundamental and are composed of other particles including quarks.

It has been shown that a proton can be made to change into a neutron and that protons and neutrons are made of quarks.

(a) Name **one** process in which a proton changes to a neutron.

___

___

(1)

(b) Name the particle interaction involved in this process.

___

___

(1)

(c) Write down an equation for the process you stated in part **(a)** and show that the baryon number and lepton number are conserved in this process.

baryon number ___

___

___

lepton number ___

___

___

(2)

(d) The strange quark was used to explain the existence of particles whose tracks had been seen in experiments in the early 1950s. These were unexplained at that time and were referred to as 'strange particles'. One of these particles was later named the K^+ kaon.

State the quark composition of a K^+ kaon.

___

___

(1)

(e) A K^+ kaon decays into a π^+ particle and a π° particle.

Explain **one** property which is conserved and **one** property which is not conserved in this decay.

conserved ____

____

not conserved ____

(2)

(Total 7 marks)

Q32.

Which nucleus has a smaller value of specific charge than the nucleus $^{18}_{8}O$?

A $^{7}_{3}Li$ ☐

B $^{11}_{5}B$ ☐

C $^{13}_{6}C$ ☐

D $^{37}_{17}Cl$ ☐

(Total 1 mark)

Q33.

When bombarded with an α particle the nuclide $^{25}_{12}Mg$ changes into another nuclide with the emission of a neutron and γ radiation.

What are the correct values for the nucleon number and proton number of the nuclide which is formed?

	Nucleon number	Proton number	
A	29	14	☐
B	29	12	☐
C	28	14	☐
D	27	12	☐

(Total 1 mark)

Q34.

Which sequence of radioactive emissions results in the formation of an isotope of the original element?

A one α particle and one β^- particle ☐

B one α particle and two β^- particles ☐

C two α particles and one β^- particle ☐

D two α particles and two β^- particles ☐

(Total 1 mark)

Q35.

Which statement concerning the forces between particles is **incorrect**?

A Leptons experience the weak interaction. ☐

B Leptons experience the strong interaction. ☐

C Hadrons experience the weak interaction. ☐

D Hadrons experience the strong interaction. ☐

(Total 1 mark)

Q36.

What of the following is a hadron of zero charge?

A neutrino ☐

B photon ☐

C proton ☐

D neutron ☐

(Total 1 mark)

Q37.

Two coherent sources generate sound waves of wavelength 0.40 m. The waves leave the sources in phase. A detector some distance from the sources receives the sound waves. The path difference between the detector and the sources is 0.90 m.

What is the phase difference between the waves arriving at the detector?

A zero ☐

B 45° ☐

C 90° ☐

D 180° ☐

(Total 1 mark)

Q48.

A nucleus of a particular element decays, emitting a series of α and β^- particles.

Which of the following series of emissions would result in an isotope of the original element?

A $1\ \alpha$ and $1\ \beta^-$ ○

B $1\ \alpha$ and $2\ \beta^-$ ○

C $2\ \alpha$ and $1\ \beta^-$ ○

D $2\ \alpha$ and $2\ \beta^-$ ○

(Total 1 mark)

Q49.

Which equation shows the process of annihilation?

A $\pi^- + \pi \longrightarrow \gamma$ ○

B $p + \overline{p} \rightarrow \gamma + \gamma$ ○

C $\beta^- + p \longrightarrow \gamma$ ○

D $\gamma + \gamma \longrightarrow \beta^+ + \beta^-$ ○

(Total 1 mark)

Q50.

Which of the following is **not** made of quarks?

A kaon ○

B muon ○

C neutron ○

D pion ○

(Total 1 mark)

Q51.

What is the quark structure for antiprotons?

A $\bar{u}\bar{d}$ ○

B $\bar{d}\bar{d}\bar{s}$ ○

C $\bar{d}\bar{d}\bar{u}$ ○

D $\bar{u}\bar{u}\bar{d}$ ○

(Total 1 mark)

Q52.

The element uranium has an isotope $^{237}_{92}U$.

(a) Explain what is meant by an isotope.

____

____

____

____

(2)

(b) Determine the charge in coulomb of the $^{237}_{92}U$ nucleus.

charge = ______________________ C

(2)

(c) A positive ion of $^{237}_{92}U$ has a charge of $+4.80 \times 10^{-19}$ C.

Determine the number of electrons in the ion.

number of electrons = ______________________

(2)

(d) $^{237}_{92}U$ decays by β^- emission to form an isotope of neptunium (Np).

Complete the equation for this decay.

$$^{237}_{92}U \rightarrow \,^{\cdots\cdots}_{\cdots\cdots}Np + \,^{\cdots\cdots}_{\cdots\cdots}\beta^- + \ldots\ldots\ldots$$

(3)

(Total 9 marks)

Q53.

The positive kaon (K⁺) has a strangeness of +1.

(a) Which of the following is the quark composition of the positive kaon?
Tick (✓) the correct answer.

	✓ if correct
$\bar{u}s$	

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

(1)

(b) The equation shows a possible decay of the positive kaon.

$$K^+ \longrightarrow \mu^+ + \nu_\mu$$

(i) Show that lepton number is conserved in this decay.

(1)

(ii) State a quantity that is not conserved in this decay.

____

(1)

(iii) Complete the following table using ticks to indicate correct classifications for each particle. The first column has been completed for you.

	Charged	**Hadron**	**Meson**	**Baryon**	**Lepton**
K^+	✓				
μ^+	✓				
ν_μ					

(3)

(c) The positive kaon can also decay to form a π^+ and one other particle X.
Deduce the identity of X.

____

____

____

____

____

____

(3)

(Total 9 marks)

Q54.

Under certain conditions a photon may be converted into an electron and a positron.

(a) State the name of this process.

____

(1)

(b) For the conversion to take place the photon has to have an energy equal to or greater than a certain minimum energy.

(i) Explain why there is a minimum energy.

____

____

(2)

(ii) Show that this minimum energy is about 1 MeV.

(1)

(iii) Explain what happens to the excess energy when the photon energy is greater than the minimum energy.

____

____

(1)

(iv) A photon has an energy of 1.0 MeV.

Calculate the frequency associated with this photon energy.
State an appropriate unit in your answer.

frequency = __________ unit = __________

(4)

(Total 9 marks)

Q55.

(a) Name the only stable baryon.

____

(1)

(b) (i) When aluminium-25($^{25}_{13}$Al) decays to magnesium-25 (Mg-25) an electron neutrino (ν_e) and another particle are also emitted.

Complete the equation to show the changes that occur.

$$^{25}_{13}\text{Al} \rightarrow \,^{25}_{\cdots\cdots}\text{Mg} + \,^{\cdots\cdots}_{\cdots\cdots}\cdots\cdots\cdots + \nu_e$$

(2)

(ii) Name the exchange particle responsible for the decay.

____

(1)

(Total 4 marks)

Q56.

The table below contains five statements that refer to isotopes and some radium isotopes.

	$^{223}_{88}\text{Ra}$	$^{224}_{88}\text{Ra}$	$^{225}_{88}\text{Ra}$	$^{226}_{88}\text{Ra}$
Isotope with the smallest mass number	✓			
Isotope with most neutrons in nucleus				
Isotope with nucleus which has the largest specific charge				
Isotope decays by β^- decay to form $^{225}_{89}\text{Ac}$				
Isotope decays by alpha decay to form $^{220}_{86}\text{Rn}$				

(a) Complete the table by ticking **one** box in each row to identify the appropriate isotope. The first row has been completed for you.

(4)

(b) (i) An atom of one of the radium isotopes in the table is ionised so that it has a charge of $+3.2 \times 10^{-19}$ C.

State what happens in the process of ionising this radium atom.

____

____

(1)

(ii) The specific charge of the ion formed is 8.57×10^{5} C kg^{-1}.

Deduce which isotope in the table has been ionised. Assume that both the mass of a proton and the mass of a neutron in the nucleus is 1.66×10^{-27} kg.

isotope = ____________________

(3)
(Total 8 marks)

Q57.

The equation shows an interaction between a proton and a negative kaon that results in the formation of particle, X.

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

(a) (i) State and explain whether X is a charged particle.

____

____

(2)

(ii) State and explain whether X is a lepton, baryon or meson.

____

____

(2)

(iii) State the quark structure of the K^-, K^+ and the K^0.

K^- ____

K^+ ____

K^0 ____

(3)

(iv) Strangeness is conserved in the interaction.

Determine, explaining your answer, the quark structure of X.

____

____

____

____

(3)
(Total 10 marks)

Q58.

(a) Baryons, mesons and leptons are affected by particle interactions.

Write an account of these interactions. Your account should:

- include the names of the interactions
- identify the groups of particles that are affected by the interaction
- identify the exchange particles involved in the interaction

- give examples of **two** of the interactions you mention.

The quality of your written communication will be assessed in your answer.

(6)

(b) Draw a labelled diagram that represents a particle interaction.

(3)
(Total 9 marks)

Q59.

(a) Complete the following equation for beta minus (β^-) decay of strontium-90 ($^{90}_{38}\mathrm{Sr}$) into an isotope of yttrium (Y).

$$^{90}_{38}\mathrm{Sr} \longrightarrow {}^{\cdots\cdots}_{\cdots\cdots}\mathrm{Y} + {}^{\cdots\cdots}_{\cdots\cdots}\beta^- + {}^{0}_{0}\cdots\cdots$$

(3)

(b) During β^- decay of a nucleus both the nucleon composition and the quark composition change.
State the change in quark composition.

(1)

(c) A positive kaon consists of an up quark and an antistrange quark $(u\,\bar{s})$. This kaon decays by strong and weak interactions into three pions. Two of the pions have quark compositions of $(u\,\bar{d})$. The third pion has a different quark composition.

(i) Name the unique family of particles to which the kaon and pions belong.

____

(1)

(ii) Tick the box corresponding to the charge of the third pion.

positive ☐ negative ☐ neutral ☐

(1)

(iii) Positive kaons have unusually long lifetimes.
Give a reason why you would expect this to be the case.

____

____

(1)

(iv) Name the exchange particles which are involved in the strong and weak interactions of the kaon.

strong interaction ____________________

weak interaction ____________________

(1)

(Total 8 marks)

Q1.

(a) THREE FROM:
the strong interaction ✓
has short range OR mention range (less than 5 fm) ✓
attraction up to 5 fm ✓
repulsive (any distance below 1fm) ✓
is zero/negligible beyond 5 fm ✓
only affects hadrons/ baryons and mesons ✓
mediated by gluons/pions ✓

*If **wrong** interaction identified then zero marks*

If refer to strong interaction correctly then ignore any subsequent reference to other interactions

1
1
1
(3 max)

(b) in alpha decay number of nucleons/protons and neutrons is unchanged OR baryons in parent nucleus equals the total number of baryons in daughter nucleus and the alpha particle ✓

1

in beta decay a neutron changes into a proton (and both have same baryon number) ✓

1

beta (-) particle and antineutrino have zero baryon number/beta(+) and neutrino have zero baryon number ✓

If only refer to baryon number/nucleon number of alpha particle then do not award first mark

Can be shown by equations

e.g. ${}^{A}_{Z}\mathrm{X} \rightarrow {}^{A-4}_{Z-2}\mathrm{Y} + {}^{4}_{2}\alpha$

Second marking point can also be shown in equation

1

(c) quark structure $\pi^{-} = \bar{u}d$ and p = uud
quark structure kaon = $d\bar{s}$ ✓

1

hence as strong interaction quark structure Λ^0 = uds ✓

If two of the quark structures correct then 1 mark

Any correct answer (uds) full marks

1

(d) strangeness is not conserved/lost ✓

1

(e) TWO FROM:
results of experiments must be independently checked/validated/peer reviewed before they are accepted/can be confirmed ✓
particle accelerators are very expensive and collaboration helps to spread the cost of building them ✓
many skills and disciplines are required (which one team are unlikely to have) ✓
lots of data to process (so more teams needed) ✓

1
1

(2 max)

[11]

Q2.

(a) Mass of alpha particle = $\frac{2\times1.6\times10^{-19}}{4.81\times10^{7}}$ =6.6(53) × 10^{-27} (kg)

Allow mass = 2 × m_p + 2 × m_n = 6.696 × 10^{-27} kg

Allow mass = 4 × 1.66 × 10^{-27} kg = 6.64 × 10^{-27} kg

Allow mass = 4 × 1.67 × 10^{-27} kg = 6.68 × 10^{-27} kg

Allow slight rounding on mass (must be correct to 2 sf)

OR

Correctly re-arranged k.e. equation (with v^2 or v as subject) with 8.1 × 10^{-13} (J) substituted correctly $_1$✓

1.56 × 10^7 seen $_2$✓

Condone ***incorrect mass*** *in otherwise correct substitution* ***with v or v²******recognisable*** *as subject .*

Alternative approaches are:

$$v=\sqrt{\frac{E_k\times\text{specific charge}}{e}}$$

$$v=\sqrt{\frac{2\times E_k}{m_\alpha}}$$

Must see answer to at least 2 sf

Must see attempt to use one of the alternative approaches to support correct answer

2

(b) Use of $W = Fs$, F = 8.1 × 10^{-13} ÷ 3.5 × 10^{-2} $_1$✓

(F=) 2.3 × 10^{-11} (N) $_2$✓

Condone POT error

Correct answers gets 2 marks

OR

Use of an appropriate equation of motion to find a **and** $F = ma$

(allow their mass and their velocity in this sub) $_1$✓

Condone POT error

(F=) 2.3 × 10^{-11} (N) $_2$✓

Condone POT

OR

Use of an appropriate equation of motion to find t **and** $F = \Delta mv/t$

(allow their mass and their velocity in this sub) $_1$✓

(F=) 2.3 × 10^{-11} (N) $_2$✓

[answer is

$$\frac{(\text{their speed})^2 \times (\text{their } m_\alpha)}{0.070}$$

Using 2 × 10^{7} m s^{-1} yields(5.71 × 10^{15} × their m$_\infty$) – allow 1 sf answer in this case

Expect to see 3.8 × 10^{-11} (N) or 4 × 10^{-11} (N)]

2

(c) (Number of ions formed over range =)

5.1 × 10^{4} × 3.5 seen **or** 1.785 × 10^{5} (ions) seen

OR

8.1 × 10^{-13} converted to eV seen $_1$✓

8.1 × 10^{-13} ÷ 1.785 × 10^{5}

OR

5.06 × 10^{6} ÷ 1.785 × 10^{5} seen $_2$✓

Condone POT error in first mark

Ignore units

8.1 × 10^{-13} ÷ (5.1 × 10^{4} × 3.5) is worth 1st and 2nd marks

Condone POT errors in second mark

Correct answer obtains 3 marks

28 (.4) (eV) $_3$✓

99(.3) (eV) scores 1 mark

3

(d) (Q =) 0.85 × 10^{-3} × 1.2 × 10^{-9} = 1.02 × 10^{-12}

OR

n = (their Q) ÷ 1.6 × 10^{-19} $_1$✓

n = 6.4 × 10^{6} (c.a.o.) $_2$✓

Condone one POT error for one mark

2

(e) At 3.5 cm the pd drops / the current begins

OR

When the source is 10 cm away no ionisation occurs in the air gap (because the alpha particles have insufficient range to reach the air gap)

OR

When the radioactive source is <u>close enough</u> (approx. 5 cm) ionisation occurs ✓

OR

When beyond 3.5 cm no change in pd / current equals zero

Must be sense of abrupt change

MAX 3

When ionisation occurs / charge carriers are liberated in the air gap:

Allow more ionisation for second mark

resistance has decreased

OR

current increases (from zero)

OR

the potential difference decreases (with a maximum current) (to its minimum value) (across the air gap)✓

From 10 cm separation until 5 cm (approx) separation nothing changes / appreciates that pd is 4500 V / pd across gap = 4500 V until ionisation occurs ✓

Current is produced: the pd across 5 MΩ resistor is 4250 V / most pd is across the 5 MΩ resistor / small pd across air gap ✓

Current is produced and the pd across the air gap is 250 V✓

Current is produced and the pd across the air gap is 250 V✓

3

[12]

Q3.

B

[1]

Q4.

C

[1]

Q5.

B

[1]

Q6.

C

[1]

Q7.

C

[1]

Q8.

C

[1]

Q9.

A

[1]

Q10.

B

[1]

Q11.

(a) Neutron

Condone misspelling eg nuetron

1

(b) <u>Weak</u> (interaction)

Ignore nuclear or references to beta

1

(c) Bosons

Accept 'exchange particles'

Do not allow 'force mediator'

1

(d) charge number

2/3 -1/3 – 1/3 → 2/3 +-1/3 + 2/3 - 1 + 0 ✓

Ignore equation if given, marking should be based on the numbers

baryon number

1/3 + 1/3 + 1/3 → 1/3 + 1/3 + 1/3 + 0 + 0 ✓

Allow 1 for both correct in terms of n & p instead of quarks:

0 → +1 + -1 + 0

1 → 1 + 0 + 0

2

(e) proton

Allow 'free proton'

1

(f) Electron + an electron antineutrino + muon neutrino

All 3 needed

Condone anti-electron neutrino for electron anti-neutrino

No credit given for symbols

Allow antiparticle answer: positron, electron neutrino, muon antineutrino

1

[7]

Q12.

A

[1]

Q13.

C

[1]

Q14.

A

[1]

Q15.

(a) $^{40}_{19}\text{K} + ^{0}_{-1}e \rightarrow ^{40}_{18}\text{Ar} + \nu_{(e)}$ ✓ ✓

first mark for 40 and 18

second mark for electron neutrino

if negative superscript on neutrino mark not awarded

1
1

(b) is the weak interaction/weak nuclear force ✓
because involves leptons <u>and</u> hadrons / because quark character / flavour / identity / type changed ✓

allow change in quark composition

allow second mark if applied to stated interaction e.g. up quark changes to down quark

1
1

(c) (use of $E=hf$)

energy in J = $1.46 \times 10^{6} \times 1.6 \times 10^{-19}$ ✓ (= 2.336×10^{-13})

$$f = \left(\frac{E}{h} =\right) = \frac{2.336 \times 10^{-13}}{6.63 \times 10^{-34}} \text{ AND } \lambda = \frac{3 \times 10^{8}}{f}$$

OR $\lambda = \left(\frac{hc}{E} = \right)\frac{3 \times 10^{8} \times 6.63 \times 10^{-34}}{2.336 \times 10^{-13}}$ seen directly ✓

1 for the attempt at the conversion to J allowing POT

1 for attempt to sub in hf and c/λ (or hc/λ)

allow energy

substituted in MeV or eV for second mark

1 for the correct answer (not awarded if eV used or MeV or if POT error)

8.51×10^{-13} m ✓

Accept 8.52×10^{-13}

1
1
1

(d) identifies the decay as beta emission ✓
so will expect to see:

2 from 4

electron released (from nucleus)

correct details of how electron detected
antineutrino released
no photon released

If stated incorrect interaction e.g. beta plus decay the wrong Physics and no consequential error(CE) and therefore zero.

If no interaction stated then can score next 2 marks.

e.g. cloud chamber or absorption

If given correct equation for beta decay award mark for electron and antineutrino

3

[10]

Q16.

B

[1]

Q17.

A

[1]

Q18.

C

[1]

Q19.

D

[1]

Q20.

C

[1]

Q21.

C

[1]

Q22.

D

[1]

Q23.

B

[1]

Q24.

(a) $q\bar{q}$✓

1

(b) Total energy = 2keV + 2 × 511 keV = 1024 keV✓

= 1024 × 1.6 × 10^{-19} = 1.64 × 10^{-13}J✓

Energy of each photon = 1.64 × 10^{-13}/2 = 8.19 × 10^{-14} (J) ✓

First mark for calculating the total energy in keV.

Second mark is for converting correctly into joules.

Third mark is for dividing by two so ecf for incorrect conversion into joules. Student must show at least 3sf.

3

(c) $$\lambda = \frac{hc}{E} = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{8.19 \times 10^{-14}}$$ ✓

= 2.43 × 10^{-12} (m) ✓

First mark for the correctly rearranged equation or correct values substituted into equation.

Correct answer only scores 2 marks, ecf from 1 ***(b)***

2

(d) E_k= 2 keV = 2000 × 1.6 × 10^{-19} J = 3.2 × 10^{-16}J✓

$$v = \sqrt{\frac{2E_k}{m}} = \sqrt{\frac{2 \times 3.2 \times 10^{-16}}{9.11 \times 10^{-31}}}$$ ✓

= 2.65 × 10^{7}(m s^{-1}) ✓

First mark for converting KE into joules.

Second mark for rearranging equation correctly or substituting correct values into equation.

Third mark for correct answer, must be to at least 3sf.

3

(e) $$\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 2.65 \times 10^{7}}$$ ✓

= 2.75 × 10^{-11}(m) ✓

First mark for rearranging equation correctly or substituting correct values into equation.

Second mark for correct answer.

2

(f) Recognition that separation is 1.5 × 10^{-10} m and compared to 0.28 × 10^{-10} (ecf)✓

wavelength is about 5 times less than gap width✓

$$\sin\theta = \frac{\lambda}{d} = 0.2 \rightarrow \theta \sim 11^{\circ}$$ ✓

yes (diffraction would be observable)✓

Or words to that effect

4

[15]

Q25.

D

[1]

Q26.

D

[1]

Q27.

A

[1]

Q28.

C

[1]

Q29.

D

[1]

Q30.

C

[1]

Q31.

(a) Any suitable process such as electron capture or beta plus decay. ✓

1

(b) The weak interaction ✓

1

(c) Valid equation must be given or no marks for the question.

For electron capture:

baryon number conserved 1 + 0 = 1 + 0 ✓

lepton number conserved 0 + 1 = 0 + 1 ✓

Baryon and Lepton numbers to be conserved

2

(d) up and antistrange ✓

1

(e) conserved any correct answer such as charge ✓

not conserved is strangeness which is 1 before decay and 0 after decay ✓

2

[7]

Q32.

A

[1]

Q33.

C

[1]

Q34.

B

[1]

Q35.

B

[1]

Q36.

D

[1]

Q37.

C

[1]

Q48.

B

[1]

Q49.

B

[1]

Q50.

B

[1]

Q51.

D

[1]

Q52.

(a) (isotopes have)

same number of protons ✓

allow atomic mass / proton number

different numbers of neutrons ✓

allow mass number / nucleon number

TO where mix up atomic number and mass number

2

(b) $92 \times 1.60 \times 10^{-19}$ ✓

correct power

penalise minus sign on answer line

(+)1.47×10^{-17} (C) ✓

Allow 2 sf answer 1.5×10^{-17} (C)

Pay attention to powers on answer line

2

(c) ($4.8 \times 10^{-19} \div 1.60 \times 10^{-19}$ =) 3 ✓

or

$1.47 \times 10^{-17} - 4.8 \times 10^{-19}$ (= Q) (ecf)

(92 − 3 =) 89 ✓

95 on answer line 1 mark

$$\left(n = \frac{Q}{e} = \frac{1.47 \times 10^{-17} - 4.8 \times 10^{-19}}{1.6 \times 10^{-19}}\right) = 89 \text{ (ecf)}$$

Integer value for n

2

(d) $^{237}_{92}\text{U} \rightarrow {}^{237}_{93}\text{Np} + {}^{0}_{-1}\beta + \overline{\nu_{(e)}}$ ✓ ✓ ✓

one mark for:

- *both numbers correct on Np*
- *both numbers correct on β^-*
- *correct symbol for (electron) antineutrino*

3

[9]

Q53.

(a)

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

only third box from top ticked

allow crosses in any other box

1

(b) (i) (lepton number of $K^+ = 0$)

lepton number of $\mu^+ = -1$ lepton number of $\nu_\mu = +1$ ✓

(hence lepton number zero before and after)

need to see

$0 \longrightarrow -1 + 1$ ✓

(And $0 \longrightarrow 0$)

Must be in correct order

1

(ii) Strangeness (number) ✓

allow <u>rest</u> mass

Not meson number

1

(iii)

	charged	hadron	meson	baryon	lepton
K^+	(✓)	✓	✓		
μ^+	(✓)				✓
ν_μ					✓

one mark for each correct row

ticks in correct boxes only

allow crosses in other box(es)

3

(c) cannot be a lepton (to conserve lepton number) / cannot be a baryon (to conserve baryon number) / must be a meson

maximum of one mark for either of first marking point

cannot have a charge (to conserve charge) ✓

(must be) π^0 ✓

can be done by BLQ table for first two marks

TO on conservation wrong statements (−1 for each incorrect applied to the first two marking points)

allow K^0 as must be a meson

allowing strangeness to be conserved

3

[9]

Q54.

(a) pair production ✓

1

(b) (i) energy of photon needs to provide at least the <u>rest</u> masses ✓

OR at least the <u>rest</u> energy ✓

of the electron <u>and</u> positron / of (both) particles / of particle and antiparticle ✓

Of the electron and positron / of (both) particles of particle and antiparticle ✓

Can't score 2nd mark without having scored 1st

(allow particles or products)

TO on any suggestion of particles have KE

2

(ii) minimum energy = 2 × 0.510999 = 1.021998 (MeV) ✓

must see working

***and** final answer must be at least 3 sf*

allow detailed argument in reverse

0.5 Mev close to 0.511 MeV

Or $E=mc^2$ leading to 1.024875 MeV

Or 2 × 5.5 × 10^{-4} × 931.5 = 1.02 MeV

1

(iii) (electron / positron have) kinetic energy ✓

thermal energy n/e

Momentum n/e

1

(iv) (attempts to convert energy to joules)

energy = 1.0 × 10^6 × 1.60 × 10^{-19} = 1.6 × 10^{-13} (J) ✓

Condone power 10 error on MeV conversion to J

(use of $E = hf$)

Their energy ÷ 6.63 × 10^{-34} = f ✓

Must see subject or their f on answer line consistent with working

f = 2.4 × 10^{20} ✓ cao

Hz (condone s^{-1}) ✓

Capital H and lower case z (for symbol)

Allow word written as Hertz (h lower case)

4

[9]

Q55.

(a) proton

1

(b) (i) β^+ identified even if numbers incorrect or correct numbers for β^+ **and** proton number on Mg correct

β or β^+ identified and all numbers correct

i.e Second mark not awarded if numbers are correct but there is a minus on the β particle

Allow 1 for consistent equation for β^- decay

2

(ii) W^+ (condone W but not W^-)

1

[4]

Q56.

(a)

	$^{223}_{88}Ra$	$^{224}_{88}Ra$	$^{225}_{88}Ra$	$^{226}_{88}Ra$
Isotope with smallest mass number	(✓)			
Isotope with most neutrons in nucleus				✓
Isotope with nucleus that has highest specific charge	✓			
Isotope that decays by β^- decay to form $^{225}_{89}Ac$			✓	
Isotope that decays by alpha decay to form $^{220}_{86}Rn$		✓		

one mark for each correct row (ignore first row as already ticked)

allow cross instead of tick and ignore any crossed out ticks

if more than one tick in a row then no mark

4

(b) (i) the atom has lost two electrons✓

1

(ii) (*use of specific charge = charge ÷ mass*)

mass = $3.2 \times 10^{-19} \div 8.57 \times 10^{5} = 3.734 \times 10^{-25}$ (kg)

mass number = $3.734 \times 10^{-25} \div 1.66 \times 10^{-27}$ ✓(= 225)

hence $^{225}_{(88)}Ra$ OR 225✓✓

OR

calculate specific charge for each isotope✓

hence $^{225}_{(88)}Ra$ OR 225✓✓

ignore any reference to electrons
first mark for deduction
bald correct answer scores 2 marks
don't need radium symbol or 88

wrong answer scores zero

3

[8]

Q57.

(a) (i) X must have a negative charge✓

to conserve charge✓

second mark dependent on first i.e. conserve charge alone scores nothing *can gain second mark by showing balanced equation*

2

(ii) X must be a baryon✓
to conserve baryon number✓

here two marks are independent i.e. conserve baryon number alone scores 1 mark

can gain second mark by showing balanced equation

2

(iii) K^-: s $\bar{u}$ OR strange anti-up ✓

K^+: u $\bar{s}$ OR up anti-strange✓

K^0: d $\bar{s}$ OR s$\bar{d}$ OR down anti-strange OR strange anti–down✓

in each case the symbols or words can be in either order

must be a bar over anti – quark
can be upper case letters e.g. U

3

(iv) (strangeness on LHS is -1)
strangeness on RHS without X is +2 / strangeness of X is -3 ✓
thus sss
OR
strangeness on RHS without X is +2 / strangeness of X is -1✓
thus sdd✓✓

correct strangeness without X on RHS is minimum working needed for first mark
next two marks awarded for correct quark structure

3

[10]

Q58.

(a) **The student's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.**

The student's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria.

High Level (Good to excellent): 5 or 6 marks
The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question.

Student names strong, weak and electromagnetic interactions. Identifies that only hadrons experience the strong interaction but hadrons and leptons experience weak interaction. Charged particles experience electromagnetic interaction. Is able to identify all exchange particles such as gluons, W+ and W- and virtual photons. Gives examples of two of the interactions i.e. electrons repelling, electron capture, beta decay.

Intermediate Level (Modest to adequate): 3 or 4 marks
The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate.

Student names strong, weak and electromagnetic interactions. Identifies that *only hadrons experience the strong interaction but hadrons and leptons experience weak interaction. Charged particles experience electromagnetic interaction. Is able to identify some exchange particles such as gluons, W^+ and W^- and virtual photons.*

Low Level (Poor to limited): 1 or 2 marks
The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate.

Student names strong, weak and electromagnetic interactions. Identifies that only hadrons experience the strong interaction. Identifies one exchange particle.

The explanation expected in a competent answer should include a coherent selection of the following points concerning the physical principles involved and their consequences in this case.

Names of interactions – strong, weak and electromagnetic
hadrons experience strong
hadrons and leptons experience weak
charged particles experience electromagnetic
identify exchange particles
give examples of various interactions e.g. electron capture
(either weak interaction or electromagnetic or strong interaction)
first mark conservation at left hand junction of charge, baryon and lepton number ✓
second mark conservation at right hand junction of charge, baryon and lepton number ✓
third mark for correct exchange particle ✓

ignore any reference to gravity
ignore any Feynman diagrams electrostatic not allowed as alternative for electromagnetic

Properties of interactions

- *correct exchange particle ($W^{(+/-)}$boson / Z_0 boson, (virtual) photon, gluon / pion) NB sign on W not required*
- *correct group of particles affected (strong: baryons andmesons, weak: baryons, mesons and leptons, electromagnetic: charged particles)*
- *example of the interaction*

Lower band

1 mark – two interactions OR one interaction and one property for that interaction

2 marks – two interactions and one property for one interaction

Middle band

3 marks – two interactions plus two properties

4 marks – two interactions plus minimum of four properties (e.g. 3 props plus 1 OR 2 props plus 2), if three interactions quoted then properties can be spread between the 3 e.g. one property for each (3) plus one additional

Top band

5 marks – 3 interactions plus two properties for each

6 marks – must give first two properties for all three interactions AND correctly state two examples of interactions *e.g. electron capture example of weak, strong nuclear responsible for binding protons / neutrons / baryons together*

A table may help:

	strong	weak	EM
property 1			
property 2			
property 3			

(b)

if exchange particle not identified but baryon and lepton numbers conserved on both sides − 1 mark
ignore orientation of line showing exchange particle or any arrows on exchange particle line when awarding first two marks

if arrows on incoming and outgoing interacting particles in wrong direction then lose mark

if lines do not meet at a junction lose 1 mark
***with third mark** orientation of exchange particle line must be consistent with exchange particle shown and no arrow required*

if exchange particle line is horizontal (for weak) then must be a correct arrow
arrow overrides slope

3

[9]

Q59.

(a) (90,39)

B1

(0,-1)

B1

$\bar{\nu}_e$

B1
3

(b) d→u
or
Number of u quarks increases by 1 and number of d quarks decreases by 1

B1
1

(c) (i) Meson

Do not allow hadron

B1
1

(ii) Negative box ticked

B1
1

(iii) Characteristic of particles with strange quarks / they contain the strange quark / they have strangeness

B1
1

(iv) Gluon, W ($^+$ or $^-$) (boson) or Z^o

B1
1

[8]

Q1.

This question was about particle physics and gave students the opportunity to demonstrate their knowledge of the fundamental interactions and basic quark structure.

(a) This required a description of the strong interaction and it was well answered, with just under half of students gaining all three marks. Most students appreciated the type of interaction involved and were able to provide correct properties. The range of repulsion and attraction of the interaction seemed to be well understood.

(b) This question proved to be more challenging; only 11.3% of students gained maximum marks here. This was mainly due to poor structuring of answers so it was not clear how baryon number was being conserved in these decays. Many students concentrated on the baryon number of the alpha particle without referring to the baryon numbers of the nuclei involved. With beta decay it was common to see responses that showed how the baryon number had not changed as a neutron changed to a proton. It was, however, less common to see a discussion of the other particles involved and why, because they were leptons, they did not affect baryon number.

(c) There was reasonably good discrimination in this question. Over half of the students were able to provide a correct quark structure for one of the particles involved but only the best students were able to deduce the correct quark structure of the lambda particle.

(d) This question was well answered with many students (53.7%) appreciating that strangeness was not conserved.

(e) Over half of the students managed to come up with a reason for many teams being beneficial. However, only a few students (5.1%) were able to come up with more than one reason.

Q2.

(a) There were a number of stages to this “show that” question. Because of its level of demand the mark scheme was less stringent than usual about how “show that” calculations should be presented. However, students should be encouraged to ensure they have fully demonstrated how the answer is obtained. These pieces of advice should be considered:

- any equations used should be written with subjects seen at each stage of the calculation;
- mid-calculation rounding should be avoided;
- the answer should be quoted to more significant figures than the value they have been asked to find.

(b) The main error seen, when using F = ma and equations of motion, was not taking into account speed changing when calculating the time to stop. Students who identified the questions as being set up for a “work done = change in kinetic energy” generally obtained all marks (27.3%).

(c) Good students were able successfully to complete this calculation (23.1%) whereas lower performing students appeared to have little appreciation of the problem and were able to make only limited progress, by perhaps finding the number of ions or converting the energy into electron volts.

(d) Students failed to gain marks here for a number of the following common reasons: dividing the current by the time, using $2 \times 1.6 \times 10^{-19}$ for each charge carrier rather than 1.6×10^{-19}, and misremembering the prefix nano- as 10^{-12}.

(e) This question proved to be inaccessible to all but the very best students. Only 10.7% of students managed to score anything on this item. The number of factors they had to consider proved too challenging for most. Where students realised that ionisation occurred when the alpha source was close enough, they often got confused about the effect this had on the current in the circuit and the resistance and potential difference across the air gap. Many students thought that an increase in current could only occur when the potential difference across the air gap increased.

Q3.

The majority of students (63.3%) were able to identify the correct answer. The most common incorrect answer was A; here students correctly identified the isotope but had not given sufficient thought to P’s nucleon number.

Q4.

This question had a good success rate with most students (61.4%) selecting the correct answer.

Q5.

Students demonstrated a good knowledge of particle physics with the majority (62.7%) able to identify particle Q and the quark structure of particle R.

Q6.

Here, again, most students (70.1%) selected the correct response. The most common wrong answer was D.

Q7.

75.2% correct

Q8.

46.1% correct

Q9.

68.0% correct

Q10.

89.2% correct

Q11.

This question about neutron decay gave students an opportunity to demonstrate their knowledge and understanding of particle physics, a topic that traditionally scores well at A-level. It included several single word responses that were provided correctly by the majority of students.

(a) This was the most accessible question on the paper, with over 90% of students providing the correct answer.

(b) Although this was also correctly answered by the majority of students, there was some confusion concerning the word ‘interaction’, with ‘beta decay’ being a popular incorrect answer. Correct answers that included references to beta decay were credited with the mark.

(c) Most students were familiar with the term ‘boson’ or gave the answer ‘exchange particle’. Other answers appeared to be the random naming of a familiar particle, such as pion, muon, etc.

(d) This question proved to be more challenging with approximately half of the students only receiving one mark for failing to express their answers in terms of quarks. Other common errors included missing out the baryon number of the leptons (0) or the zero charge on the antineutrino. A surprisingly large number of students tried to answer using extended writing rather than using an equation approach such as the one provided in the mark scheme.

(e) This straightforward piece of recall was provided by a large majority of students. There was no particular incorrect answer.

(f) In this question students needed to provide a lot of information for the single mark available. Unsurprisingly, perhaps, this was one of the least accessible questions on the paper. Few students attempted to provide a reasoned answer based on conservation of electron and muon lepton numbers, i.e. conservation of muon lepton number requires a muon neutrino to be produced; conservation of charge suggests an electron is also produced; and conservation of electron lepton number requires the production of an electron antineutrino.

Q12.

Students are generally quite strong on the topic of particle physics; over 60% of students obtained the correct answer, with distractor C being a common incorrect answer. Students need to be made aware that hadrons can interact via all four fundamental forces and that the weak interaction is not exclusive to leptons.

Q13.

The most popular incorrect response was distractor B. Students need to ensure that they have taken account of the information and avoid pitfalls of this type. Terms such as number of neutrons and nucleon number should be treated with caution; it is important that students can distinguish between these terms in questions such as this.

Q14.

Just over 50% of students selected the correct answer. The most frequent incorrect response was distractor D; students were familiar with the possible non-conservation of strangeness in decay but did not know that strangeness must be conserved in the production of strange particles.

Q15.

This question was generally well answered. In question (a), students had to complete the electron capture equation. While the majority were able to correctly identify the mass number and atomic number for argon, they were less successful at identifying the electron neutrino, with responses giving the particle as a neutron or gamma photon being quite common.

Identifying the fundamental interaction involved as the weak interaction proved to be very accessible and over 80% of students were able to do this. They were less successful, however, in giving a reason. This was mainly because they did not refer to the interaction shown, giving answers which only mentioned leptons. They either needed to refer to the change of quark, or state that the interaction involved both hadrons and leptons.

The calculation in question (c) was well answered and over two-thirds of students scored full marks. The common errors for those who did not were either failing to convert energy to joules, or a power of ten mistake.

Question (d) was an example of students being required to make a judgement, and many good responses were seen. A significant proportion of students did, however, give generic answers indicating how they would distinguish between alpha, beta and gamma decay. This did not answer the question which required them to state what interaction was occurring to produce calcium–40 from the potassium isotope.

Q48.

Although decay series per se are on the A2 specification, this question tested the consequence of alpha and beta decay on proton number, as well as the student's understanding of isotopes. It proved to be very accessible with 84% of students getting the correct answer. The most common distractor was C, confusing alpha and beta decay perhaps.

Q49.

Students generally find most aspects of the particle physics topic fairly straightforward. This question was no exception with 83% of students remembering the need for two gamma photons to be produced. A was the most common distractor, chosen by students who forgot this important point perhaps.

Q50.

With 87% of students choosing the correct answer, few students had any difficulty with this question. The remaining answers were fairly evenly spread between the three distractors.

Q51.

This was the most accessible question on the paper with 95% of students able to recall the quark structure of an antiproton. C was the most popular distractor, chosen by students confusing protons and neutrons perhaps.

Q52.

This question was well done by the vast majority of students.

On the whole, the calculations were done correctly. Mistakes seen in part (b) included students presenting the specific charge as their answer due to rote application of a method without due regard to the question. Part (c)'s errors were mostly due to incomplete calculations where students determined the number of electronic charges but failed to take this away from the proton number. Surprisingly almost 20% of students were unable to complete the decay equation in part (d).

Q53.

Again there was a high level of competency demonstrated in this question, indicating students' familiarity with this topic. Part (c) showed the greatest level of discrimination between students of differing abilities. Grade A typically obtained all 3 marks and produced a well-structured case to support their deduction. Other students would identify X but would provide limited communication to support this.

Q54.

There was lots of success for the majority of students in this question.

Students failed to gain credit when they did not address the fact that the energy was the minimum energy in part (b)(i). They needed to emphasise that this was the energy required to produce the rest masses of the electron and the positron and that any energy below this was insufficient. Weaker responses attempted an explanation based on the photoelectric effect or suggested that this minimum was greater than the rest masses of the particles produced. Part (b)(ii) was well done with over two thirds of students achieving 4 marks. Mistakes seen were mainly due to inclusion of power of ten errors in converting MeV into joules.

Q55.

(a) There were many correct answers, the neutron being the most common incorrect response.

(b) (i) This was generally well done and most students were able to score one or both marks.

(ii) Only a fifth of the students identified the W+ particle or W which was an accepted alternative.

Q56.

Completing the table in (a) proved to be a straightforward task for the majority of students and full marks were commonly seen. (b) proved more challenging. In the first part many students appreciated what is meant by ionization but failed to relate it directly to the situation, giving generic answers instead of stating that two electrons had left the atom.

Calculations involving specific charge have often proved discriminating in previous exams and this was certainly the case this time. Only the more able students were able to convincingly deduce the correct isotope.

Q57.

The first three parts of this question were well done and students demonstrated that they were familiar with the relevant conservation laws and could also quote the quark structures of the kaons. A minority did lose marks in (a)(i) however, because they did not state the charge of particle X and merely stated that it was charged.

(a)(iv) was much more discriminating and weaker students did not really appreciate that conservation laws were needed to make the deduction and only the strongest students identified that the strangeness of X was either −3 or −1 depending on the quark structure they used for the K^0.

Q58.

(a) assessed the quality of written communication and it has often proved to be the case that student answers were much more confident than when they are asked to provide an extended answer to a question based on a topic from the electricity part of the specification. Some very good answers were seen with students clearly identifying three interactions. Weaker students did confuse the properties of these interactions and it was not uncommon to see an incorrect exchange boson linked to an interaction, for example the W^+ with the strong interaction. There was a tendency for students to be a little vague when discussing the weak interaction. A common example of this was statements linking the weak interaction to leptons but not hadrons even though examples of interactions involving both of these classes of particles were then given.

The Feynman diagram in (b) generated some good answers with over half the students scoring full marks. The commonest examples seen were electron capture and the repulsion of two electrons.

Q59.

(a) This was generally well done. Common errors were to neglect to identify the antineutrino or indicating that it was an electron antineutrino. There was a significant proportion who wrote the equation as for positron decay.

(b) Fewer than half the candidates realised that the change was a down quark to an up quark

(c) (i) This was known by most candidates.

(ii) Well over half gave the correct response.

(iii) A majority of the candidates appreciated that strangeness is responsible for longer than usual lifetimes.

(iv) Both parts had to be correct to score the mark which was gained by half the candidates. It was essential that the gluon and not a pion was stated for the strong interaction. The exchange particle in the weak interaction was more often correct.