1 (a) A particle is made up from an anti-up quark and a down quark.

(i) Name the classification of particles that has this type of structure.

____

(1)

(ii) Find the charge on the particle.

(1)

(iii) State the baryon number of the particle.

(1)

(b) A suggested decay for the positive muon (μ^+) is

$$\mu^+ \rightarrow e^+ + \nu_e$$

Showing your reasoning clearly, deduce whether this decay satisfies the conservation rules that relate to baryon number, lepton number and charge.

Baryon number ____

Lepton number ____

Charge ____

(3)

(Total 6 marks)

2 (a) State the quark substructure of a neutron.

____

(2)

(b) Circle the terms below that can be used to describe a neutron.

antiparticle baryon fundamental particle hadron lepton meson

(2)

(Total 4 marks)

3 (a) State whether or not each of the following properties of a baryon is conserved when it decays by the weak interaction.

charge ____

baryon number ____

strangeness ____

(2)

(b) State, with a reason, whether or not each of the following particle reactions is possible.

(i) $p + \pi^- \rightarrow K^- + \pi^+$

(ii) $p + \bar{\nu} \rightarrow n = e^+$

(4)

(Total 6 marks)

4 State the differences in quark structure between a meson and a baryon.

(Total 2 marks)

5 A negative pion (π^-) is a meson with a charge of −1e.

State and explain the structure of the π^- in terms of up and down quarks.

(Total 3 marks)

6 (a) Name **two** hadrons.

(b) Name **two** leptons which are also antiparticles.

(c) State a possible quark structure of the pion π^0.
A table of the properties of quarks is given in the Data booklet.

___

(d) A K^- kaon is a strange particle.
State **one** characteristic of a strange particle.

___

___

(Total 4 marks)

7 Nuclei of $^{218}_{84}Po$ decay by the emission of an α particle to form a stable isotope of an element X.
You may assume that no γ emission accompanies the decay.

(a) (i) State the proton number and the nucleon number of X.

proton number ___

nucleon number ___

(ii) Identify the element X.

___

(2)

(b) Each decaying nucleus of Po releases 8.6×10^{-13} J of energy.

(i) State the form in which this energy *initially* appears.

___

(ii) Using **only** the information provided in the question, calculate the difference in mass between the original $^{218}_{84}Po$ atom and the combined mass of an atom of X and an α particle.

speed of light in vacuum = 3.0×10^8 m s^{-1}

___

___

___

___

(3)
(Total 5 marks)

8 (a) An ion of plutonium $^{239}_{94}Pu$ has an overall charge of $+1.6 \times 10^{-19}$C.

For this ion state the number of

(i) protons ____________________

(ii) neutrons ____________________

(iii) electrons ____________________

(3)

(b) Plutonium has several *isotopes*.

Explain the meaning of the word isotopes.

____

____

____

(2)

(Total 5 marks)

9 Under certain circumstances it is possible for a photon to be converted into an electron and a positron.

(a) State what this process is called.

____

(1)

(b) A photon must have a minimum energy in order to create an electron and a positron.

Calculate the minimum energy of the photon in joules. Give your answer to an appropriate number of significant figures.

minimum energy = ____________________ J

(3)

(c) A photon of slightly higher energy than that calculated in part (b) is converted into an electron and a positron.

State what happens to the excess energy.

____

____

(1)

(d) Describe what is likely to happen to the positron shortly after its creation.

____

____

____

____

(2)

(Total 7 marks)

10 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.

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

(3)

(Total 9 marks)

11 An atom of argon $^{37}_{18}Ar$ is ionised by the removal of two orbiting electrons.

(a) How many protons and neutrons are there in this ion?

______________________ protons

______________________ neutrons

(2)

(b) What is the charge, in C, of this ion?

____

____

(2)

(c) Which constituent particle of this ion has

(i) a zero charge per unit mass ratio,

____

____

(ii) the largest charge per unit mass ratio?

____

(2)

(d) Calculate the percentage of the total mass of this ion that is accounted for by the mass of its electrons.

____

____

____

____

(3)
(Total 9 marks)

12 (a) There are a number of ways in which u, d and s quarks and their associated antiparticles may be combined to form mesons. Use the table 'properties of quarks', in the Data booklet, to complete parts (i) to (iii).

(i) The kaon K^- has a strangeness $^-1$. Write down its quark composition.

K^- ____

(ii) The kaons K^0 and K^+ both have strangeness +1. Write down their quark composition.

K^0 ____

K^+ ____

(iii) Write down the quark composition of a proton.

p ____

(5)

(b) In the strong interaction,

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

deduce the quark composition of, and state the type of, hadron represented by X.

____

____

(2)

(c) A positive muon may decay to a positron and two neutrinos. Write down an equation representing the muon decay.

$\mu^+ \rightarrow$

(2)
(Total 9 marks)

13 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)

14 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)

15 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)

16 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)

17 What are the numbers of hadrons, baryons and mesons in an atom of ${}^{7}_{3}Li$?

	hadrons	**baryons**	**mesons**	
A	7	3	3	
B	7	4	4	
C	7	7	0	
D	10	7	0	

(Total 1 mark)

18 Electron capture can be represented by the following equation.

$$p + e^{-} \rightarrow X + Y$$

Which row correctly identifies **X** and **Y**?

	X	**Y**	
A	p	K^{-}	
B	e^{-}	e^{+}	
C	n	V_e	
D	n	π^0	

(Total 1 mark)

Mark schemes

1 (a) (i) meson (not muon)

B1

1

(ii) –1 or -1.6×10^{-19} C or –e

B1

1

(iii) 0

B1

1

(b) baryon number 0 → 0 + 0 (satisfied or ✓s)
(allow statement that as these are all leptons baryon number is not relevant owtte)

B1

lepton number –1 → –1 + 1 × or not satisfied

B1

charge (+)1 → (+)1 + 0 (satisfied or ✓s)

B1

3

[6]

2 (a) Three quarks mentioned; at least one u, one d

C1

udd A1

2

(b) hadron

B1

Baryon

B1

2

[4]

3 (a) charge – yes*

baryon number – yes*

strangeness – no*

* all correct **(1) (1)**

deduct one for each incorrect answer

(max 2)

(b) (i) no **(1)**

strangeness [or baryon number] not conserved **(1)**

(ii) yes **(1)**

charge <u>and</u> baryon number conserved **(1)**

(4)

[6]

4 meson has 2 quarks; baryon has 3 quarks/3 antiquarks

B1

good extra detail

B1

[2]

5 2 quarks

M1

down and anti-up

A1

–1 / 3 + (–2 / 3) = – 1

A1

[3]

6 (a) any two hadrons e.g. proton, neutron, pion, kaon, etc. **(1)**

(b) any two antiparticle leptons e.g. e^+, μ^+, anti-(electronic) neutrino etc **(1)**

(c) $d\bar{d}$ (or $u\bar{u}$ or $\frac{1}{\sqrt{2}}(d\bar{d} + u\bar{u})$)

(d) usually created in pairs (*)
normally decays into combinations of π, p and n (*)
contains at least one strange quark (*)
usually decays via the weak interaction (*)
half - life is relatively long compared with half -life of typical particle decaying via strong interaction (*)
(*) any one **(1)**

[4]

7 (a) (i) proton number 82 and nucleon number 214 **(1)**

(ii) Pb **(1)**

2

(b) (i) kinetic energy [or <u>electrostatic</u> potential energy] **(1)**

(ii) $\Delta m = \frac{E}{c^2}$ **(1)**

$= \frac{8.6 \times 10^{-13}}{(3 \times 10^8)^2} = 9.6 \times 10^{-30}$ kg **(1)**

3

[5]

8 (a) (i) 94 (protons) **(1)**

(ii) 145 (neutrons) **(1)**

(iii) 93 (electrons) **(1)**

3

(b) same number of protons
[or same atomic number] **(1)**

different number of neutrons/nucleons
[or different mass number] **(1)**

2

[5]

9 (a) pair production ✓

1

(b) (energy = 2 × rest mass energy)
energy = 2 × 0.510999 = 1.021998 (MeV) ✓
energy = $1.021998 \times 1.60 \times 10^{-13} = 1.64 \times 10^{-13}$ J ✓
(3 sig figs ✓)

If miss out 2 factor can get CE
Can use $E=2mc^2$
First mark for full substitution and second mark for answer

3

(c) kinetic energy (of electron and positron) ✓

KE of photon gets zero

1

(d) (meet an electron and) annihilate ✓
(converting into two or more) photon<u>s</u> ✓ OR gamma rays

2

[7]

10 (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

$(+)1.47 \times 10^{-17}$ (C) ✓

Allow 2 sf answer 1.5×10^{-17} (C)

Pay attention to powers on answer line

2

(c) ($4.8 \times 10\text{-}19 \div 1.60 \times 10^{-19}$ =) 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) ${}^{237}_{92}U \rightarrow {}^{237}_{93}Np + {}^{0}_{-1}\beta + \overline{\nu_{(e)}}$ ✓ ✓ ✓

one mark for:

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

3

[9]

11 (a) 18 (protons) **(1)**
(37 – 18 gives) 19 (neutrons **(1)**

2

(b) (charge) = 2^+ or 2^- **(1)**
$Q = 2 \times 1.60 \times 10^{-19} = 3.2 \times 10^{-19}$ (C) **(1)**

2

(c) (i) neutron **(1)**

(ii) electron **(1)**

2

(d) $(\%) = \dfrac{16 \times 9.11 \times 10^{-31}}{1.67 \times 10^{-27} \times 37}$ **(2)** (for correct nuclear mass and substitution)

$(= 2.36 \times 10^{-4}) = 2.36 \times 10^{-2}$ (%) **(1)**

3

[9]

12 (a) (i) $K^- = s\bar{u}$ **(1)(1)** [one mark for s and an antiquark]

(ii) $K^0 = d\bar{s}$
$K^+ = u\bar{s}$ **(1)**

(iii) p = uud **(1)**

(5)

(b) X = sss **(1)** (= Ω^-)
baryon **(1)**

(2)

(c) $\mu^+ \rightarrow e^+ + \nu e + \bar{\nu}_\mu$ $(+Q)$

all correct **(1)** **(1)** [deduct one mark for each error]

(2)

[9]

13 D

[1]

14 C

[1]

15 A

[1]

16 D

[1]

17 C

[1]

18 C

[1]

Examiner reports

1 (a) (i) The majority identified that particles with this type of structure are mesons.

(ii) This should have been an easy mark using the information on the formula sheet but this was not the case for a significant proportion of the candidates who misread information from the table or made careless arithmetical errors (e.g.–2/3 – 1/3 = 1, 1/3 or –1/3).

(iii) Errors similar to those in (ii) were made in this part by a significant number of candidates.

(b) This was often well done with a clear conclusion that lepton number was not conserved. It was acceptable for candidates to state that as there were no baryons involved in the equation the conservation of baryon number did not apply. The main error in dealing with charge was to assign a charge to the neutrino.

2 (a) Almost all were able to indicate the correct quark substructure of the neutron. However these answers were often couched simply as, for example, 'udd' without any definition of these symbols leaving the examiners to infer what candidates meant.

(b) Again, many knew that the terms baryon and hadron are used to describe a neutron, but far too many also suggested that the neutron is a fundamental particle. A small group of candidates used the lepton response as an alternative to hadron.

3 This question, on particles and their conservation, was much more discriminating than similar questions have been in previous years. It has been common for a majority of candidates to obtain full marks in such questions. Half of the candidates did not know that *strangeness* is not necessarily conserved in a weak interaction.

Many errors were also seen in part (b). The most common was that charge was not thought to balance in both equations. The errors came from candidates not realising that the proton was positively charged

4 Many candidates were able to suggest that mesons have two quarks and that baryons have three, but fewer were able to give good additional detail (for example, that mesons have a quark and anti-quark structure). A sizeable minority reversed the quark count in the arrangement of the two types of particle.

5 Marks gained for this part hinged on whether or not candidates were aware that a meson consists of a quark-antiquark pair. When this was known the candidate usually went on to correctly assess that a negative pion could only be a down quark or an anti-up quark. A slight minority were unable to access any marks, believing that a meson comprises of three quarks.

6 This question was generally done well, even though the parts of the question became progressively more difficult. Naming two hadrons was an easy task, but only the best candidates could state clearly a characteristic of a strange particle.

7 Part (a) was answered well by the great majority of candidates, although a significant number reversed the values of proton number and nucleon number.

Surprisingly, part (b)(i) caused many candidates difficulty, with too many believing that heat was the form of the initial energy. Those candidates who answered *potential energy* without making it clear that it was electrostatic were not allowed the mark. There were very many correct answers to part (b)(ii).

The usual error was failure to use $E = mc^2$ or, when doing so, failure to square c. The unit of m was often wrong.

8

Over 50% of the candidates lost one or more marks on this easy opening question. The most common error was giving the wrong number of electrons, by mistakenly taking the charged ion as a neutral atom. Also, a worrying number of candidates did not answer part (b) correctly because they were confused between neutrons and protons. Many candidates did not refer to the number of protons when discussing isotopes but simply stated that isotopes were the same atom with different numbers of neutrons.

9

This question required an understanding of the mechanism of pair production and whilst the majority of candidates were able to name the process, a significant number of them were unclear of the details. This was particular noticeable in part (b) where candidates were required to calculate the minimum energy required to create an electron positron pair. Only about 27% of candidates managed to do this successfully. The most common error was a failure to convert the rest mass of the electron and positron into joules. Some candidates did use the masses of the particles and Einstein's mass energy equivalence equation to determine the frequency. This is of course perfectly acceptable even though the equation is in unit 5. This calculation required an answer to an appropriate number of significant figures and as this was a stand-alone mark, many candidates were awarded it even though their frequency was incorrect.

Part (c) generated some good answers although about a third of candidates did not appreciate that higher frequency photons would result in the electron and positron having more kinetic energy. In part (d) many candidates realised that the positron would annihilate but over half thought that this due to the positron meeting the original electron.

10

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).

11

Part (a) usually gave a good start to the majority of candidates. In part (b) there was an even split between candidates who gave the answer as +2 and those who gave the correct answer in coulombs. The final answer was also sometimes given a negative value. The results in part (c) were, in general, correct.

In part (d) only the better candidates completed the calculation. The usual errors involved using the wrong number of electrons or nucleons or not using consistent mass units. In recent examinations it has been quite common for candidates to make errors when calculating percentages but in this question this error was not often seen.

12 Most candidates could write down the quark composition of the proton in part (a)(iii) but only a small majority could answer the other sections to part (a).

Part (b) was tackled properly only by the best candidates. It was apparent that many candidates tried to identify the actual particle X instead of stating whether it was a baryon or a meson.

Only the best candidates gained full marks in part (c). Only a few included the antineutrino and even fewer included the correct subscripts.