1 A radioactive isotope of carbon is represented by ${}^{14}_{6}C$.

(a) Using the same notation, give the isotope of carbon that has two fewer neutrons.

___

(1)

(b) Calculate the charge on the ion formed when **two** electrons are removed from an atom of ${}^{14}_{6}C$.

___

___

___

(2)

(c) Calculate the value of $\frac{\text{charge}}{\text{mass}}$ for the nucleus of an atom of ${}^{14}_{6}C$.

___

___

___

(2)

(Total 5 marks)

2 A carbon-14 nucleus undergoes β^- decay, forming a new nucleus, releasing a β^- particle and one other particle which is difficult to detect.

(a) Write down the proton number and the nucleon number of the new nucleus.

proton number ___

nucleon number ___

(b) Name the particle which is difficult to detect.

___

(c) Name the baryons and leptons involved in the decay.

baryons ___

leptons ___

(d) Give the quark structure for the neutron and the proton.

neutron ____

proton ____

Hence state the quark transformation that occurs during β^- decay.

____

(Total 7 marks)

3 (a) How many protons, neutrons and electrons are there in an atom of $^{14}_{6}C$?

________________ protons

________________ neutrons

________________ electrons

(2)

(b) The $^{14}_{6}C$ atom loses two electrons.
For the ion formed;

(i) calculate its charge in C,

____

(ii) state the number of nucleons it contains,

____

(iii) calculate the ratio $\frac{\text{charge}}{\text{mass}}$ in C kg^{-1}.

____

____

____

____

(4)

(Total 6 marks)

4 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.

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

(3)

(Total 9 marks)

5 Helium is the second most abundant element in the universe. The most common isotope of helium is ${}^{4}_{2}He$ and a nucleus of this isotope has a rest energy of 3728 MeV.

In 2011, at the Relativistic Heavy Ion Collider, anti-helium nuclei were produced. Nuclei of anti-helium are made up of antiprotons and antineutrons.
It is suggested that an antineutron can decay to form an antiproton in a process similar to β^- decay.

In one particular collision between an anti-helium nucleus and a helium nucleus, the nuclei are annihilated and two photons are formed.

(a) State what is meant by isotopes.

____

____

____

____

(2)

(b) Explain why two photons are formed instead of a single photon when a helium nucleus annihilates with the anti-helium nucleus.

____

____

____

____

____

____

____

____

(2)

(c) Calculate, using data from the passage, the maximum frequency of the photons produced in this annihilation of a ${}^{4}_{2}\text{He}$ nucleus.

frequency = ____________________ Hz

(4)

(d) Complete this equation for the possible decay of an antineutron.

$${}^{1}_{0}\overline{\text{n}} \rightarrow {}^{\;1}_{-1}\overline{\text{p}} + {}^{\_\_}_{\_\_}\_\_\_\_ + \_\_\_\_$$

(2)

(e) What interaction would be responsible for the decay in **part (d)**?
Tick (✓) the correct answer in the right-hand column.

	✓ if correct
electromagnetic	
gravitational	
strong nuclear	
weak nuclear	

(1)
(Total 11 marks)

6 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)

7 A radium-288 nuclide ($^{228}_{88}Ra$) is radioactive and decays by the emission of a β^- particle to form an isotope of actinium (Ac).

(a) Complete the equation for this decay.

$$^{228}_{88}Ra \rightarrow ^{....}_{....}Ac + ^{....}_{....}\beta^- + ...$$

(3)

(b) β^- decay is the result of a neutron within a nucleus decaying into a proton. Describe the change in the quark sub-structure that occurs during the decay.

___

___

___

(1)

(Total 4 marks)

8 Leptons, mesons and baryons are three classes of sub-atomic particles.

(a) Some classes of particles are fundamental; others are not. Circle the correct category for each of these three classes.

leptons	fundamental/not fundamental
mesons	fundamental/not fundamental
baryons	fundamental/not fundamental

(1)

(b) Name the class of particles of which the proton is a member.

___

(1)

(c) By referring to the charges on up and down quarks explain how the proton has a charge of $+1e$.

___

___

___

(2)

(Total 4 marks)

9 (a) State the combination of quarks that makes up a neutron.

___

(1)

(b) When a neutron decays, a down quark changes into an up quark as shown by the following reaction.

$$d \rightarrow u + \bar{e} + \bar{\nu}_e$$

(i) Show, in terms of the conservation of charge, baryon number and lepton number, that this transformation is permitted.

(3)

(ii) State the products arising from the decay of an anti-down quark, $\bar{d}$.

___

___

(1)

(Total 5 marks)

10 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)

11 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)

12 Artificial radioactive nuclides are manufactured by placing naturally-occurring nuclides in a nuclear reactor. They are made radioactive in the reactor as a consequence of bombardment by

A α particles.

B β particles.

C protons.

D neutrons.

(Total 1 mark)

13 In a nuclear reaction ${}^{14}_{7}N$ is bombarded by neutrons. This results in the capture of one neutron and the emission of one proton by one nucleus of ${}^{14}_{7}N$. The resulting nucleus is

A ${}^{13}_{7}N$

B ${}^{14}_{6}C$

C ${}^{12}_{6}C$

D ${}^{14}_{8}O$

(Total 1 mark)

14 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)

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

A kaon ⬭

B muon ⬭

C neutron ⬭

D pion ⬭

(Total 1 mark)

16 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 α and 1 β^- ⬭

B 1 α and 2 β^- ⬭

C 2 α and 1 β^- ⬭

D 2 α and 2 β^- ⬭

(Total 1 mark)

1 (a) $^{12}_{6}C$ **(1)**

1

(b) 2e **(1)**

$= (2 \times 1.6 \times 10^{-19}) = 3.2 \times 10^{-19}$ C **(1)**

2

(c) $\left(\frac{Q}{m}\right) = \frac{6 \times 1.6 \times 10^{-19}}{14 \times 1.67 \times 10^{-27}}$ **(1)**

$= 4.1$**(1)** $\times 10^{7}$ C kg^{-1} **(1)**

2

[5]

2 (a) 7,14 **(1)**

(b) (anti) neutrino **(1)**

(c) proton, neutron **(1)**
electron, (anti) neutrino **(1)**

(d) udd **(1)**
uud **(1)**
d $\rightarrow$ u **(1)**

[7]

3 (a) 6 (protons) and 6 (electrons) **(1)**
8 (neutrons) **(1)**

2

(b) (i) $(2 \times 1.6 \times 10^{-19}) = 3.2 \times 10^{-19}$ (C) **(1)**

(ii) 14 **(1)**

(iii) $m = 14 \times 1.67 \times 10^{-27}$ (kg) **(1)**

$\frac{Q}{M} = \left(\frac{3.2 \times 10^{-19}}{14 \times 1.67 \times 10^{-27}}\right) = 1.4 \times 10^{7}$ (C kg^{-1}) **(1)**

(1.37×10^{7} (C kg^{-1}))

(allow C.E for values from (i) and (ii))

4

[6]

4 (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 × 10-19 ÷ 1.60×10^{-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]

5 (a) atoms/nuclei with same number of protons/atomic number ✓

atom/nuclei seen at least once

1

but different numbers of neutrons/mass number ✓

1

(b) momentum must be conserved ✓

1

so need two photons travelling in different directions ✓

1

(c) rest energy = 2 × 3728 = 7456 ✓ (MeV)

must show doubling OR explain that is halved because two photons OR implied because 1.193 × 10^{-9}

1

rest energy = 1.193 × 10^{-9} ✓ (J)

1

use of energy of each photon = *hf* ✓

no working but correct answer scores last three marks

1

f = (1.193 × 10^{-9}/2) /6.63 × 10^{-34} = 8.997 × 10^{23} ✓ (Hz)

RANGE: 8.90 × 10^{23} − 9.00 × 10^{23}

1

(d) ${}^{1}_{0}\overline{\mathrm{n}} \rightarrow {}^{1}_{-1}\overline{\mathrm{p}} + {}^{0}_{1}\overline{e} + \nu_{(e)}$ ✓✓

Can use e^+ OR β in place of e

1

Allow slight loop in bottom of neutrino but must not look like gamma

1

(e)

electromagnetic	
gravitational	
strong nuclear	
weak nuclear	✓

1

[11]

6 (a) pair production ✓

1

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

If miss out 2 factor can get CE
Can use E=2mc²
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]

7 (a) ${}^{228}_{89}Ac$ **B1**

$^{0}_{-1}\beta$ **B1**

suitable anti - neutrino indication (anti - neutrino not required) **B1**

(b) Down quark changes to up quark **B1**

[4]

8 (a) lepton fundamental
meson, baryon not fundamental
allow underline or crossing out wrong options **B1**

(1)

(b) (i) baryon / hadron **B1**

(1)

(ii) u u d **B1**

$+\frac{2}{3}+\frac{2}{3}-\frac{1}{3}$ = +1(e) **B1**

(2)

[4]

9 (a) d + d + u **B1**

(1)

(b) (i) conservation of charge: –1 / 3 = +2 / 3 + (–1) + 0 **B1**

conservation of baryon number: 1 / 3 = 1 / 3 + 0 + 0 **B1**

conservation of lepton number: 0 = 0 + (+1) + (–1) **B1**

(3)

(ii) anti up–quark plus positron plus electron neutrino **B1**

(1)

[5]

10 D

[1]

11 C

[1]

12 D

[1]

13 B

[1]

14 D

[1]

15 B

[1]

16 B

[1]

Examiner reports

1 Answers to this question generated many errors. Less than 50% of the candidates gained full marks for what was really an easy starter question. In part (b), the incorrect answer of +4e appeared very frequently and likewise, in part (c), the incorrect inclusion of the electron mass was a very common occurrence. Additionally, calculation errors, failure to give the correct units and significant figure errors all contributed to an overall poor performance.

2 This question was very well answered and it was pleasing to see that many candidates were able to recall most of the appropriate information from this relatively new part of the syllabus.

3 Only the weakest candidate found difficulty with parts (a) and (b)(ii), but many more candidates failed to calculate the charge of the ion and an answer of $4 \times 1.6 \times 10^{-19}$ C was extremely common. It was surprising to see how few candidates answered (b)(iii) correctly; one source of trouble being that many incorrect constants, other than the correct mass of a nucleon, were introduced into the calculation.

4 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).

5 In this question students were required to extract information from an introductory passage. Part (a) was a straightforward starter but a significant proportion of answers were spoilt by a lack of precision. Students were required to mention atoms or nuclei in their responses and a significant proportion did not do this. Part (b) required an explanation as to why two photons were produced. A number of students seemed to think this was necessary due to energy conservation. Of those who realised this was due to momentum conservation, a significant proportion then failed to appreciate the importance of the photons travelling in different directions. Part (c) was an extended calculation and students were told to calculate the maximum frequency of the photons produced in the annihilation of the two nuclei. Maximum was necessary to indicate that the whole rest energy of the nuclei should be used and excluded the possibility of calculating the frequency of photons produced due to annihilation of individual nucleons within the helium and anti-helium nuclei. It is true that higher frequency photons would be produced if the nuclei had significant kinetic energy but students were told to use information from the passage in which there was no mention of kinetic energy. For full marks students needed to explain how they dealt with two nuclei annihilating and two photons being produced. Parts (d) and (e) were well answered and the only common error was a failure to identify the positron correctly in the equation.

6 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.

7

(a) The equation was completed well by a large proportion of the candidates but there was a significant number who could make no valid attempt. The β^- was usually correct, but common errors were to quote $^{228}_{87}Ac$ together with an ambiguous symbol for the antineutrino. Examiners required candidates to make it clear that the third particle was an *anti-neutrino*.

(b) This was well answered by the majority who knew that a down quark changes to an up quark when the neutron decays to a proton.

8 This question was extremely well answered with the majority of candidates gaining at least three of the four marks.

(a) A sizeable minority of candidates circled the complete opposite of all the correct answers. It is essential that candidates read the questions carefully.

(b) Credit was given for those candidates stating that the proton is a hadron.

(c) Answers were usually very clearly laid out and correct.

14 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.

15 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.

16 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.