

1

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)

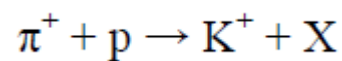
2

- (a) Complete the table comparing some of the properties of the positive pion, π^+ , and the proton.

Name	π^+	Proton
Relative charge	+1	
Baryon number		
Quark composition		

(5)

- (b) When a positive pion interacts with a proton, a kaon can be produced, along with another strange particle, as shown in this equation



Circle the type of interaction shown in this equation.

Electromagnetic

Gravitational

Strong Nuclear

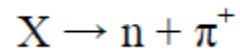
Weak Nuclear

(1)

- (c) Deduce the relative charge, baryon number and strangeness of particle X.

(3)

- (d) Particle X can decay to produce a neutron and positive pion as shown in this equation



Circle the type of interaction shown in this equation.

Electromagnetic

Gravitational

Strong Nuclear

Weak Nuclear

(1)

- (e) Explain your answer.

(2)

- (f) The neutron and positive pion will then decay. The positive pion can decay into a positron and an electron neutrino.

Write down the equation for the decay of the neutron.

(2)

- (g) Explain why no further decays occur.

(2)

(Total 16 marks)

3

- (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)

4

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



(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)

5

(a) The table gives information about some fundamental particles.

Complete the table by filling in the missing information.

particle	quark structure	charge	strangeness	baryon number
	uud		0	
Sigma ⁺	uus	+ 1		
	$u\bar{d}$		0	0

(7)

(b) Each of the particles in the table has an antiparticle.

(i) Give **one** example of a baryon particle **and** its corresponding antiparticle.

particle _____

antiparticle _____

(1)

(ii) State the quark structure of an antibaryon.

(1)

(iii) Give **one** property of an antiparticle that is the same for its corresponding particle and **one** property that is different.

Same _____

Different _____

(2)

(Total 11 marks)

6

Which of the following is **not** true?

A Each meson consists of a single quark and a single antiquark.

☐

B Each baryon consists of three quarks.

☐

C The magnitude of the charge on every quark is $\frac{1}{3}$

☐

D A particle consisting of a single quark has not been observed.

☐

(Total 1 mark)

7

(a) (i) Name two baryons.

(2)

(ii) State the quark structure of the pion π^+ .

(1)

- (b) (i) The K^+ kaon is a strange particle. Give **one** characteristic of a strange particle that makes it different from a particle that is not strange.

(1)

- (ii) One of the following equations represent a possible decay of the K^+ kaon.

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

$$K^+ \rightarrow \mu^+ + \bar{\nu}_\mu$$

State, with a reason, which one of these decays is not possible.

(2)

- (c) Another strange particle, X , decays in the following way:

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

- (i) State what interaction is involved in this decay.

(1)

- (ii) Show that X must be a neutral particle.

(1)

- (iii) Deduce whether X is a meson, baryon or lepton, explaining how you arrive at your answer.

(2)

(iv) Which particle in this interaction is the most stable?

(1)

(Total 11 marks)

8

- (a) (i) Give an example of an exchange particle other than a W^+ or W^- particle, and state the fundamental force involved when it is produced.

exchange particle _____

fundamental force _____

- (ii) State what roles exchange particles can play in an interaction.

(4)

- (b) From the following list of particles,

p $\bar{n}$ ν_e e^+ μ^- π^0

identify **all** the examples of

(i) hadrons, _____

(ii) leptons, _____

(iii) antiparticles, _____

(iv) charged particles. _____

(4)

(Total 8 marks)

9

- (a) Quarks may be combined together in a number of ways to form sub-groups of hadrons. Name **two** of these sub-groups and for each, state its quark composition.

sub-group 1 _____

sub-group 2 _____

(3)

(b) A free neutron is an unstable particle.

(i) Complete the following to give an equation that represents the decay of a neutron.

$n \rightarrow$

(ii) Describe the change that occurs to the quark structure when a neutron decays.

(4)

(Total 7 marks)

10

Some subatomic particles are classified as *hadrons*.

(a) What distinguishes a hadron from other subatomic particles?

(1)

(b) Hadrons fall into two subgroups. Name each subgroup and describe the general structure of each.

subgroup 1 _____

subgroup 2 _____

(3)

- (c) The following equation represents an event in which a positive muon collides with a neutron to produce a proton and an antineutrino.

$$n + \mu^+ \Rightarrow p + \bar{\nu}_\mu.$$

Show that this equation obeys the conservation laws of charge, lepton number and baryon number.

(3)

(Total 7 marks)

11

- (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)

12

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

(Total 2 marks)

13

Neutrons were discovered when beryllium, ${}^9_4\text{Be}$, was bombarded with alpha particles.

An alpha particle knocked a neutron out of a beryllium nucleus producing a carbon nucleus, **C**.

(a) Write down the equation that describes this reaction.

(2)

(b) (i) Describe the quark substructure of a neutron.

(1)

(ii) Describe how the quark substructure of a meson differs from that of a baryon such as a neutron.

(1)

(Total 4 marks)

14

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

A kaon

☐

B muon

☐

C neutron

☐

D pion

☐

(Total 1 mark)

15

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)****16**

- (a) Name **three** types (or *flavours*) of quark.

(2)

- (b) By referring to the charges on quarks, explain why the neutron is uncharged.

(2)**(Total 4 marks)****17**

- (a) The Σ^+ particle is a baryon with strangeness -1 .

- (i) How many quarks does the Σ^+ particle contain?

answer _____

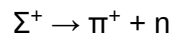
(1)

(ii) How many of the quarks are strange?

answer _____

(1)

(b) The Σ^+ decays in the following reaction



(i) State **two** quantities that are conserved in this reaction.

(2)

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

(1)

(iii) What interaction is responsible for this reaction?

(1)

(iv) Into what particle will the neutron formed in this reaction eventually decay?

(1)

(Total 7 marks)

18

(a) Give the number of nucleons and the number of electrons in an atom of $^{22}_{11}\text{Na}$.

nucleons _____

electrons _____

(2)

- (b) The isotope $^{22}_{11}\text{Na}$ is a positron emitter. In positron emission an up quark undergoes the following change,

$$u \rightarrow d + \beta^+ + \nu_e.$$

Show that charge, lepton number and baryon number are conserved in this decay.

charge _____

lepton number _____

baryon number _____

(3)

- (c) Describe what happens when a positron collides with an electron.

(2)

(Total 7 marks)

19

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	ν _e	
D	n	π ⁰	

(Total 1 mark)

20

- (a) State what is produced when an electron and a positron annihilate each other.

(1)

- (b) (i) Explain why mass is not necessarily conserved when particles interact or decay.

(1)

- (ii) Momentum is conserved in all particle interactions. Name the **three** other conservation laws that are obeyed in **all** nuclear interactions.

(3)

(Total 5 marks)

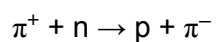
21

- (a) Complete the table by naming **one** example of each type of particle.

type of particle	example
lepton	
baryon	
meson	

(3)

- (b) The following reaction cannot occur.



- (i) State and explain which conservation law would be broken by this reaction.

(2)

- (ii) State and explain **one** conservation law that would **not** be broken in this reaction.

(1)

- (c) Describe what happens when a proton and an antiproton collide.

(2)

(Total 8 marks)

22

- (a) (i) Explain what is meant by an *exchange particle*.

(2)

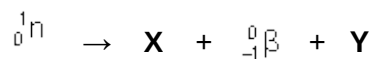
- (ii) Name the exchange particle that mediates the strong force.

(1)

- (iii) The weak nuclear force acts over a much shorter distance than the strong force. Explain **two** differences between the relevant exchange particles that account for this.

(2)

- (b) The following equation shows the β^- decay of a free neutron.



Identify each of the particles **X** and **Y**.

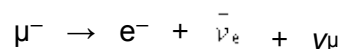
Show the appropriate nucleon and proton number for each of the particles.

X _____

Y _____

(2)

- (c) For a decay to be possible each of baryon number, lepton number and charge must be conserved. Use these rules to show that the following decay is possible.



conservation of baryon number:

conservation of lepton number:

conservation of charge:

(3)

(Total 10 marks)

23

A physicist, who is attempting to analyse a nuclear event, suggests that a π^- particle and a proton collided and were annihilated with the creation of a neutron, a π^+ particle, and a K^- particle.

π and K particles are mesons. The baryon and lepton numbers of both these mesons are zero.

- (a) Write down the equation that represents this interaction.

(1)

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

(4)

(Total 5 marks)

Mark schemes

1 C

[1]

2 (a)

1✓
0✓ 1✓
⋮
ud✓ uud✓
1 mark each

5

(b) Strong nuclear circled✓

1

(c) Charge $1 + 1 = 1 + X$ $X = 1$ ✓

1

Baryon number $0 + 1 = 0 + X$ $X = 1$ ✓

1

Strangeness $0 + 0 = 1 + X$ $X = -1$ ✓

1

Any order

(d) Weak nuclear circled✓

1

(e) Strangeness of X is -1,

First mark is for showing that strangeness changes

The strangeness of the pion and neutron are both zero

1

The strangeness changes from -1 to 0✓

This can only occur in weak interactions. ✓

Second is for stating that this can only happen if the interaction is weak.

1

(f)

—
First mark is for the proton

1

$n \rightarrow p \checkmark + \beta^- + \nu_e \checkmark$

Second is for the beta minus and antineutrino.

1

- (g) The only particles remaining are electrons / positrons and neutrinos / antineutrinos which are stable ✓

1

1

And a proton which is the only stable baryon ✓

1

1

[16]

3

- (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 and mesons, 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]

4

(a) (90,39)

B1

(0,-1)

B1

$\bar{\nu}^e$

B1

3

(b) $d \rightarrow u$
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 Z⁰

B1
1

[8]

5

(a)

particle	quark structure	charge	strangeness	baryon number
proton✓	uud	+ 1✓	0	1✓
sigma ⁺	uus	+1	-1✓	1✓
π ⁺ ✓	u $\bar{d}$	+1✓	0	0

7

- (b) (i) examples:
proton, antiquarks✓

1

- (ii) consists of 3 antiquarks✓

1

- (iii) same (rest) mass (energy)✓
difference eg baryon number/charge✓

2

[11]

6

C

[1]

7

(a) (i) any two eg proton, neutron ✓✓

2

(ii) $u\bar{d}$ ✓

1

(b) (i) contains a strange quark

or longer half life than expected

or decays by weak interaction ✓

1

(ii) the second one is not possible ✓

because lepton number is not conserved ✓

2

(c) (i) weak (interaction) ✓

1

(ii) mention of charge conservation

or charge conservation demonstrated by numbers ✓

1

(iii) X must be a baryon ✓

baryon number on right hand side is +1 ✓

2

(iv) proton/p ✓

1

[11]

8

(a) (i) Z^0 with the weak interaction

gluons or pions with the strong nuclear force

γ photons with electromagnetic interaction

gravitons with gravity

(any exchange particle **(1)** and corresponding interaction **(1)**)

(ii) transfers energy

transfers momentum

transfers force

(sometimes) transfers charge any two **(1)(1)**

4

(b) $p \bar{n} \pi^0$ (1)

$V_e e^+ \mu^-$ (1)

$\bar{n} e^+$ (1)

$p e^+ \mu^-$ (1)

4

[8]

9

(a) baryon qqq
antibaryon $\bar{q}\bar{q}\bar{q}$
meson $q\bar{q}$

two names (1)

composition of each sub-group (1) (1)

3

(b) (i) $n \rightarrow p$ (1) + $\begin{smallmatrix} 0 \\ -1 \end{smallmatrix} \beta^-$ (1) + $\bar{\nu}_{(e)}$ (1)

(ii) a down (d) quark changes to an up (u) quark
[or udd changes to uud] (1)

4

[7]

10

(a) hadrons are subject to the strong nuclear force
[or hadrons consist of quarks (or antiquarks)] (1)

1

(b) (i) baryons and mesons (1)

baryons consist of three quarks

antibaryons consist of three antiquarks

mesons consist of a quark and an antiquark (any two) (1) (1)

3

(c) Q: $0 + 1 = 1 + 0$ (1)

L: $0 - 1 = 0 - 1$ (1)

B: $1 + 0 = 1 + 0$ (1)

3

[7]

11

(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 and baryon number conserved **(1)**

(4)
[6]

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

B1

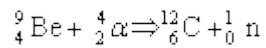
good extra detail

B1

[2]

13 (a) $\text{Be} + \alpha \Rightarrow \text{C} + \text{n}$

(condone N; any other symbol must be defined as a neutron)



B1

(Condone other symbols if Z and A correct)

B1

2

(b) (i) udd (1 up quarks and 2 down quarks)

B1

1

(ii) A meson has only two quarks
 (whereas a baryon has three)

B1

1

[4]

14 B

[1]

15 (a) lepton fundamental

meson, baryon not fundamental

allow underline or crossing out wrong options **(1)**

(b) (i) baryon/hadron **(1)**

(ii) u u d **(1)**

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

3

[4]

16

(a) up, down, strange (allow charm, top, bottom)

any two **(1)** any three **(1)(1)** (not u, d, s etc)

B2

2

(b) udd **(1)**

B1

$$+2/3(e) -1/3(e) -1/3(e) \text{ **(1)**}$$

B1

2

[4]

17

(a) (i) three **(1)**

one **(1)**

2

(b) (i) charge **(1)**

baryon number **(1)**

lepton number **(1)**

mass **(1)**

energy **(1)**

momentum **(1)**

max 2

(ii) strangeness **(1)**

(iii) weak interaction/(nuclear) force **(1)**

(iv) proton **(1)**

5

[7]

18	(a) 22 (nucleons) (1) 11 (electrons) (1)		2	
	(b) charge: $+\frac{2}{3} = -\frac{1}{3} + 1 + 0$ (1) lepton number: $0 = 0 - 1 + 1$ (1) baryon number: $\frac{1}{3} = \frac{1}{3} + 0 + 0$ (1)		3	
	(c) the electron and the positron are annihilated (1) γ photon(s)/ γ ray(s) are produced (1) specifying two (γ) photons/rays (1) masses converted into energy (1)		max 2	[7]
19	C			[1]
20	(a) γ / (pair of) gamma (ray(s))/ Z_0 (particles) (followed by gamma rays) / photon(s) of electromagnetic radiation	B1	1	
	(b) (i) mass can be converted to energy and vice versa	B1	1	
	(ii) charge	B1		
	baryon <u>number</u>	B1		
	lepton <u>number</u>	B1		
	minus 1 for each incorrect answer if more than 3 answers are given		3	[5]

21	(a)	electron/neutrino/tau/muon				
						B1
		proton/neutron				
						B1
		kaon/k particle/k meson/pion/pi meson				
						B1
						3
	(b)	(i)	charge			
						M1
			correct equation: $1 + 0 \neq 1 + (-1)$			
			1 mark lost for additional conservation law stated as broken			
						A1
						2
		(ii)	any other correct conservation (lepton: $0 + 0 = 0 + 0$; baryon: $0 + 1 = 1 + 0$; strangeness: $0 + 0 = 0 + 0$)			
						B1
						1
	(c)		annihilation			
						B1
			release of energy/pair of gamma rays			
						B1
						2

(ii) gluons lighter/(w) bosons more massive

B1

(iii) gluons have longer range/(w) bosons have shorter range
not distance

B1

5

(b) $\frac{1}{2}p$

B1

$\frac{0}{0} \frac{-}{\nu}$ in either order

B1

2

(c) baryon $0 \rightarrow 0 + 0 + 0$

B1

lepton $1 \rightarrow 1 + (-1) + 1$

B1

charge $-1 \rightarrow (-1) + 0 + 0$

B1

3

[10]

23

(a) $\pi^- + p^{(+)} = n + \pi^+ + K^-$

B1

(b) Charge conservation equation correct

M1

Baryon conservation equation correct

M1

Lepton conservation equation correct

M1

All comments and checks consistent

A1

[5]