Mark schemes

1. (a) 126 ✓

1

(b) A neutron decays into a proton

Or

$n \rightarrow p + e^{(-)} + \bar{\nu}_e$ ✓

Allow a neutron changes to a proton. (owtte) Accept the decay equation of a neutron / bismuth

• *Statement that neutron converts to proton* ✓

• *all numbers correct and context* ✓

$^{210}_{83}Bi \rightarrow {}^{210}_{84}Po + {}^{0}_{-1}e + ({}^{0}_{0}\bar{\nu}_e)$

Proton number **increases by one** when Bi-210 decays and describes beta minus

Condone missing (or incorrect) neutrino or symbol for bismuth

OR

Bi-210 has **one fewer proton** (than Po-210) and describes beta minus in words

OR

Po-210 has **one more proton** (than Bi-210) and describes beta minus in words

Or

Proton number **increases from 83 to 84** and describes beta minus in words ✓

Allow proton number increases where there is a clear statement that a neutron has decayed into a proton.

2

(c) (Missing) energy carried off by third particle

Or

(A third particle must be produced) for conservation of energy✓

Accept energy is converted into mass of third particle.

Where third particle is named must be a neutrino or an antineutrino.

There is missing energy (When) a beta (particle) has less than 1.2 MeV (of kinetic energy).

Or

The law of conservation of energy appears to be violated when beta (particle) has less than 1.2 MeV ✓

Identify there is difference between 1.2 MeV and E_k.

(d) (It must be an electron antineutrino to) conserve lepton number✓

An electron and (electron) antineutrino have lepton numbers of opposite signs.

Or

An electron and (electron) antineutrino have a (total) lepton number of zero. ✓

Alternative for 2nd Marking point:

Appropriate particle equation seen annotated with correct lepton numbers.

Alternative:

Producing an (electron) neutrino wouldn't conserve lepton number ✓

An electron and (electron) neutrino have lepton numbers of the same sign.

Or

An electron and (electron) neutrino have a (total) lepton number equal to 2. ✓

Alternative 2nd marking point:

Appropriate particle equation seen annotated with correct lepton numbers.

2

(e) (**X** =) W-minus (boson) / W^- (boson) ✓

(**Y** =) neutron / n ✓

2

(f) Lepton (in the water molecule) is an electron ✓

Must state that lepton (in the water) is an electron for all 3 marks

and

Max 2 from

annihilation ✓

gamma photon**s** are produced ✓

Two (gamma) photons are produced (that travel) in opposite directions. ✓

Penalise answers that list other products in MP3 and MP4

3

(g) **Max 3**

The positron because:

positron is charged and the (electron) antineutrino ($\bar{\nu}_{(e)}$) is neutral ✓

The antineutrino only interacts via the weak interaction / The positron interacts via the electromagnetic interaction (and weak interaction)✓

The antineutrino's (weak) interaction is shorter range / the antineutrino is less likely to get close enough to interact (with particles in the water so will travel further) / the antineutrino will interact with fewer particles✓

The positron's (electromagnetic) interaction has a longer range / the positron does not have to be so close to interact (with particles in the water so will travel a shorter distance) / the positron will interact with more particles✓

Must have the correct conclusion for 3 marks.

3

[15]

2. A

$-1.3 \times 10^{7}\ C\ kg^{-1}$

[1]

3. D

W^{+}

[1]

4. A

$\Lambda^{0} + \pi^{-}$

[1]

5. B

$1.2 \times 10^{-14}\ m$

[1]

6. D

repulsive attractive negligible

[1]

7. C

$p + e^{-} + \bar{\nu}_{e}$

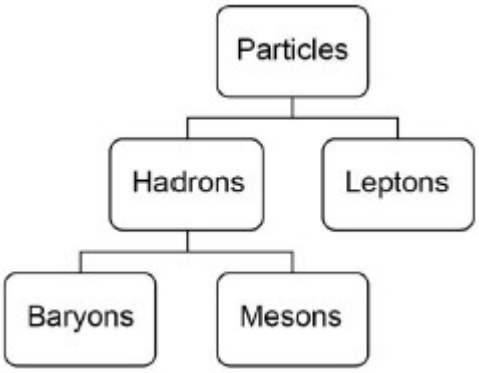
[1]

8. C

using monochromatic light of higher frequency

[1]

9. A



[1]

10. (a) MP1 is for evidence of determining the charge on the nucleus. ✓

Charge = $4.39 \times 10^{7} \times 8.02 \times 10^{-26}$ kg

(= 3.52×10^{-18} C)

MP2 is for evidence of determining either the number of protons OR the number of nucleons. ✓

Number of protons = charge/1.6×10^{-19} (= 22)

OR

Number of nucleons

= 8.02×10^{-26} / 1.67×10^{-27} (= 48)

MP3 is for determining number of neutrons. ✓

Number of neutrons = 48 – 22 = 26

Note use of 1.7 gives 27 neutrons and loses MP3

3

(b) Evidence of conversion of MeV to J ✓

Energy = $2.15 \times 10^{8} \times 1.6 \times 10^{-19}$ (= 3.44×10^{-11} J) - allow POT error in MP1

Substitution into KE equation ✓

$v^2 = 2E/m = 8.58 \times 10^{14}$

Correct final answer ✓

$v = 2.9(3) \times 10^{7}$ m s^{-1}

3

(c) $\pi^+ \rightarrow e^+ + \nu_e$

OR

charge: 1 = 1 + 0✓

B: 0 = 0 + 0

AND

L: 0 = –1 + 1✓

(S: 0 = 0 + 0)

(d) ($K^+ \rightarrow \mu^+ + \nu_\mu$)

Correct strangeness

+1 = 0 + 0 ✓

Weak interaction so strangeness can change (by 0, +1 or –1) ✓

2

(e) Decay consistent with Q B L conservation✓

Equation involving pions ✓

e.g.

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

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

2

[12]

11. A

[1]

12. A

$\alpha + \beta^- + \beta^- + \alpha + \alpha$

[1]

13. A

up quark *down quark* *neutrino*

[1]

14. B

It has a charge of -1.6×10^{-19} *C.*

[1]

15. (a) Lepton number = 0 **and** Strangeness = 0 ✓

charge = (+)1(e) ✓

accept (+) 1.6×10^{-19} *(C)*

condone lack of unit

2

(b) Proton / p / $^1_1\mathrm{H}$ ✓

Apply ECF to answers any particle other than a proton.

The particle must be correct for the given L, S and Q. (clip with (a))

1

(c) Tick in first box only ✓

(electron) antineutrino $\bar{\nu}_{(e)}$

1

(d) The marking scheme for this question includes an overall assessment for the quality of written communication (QWC). There are no discrete marks for the assessment of QWC but the candidate's QWC in this answer will be one of the criteria used to assign a level and award the marks for this question.

Mark	Criteria	QWC
6	**All 3 areas A, B and C covered Only allow minor omissions**	**The student presents the relevant information coherently, employing structure, style and SP&G to render meaning clear. The text is legible.**
5	**2 complete descriptions with one partial from A, B and C.**	
4	**Full description of one area, with partial description of two other. OR Full description of two areas with very little on third or nothing at all.**	**The student presents relevant information in a way which assists the communication of meaning. The text is legible. SP&G are sufficiently accurate not to obscure meaning.**
3	**A full description of one area and a partial description of one area. OR A partial discussion of all three areas.**	
2	**A full description of one area. OR A partial discussion of two areas.**	**The student presents some relevant information in a simple form. The text is usually legible. SP&G allow meaning to be derived although errors are sometimes obstructive.**
1	**Only one area covered, and that partially.**	
0	**No relevant information**	

The following statements are likely to be present.

Area A
Hadrons properties:
- Identifies hadrons as consisting of quarks
- May interact via the strong nuclear force

Area B
General structure:
- Two classes are mesons and baryons
- quark-antiquark: meson
- Quark, quark, quark: baryon

Area C
Stability of free hadron:
- Only stable free baryon is proton
- Example of decay of a free meson or baryon e.g. kaon decay into pions / states neutron decays into a proton

6

[10]

16. (a) (mass of ion =) 1.8(4) × 10^{-26} (kg) ✓

1

(b) (Mass of ion divided by mass of nucleon=) 10.6 or 10.8 ✓ ECF

allow 1 mark for 10 seen as final answer

(number of nucleons=) 11 ✓ **ECF**

whole number not in standard form

2

(c) Same number of protons ✓

X has more neutrons (than **Y**)
Or
Y has fewer neutrons (than **X**) ✓

*Allow 'same proton number' but **not** same 'atomic number'*

Allow: isotopes have same number of protons

Condone any mention of electrons

'X has more nucleons' or 'Y has fewer nucleons' insufficient

2

(d) Specific charge on ion **X** is less than specific charge on **Y**
Or
Specific charge on ion **Y** is greater than specific charge on **X** ✓

Specific charge is inversely proportional to mass (for the same charge) ✓

Or words to that effect

Where equation is stated, the symbols must be defined or standard symbols must be used.

2

(e) Specific charge of sample determined correctly ✓
Specific charge of each sample determined correctly ✓
Sample 2 has a greater percentage **because** it has a higher specific charge ✓
Or
Mean mass of a nucleon in a sample determined correctly ✓
Mean mass of a nucleon in each sample determined correctly ✓
Sample 2 has a greater percentage **because** the nucleons have a lower mean mass. ✓

Or
Mean mass of a nucleon in a sample determined correctly ✓
Multiples by this average by number of nuclei in the other sample ✓
Sample 2 has a greater percentage **because** the nucleons in sample 2 have a lower average mass. Or
Sample 2 because it has a lower mass if both samples had the same number of ions ✓

Or

10^9 times smaller in number but more than 10^9 times smaller mass ✓
(Therefore) sample 2 must have a lower mean mass (than sample 1) ✓
Sample 2 has a greater percentage of **Y because Y** has less mass than X ✓

Mean mass of a nucleon sample 1=

1.8×10^{-26} kg

Mean mass of a nucleon sample 2 =

1.77×10^{-26} kg

Specific charge of sample 1 = 8.8×10^6 (C kg^{-1})

Specific charge of sample 2 = 9.0×10^6 (C kg^{-1})

Conclusion must be supported by at least one relevant, correct calculation

Condone one power of ten error in one calculation.

Accept converse statements.

Condone incorrect units

3

[10]

17. **A**

[1]

18. **C**

[1]

19. **B**

[1]

20. **D**

[1]

21. (a) Award each mark independently

Lepton number not conserved therefore not possible ✓

Lepton numbers for particles correct ✓

Any incorrect quantum number equation (for Q, B or S) loses MP2.

Eg 0 = 1 −1 −1 (for lepton number)

OR 0 = 0 −1 +0 (for muon lepton number)

Alternative for MP2

reference to missing muon neutrino in order to balance/conserve (muon) lepton number.

2

(b) up anti-up

AND

down anti-down ✓

Either order

Credit symbols

But do not condone any use of capital letter

1

(c) Identification of quarks in either neutral kaon correct, ie kaon d $\overline{s}$

OR anti-kaon $\overline{d}$ s ✓

Identification of quarks in other kaon correct, with statement that they are not the same. ✓

Alternative:

Kaon has strangeness +1 ✓

Anti-kaon has strangeness –1 and is therefore not the same. ✓

Allow max 1 if

- *quark configurations wrong way round.*
- *value of strangeness is wrong way round*
- *statement that strangeness is different without reference to value.*
- *strangeness and quarks given but one of them is incorrect.*

2

(d) Award each mark independently

Links hadrons to strong nuclear force (snf)

OR identifies snf as forcing holding nucleus together ✓

OR

(only) pion and muon have correct rest energy with no mention of kaon.

Reason why it cannot be the kaon ✓

For MP2: kaon rest energy is not between those of electron and half that of nucleon. (values quoted from data booklet)

Reason why it cannot be the muon ✓

For MP3: muon is a lepton (and does not experience snf)

pion is the particle as it (has mass in range and) is a hadron (and therefore experiences snf) ✓

An incorrect statement amount a particle negates the mark for that particle.

Rest energies/MeV:

kaon 493.821 or 497.762

pion 139.576 or 134.972

muon 105.659

nucleon 938.257 or 939.551

4

[9]

22. **B**

[1]

23. **B**

[1]

24. **B**

[1]

25. **D**

[1]

26. **A**

[1]

27. **B**

[1]

28. **C**

[1]

29. **B**

30. **C**

[1]

31. **C**

[1]

32. **A**

[1]

33. **B**

[1]

34. (a) Neutron

Condone misspelling eg nuetron

1

(b) Weak (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]

35. **A**

[1]

36. **C**

[1]

37. **A**

[1]

38. **B**

[1]

39. (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 rest 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]

40. (a) pair production ✓

1

(b) (i) energy of photon needs to provide

at least the rest masses ✓

OR at least the rest energy ✓

of the electron and 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]