1. (a) (i) $\overline{\nu_e} + p \rightarrow n$ **(1)** $+ e^+$ **(1)**

(ii) weak **(1)**

(iii) W^+ or W^- **(1)** 4

(b) γ photon or high energy photon/kinetic energy **(1)**
converted to a particle and its antiparticle **(1)**
$p + \overline{p}$ or $e^- + e^+$ **(1)** 3
QWC 1
[7]

2. (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]

3. (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 $\overline{n}$ π^0 **(1)**

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

$\overline{n}\, e^+$ **(1)**

$p e^+ \mu^-$ **(1)** 4
[8]

4. (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]

5. (a) pair production **(1)** 1

(b) (i) the γ ray must provide enough energy to provide for the (rest) mass **(1)**

any extra energy will provide the particle(s) with **kinetic** energy **(1)**

(ii) (0.511 + 0.511) = 1.022 (MeV) **(1)** 3

(c) any pairing of a particle with its corresponding antiparticle (e.g. $p + \bar{p}$) **(1)** 1

[5]

6. (a) $n + \nu_{(e)}$ **(1)(1)**

μ^- **(1)**

K^+ **(1)** 4

(b) $d \rightarrow u + \beta^- + \nu_{(e)}$ **(1)(1)** 2

(c) (i) weak interaction **(1)**

lepton **(1)**

electromagnetic and gravitational **(1)** 3

[9]

7. (a) 55 protons

55 electrons **(1)**

82 neutrons **(1)** 2

(b) (i) same number of protons **(1)**

different number of neutrons **(1)**

(ii) ${}^{134\to154}_{55}\text{Cs}$ **(1)** 3

(c) specific charge (= charge/mass) = 55 × 1.6 × 10^{-19}/137 × 1.67 × 10^{-27} **(1)**

3.85 × 10^{7} **(1)** C kg^{-1} **(1)** 3

[8]

8. (a) (i) $q\bar{q}$; qqq; $\overline{qqq}$

(1)(1) (**(1)** for just two combinations)

(ii) $\pi^{+} = u\bar{d}$ **(1)**

$\bar{p} = \bar{d}\bar{u}\bar{u}$ **(1)** 4

(b) (i) strangeness = –3

charge = –1

baryon number = +1

lepton number = 0

(1)(1)(1) if all correct – lose one for each error

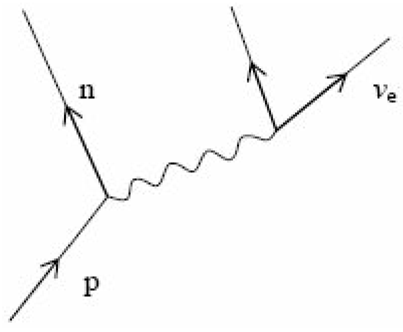
(ii) the proton **(1)** 4

[8]

9. (a) n **(1)**

p **(1)**

ν_e **(1)**



3

(b) (i) γ photon **(1)**

(ii) γ is massless
γ has infinite range
γ does not carry charge 3

(1)(1) any two

(c) (i) all properties/quantum numbers (e.g. charge, strangeness) are opposite **(1)**

but the masses are the same **(1)**

(ii) π^o **(1)**

$\overline{K}^\circ$ **(1)**

γ **(1)** 5

[11]

10. (a) (i) electromagnetic **(1)**

photon (or γ) **(1)**

(ii) charge

mass

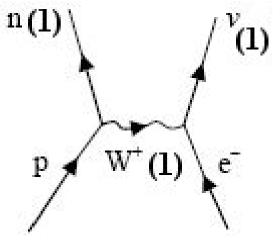
lepton number

baryon number

strangeness

any two **(1)(1)** 4

(b) (i)



(ii) weak **(1)**

(iii) charge **(1)**

charge before = + and **-** = 0 same after **(1)**

baryon number **(1)**

+1 before (p) and +1 after (n) **(1)**

lepton number **(1)**

+1 before and +1 after **(1)**

or strangeness

(iv) if a reliable experiment does not support a hypothesis **or** experiment proves/disproves/checks theory **(1)**

the hypothesis must be changed/rejected **or** hypothesis/theory can be extended to other areas **(1)** 10

[14]

11. (a) isotopes (are varieties of the same element that) have the same number of protons/atomic number/proton number **(1)**

but different numbers of neutrons/nucleons/atomic mass **(1)** 2

(b) 8

	number of protons	number of neutrons	specific charge of nucleus/ C kg^{-1} **(1)**
first isotope	92	143	$= 92 \times 1.6 \times 10^{-19}$ **(1)** $/(92 \times 1.67 \times 10^{-27}$ $+ 143 \times 1.67 \times 10^{-27})$ **(1)** $= 3.8 \times 10^{7}$ **(1)**
second isotope	92 **(1)**	$3.7 \times 10^{7} = 92 \times 1.6 \times 10^{-19}$ $/(A \times 1.67 \times 10^{-27})$ **(1)** $A \times 1.67 \times 10^{-27} =$ $92 \times 1.6 \times 10^{-19}/3.7 \times 10^{7}$ A = 238 **(1)** number of neutrons = 238 – 92=146 **(1) or** 148 if used u **or** 147 (depends on rounding)	3.7 ×107

[10]

12. (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]

13. (a) (i) particles that experience the strong (nuclear) force/interaction **(1)** 1

(ii) particles composed of **three quarks (1)** 1

(iii) particles composed of a quark and an antiquark **(1)** 1

(b) similarity: but the same (rest) mass **or** rest energy **(1)**

difference: **opposite** quantum states eg charge **(1)** 2

(c)

	charge/C	baryon number	quark structure
antiproton	-1.6×10^{-19}	–1	$\bar{u}\bar{u}\bar{d}$

–1 for each error 2

(d) (i) weak interaction **(1)**

strange not conserved or there is a change/decay of quark (flavour) **(1)** 2

(ii) **any two**

eg charge

baryon number

(muon) lepton number 2

[11]

14. (a) (i) an electron **(1)** 1

(ii) change in A = 0 **(1)**

change in Z = +1 **(1)** 2

(b) (i) ${}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e + \overline{\upsilon_e}$ **(1)**

or $n \rightarrow p + e^{-} + \overline{\upsilon_e}$

or $d \rightarrow u + e^{-} + \overline{\upsilon_e}$ 1

(ii) lepton number must be conserved **(1)**

lepton number before decay equals zero

hence after decay lepton number of electrons cancels with lepton number of anti-neutrino **or** zero on both sides **(1)** 2

(iii) hypothesis needs to be tested by experiment **(1)**

experiment must be repeatable **(1)**

or hypothesis rejected 2

[8]