**1.** (a) (i)  + p  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 +  or e– + e+ **(1)** 3  
 QWC 1

[7]

**2.** (a)  **(1)** 1

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

 (2 × 1.6 × 10−19)  3.2 × 10−19 C **(1)** 2

(c) **(1)**

 4.1**(1)** × 107 C kg−1 **(1)** 2

[5]

**3.** (a) (i) Z0 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  π0 **(1)**

*V*ee+µ− **(1)**

e+ **(1)**

pe+µ− **(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 + ) **(1)** 1

[5]

**6.** (a) n + *v*(e) **(1)(1)**

–  **(1)**

K+  **(1)** 4

(b) d  u + – + *v(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)  **(1)** 3

(c) specific charge (= charge/mass) = 55 × 1.6 × 10–19/137 × 1.67 × 10–27 **(1)**

3.85 × 107 **(1)** C kg–1 **(1)** 3

[8]

**8.** (a) (i) ; qqq; 

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

(ii) π+ =  **(1)**  
 **(1)** 4

(b) (i) strangeness = –3

charge = –1

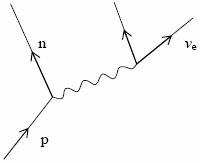
baryon number = +1

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)**  
*v*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) πº **(1)**

 **(1)**

γ **(1)** 5

[11]

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

photon (or γ) **(1)**

(ii) charge

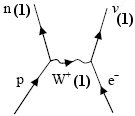
mass

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 × 1.6 ×10–19 **(1)** /(92 × 1.67 × 10–27 + 143 × 1.67 × 10–27) **(1)** = 3.8 × 107 **(1)** |
| second isotope | 92 **(1)** | 3.7 × 107 = 92 × 1.6 × 10–19 /(A × 1.67 × 10–27) **(1)** A × 1.67 × 10–27 = 92 × 1.6 × 10–19/3.7 × 107 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 |  |

–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)  **(1)**

**or** *n* → *p* + *e*– + 

**or** *d* → *u* + *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]