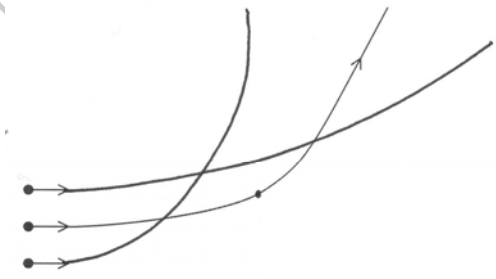
Question Number	Answer		Mark
1(a)	To prevent interaction/deflection/collision of the alpha particle with the air. [do not accept: 'don't get in the way' , 'cause ionisation', 'interfere with'. Looking for a definite interaction between the alpha and the air molecules. Accept air particles]	**(1)**	**1**
1(b)	**MAX TWO** Nucleus (very) much smaller than separation of nuclei **Or** nucleus (very) much smaller than the atom Nucleus is charged (don't penalise if candidate says positively charged) Nucleus is (very) dense **Or** nucleus is massive **Or** nucleus contains most of the mass (no credit for candidates referring to the atoms and not the nucleus.)	**(1)** **(1)** **(1)**	**2**
1(c)	**Top Particle** Path curves up with less deflection than for particle shown and must cross the printed line. **Or** a straight path. **Bottom Particle** Path curves up with more deflection than for particle shown Greatest curvature before greatest curvature of particle shown. (dependent mark) <u>Example</u> 	**(1)** **(1)** **(1)**	**3**
	Total for question 1		**6**

Question Number	Answer		Mark
2(a)	4 is the number of nucleons **Or** number of neutrons and protons **Or** mass number **Or** nucleon number 2 is the number of protons **Or** proton number **Or** atomic number	**(1)** **(1)**	**2**
2(b)(i)	(The particles are moving) close to the speed of light	**(1)**	**1**
2(b)(ii)	To create particle /antimatter **Or** To allow (large) repulsive forces to be overcome **Or** To break the particles (into their constituents)	**(1)**	**1**
2(b)(iii)	Mass = 4u (accept use of $4m_p$) Use of $E = mc^2$ Division by e Mass = 3.74 (GeV/c^2) (use of mass of proton instead of u → 3.76 GeV/c^2) Example of calculation mass = $4 \times 1.66 \times 10^{-27}$ kg = 6.64×10^{-27} kg $mc^2 = 6.64 \times 10^{-27}$ kg × (3×10^8 m s^{-1})^2 = 6.0×10^{-10} J 6.0×10^{-10} J / 1.6×10^{-19} Mass = 3.74 GeV/c^2	**(1)** **(1)** **(1)** **(1)**	**4**
2(b)(iv)	They meet matter (helium nuclei) and annihilate	**(1)**	**1**
2(b)(v)	Use of $E = hf$ ecf E from (iii) Frequency = 9.02×10^{23} Hz (using 3.74 GeV/c^2) (3.76 GeV/c^2 →9.07×10^{23} Hz 4 GeV/c^2 →9.65×10^{23} Hz) (half or double these values, due to a stray 2 can score 1st mark) (use of $\lambda = h/p$ scores 0) Example of calculation f = $3.74 \times 10^9 \times 1.6 \times 10^{-19}$ J / 6.63×10^{-34} Js f = 9.02×10^{23} Hz	**(1)** **(1)**	**2**
2(c)(i)	Quark and antiquark	**(1)**	**1**
2(c)(ii)	$\bar{p}$ consists of $\bar{u}\,\bar{u}\,\bar{d}$ - ⅔e -⅔e + ⅓e = -e must be consistent with structure of $\bar{p}$ $\bar{n}$ consists of $\bar{d}\,\bar{d}\,\bar{u}$ + ⅓e + ⅓e - ⅔e = 0 must be consistent with structure of $\bar{n}$ (The sum must be clearly shown for marks 2 & 4)	**(1)** **(1)** **(1)** **(1)**	**4**
	Total for question 2		**16**

Question Number	Answer		Mark
***3**	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) Reference to electric <u>field</u> **Any three from** particles accelerate when in the gaps **Or** particles gain energy when in the gaps p.d. / polarity / supply reverses while particles are in the tube p.d./ polarity / supply switches at constant time interval **Or** p.d./supply has a constant frequency **(**Drift) tubes get longer so particles are in tubes for the same time	**(1)** **(1)** **(1)** **(1)** **(1)**	**4**
	Total for Question 3		**4**

Question Number	Answer		Mark
4(a)(i)	Charge of Ω is negative /−(1) due to conservation of charge (accept demonstration by equation) Ω baryon because 3 quarks (are needed for strangeness of −3) **Or** to conserve Baryon number since proton has B = 1	**(1)** **(1)**	**2**
4(a)(ii)	Marks awarded for the kaon particles and proton K^- $s\bar{u}$ p uud K^+ $u\bar{s}$ K^0 $d\bar{s}$ The quarks for each particle can be in any order	**(1)** **(1)** **(1)** **(1)**	**4**
4(b)(i)	Finds mass of (stationary) particles Subtracts 2× rest mass proton Divides by 2 to give E_k = 1320 (MeV) (for MP1 &2 ignore units and further calculations involving c^2) <u>Example of calculation</u> mass of new particles = 938+(14 × 140)+494+1115 = 4507 MeV/c^2 E_k required = 4507 MeV Before collision, $E_{total} = E_k + E_{mass}$ E_k = 4507 - (2×938) = 2631 MeV E_k for each proton = 1315.5 MeV	**(1)** **(1)** **(1)**	**3**
4(b)(ii)	Evidence that (conservation of) momentum is being considered (if one particle is moving) total momentum before collision is not zero **Or (**for the interaction to occur, initial) momentum must/should be zero **Or** not all of the (kinetic) energy can be used to create particles / mass (only award MP2 if it is related to conservation of momentum) (if the candidate states that momentum is not conserved, allow MP1 only)	**(1)** **(1)**	**2**
	Total for Question 4		**11**

Question Number	Answer		Mark
5(a)	(+2/3) + (−1/3) + (−1/3) = 0 **Or** (+)2/3 −1/3 −1/3 = 0 **Or** (+)2/3e −1/3e −1/3e = 0 [summation to 0 must be shown]	**(1)**	**1**
5(b)	Δ^-/baryon has 3 quarks π^-/meson has a quark antiquark (Accept 2quarks, one quark and one antiquark)	**(1)** **(1)**	**2**
5(c)	$\Delta^{++} \rightarrow$uuu π charge$\rightarrow$ +1 **Or** +e **Or +** 1.6×10^{-19} C	**(1)** **(1)**	**2**
	Total for Question 5		**5**

Question Number	Answer		Mark
***6(a)**	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) Magnetic field/force is perpendicular to path/velocity /motion(of charged particles). (Magnetic) force / acceleration to centre (of circle) **Or** (magnetic) force acts as centripetal force See a relevant equation: $F = Bqv$ **Or** $Bqv = mv^2/r$ **Or** $r = p/BQ$ Sensible comment on variables based on r being constant	**(1)** **(1)** **(1)** **(1)**	**4**
6(b)	Reference to $r = p/BQ$ Leading to a statement that indicates that the (strength of the) magnetic field needs to increase (**dependent mark**)	**(1)** **(1)**	**2**
6(c)(i)	Use of $E = mc^2$ $E = 1.64 \times 10^{-13}$ (J) (candidates who do not multiply by 2 can score MP1) <u>Example of calculation</u> $E = mc^2$ $E = 2 \times 9.1 \times 10^{-31}$ kg $\times$ (3×10^8 m s^{-1})^2 $E = 1.64 \times 10^{-13}$ J	**(1)** **(1)**	**2**
6(c)(ii)	Divide by 1.6×10^{-13} to convert J to MeV Divide by 2 Rest mass = 5.1×10^{-1} (MeV/c^2) ecf E from (i) (for MP1&2 ignore any additional use of c^2) If candidates omit the factor 2 in (i) and the factor 2 in (ii) they can score 2 marks for (ii) If candidates do a new calculation for a single electron, they score max 2 as they have not used their minimum energy from (i) <u>Example of calculation</u> $E = (1.64 \times 10^{-13}$ J)/ (1.6×10^{-13} C) = 1.02 MeV Divide by 2 to find energy for one particle $\rightarrow 5.1 \times 10^{-1}$ MeV Rest mass = 5.1×10^{-1} MeV/c^2	**(1)** **(1)** **(1)**	**3**
	Total for Question 6		**11**

Question Number	Answer	Mark
7(a)	Most alpha particles passed straight through (the gold foil) **Or** most alpha particles were undeflected (1) Some/few alpha particles were deflected/deviated/scattered (through small angles, indication of $<90^{o}$) (1) Very few were deflected through an angle greater that 90^{o} **Or** <1% came straight back **Or** 1 in 8000 came straight back (1)	**3**
7(b)	Use of $F = kQ_1Q_2/r^2$ (1) Use of 2 and 79 (1) F = 18 N (1) <u>Example of calculation</u> $F = \frac{8.99\times10^{9}\ \text{N m}^2\ \text{C}^{-2}\times(2\times1.6\times10^{-19}\text{C})\times(79\times1.6\times10^{-19}\text{C})}{(4.5\times10^{-14}\text{m})^2} = 17.96\ \text{N}$	**3**
	Total for question 7	**6**

Question Number	Answer	Mark
8(a)	See energy = QV **Or** $W=QV$ **Or** $E=QV$ **Or** $F=EQ$ **and** $E=V/d$ (1) Equate QV and $\frac{1}{2}mv^2$ **Or** equate QV and $\frac{p^2}{2m}$ (1)	**2**
***8(b)**	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) the (magnetic) field acts at a right angle to the direction of motion **Or** the velocity of the ion is perpendicular to the (magnetic) field (1) the force is perpendicular to the direction of motion. (1) the force acts as a centripetal force **Or** this is the condition for circular motion (1)	**3**
8(c)	See mass of ion = $80 \times 1.66 \times 10^{-27}$ (kg) in velocity/p calculation **Or** 1.328×10^{-25} (kg) in velocity/p calculation (1) Use of $m/Q = 2V/v^2$ with $Q = (-)\ 1.6\text{x}10^{-19}$ (C) (1) Use of $BQv = \frac{mv^2}{r}$ **Or** use of $r = \frac{p}{BQ}$ **and** $p = mv$ (do not award this mark if speed of light is used) (1) r = 0.47 m (1) <u>Example of calculation</u> $m/Q = 2V/v^2$ $v = \sqrt{(2VQ/m)}$ $v = \sqrt{\frac{2 \times 3000\ \text{V} \times 1.6 \times 10^{-19}\ \text{C}}{80 \times 1.66 \times 10^{-27}\text{kg}}}$ $v = 8.5 \times 10^4$ (ms^{-1}) $r = mv/BQ$ $r = \frac{80 \times 1.66 \times 10^{-27}\text{kg} \times 8.5 \times 10^4\text{m s}^{-1}}{0.15\ \text{T} \times 1.6 \times 10^{-19}\text{C}}$ $r = 4.7 \times 10^{-1}$ m	**4**
	Total for question 8	**9**

Question Number	Answer	Mark
9(a)	p is uud (1) n is udd (1) (If candidates have p and n correct but think neutrino or beta plus (e^+) are composed of quarks, score 1 mark only)	**2**
9(b)	Identifies the charge of all four particles **Or** see $+1 \rightarrow 0 + (+1) + 0$ (assume charge written in same order as symbols in equation unless otherwise stated) (1) Charge is conserved (1) (Only award MP2 if an attempt at MP1 has been made, e.g. candidate only identifies positive particles) (Accept methods that use charge conservation of individual quarks of the proton and neutron. However, those who think the neutrino or beta plus (e^+) are composed of quarks can only score a max of 1 mark)	**2**
9(c)	See 1.58 + 0.511 + 0.511 **Or** 2.602 (MeV) (1) Conversion of eV to J (multiply by 1.6×10^{-19}) (1) (Ignore any use of c^2 for this mark) Use of E = hf **and** use of $\lambda = c/f$ **Or** use of $E = \frac{hc}{\lambda}$ (1) $\lambda = 9.6 \times 10^{-13}$ m (1) (Use of $\frac{1}{2}mv^2$ to find *v* to use de Broglie equation scores 0/4) <u>Example of calculation</u> total energy$= (1.022 + 1.58\ \text{J}) \times 1.6 \times 10^{-19}\ \text{C} \times 1 \times 10^{6}$ $= 4.16 \times 10^{-13}$ J $\lambda = \frac{(6.63 \times 10^{-34}\ \text{J s} \times 3 \times 10^{8}\ \text{m s}^{-1})}{(0.5 \times 4.16 \times 10^{-13}\text{J})} = 9.56 \times 10^{-13}$ m	**4**

9(d)(i)	Use of $p = E/c$ with value of c = 3.0×10^8 m s^{-1} (p=1.067×10^{-17} kg m s^{-1}) (do not penalise use of eV for *E*) (1) Use of $\lambda = h/p$ with their value for p (1) λ=6.2×10^{-17} m (1) (Candidates who substitute into p=mv to find v (> c) can score a maximum of 1 mark only) <u>Example of calculation</u> $\lambda = \frac{hc}{E} = \frac{6.63\times10^{-34}\text{ J s} \times 3\times10^{8}\text{ m s}^{-1}}{20\times10^{9}\text{ J C}^{-1} \times 1.6\times10^{-19}\text{ C}} = 6.2 \times 10^{-17}$ m	**3**

9(d)(ii)	**Either** Idea that path of electrons may be deflected (1) Due to the (electrostatic) force between electrons and protons / quarks (1) **Or** Diffraction (1) wavelength of electron is similar to diameter/gap for proton/quark (1)	**2**
	Total for question 9	**13**