Q1.

Question Number	Answer	Mark
	A	**1**

Q2.

Question Number	Answer	Mark
(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°) (1) Very few were deflected through an angle greater that 90° **Or** <1% came straight back **Or** 1 in 8000 came straight back (1)	**3**
(b)	Use of $F = kQ_1Q_2/r^2$ (1) Use of 2 and 79 (1) $F = 18$ N (1) Example of calculation $F = \frac{8.99\times10^{9}\ \text{N m}^2\ \text{C}^{-2}\times(2\times1.6\times10^{-19}\text{C})\times(79\times1.6\times10^{-19}\text{C})}{(4.5\times10^{-14}\text{m})^2} = 17.96\ \text{N}$	**3**
	Total for question	**6**

Q3.

Question Number	Answer	Mark
	The only correct answer is C because a positively charged particle could be used ***A** is not correct because this is a reason for using electrons* ***B** is not correct because this is a reason for using electrons* ***D** is not correct because this is a reason for using electrons*	**1**

Q4.

Question Number	Answer	Mark
	C – baryon: $\bar{d}\,\bar{u}\,\bar{u}$; meson: $c\,\bar{s}$	1
	Incorrect Answers: A – baryon should be 3 quarks or 3 antiquarks, meson should be quark-antiquark B – meson should be quark-antiquark D – baryon should be 3 quarks or 3 antiquarks	

Q5.

Question Number	Answer	Mark
	C	1

Q6.

Question Number	Answer	Mark
	B	1

Q7.

Question Number	Answer	Mark
	C is the correct answer A, B and D are fundamental particles	1

Q8.

Question Number	Answer		Mark
(a)	p is uud n is udd (If candidates have p and n correct but think neutrino or beta plus (e^+) are composed of quarks, score 1 mark only)	(1) (1)	**2**
(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) Charge is conserved (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)	(1) (1)	**2**
(c)	See 1.58 + 0.511 + 0.511 **Or** 2.602 (MeV) Conversion of eV to J (multiply by 1.6×10^{-19}) (Ignore any use of c^2 for this mark) Use of E = hf **and** use of $\lambda = c/f$ **Or** use of $E = \frac{hc}{\lambda}$ $\lambda = 9.6 \times 10^{-13}$ m (Use of $\frac{1}{2}mv^2$ to find v to use de Broglie equation scores 0/4) Example of calculation 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 $\lambda = \frac{(6.63\times10^{-34}\ \text{J s} \times 3\times10^{8}\ \text{m s}^{-1})}{(0.5 \times 4.16\times10^{-18}\text{J})} = 9.56 \times 10^{-13}$ m	(1) (1) (1) (1)	**4**

Question Number	Answer		Mark
(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) Use of $\lambda = h/p$ with their value for p $\lambda = 6.2 \times 10^{-17}$ m (Candidates who substitute into p=mv to find v (> c) can score a maximum of 1 mark only) Example of calculation $\lambda = \frac{hc}{E} = \frac{6.63\times10^{-34}\ \text{J s} \times 3\times10^{8}\ \text{m s}^{-1}}{20\times10^{9}\ \text{J C}^{-1} \times 1.6\times10^{-19}\ \text{C}} = 6.2 \times 10^{-17}$ m	(1) (1) (1)	**3**
(d)(ii)	**Either** Idea that path of electrons may be deflected Due to the (electrostatic) force between electrons and protons / quarks **Or** Diffraction wavelength of electron is similar to diameter/gap for proton/quark	(1) (1) (1) (1)	**2**
	Total for question		**13**

Q9.

Question Number	Answer	Mark
	The only correct answer is C A *is not correct because charge is conserved* B *is not correct because charge is conserved* D *is not correct because charge is conserved*	**1**

Q10.

Question Number	Answer		Mark
(a)	Uses energy units = kg $m^2 s^{-2}$ Uses momentum units = kg m s^{-1} multiplied by m s^{-1} Convincing algebra to show units for each term the same Use of units for E, mc^2 and pc acceptable as this is dimensionally correct	(1) (1) (1)	**3**
(b)	States if $v = 0$ then $p = 0$ **Or** See $E^2 = m^2c^4$ $E=mc^2$ (dependent mark)	(1) (1)	**2**
(c)	$E^2 = p^2c^2$, take square root (→ $E = pc$) Use of mc^2 for electron **Or** Use of m^2c^4 for electron Use of conversion factor of 1.6×10^{-19} C (for J to eV or eV to J) Compares correct values for electron: $0.26\ (\text{MeV})^2 << 2.0 \times 10^9\ (\text{MeV})^2$ **Or** E^2 is 7.8×10^9 times bigger **Or** $6.7 \times 10^{-27}\ \text{J}^2 << 5.2 \times 10^{-17}\ \text{J}^2$ **Or** 8.2×10^{-14} J $<< 7.2 \times 10^{-9}$ J **Or** 0.51 MeV << 45 GeV **Or** E is 8.8×10^4 times bigger <u>Example of calculation</u> $mc^2 = (9.11 \times 10^{-31}\ \text{kg}) \times (3 \times 10^8\ \text{m s}^{-1})^2) = 8.2 \times 10^{-14}$ J $8.2 \times 10^{-14}\ \text{J} / 1.6 \times 10^{-19}\ \text{C} = 0.51$ MeV $m^2c^4 = 6.7 \times 10^{-27}\ \text{J}^2 = 0.26\ (\text{MeV})^2$ $(45\ \text{GeV})^2 = (45000\ \text{MeV})^2 = 2.0 \times 10^9\ (\text{MeV})^2 = 5.2 \times 10^{-17}\ \text{J}^2$ (7.8×10^9 times bigger)	(1) (1) (1) (1)	**4**
	Total for question		**9**

Q11.

Question Number	Answer		Mark
(a)	to ensure a single path for the alpha particles **Or** otherwise alpha particles would travel in all directions **Or** to act as a collimator	(1)	
	(because) alpha particles are absorbed by lead	(1)	**2**
	(lead absorbs alpha particles travelling in directions other than towards the foil gets both marks)		
* (b)	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate)		
	Conclusion 1 Observation - most of the alpha particles were undeflected **Or** most of the alphas went straight through	(1)	
	from this they could conclude – that most did not get near enough to any matter to be affected	(1)	
	Conclusion 2 Observation - a few particles were deflected (by small angles)	(1)	
	from this they could conclude – only a few particles came close enough to charge to be affected	(1)	
	Conclusion 3 Observation - a very small proportion of alpha particles were deflected through more than 90°	(1)	
	from this they could conclude that the nucleus must have mass much greater than the alpha particle mass in order to cause this deflection	(1)	**6**
(c)	Top: 4, 222 Bottom: 2, 86	(1) (1)	**2**
(d)	Use of $E_k = ½ mv^2$ Use of $W = QV$ $V = 2.33 \times 10^6$ V = 2.33 MV	(1) (1) (1)	**3**
	<u>Example of calculation</u> Use of $E_k = ½ mv^2 = ½ \times 4.00 \times 1.66 \times 10^{-27}$ kg $\times (1.50 \times 10^7$ m s$^{-1})^2$ $= 7.47 \times 10^{-13}$ J Use of $V = 7.47 \times 10^{-13}$ J $\div (2 \times 1.6 \times 10^{-19}$ C) $= 2.33 \times 10^6$ V = 2.33 MV		
	Total for question		**13**

Q12.

Question Number	Answer		Mark
(a)	Quark and an anti-quark **Or** q + $\bar{q}$	(1)	**1**
(b)	Anti-proton: $\bar{u}\bar{u}\bar{d}$ Anti-neutron: $\bar{u}\bar{d}\bar{d}$	(1) (1)	**2**
(c)	Adds the 3 energies (2034 MeV) Conversion of MeV to J Use of E = hf **and** use of $\lambda = c/f$ $\lambda = 1.2 \times 10^{-15}$m (Use of de Broglie equation can only score MP1 & 2) Example of calculation total energy = $((1876 + 158) \times 10^{6}\text{eV}) \times 1.6 \times 10^{-19}\text{C}$ $= 3.25 \times 10^{-10}$ J $\lambda = \frac{(6.63\times10^{-34}\text{ J s} \times 3\times10^{8}\text{ m s}^{-1})}{(3.25\times10^{-10}\text{ J} / 2)} = 1.22 \times 10^{-15}$ m	(1) (1) (1) (1)	**4**
	Total for question		**7**

Q13.

Question Number	Answer		Mark
(a)	Multiply by 1.60×10^{-19} C Divide by $(3.00 \times 10^{8}\text{ m s}^{-1})^2$ $m = 2.24 \times 10^{-28}$ (kg) Example of calculation $m = 126 \times 10^{6} \times 1.60 \times 10^{-19}\text{ C} \div (3.00 \times 10^{8}\text{ m s}^{-1})^2$ $= 2.24 \times 10^{-28}$ kg	**(1)** **(1)** **(1)**	**3**
(b)	Use of $\Delta E = c^2\Delta m$ (ecf for m from (a)) **Or** $\Delta E = 126 \times 10^{6} \times 1.60 \times 10^{-19}$ C Use of $E = hf$ $f = 1.52 \times 10^{22}$ Hz Example of calculation For one photon, $\Delta E = 2.24 \times 10^{-28}$ kg $\times (3.00 \times 10^{8}\text{ m s}^{-1})^2 / 2$ $= 1.01 \times 10^{-11}$ J $f = 1.01 \times 10^{-11}$ J / 6.63×10^{-34} J s	**(1)** **(1)** **(1)**	**3**
(c)	States initial charge = 0 and applies conservation of charge to show statement is incorrect (accept initial lepton number = 0 and applies conservation of lepton number to show statement is incorrect) Particle path shows (two) different directions of curvature Must really be 2 electrons and 2 positrons/antielectrons (accept 2 negative and 2 positive particles)	**(1)** **(1)** **(1)**	**3**
	Total for question		**9**

Q14.

Question Number	Answer	Mark
	A - muon	**1**
	Incorrect Answers: B – a neutron is not a lepton C – a pion is not a lepton D – a proton is not a lepton	

Q15.

Question Number	Answer	Mark
	The only correct answer is **B** A is not the correct answer because it does not violate conservation of charge or lepton number C is not the correct answer because it does not violate conservation of charge or lepton number D is not the correct answer because it does not violate conservation of charge or lepton number	**1**

Q16.

Question Number	Answer	Mark
	The only correct answer is C ***A** is not correct as an electron is a lepton.* ***B** is not correct as a neutrino is a lepton.* ***D** is not correct as a positron is the antiparticle of an electron so it is a lepton.*	**(1)**

Q17.

Question Number	Answer	Mark
	The only correct answer is D because an electron is a lepton. A Is not correct because a pion is a type of hadron called a meson, so it is not a fundamental particle, because it is made up of quarks, so it cannot be a lepton B Is not correct because a photon is a massless gauge boson in the electroweak interaction, and therefore not a lepton C Is not correct because a neutron is a type of hadron called a baryon, so it is not a fundamental particle, because it is made up of quarks, so it cannot be a lepton	**1**

Q18.

Question Number	Answer	Mark
	The only correct answer is A B *is not correct because they have subtracted 4 protons and added 4 neutrons* C *is not correct because number of neutrons is total number of p and n* D *is not correct because they have subtracted 4 p and total nucleon number is wrong*	**1**

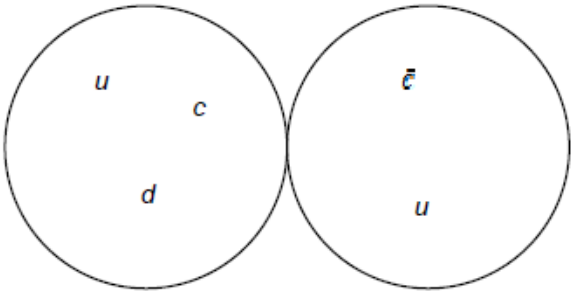
Q19.

Question Number	Answer	Mark
	The only correct answer is A because the lambda particle is neutral but the products would have a charge of +1, violating conservation of charge, so the process is disallowed B Is not correct because the products are neutral and other conservation laws are obeyed so the process is not disallowed C Is not correct because the products are neutral and other conservation laws are obeyed so the process is not disallowed D Is not correct because the products are neutral and other conservation laws are obeyed so the process is not disallowed	**1**

Q20.

Question Number	Answer	Mark
	The only correct answer is B because this has been calculated using $4.8 \times 10^6 \times 1.6 \times 10^{-19}$ C $\div (3.0 \times 10^8$ m s$^{-1})^2$ A Is not correct because this has been calculated with eV rather than MeV, i.e. $4.8 \times 10^6 \times 1.6 \times 10^{-19} \div (3.0 \times 10^8$ m s$^{-1})^2$ C Is not correct because the value of *c* has not been squared, i.e. $4.8 \times 10^6 \times 1.6 \times 10^{-19}$ C $\div 3.0 \times 10^8$ m s^{-1} D Is not correct because 1.6×10^{-19} C has been omitted, i.e. $4.8 \times 10^6 \times 1.6 \times 10^{-19}$ C $\div (3.0 \times 10^8$ m s$^{-1})$	**1**

Q21.

Question Number	Answer		Mark
(a)	Baryon - 3 quarks	**(1)**	
	Meson - quark-antiquark	**(1)**	
	baryon - *ucd*; meson - $\bar{c}u$ **Or** baryon - *uud*; meson - $\bar{c}c$	**(1)**	**3**
	 baryon meson		
(b)	Use of eV conversion using 1.6×10^{-19} C	**(1)**	
	Use of $\Delta E = c^2 \Delta m$	**(1)**	
	$m = 7.79 \times 10^{-27}$ (kg)	**(1)**	**3**
	Example of calculation 4.38×10^{9} eV $\times 1.6 \times 10^{-19}$ C = 7.01×10^{-10} J $m = 7.01 \times 10^{-10}$ J $\div (3 \times 10^{8}$ m s$^{-1})^2$ $= 7.79 \times 10^{-27}$ kg		
(c)(i)	Use of $v = s/t$	**(1)**	
	Calculated speed = 2.64×10^{10} m s^{-1}	**(1)**	
	Comparison with speed of light **and** relevant comment (e.g. this is impossible or relativistic effects apply) (Accept correct reference to specific relativistic effect.)	**(1)**	**3**
	Example of calculation $v = 3.9 \times 10^{-2}$ m $\div 1.48 \times 10^{-12}$ s $= 2.64 \times 10^{10}$ m s^{-1}		
*** (c)(ii)**	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) Any 4: Particle creation		
	Mass-energy is conserved	**(1)**	
	(High energy required) to create particles with large/larger mass	**(1)**	
	because $\Delta E = c^2 \Delta m$ and c^2 is a large multiplying factor	**(1)**	
	Overcoming repulsive forces		
	There are (electrostatic) repulsive forces between protons	**(1)**	
	(and high energies are required) so repulsive force can be overcome	**(1)**	
	to allow protons to get close to each other	**(1)**	**4**
	Total for question		**13**

Q22.

Question Number	Answer		Mark
(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
(b)	Δ^-/baryon has 3 quarks π^-/meson has a quark antiquark (Accept 2quarks, one quark and one antiquark)	(1) (1)	2
(c)	$\Delta^{++} \rightarrow uuu$ π charge$\rightarrow +1$ **Or** $+e$ **Or** $+1.6 \times 10^{-19}$ C	(1) (1)	2
	Total for Question		5