Question Number	Answer	Mark
1(a)	2/3 that of a proton / 2/3 x 1.6 x 10^{-19} (C)	**(1)**
1(b)	Mass = 80 MeV/c^2 charge = +1/3	**(1)** **(1)**
1(c)	Recognition M means 10^6 Convert eV to J or divide by c^2 eg 4 x 10^6 x1.6 x 10^{-19} or /9x10^{16} Answer 7.1 x 10^{-30} (kg)	**(1)** **(1)** **(1)**
1(d)(i)	Kaon Meson Omega baryon	**(1)** **(1)**
1(ii)	K^- + p = K^+ + K^o + Ω^- [accept p or p^+ ;do not accept K for K^o ;signs must be top right]	**(1)** **(1)**
1(iii)	Kaon plus = u $\bar{s}$ Kaon neutral = d $\bar{s}$ or s $\bar{d}$ [both marks can be inferred if equation in d(ii) is fully written in quark combinations)	**(1)** **(1)**
1(iv)	QWC i and iii – Spelling of technical terms must be correct and the answer must be organised in a logical sequence Momentum conserved Charge conserved Energy / mass conserved E =mc^2 <u>Kinetic</u> Energy (of kaon minus) is responsible Momentum of three particles after = momentum of kaon before Total charge 0 / charge before and after is 0 Conservation of Baryon no, quark no, strangeness	 **(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(allow only 1 mark max from these 3)**
		5 max
	Total for question	**17**

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)**	
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)**	
2b)(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)**	
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		**16**

Question Number	Answer		Mark
3(a)	To curve the tracks/paths **Or** to produce a centripetal force/acceleration **Or** to allow particles to spiral **Or** to produce an arc **Or** to produce circular motion So that momentum/energy/charge/ velocity/mass can be investigated	**(1)** **(1)**	**2**
3(b)	The <u>radius</u> of curve gets less **Or** curvature increases (Because) particle slows down **Or** loses energy **Or** loses momentum	**(1)** **(1)**	**2**
3c)	(Magnetic field) out of page	**(1)**	
3(d)(i)	Does not leave a track **Or** there is only one visible track for μ^+ Clear demonstration of charge conservation in this situation	**(1)** **(1)**	**2**
3(d)(ii)	Reference to momentum Reference to change of direction of the visible path (Hence) another particle must have an equal but opposite change of momentum **Or** another particle produced to conserve momentum	**(1)** **(1)** **(1)**	**3**
	Total for question		**10**

Question Number	Answer		Mark
4(a)	Same mass (do not credit similar mass) Opposite charges on nucleus **Or** atom not charged/neutral (do not credit 'atoms have opposite charges'. A correct statement in terms of charges on all four particles gets 2nd mark.) (Ignore references to Baryon number, Lepton number and quarks)	**(1)** **(1)**	**2**
4(b)	Use of $F = k Q_1 Q_2 / r^2$ Magnitude of both charges is 1.6×10^{-19} C Force = 8.2×10^{-8} N <u>Example of calculation</u> $F = 8.99 \times 10^{9}$ N m^2 C^{-2} $(1.6 \times 10^{-19}$ C$)^2$ / $(5.3 \times 10^{-11})^2$ $F = 8.19 \times 10^{-8}$ N	**(1)** **(1)** **(1)**	**3**
4(c)	Atoms are not charged Magnetic / electric fields have no effect (Can't be contained in particle accelerators is not sufficient and ignore all comments about annihilation)	**(1)** **(1)**	**2**
4(d)(i)	Use of $E = mc^2$ Total mass involved is 2 mg (ignore powers of 10 error) Energy = 1.8×10^{11} (J) <u>Example of calculation</u> Energy = 2×10^{-6} kg $(3 \times 10^{8}$ m s$^{-1})^2$ Energy = 1.8×10^{11} J	**(1)** **(1)** **(1)**	**3**
4(d)(ii)	Need a lot of energy (to produce anti-matter)	**(1)**	
	Total for question		**11**