Question Number	Answer	Mark
1(a)	Photon causes no ionisation **(1)**	**1**
1(b)	The ejected electron has higher speed/momentum **(1)** Refers to $r = mv/BQ$ so r is bigger **(1)**	**2**
1(c)	Charge before collision = 0 **Or** identifies that both photon and hydrogen are neutral **(1)** Identifies that after collision hydrogen charge = +1 **and** electron charge = -1 (×2) **and** positron charge = +1 **(1)** (do not accept an electron position pair is neutral)	**2**
1(d)	**Either** The velocity/E_k of the ionised hydrogen atom is very small (accept negligible or zero) after collision **Or** it is stationary **(1)** (Compared to other particles in the interaction) the hydrogen atom has a large mass **(1)** **Or** The interaction is with the atomic electron not the nucleus **(1)** so the nucleus doesn't move **(1)**	**2**
	Total for question	**7**

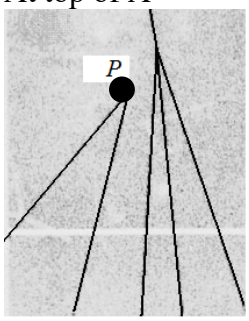
Question Number	Answer	Mark
2(a)	$\bar{u}d$ **(1)**	**1**
2(b)	Conversion to Joules by $\times 1.6 \times 10^{-19}$ (C) **(1)** Divide by $(3 \times 10^8)^2$ **(1)** Mass = 2.49×10^{-28} kg **(1)** Example of calculation Mass = 140×10^6 eV $\times 1.6 \times 10^{-19}$ J eV^{-1} / $(3 \times 10^8$ m s$^{-1})^2$ Mass = 2.49×10^{-28} kg	**3**
	Total for question	**4**

Question Number	Answer		Mark
***3(a)**	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) **Electric field** Provides a force on the proton/particle Which accelerate the proton/particle **Or** gives energy to the protons/particles **Magnetic field** Provides a force on a moving proton **Or** Provides a force at right angles to the direction of motion (of the protons) Acts as a centripetal force **Or** produces circular motion **Additional detail about either field** E field across gap only **Or** The idea that the E field is reversed /alternates every half cycle **Or** B field perpendicular to the Dees (this mark may be awarded from a diagram)	**(1)** **(1)** **(1)** **(1)** **(1)**	**5**
3(b)	Division by e (ignore powers of 10 error) multiplication by c^2 Mass = 0.14 (GeV/c^2) Example of calculation Mass = $(2.5 \times 10^{-28}$ kg $\times 9 \times 10^{16}$ m^2 s$^{-2})/1.6 \times 10^{-19}$ C Mass = 0.14×10^{9} eV/c^2 = 0.14 GeV/c^2	**(1)** **(1)** **(1)**	**3**
3(c)	2/3 charge of a proton **Or** 2/3 charge of a positron **Or** 2/3 positive value of the charge on an electron **Or** 2/3e^+	**(1)**	**1**
3(d)(i)	<table><tr><th>Particle</th><th>Quark combination</th></tr><tr><td>K^-</td><td>$\bar{s}u$</td></tr><tr><td>K+</td><td>$\bar{u}s$</td></tr><tr><td>K0</td><td>$\bar{s}d$ or $\bar{d}s$</td></tr></table>	**(1)** **(1)** **(1)**	**3**
3(d)(ii)	Mass-energy is conserved **Or** a comment about $E = m c^2$ Appropriate reference to colliding particles having mass and kinetic energy The extra mass comes from the kinetic energy.	**(1)** **(1)** **(1)**	**3**
	Total for question		**15**

Question Number	Answer	Mark
4(a)	<table><tr><th>Meson</th><th>Ch e</th><th>Strangeness</th></tr><tr><td>$u\bar{s}$</td><td>+</td><td>+</td></tr><tr><td>$d\bar{s}$</td><td>0</td><td>+</td></tr><tr><td>$s\bar{u}$</td><td>-</td><td>-</td></tr><tr><td>$s\bar{d}$</td><td>0</td><td>-</td></tr></table> **(1)** **(1)** **(1)** **(1)** 1 mark for each correct row. Antiquark can be before quark. (If the + are missing. e or 1.6×10^{-19} appears in charge column apply a 1 mark total penalty.)	**4**
4(b)	(Different) masses/lifetimes/stabilities/decay products **(1)** (accept mass-energy but not energy or weight)	
	Total for question	**5**

Question Number	Answer		Mark
5	[Some candidates calculate energy × 2 and divide by 2 later on. Others omit use of 2. Both methods are correct]		
	Uses only mass of 9.11×10^{-31} kg	**(1)**	
	Use of $E = mc^2$ for 1 or 2 particles	**(1)**	
	Use of $E = hf$	**(1)**	
	Use $c = f\lambda$	**(1)**	
	Wavelength = 2.43×10^{-12} m	**(1)**	**5**
	(Common wrong answers are 1.21×10^{-12} m and 0.60×10^{-12} m. These score 4 marks for correct method see below)		
	Some candidates are getting the correct value using only $\lambda = h/p$ using the mass of the positron and the speed of light to find a momentum. This method scores1 for mass of electron/positron Some candidates are using $E = mc^2$ and $\lambda = h/p$ They could score the first two marks.		
	Example of calculation $E = (9.11 \times 10^{-31}\text{ kg}) \times (9 \times 10^{16}\text{ m}^2\text{ s}^{-2}) = 8.2 \times 10^{-14}$ J $f = (8.2 \times 10^{-14}\text{ J}) / (6.63 \times 10^{-34}\text{ Js})$ $\lambda = (3 \times 10^{8}\text{ ms}^{-1}) / (1.2 \times 10^{20}\text{ s}^{-1})$ $\lambda = 2.43 \times 10^{-12}$ m		
	Total for question		**5**

Question Number	Answer		Mark
6(a)	A sensible comment such as: A reference to symmetry Quarks in pairs (in the particle generations) 6 leptons known but only 5 quarks (do not credit for each quark there has to be an anti-quark)	**(1)**	**1**
6(b)(i)	Same mass Opposite charge	**(1)** **(1)**	**2**
6(b)(ii)	Conserve momentum Initial (total) momentum is zero (Ignore reference to other conservation laws)	**(1)** **(1)**	**2**
6(c)(i)	Recognise (G)eV units of energy (E = m c^2 so) E/c = mc = momentum (conditional mark) **Or** recognise (G)eV/c^2 is unit of mass Momentum is mass x velocity (conditional mark)	**(1)** **(1)** **(1)** **(1)**	**2**
6(c)(ii)	Vectors added in sequence after μ_2 Direction and magnitude of J3 and J4 accurate Judge by eye and do not penalise missing arrows	**(1)** **(1)**	**2**
6(c)(iii)	94 - 99 (GeV/c)	**(1)**	
6(c)(iv)	7 values added together including the value from (iii) **Or** total length of vectors and × 10 (method mark)	**(1)**	**1**
6(c)(v)	Value in (iv) or 300 divided by 2	**(1)**	
6(c)(vi)	**Max 2** Large mass **Or** top quark (very) heavy Large amount of energy required **Or** issue of providing sufficient energy Availability of antimatter is poor Difficulty of storing antimatter	 **(1)** **(1)** **(1)** **(1)**	**2**
	Total for question		**14**

Question Number	Answer		Mark
7(a)	to keep the time spent in each tube the same **Or** so that frequency of <u>alternating</u> pd/voltage constant (do not accept reference to ac currents)	**(1)**	**1**
7(b)(i)	At top of Λ  	**(1)**	**1**
7(b)(ii)	No <u>track/trail</u> to this point (as no charge) Then two tracks (as two charged particles)	**(1)** **(1)**	**2**
7(b)(iii)	$D^0 \rightarrow k^+ + \pi^-$ Correct symbols , do not accept pi as a word Correct charge symbols as above, top right of each term. Wrong position or extra ones loses this mark (any extra particles or gamma 0/2)	**(1)** **(1)**	**2**
***7(b)(iv)**	(QWC- Work must be clear and organised in a logical manner using technical wording where appropriate.) Charge: +1 -1= 0 (the positive sign must be used, 1 -1 = 0 is not enough) **Or** reference to positive and negative charges cancelling. Energy/mass/mass-energy: of D is equal to that of the new particles Momentum: Of D is equal to sum/total of momentum of new particles	**(1)** **(1)** **(1)** **(1)** **(1)** **(1)**	**6**
7(c)(i)	$c\bar{u}$	**(1)**	**1**
7(c)(ii)	$u\bar{d}$ **or** $u\bar{s}$ **or** $c\bar{d}$ **or** $c\bar{s}$ (allow words)	**(1)**	**1**
	Total for question		**14**