Name: _____

Particle accelerators

Mark Scheme

Date:

Time:

Total marks available:

Total marks achieved: _____

Mark Scheme

Q1.

Question Number	Answer	Mark
	C	1

Q2.

Question Number	Answer	Mark
	C	1

Q3.

Question Number	Answer	Mark
	A	1

Q4.

Question Number	Answer	Mark
	C	1

Q5.

Question Number	Answer	Mark
	C	1

Q6.

Question Number	Answer	Mark
	C	1

Q7.

Question Number	Acceptable answers	Additional guidance	Mark
	• Neutral particles do not leave a track/ionise (1) • Reference to conservation laws to deduce the properties of particles (1) • Tracks of decay particles can determine momentum of lambda particle (1)		3

Q8.

Question Number	Answer	Mark
*	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) **Alternating p.d. max 2** Electric field/ p.d. accelerates particles **Or** Electric field /p.d. gives particles energy **(1)** Constant time period **Or** constant frequency **(1)** Polarity of dees switches every half cycle **Or** P.d. switches every half cycle **(1)** **Magnetic field max 2** Magnetic field/force at right angles to particles path **(1)** Maintains circular motion (whilst in dees) **Or** Experiences centripetal force/acceleration (whilst in dees) **(1)** Radius of circle increases as particles get faster	**4**
	Total for question	**4**

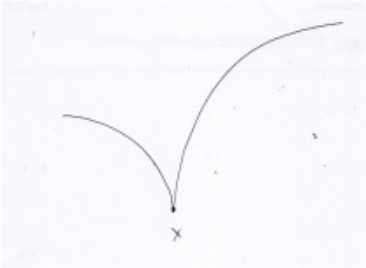
Q9.

Question Number	Acceptable Answer		Additional Guidance	Mark
	• Use of $W = QV$	(1)	Example of calculation: $\frac{1}{2}mv^2 = eV$ $\therefore v = \sqrt{\frac{2\times1.6\times10^{-19}\text{C}\times8.5\times10^{3}\text{V}}{(34.97\times1.66\times10^{-27})\text{kg}}} = 2.16\times10^{5}\text{ms}^{-1}$	
	• Use of $KE = \frac{1}{2}mv^2$	(1)		
	• Use of $1\text{u} = 1.66\times10^{-27}$ kg	(1)		
	• $v = 2.16\times10^{5}$ (m s^{-1})	(1)		4

Q10.

Question Number	Answer		Mark
	At **X** the idea that 2 particles are produced	(1)	
	One is uncharged/neutral so no track	(1)	
	charged particle has same charge as incident particle to conserve charge **Or** path of (new) charged particle changes to conserve momentum	(1)	
	At **Y** Neutral particle decays into two charged particles.	(1)	
	Tracks curve in opposite directions as particles oppositely charged. **Or** particles have (equal and) opposite charge to conserve charge **Or** particles have equal (magnitude of) momenta since their (radius of) curvature is the same.	(1)	5

Q11.

Question Number	Answer		Mark
	Diagram: Path curves in opposite sense	**(1)**	
	With a greater radius of curvature [For Mp2 drawn line must start at X , upwards at less than 45° to vertical and go above printed line. Look at curvature close to X, do not penalise if later it curves more/less.]	**(1)**	
	 **Explanation: (these marks are independent of the diagram)** (Antihelium) has opposite charge (to proton) **Or** reference to proton +ve **and** antihelium -ve	**(1)**	
	See $r = p/BQ$	**(1)**	
	r is doubled **Or** p/Q is doubled	**(1)**	**5**
	[equation may appear near diagram.]		
	Total for question		**5**

Q12.

Question Number	Answer		Mark
(a)	Only (moving) charged particles are deflected by a magnetic field **Or** Only charged particles can be accelerated to produce a beam	**(1)** **(1)**	**1**
(b)	Into the page	**(1)**	**1**
(c)	Use of $F = mv^2/r$ **Or** use of $r = p/BQ$ Use of $F = Bqv$ **Or** use of $p = mv$ $m = 6.64 \times 10^{-26}$ kg Example of calculation $mv^2/r = Bqv$ $m = Bqr/v = (0.673\ \text{T} \times 1.6 \times 10^{-19}\ \text{C} \times 7.40 \times 10^{-2}\ \text{m}) / 1.20 \times 10^{5}\ \text{m s}^{-1}$ $m = 6.64 \times 10^{-26}$ kg	**(1)** **(1)** **(1)**	**3**
(d)	Semicircle drawn starting from same initial point and a smaller radius	**(1)**	**1**
	Total for question		**6**

Q13.

Question Number	Answer	Mark
*	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) **Max 6** **Fixed target** There is momentum before the collision so there must be momentum after the collision. (1) So particle(s) created must have some kinetic energy (1) So not all KE converted to mass (1) **Colliding beams** (If particles have the same mass and speed), total initial momentum is zero (1) Momentum after collision will be zero (1) If one stationary particle is created (1) All of the kinetic energy of the particle is converted to mass (1)	6
	Total for question	6

Q14.

Question Number	Acceptable answers	Additional guidance	Mark
*	This question assesses a student's ability to show a coherent and logical structured answer with linkage and fully-sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content. Number of indicative points seen in answer / Number of marks awarded for indicative points 6 / 4 5-4 / 3 3-2 / 2 1 / 1 0 / 0 **Indicative content** • There is an alternating p.d./E-field • P.d./E-field accelerates protons between dees • Magnetic field perpendicular to plane of dees • Proton path curved by magnetic field • As velocity of protons increases radius of path in dees increases • The time for which a proton is in a dee remains constant Or the frequency of p.d./E-field is constant	Guidance on how the mark scheme should be applied: The mark for The following table shows how the marks should be awarded for structure and lines of reasoning Answer shows a coherent and logical structure with linkage and fully sustained lines of reasoning demonstrated throughout – 2 Answer is partially structured with some linkages and lines of reasoning – 1 Answer has no linkage between points and is unstructured – 0 **Number of IC points** / **Possible linkage marks** 0, 1 / 0 2, 3 / 1 4, 5, 6 / 2 IC2 accept 'in the gap' for between dees. Accept increases E_k for accelerates IC3 accept vertical or upwards for perpendicular to plane. IC5 accept reference to $r = p/BQ$	6

Q15.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	• The ions experience a force perpendicular to their velocity (and the magnetic field) **(1)** • The (resultant) force on the ions causes an acceleration at right angles to their velocity **(1)** **Or** There is a magnetic force acting towards the centre of the path	For velocity accept direction of motion or direction of travel	**2**

Question Number	Acceptable Answer	Additional Guidance	Mark
(ii)	• Use of $r = \frac{mv}{BQ}$ **(1)** • $r = 0.23$ m **(1)**	Example of calculation: $r = \frac{mv}{BQ}$ $= \frac{(34.97 \times 1.66 \times 10^{-27})\,\text{kg} \times 2.2 \times 10^{5}\,\text{m s}^{-1}}{0.35\,\text{T} \times 1.6 \times 10^{-19}\,\text{C}} = 0.228\,\text{m}$	**2**

Question Number	Acceptable Answer	Additional Guidance	Mark
(iii) 1	• path drawn with less curvature (less overall deflection) **(1)**	MP1 awarded for path in the magnetic field	**1**

Question Number	Acceptable Answer	Additional Guidance	Mark
(iii) 2	• ions are more massive **(1)** • ions have the same charge so the radius of the path would be greater **(1)**		**2**

Q16.

Question Number	Answer		Mark
(a)	The idea that electron(s) have been removed/added from an atom/molecule/particle.	(1)	1
(b)	Flemings left hand (rule) **Or** FLHR	(1)	1
(c)	**Max 5** Only charged particles leave a trail so photon is neutral **Or** the two particles produced are charged because they leave a track Particles are oppositely charged because they curve/spiral in opposite directions **Or** Particles are oppositely charged to conserve charge (Applying FLHR) , top particle is positive and bottom one negative. Because they have the same curvature/radius on the spirals **Or** because the paths have identical shape Particles have the same momentum The photon enters from the left because the (resultant) momentum afterwards is to the right.	(1) (1) (1) (1) (1) (1)	5
	Total for question		7

Q17.

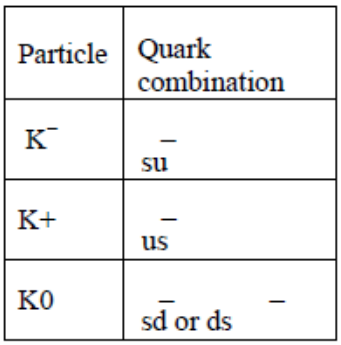
Question Number	Answer		Mark
(i)	Outward spiral from centre in either direction, minimum of two complete loops	(1)	1
(ii)	Direction consistent with diagram: Clockwise path, field out of page Anticlockwise path, field into page	(1)	1
(iii)	Electric field/p.d. between dees causes (resultant) force/acceleration	(1)	
	Proton makes half a revolution in half a cycle of the a.c. **Or** facing dee (always) negative when proton reaches gap. **Or** whenever the proton gets to a gap, the p.d. has reversed	(1)	
	k.e./speed (only)increases each time the proton crosses the gap **Or** work done by the field in the gap increases the k.e.	(1)	3
(iv)	$Bev=mv^2/r$ **Or** $r=p/Be$	(1)	
	$v=2\pi r/T$	(1)	
	$T=1/f$ (seeing $f=v/(2\pi r)$ scores MP2 & 3)	(1)	
	Or		
	$Bev = mr\omega^2$	(1)	
	$v = r\omega$	(1)	
	$\omega = 2\pi f$ (seeing $v/r = 2\pi f$ scores MP2 & 3)	(1)	3
(v)	Use of $B= 2\pi fm/e$ with mass of proton	(1)	
	$f=1.8 \times 10^4$ Hz	(1)	2
	<u>Example of calculation</u> $f = eB/ 2\pi m$ $f = (1.6 \times 10^{-19}\ C \times 1.2 \times 10^{-3}\ T)/ (2\pi \times 1.67 \times 10^{-27} kg)$ $f=1.8 \times 10^4$ Hz		

Q18.

Question Number	Answer		Mark
(a)	$\overline{u}$d (allow $\overline{c}$d $\overline{c}$s $\overline{u}$s)	(1)	1
(b)	π^0	(1)	1
(c)	Use of $v = s/t$ $t = 2.6 \times 10^{-8}$ s Example of answer $t = 5.9$ m / 2.3×10^{8} m s^{-1} $t = 2.57 \times 10^{-8}$ s	(1) (1)	2
*(d)	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) **Max 6** Pions are charged so leave a track Pion interacts with a stationary charged particle 2 neutral particles produced Because there are gaps in the trail **Or** no tracks produced Tracks are in different directions so that momentum is conserved Both particles decay into two charged particles At each decay particles have opposite charges Because charge is conserved **Or** particles move in opposite curvature. At each decay momentum is conserved	 (1) (1) (1) (1) (1) (1) (1) (1) (1)	6
(e)(i)	Antiproton Same mass as proton **and** opposite charge	(1) (1)	2
(e)(ii)	It will annihilate with a proton/particle	(1)	1
	Total for question		13

Q19.

Question Number	Answer		Mark
*(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
(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
(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

(d)(i)	 	(1) (1) (1)	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

Q20.

Question Number	Answer		Mark
(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**
(b)(i)	(The particles are moving) close to the speed of light	**(1)**	**1**
(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**
(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**
(b)(iv)	They meet matter (helium nuclei) and annihilate	**(1)**	**1**
(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 $f = 9.02 \times 10^{23}$ Hz	**(1)** **(1)**	**2**
(c)(i)	Quark and antiquark	**(1)**	**1**
(c)(ii)	$\bar{p}$ consists of $\bar{u}\,\bar{u}\,\bar{d}$ $-\frac{2}{3}e - \frac{2}{3}e + \frac{1}{3}e = -e$ must be consistent with structure of $\bar{p}$ $\bar{n}$ consists of $\bar{d}\,\bar{d}\,\bar{u}$ $+\frac{1}{3}e + \frac{1}{3}e - \frac{2}{3}e = 0$ must be consistent with structure of $\bar{n}$ (The sum must be clearly shown for marks 2 & 4)	**(1)** **(1)** **(1)** **(1)**	**4**