PEARSON EDEXCEL A-LEVEL PHYSICS · 9PH0

PHYSICS



MARK SCHEME

TOPIC 8: NUCLEAR AND PARTICLE PHYSICS

NUCLEAR STRUCTURE AND PARTICLE ACCELERATORS

SCORE	PERCENTAGE
/353	%

STEMUP

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Mark Scheme

Q1.

Question Number	Acceptable answers	Additional guidance	Mark
	The only correct answer is A *B is not correct because the charge on an Au nucleus is 79 $\times 1.6\times10^{-19}$C* *C is not correct because the charge on an alpha particle is 2 $\times 1.6\times10^{-19}$C* *D is not correct because the charges have not been converted to C*		**1**

Q2.

Question Number	Answer	Mark
	A	**1**

Q3.

Question Number	Answer	Mark
	A	**1**

Q4.

Question Number	Answer	Mark
	D	**1**

Q5.

Question Number	Acceptable answers	Additional guidance	Mark
	• Use of $V = Q/4\pi\varepsilon_0 r$ **(1)** • Conversion MeV to J **(1)** • Use of $V = W/Q$ **(1)** • $r = 3.0 \times 10^{-14}$ m **(1)**	allow for $Q = 2$ or 79, accept $V = kQ/r$ Must use $e = 1.6 \times 10^{-19}$ C to convert atomic number to C Example of calculation: 7.7×10^6 eV $\times 1.6 \times 10^{-19}$ J eV^{-1} $= 8.99 \times 10^9$ N m^{2}C^{-2} $\times 2 \times 79 \times (1.6 \times 10^{-19}$ C$)^2 \div r$ $r = 2.27 \times 10^{-7} \div 7.7 \times 10^6$ $r = 2.95 \times 10^{-14}$ m	**4**

Q6.

Question Number	Acceptable answers	Additional guidance	Mark
	• correct values of *A* and *Z* for α and β • 5 α • 4 β	Example of calculation: $^{226}_{88}$Ra → $^{206}_{82}$Pb + *x* $^{4}_{2}$α + *y* $^{0}_{-1}$β 226 - 206 = 4 *x* *x* = 5 88 - 82 - (5 × 2) = - *y* *y* = 4 $^{226}_{88}$Ra → $^{206}_{82}$Pb + 5 $^{4}_{2}$α + 4 $^{0}_{-1}$β	**(3)**

Q7.

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**

Q8.

Question Number	Answer	Mark
	B	1

Mark Scheme

Q1.

Question Number	Answer	Mark
	B	1

Q2.

Question Number	Acceptable answers	Additional guidance	Mark
	Maximum of 4 marks for MP1,3,5 and any one of MP2,4 or 6		
	• a few alpha's reflect straight back (1)	accept deflect through large angles/more than 90°	
	• can be represented by the ball bearing being directly aimed at the centre of the "hill" (1)	MP2 dependent on being linked to MP1	
	• some alpha's slightly deflected/through small angles (1)		
	• can be represented by the ball bearing being aimed close to the centre line of the hill (1)	MP4 dependent on being linked to MP3	
	• Many/most alpha's undeflected (1)		
	• can be shown by aiming the ball bearing so that it touches/misses the edge of the hill	MP6 dependent on being linked to MP5	4 Max

Q3.

Question Number	Acceptable answers	Additional guidance	Mark
	The only correct answer is B *A is not correct because it is a correct conclusion* *C is not correct because it is a correct conclusion* *D is not correct because it is a correct conclusion*		1

Q4.

Question Number	Acceptable answers	Additional guidance	Mark
	C		1

Q5.

Question Number	Acceptable answers	Additional guidance	Mark
	Before scattering experiment: • atom containing equally distributed mass/charge **(1)** After experiment: • very small nucleus containing (almost all) the mass of the atom **(1)** • atom mainly empty space **(1)** • nucleus is charged **(1)**	alt: reference to 'plum pudding model'	**4**

Q6.

Question Number	Answer		Mark
(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**
(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**
(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**

Q7.

Question Number	Acceptable Answer	Additional guidance	Mark
(a)	An explanation that makes reference to the following: • due to the large mass and speed OR large momentum OR large energy (1) • the alpha particle would have a large change in momentum when deflected through large angles which requires a large force (1)		**(2)**

Question Number	Acceptable Answer	Additional guidance	Mark
(b)	• use of $F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$ (1) • charge of alpha $= 2 \times 1.6 \times 10^{-19}$ (C) (1) • r = 1.3×10^{-13} (m) (1) • comparison of the two distances (1) • conclusion that the alpha particle must reach a closer distance to give a larger force and relates this to the model (1)	Accept calculating a force for $r = 1.4 \times 10^{-10}$ and comparing forces Example of calculation: $r = \sqrt{8.99 \times 10^9 \text{ N m}^2\text{C}^{-2} \times \frac{(79 \times 2)(1.6 \times 10^{-19} \text{ C})^2}{2}}$ $r = 1.3 \times 10^{-13}$ m	**(5)**

Q8.

Question Number	Answer	Mark
	B	1

Q9.

Question Number	Acceptable answers	Additional guidance	Mark
	• The curved surface is (analogous to) a radial field **(1)** • (as $h \propto {}^{1}/_{r}$ then) potential (energy) $\propto {}^{1}/_{r}$ **(1)** • compares with $V \propto {}^{1}/_{r}$ around a point charge **(1)**		**3**

Q10.

Question Number	Acceptable answers	Additional guidance		Mark
	C	Most alpha particles go straight through.	The atom is mainly empty space.	**1**
	A the observation is incorrect B the observation is incorrect D the observation is correct but this is not the corresponding conclusion			

Mark Scheme

Q1.

Question Number	Acceptable answers	Additional guidance	Mark
	The only correct answer is D *A is not correct because the process described is the thermionic effect* *B is not correct because the process described is the thermionic effect* *C is not correct because the process described is the thermionic effect*		**1**

Q2.

Question Number	Answer	Additional guidance	Mark
(a)(i)	thermionic emission		**(1)**

Question Number	Acceptable Answer	Additional guidance	Mark
(a)(ii)	• equate $\frac{1}{2}mv^2$ and VQ (1) • $v = 2.3 \times 10^7$ m s^{-1} (1)	Example of calculation: $E = 1500\text{ V} \times 1.6 \times 10^{-19}\text{ C} = 2.4 \times 10^{-16}\text{ J}$ $v = \sqrt{\frac{2 \times 2.4 \times 10^{-16}\text{ J}}{9.11 \times 10^{-31}\text{ kg}}} = 2.3 \times 10^7$ m s^{-1}	**(2)**

Question Number	Acceptable Answer	Additional guidance	Mark
(b)(i)	• use of $F = EQ$ and $E = \frac{V}{d}$ (1) OR see $F = \frac{VQ}{d}$ • equate $F = ma$ and $F = EQ$ (1)		**(2)**

Question Number	Acceptable Answer	Additional guidance	Mark
(b)(ii)	• use of speed = distance/time (1) • $t = 8.7 \times 10^{-10}$ (s) (1) • use of a = $\frac{VQ}{dm}$ (1) • use of $s = ut + \frac{1}{2}at^2$ with $u = 0$ and vertical acceleration to find s (1) • $s = 3.3 \times 10^{-4}$ m (1)	Example of calculation: $t = \frac{0.02\text{ m}}{2.3 \times 10^7\text{ m s}^{-1}} = 8.7 \times 10^{-10}$ s $s = \frac{1}{2} \times \left(\frac{50\text{ V} \times 1.6 \times 10^{-19}\text{ C}}{0.01\text{ m} \times 9.11 \times 10^{-31}\text{ kg}} \right) \times (8.7 \times 10^{-10}\text{ s})^2$ $s = 3.3 \times 10^{-4}$ m	**(6)**

Question Number	Acceptable Answer	Additional guidance	Mark
(c)	• use of $V = V_0/\sqrt{2}$ (1) • vertical line (1) • positive and negative deflection shown (1) • maximum deflection 75 V (1)	Example of calculation: $V_0 = 53\text{ V} \times \sqrt{2} = 75\text{ V}$	**(4)**

Q3.

Question Number	Answer	Mark
	C	1

Q4.

Question Number	Answer	Mark
	D	1

Q5.

Question Number	Answer	Mark
	D	1

Q6.

Question Number	Acceptable Answer	Additional Guidance	Mark
	An explanation that makes reference to the following points: • The potential difference creates an electric field (1) • An (electric) field/force does work on the electrons (increasing their kinetic energy) **Or** an (electric) field/force accelerates the electrons (increasing their velocity) (1)		2

Mark Scheme

Q1.

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

Q2.

Question Number	Acceptable answers		Additional guidance	Mark
	• it does not leave a track so it is not charged	(1)	Not charged should appear in MP1 or MP2 to get 2 marks	
	• the charge before the decay is -1 (the pion) and after is -1 (the muon) + 0 (the antineutrino) so it is not charged	(1)		2

Q3.

Question Number	Answer	Additional guidance	Mark
(a)(i)	thermionic emission		**(1)**

Question Number	Acceptable Answer	Additional guidance	Mark
(a)(ii)	• equate $\frac{1}{2}mv^2$ and VQ (1) • $v = 2.3 \times 10^7$ m s^{-1} (1)	Example of calculation: $E = 1500\text{ V} \times 1.6 \times 10^{-19}\text{ C} = 2.4 \times 10^{-16}\text{ J}$ $v = \sqrt{\frac{2 \times 2.4 \times 10^{-16}\text{ J}}{9.11 \times 10^{-31}\text{ kg}}} = 2.3 \times 10^7\text{ m s}^{-1}$	**(2)**

Question Number	Acceptable Answer	Additional guidance	Mark
(b)(i)	• use of $F = EQ$ and $E = \frac{V}{d}$ (1) OR see $F = \frac{VQ}{d}$ • equate $F = ma$ and $F = EQ$ (1)		**(2)**

Question Number	Acceptable Answer	Additional guidance	Mark
(b)(ii)	• use of speed = distance/time (1) • $t = 8.7 \times 10^{-10}$ (s) (1) • use of a = $\frac{VQ}{dm}$ (1) • use of $s = ut + \frac{1}{2}at^2$ (1) with $u = 0$ and vertical acceleration to find s • $s = 3.3 \times 10^{-4}$ m (1)	Example of calculation: $t = \frac{0.02\text{ m}}{2.3 \times 10^7\text{ m s}^{-1}} = 8.7 \times 10^{-10}\text{ s}$ $s = \frac{1}{2} \times \left(\frac{50\text{ V} \times 1.6 \times 10^{-19}\text{ C}}{0.01\text{ m} \times 9.11 \times 10^{-31}\text{ kg}}\right) \times (8.7 \times 10^{-10}\text{ s})^2$ $s = 3.3 \times 10^{-4}\text{ m}$	**(6)**

Question Number	Acceptable Answer	Additional guidance	Mark
(c)	• use of $V = V_0/\sqrt{2}$ (1) • vertical line (1) • positive and negative deflection shown (1) • maximum deflection 75 V (1)	Example of calculation: $V_0 = 53\text{ V} \times \sqrt{2} = 75\text{ V}$	**(4)**

Q4.

Question Number	Answer	Mark
	C	**1**

Q5.

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 **(1)**	**4**
	Total for question	**4**

Q6.

Question Number	Acceptable answers	Additional guidance	Mark
	This question assesses a student's ability to show a coherent and logically structured answer with linkages 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. Indicative content: IC1: set of (metal drift) tubes (in a line) IC2: electrons accelerated by electric field/potential difference IC3: acceleration takes place in the gaps between tubes IC4: adjacent tubes connected to opposite terminals of a power supply or opposite charge/polarity	IC points / IC mark / Max linkage mark available / Max final mark **6** / 4 / 2 / **6** **5** / 3 / 2 / **5** **4** / 3 / 1 / **4** **3** / 2 / 1 / **3** **2** / 2 / 0 / **2** **1** / 1 / 0 / **1** **0** / 0 / 0 / **0** IC points 1 and 4 may be awarded with well-drawn diagram IC6 accept reference to distance between centres/ends of tubes must increase to give a fixed alternating frequency	**6**
	IC5: power supply/p.d./electric field is alternating (so that as electron emerges from one tube the next tube is positive) IC6: time spent in each tube must be the same so as the electrons travel faster the tubes must		
	be longer / gaps between get longer		

Q7.

<table>
<tr><th>Question Number</th><th>Acceptable answers</th><th>Additional guidance</th><th>Mark</th></tr>
<tr>
<td>*</td>
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<tr><td>1</td><td>1</td></tr>
<tr><td>0</td><td>0</td></tr>
</table>
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

</td>
<td>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
<table>
<tr><th></th><th>Number of marks awarded for structure and lines of reasoning</th></tr>
<tr><td>Answer shows a coherent and logical structure with linkage and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr>
<tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr>
<tr><td>Answer has no linkage between points and is unstructured</td><td>0</td></tr>
</table>
<table>
<tr><th>Number of IC points</th><th>Possible linkage marks</th></tr>
<tr><td>0, 1</td><td>0</td></tr>
<tr><td>2, 3</td><td>1</td></tr>
<tr><td>4, 5, 6</td><td>2</td></tr>
</table>
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 $r = p/BQ$</td>
<td>6</td>
</tr>
</table>

Q8.

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

Q9.

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	(1)	
	Particles are oppositely charged because they curve/spiral in opposite directions **Or** Particles are oppositely charged to conserve charge	(1)	
	(Applying FLHR) , top particle is positive and bottom one negative.	(1)	
	Because they have the same curvature/radius on the spirals **Or** because the paths have identical shape	(1)	
	Particles have the same momentum	(1)	5
	The photon enters from the left because the (resultant) momentum afterwards is to the right.		
	Total for question		7

Q10.

Question Number	Acceptable Answers
*	This question assesses a student's ability to show a coherent and logically structured answer with linkages 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. Indicative content: • the lambda particle is neutral • because it does not leave a track **Or** two tracks are opposite charged • momentum of proton/ pion can be determined by measuring radius of curve • using $p = Bqr$ • law of conservation of momentum can then be applied • so momentum/energy of the lambda particle can be determined

Additional Guidance	Mark
<table><tr><th>IC points</th><th>IC mark</th><th>Max linkage mark available</th><th>Max final mark</th></tr><tr><td>6</td><td>4</td><td>2</td><td>6</td></tr><tr><td>5</td><td>3</td><td>2</td><td>5</td></tr><tr><td>4</td><td>3</td><td>1</td><td>4</td></tr><tr><td>3</td><td>2</td><td>1</td><td>3</td></tr><tr><td>2</td><td>2</td><td>0</td><td>2</td></tr><tr><td>1</td><td>1</td><td>0</td><td>1</td></tr><tr><td>0</td><td>0</td><td>0</td><td>0</td></tr></table> IC4 – *p* and *r* recognisable from the context of the answer IC5 and 6 can be awarded for a labelled momentum vector triangle	**6**

Q11.

Question Number	Answer	Mark
	C	1

Q12.

Question Number	Answer	Mark
	C	1

Q13.

Question Number	Acceptable answers	Additional guidance	Mark
	The only correct answer is B A *is not correct because a cyclotron uses a magnetic field* C *is not correct because a LINAC uses an electric field* D *is not correct because a LINAC does not use a magnetic field*	Cyclotron accelerated	**1**

Q14.

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 $t = 5.9\text{ m} / 2.3 \times 10^{8}\text{ m s}^{-1}$ $t = 2.57 \times 10^{-8}$ 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**

Q15.

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)	<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
(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

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Mark Scheme

Q1.

Question Number	Answer	Mark
	A	**1**

Q2.

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<tr><th></th><th>Number of marks awarded for structure and lines of reasoning</th></tr>
<tr><td>Answer shows a coherent and logical structure with linkage and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr>
<tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr>
<tr><td>Answer has no linkage between points and is unstructured</td><td>0</td></tr>
</table>
<table>
<tr><th>Number of IC points</th><th>Possible linkage marks</th></tr>
<tr><td>0, 1</td><td>0</td></tr>
<tr><td>2, 3</td><td>1</td></tr>
<tr><td>4, 5, 6</td><td>2</td></tr>
</table>
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 $r = p/BQ$
</td>
<td>6</td>
</tr>
</table>

Q3.

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 $mv^2/r = Bqv$ $m = Bqr/v = (0.673\ T \times 1.6 \times 10^{-19}\ C \times 7.40 \times 10^{-2}\ m) / 1.20 \times 10^{5}\ m\ s^{-1}$ $m = 6.64 \times 10^{-26}$ kg	(1) (1) (1)	3
(d)	Semicircle drawn starting from same initial point and a smaller radius	(1)	1
	Total for question		6

Q4.

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

Question Number	Acceptable Answer		Additional Guidance	Mark
(ii)	• Use of $r = \frac{mv}{BQ}$ • $r = 0.23$ m	(1) (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 • ions have the same charge so the radius of the path would be greater	(1) (1)		2

Q5.

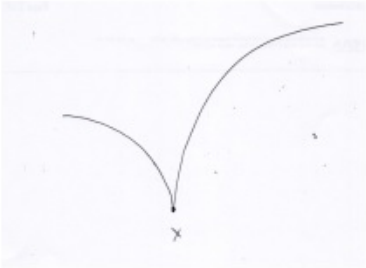
Question Number	Acceptable Answers
*	This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content. Indicative content: • the lambda particle is neutral • because it does not leave a track **Or** two tracks are opposite charged • momentum of proton/ pion can be determined by measuring radius of curve • using $p = Bqr$ • law of conservation of momentum can then be applied • so momentum/energy of the lambda particle can be determined

Additional Guidance	Mark
<table><tr><th>IC points</th><th>IC mark</th><th>Max linkage mark available</th><th>Max final mark</th></tr><tr><td>6</td><td>4</td><td>2</td><td>6</td></tr><tr><td>5</td><td>3</td><td>2</td><td>5</td></tr><tr><td>4</td><td>3</td><td>1</td><td>4</td></tr><tr><td>3</td><td>2</td><td>1</td><td>3</td></tr><tr><td>2</td><td>2</td><td>0</td><td>2</td></tr><tr><td>1</td><td>1</td><td>0</td><td>1</td></tr><tr><td>0</td><td>0</td><td>0</td><td>0</td></tr></table> IC4 – p and r recognisable from the context of the answer IC5 and 6 can be awarded for a labelled momentum vector triangle	**6**

Q6.

Question Number	Acceptable answers	Additional guidance	Mark
	• measures radius (allow between 4 cm and 6 cm) **(1)** • Use of $p = Bqr$ **(1)** • $B = 1.1$ T (range 0.95 T – 1.42 T) **(1)** • direction: out of page **(1)**	Allow use of their measured radius in MP2 Example of calculation: 9.1×10^{-20}N s $= B \times 1.6 \times 10^{-19}$C $\times 0.52$ m $B = 1.09$ T	**4**

Q7.

Question Number	Answer	Mark
	Diagram: Path curves in opposite sense **(1)** With a greater radius of curvature **(1)** [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.]  **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)** [equation may appear near diagram.]	**5**
	Total for question	**5**

Q8.

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) $f=1.8\times10^4$ Hz (1) <u>Example of calculation</u> $f=eB/2\pi m$ $f=(1.6\times10^{-19}\text{ C}\times1.2\times10^{-3}\text{ T})/(2\pi\times1.67\times10^{-27}\text{kg})$ $f=1.8\times10^4$ Hz	2

Q9.

Question Number	Acceptable Answers	Additional guidance	Mark
a	• fundamental – quarks and leptons (1) • Baryons made of 3 q (1) • Mesons made of quark and antiquark (1) • 6 quark **Or** 6 leptons (1) • Each particle has an antiparticle (1)	MP2 and 3 could be given for a named particle and its quark composition Can be inferred if either set named	5

Question Number	Acceptable Answers		Additional guidance	Mark
b	• Use of $\Delta E = \Delta mc^2$ • Conversion of J to eV • mass = 120 GeV/c^2	(1) (1) (1)	Example of calculation: $E = 2.2\times10^{-25}\text{kg}\times(3.0\times10^{8})^2(\text{ms}^{-1})^2$ $E = 1.98\times10^{-8}\text{J}$ $E = 1.98\times10^{-8}\text{J}\div1.6\times10^{-19}\text{JeV}^{-1}$ $E = 124\times10^{9}\text{eV}$	3

Question Number	Acceptable Answers		Additional guidance	Mark
c(i)	• Energy (of protons) converted to mass (of Higgs) **Or** Energy is required to overcome electrostatic repulsion between protons • Reference to $E = mc^2$ (can be written in any form) • Because c^2 is very large (E must be large) **Or** Higgs particle is massive so needs a lot of energy to create it	(1) (1) (1)	Alternative based on numerical values: Observation that Higgs mass is 120 GeV/c^2 This requires an energy of at least 120 GeV Each beam of protons would need an energy of at least 60 GeV	3
c(ii)	• Use of circumference = $2\pi r$ • Use of $p = Bqr$ • $p = 5.7\times10^{-15}$ Ns	(1) (1) (1)	Example of calculation: $r = 27000\div2\pi$ $r = 4300$ m $p = 8.3\text{T}\times1.6\times10^{-19}\text{C}\times4300\text{m}$ $p = 5.7\times10^{-15}$ Ns	3
ciii	0	(1)	zero	1

Question Number	Acceptable Answers		Additional guidance	Mark
d	• High speeds **Or** relativistic • Mass (of proton) increases • **Or** this equation is only valid at non-relativistic speeds	(1) (1)	Alt: speeds close to speed of light	2

Mark Scheme

Q1.

Question Number	Answer	Mark
	C	**1**

Q2.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• The hydrogen ion must be (about 2000 times) more massive than the electron • **Or** the electron must be (about 2000 times) less massive than the hydrogen ion (1)	Accept "proton" for "hydrogen ion"	1

Q3.

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

Q4.

Question Number	Acceptable Answer	Additional guidance	Mark
(i)	An explanation that makes reference to the following points: • energy conserved (1) • so energy needed over and above rest energy of proton in order to provide the mass of the π^0 particle (1)		**(2)**

Question Number	Acceptable Answer	Additional guidance	Mark
(ii)	• calculates rest energy of π^0 (1) • 134 GeV (1)	Example of calculation: $E_k = \frac{938\ \text{GeV}}{7} = 134\ \text{GeV}$	**(2)**

Q5.

Question Number	Answer		Mark
(a)(i)	Top line correct Bottom line correct $^{2}_{1}\text{H} + ^{3}_{1}\text{H} \rightarrow ^{4}_{2}\text{He} + ^{1}_{0}\text{n}$	(1) (1)	**2**
(a)(ii)	Attempt at mass deficit calculation $\Delta E = 0.0175$ GeV (accept 2.8×10^{-12} J) Example of calculation: $\Delta m = (3.7274 + 0.939566 - 2.8089 - 1.8756)\ \text{GeV/c}^2 = 0.0175\ \text{GeV/c}^2$ $\Delta E = 0.0175$ GeV	(1) (1)	**2**
(a)(iii)	Momentum is conserved Mass of neutron is smaller, so speed is greater $E_k = ½\ mv^2$, so E_k is larger **Or** Momentum is conserved $E_k = p^2/2m$ m of neutron is smaller, so E_k is larger	(1) (1) (1) (1) (1) (1)	**3**

(b)	Use of $\lambda = \frac{\ln 2}{t_{½}}$	**(1)**	
	Use of $A = A_0 e^{-\lambda t}$	**(1)**	
	t = 41 (years)	**(1)**	**3**
	Example of calculation: $\lambda = \frac{\ln 2}{t_{½}} = \frac{0.693}{12.3 \text{ year}} = 0.0563 \text{ year}^{-1}$ $A = A_0 e^{-\lambda t} \quad \therefore t = \frac{\ln\left(A/A_0\right)}{-\lambda} = \frac{\ln(0.1)}{-0.0563 \text{ year}^{-1}} = 40.9 \text{ years}$		

***(c)**	**QWC – Work must be clear and organised in a logical manner using technical wording where appropriate**		
	There is little possibility of a runaway fusion reaction (unlike fission)	**(1)**	
	There would not be any radioactive waste produced in the fusion process **Or** the flux of neutrons would produce radioactive isotopes when absorbed by materials in the reactor	**(1)**	
	A very/extremely high temperature (plasma) is required	**(1)**	
	Plasma must not touch reactor walls, so strong magnetic fields are required	**(1)**	
	If plasma touches the walls of the reactor its temperature falls (and fusion stops)	**(1)**	**5**
	Total for question		**15**

Q6.

Question Number	Answer		Mark
(a)	Calculate gradient of line Identify gradient with H **Or** use of v = Hd for a point on the line Use of t = 1/H $t = 4.5 \times 10^{17}$ s (accept answers in range 4.2×10^{17} s to 4.8×10^{17} s) **Alternative method:** Pair of d, v values read from the line Values chosen from the upper end of the line Use of t = d/v $t = 4.5 \times 10^{17}$ s [$\pm 0.3 \times 10^{17}$ s] [$t = 1.4 \times 10^{10}$ yr [$\pm 0.1 \times 10^{10}$ yr] Example of calculation $H = \text{gradient} = \frac{(11000-0)\times 10^3 \text{ m s}^{-1}}{(50-0)\times 10^{23} \text{ m}} = 2.2\times 10^{-18} \text{ s}^{-1}$ $t = \frac{1}{H} = \frac{1}{2.2\times 10^{-18} \text{ s}^{-1}} = 4.5\times 10^{17} \text{ s}$	(1) (1) (1) (1) (1) (1) (1) (1)	4
* (b)	**QWC – Work must be clear and organised in a logical manner using technical wording where appropriate** Measure wavelength of light (from the galaxy) Compare it to the wavelength for a source on the Earth Reference to spectral line **or** line spectrum Reference to Doppler effect/shift **Or** redshift *v* is found from: fractional change in wavelength equals ratio of speed of source to speed of light **Or** see reference to $\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$ with terms defined **Or** see reference to $z = \frac{v}{c}$ with terms defined [accept answers in terms of frequency rather than wavelength]	 (1) (1) (1) (1) (1)	5
*(c)	**QWC – Work must be clear and organised in a logical manner using technical wording where appropriate** **Max 3** (Due to the) difficulty in making accurate measurements of distances to galaxies Hubble constant has a large uncertainty **Or** age = 1/H may not be valid as gravity is changing the expansion rate Because of the existence of dark matter Values of the (average) density/mass of the universe have a large uncertainty [accept not known] (Hence) measurements of the critical density of the Universe have a large uncertainty Dark energy may mean we don't understand gravity as well as we thought we did (so it's hard to predict how gravity will determine the ultimate fate)	 (1) (1) (1) (1) (1) (1)	3

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Q7.

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

Q8.

Question Number	Acceptable Answer	Additional guidance	Mark
	An explanation that makes reference to the following points: <u>Pion/ positron</u> • radius decreasing indicates speed/momentum is decreasing (1) • smaller radius indicates positron has smaller momentum than the pion (1) • direction of deflection indicates a positive charge by LH rule (1) <u>OR</u> compares direction of deflection between positron and pion to conclude they have the same charge <u>Anti-muon</u> • short path – short lived (1)		**(6)**
	• conservation of charge indicates it has same charge as pion (1) <u>Muon neutrino OR electron neutrino</u> • no path visible indicates no charge (1)		

Q9.

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) (1)	5
	Total for question		7

Q10.

Question Number	Acceptable Answers
*	This question assesses a student's ability to show a coherent and logically structured answer with linkages 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. Indicative content: • the lambda particle is neutral • because it does not leave a track **Or** two tracks are opposite charged • momentum of proton/ pion can be determined by measuring radius of curve • using $p = Bqr$ • law of conservation of momentum can then be applied • so momentum/energy of the lambda particle can be determined

Additional Guidance	Mark
	6

IC points	IC mark	Max linkage mark available	Max final mark
6	4	2	**6**
5	3	2	**5**
4	3	1	**4**
3	2	1	**3**
2	2	0	**2**
1	1	0	**1**
0	0	0	**0**

IC4 – p and r recognisable from the context of the answer

IC5 and 6 can be awarded for a labelled momentum vector triangle

Q11.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	• Converts eV to J (1) • use of $\Delta m = \Delta E / c^2$ (1) • mass = 1.98×10^{-27} (kg) (1)	Example of calculation $m = \frac{1115\,\text{V} \times 1.6 \times 10^{-19}\text{C} \times 10^6}{(3 \times 10^8)^2(\text{ms}^{-1})^2}$ $m = 1.98 \times 10^{-27}\,\text{kg}$	3
(ii)	• Converts prefix G to M (1) **Or** M to G • Determines total energy / mass of lambda before decay (1) • kinetic energy = 4985 MeV (1)	Example of calculation 4.95 GeV = 4950 MeV Total Energy and mass before decay = 4950 + 1115 = 6065 MeV Total after = 140 + 940 + E_k E_k = 6065 – 1080 = 4985 MeV	3

Q12.

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

Q13.

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

Q14.

Question Number	Acceptable answers		Additional guidance	Mark
(i)	• Charge: -1 = -1 + 0 • Baryon number: needs to be stated as 0 • Lepton number: 0 = +1 + (-1)	(1) (1) (1)		(3)
(ii)	• Mass difference = 34 (MeV/c^2) • $E = \Delta mc^2$ so $E = 34$ MeV	(1) (1)	alt to $E = \Delta mc^2$ to show unit $\frac{MeV}{c^2} \times c^2$	(2)
(iii)	• Mass - energy • Momentum	(1) (1)		(2)

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<table>
<tr><th>Question Number</th><th>Acceptable answers</th><th>Additional guidance</th><th>Mark</th></tr>
<tr><td>*(iv)</td><td>This question assesses a student's ability to show a coherent and logically structured answer with linkages 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.

Indicative content:
• Uses velocity = distance/time
• Calculates a time = 3×10^{-5}s
• Compares with 2.2×10^{-6}s which is (15 times) smaller
• Identifies relativistic speed/effects (as velocity close to c)
• Time (between events is much) slower/longer

Or mentions time dilation

• So increase in muon lifetime</td><td><table><tr><th>IC points</th><th>IC mark</th><th>Max linkage mark</th><th>Max final mark</th></tr><tr><td>6</td><td>4</td><td>2</td><td>6</td></tr><tr><td>5</td><td>3</td><td>2</td><td>5</td></tr><tr><td>4</td><td>3</td><td>1</td><td>4</td></tr><tr><td>3</td><td>2</td><td>1</td><td>3</td></tr><tr><td>2</td><td>2</td><td>0</td><td>2</td></tr><tr><td>1</td><td>1</td><td>0</td><td>1</td></tr><tr><td>0</td><td>0</td><td>0</td><td>0</td></tr></table>
Alternative for ic 2 and 3
Calculates height of atmosphere = 653 m

Compares with 10 km which is larger

Example of calculation:
Time = $10000(m)/0.99 \times 3 \times 10^{8}(ms^{-1})$</td><td>(6)</td></tr>
</table>

Q15.

Question Number	Answer		Mark
(a)(i)	(A standard candle is) an object of known luminosity	**(1)**	**1**
(a)(ii)	Flux/brightness/intensity of standard candle is measured Inverse square law used (to calculate distance to standard candle) [Reference to measurement of apparent magnitude of star, m, and distance calculated using $m - M = 5\log(d/10\text{ pc})$ can score 2 marks]	**(1)** **(1)**	**2**
(b)(i)	An increase in the wavelength (of radiation) received from a receding source [accept in terms of a decrease in the frequency]	**(1)**	**1**
(b)(ii)	Use of $z = v/c$ and $v = H_0 d$ $[z = H_0 d/c]$ $d = 1.7 \times 10^{25}$ m <u>Example of calculation:</u> $v = zc = 0.12 \times 3\times10^8$ m s^{-1} $= 3.6 \times10^7$ m s^{-1} $d = v/H = 3.6 \times10^7$ m s^{-1}/2.1×10^{-18} s^{-1} $= 1.71 \times 10^{25}$ m	**(1)** **(1)**	**2**
***(c)**	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) **Max 3** Dark matter has mass but does not emit e-m radiation [accept light] (Dark matter proposed when) observations of galaxies indicated that they must contain more matter than could be seen. The existence of dark matter will increase the (average) density of the universe This may make it more likely that the universe is closed [accept will contract **Or** end with a "Big Crunch"] **Or** Idea that this may make the ultimate fate of the Universe less certain	**(1)** **(1)** **(1)** **(1)**	**3**
(d)	**Max 2** The universe started from a small initial point [accept Big Bang] Idea that universe has a finite age Idea that (observable universe is finite because) we can only see as far as (speed of light) × (age of universe) **Or** light reaching us must have travelled a finite distance since the Big Bang **Or** some parts of the universe are so distant, light has not had time to reach us yet	**(1)** **(1)** **(1)**	**2**
	Total for question		**11**

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Mark Scheme

Q1.

Question Number	Acceptable answers	Additional guidance	Mark
	• High energy electrons will have a short (de Broglie) wavelength **(1)** • The wavelength needs to be comparable/smaller than proton size **(1)**		**2**

Q2.

Question number	Acceptable answers	Additional guidance	Mark
	C		**1**

Q3.

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 × $(3 \times 10^8$ m $s^{-1})^2 = 6.0 \times 10^{-10}$ 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**

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Q4.

Question Number	Answer	Mark
	C	1