Mark Scheme

Q1.

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	<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> 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		

Q2.

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

Q3.

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)		

Q4.

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

Q5.

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) • $r = 1.3 \times 10^{-13}$ (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 <u>Example of calculation:</u> $r = \sqrt{8.99 \times 10^9 \text{ N m}^2\text{C}^{-2} \times \frac{(79 \times 2)(1.6 \times 10^{-19} \text{ C})^2}{2}}$ $r = 1.3 \times 10^{-13}$ m	**(5)**

Q6.

Question Number	Acceptable Answer	Additional Guidance	Mark
(a)(i)	• a π^0 may be $u\bar{u}$ **Or** $d\bar{d}$ (1) • it must be a quark combined with its own antiquark so that overall charge is 0 (1) <u>OR</u> it can only contain up or down quarks (as it is not a strange particle)	Allow $s\bar{s}$	**(2)**
(a)(ii)	mesons are made up of quarks, whereas leptons are fundamental particles (1)		**(1)**

Question Number	Acceptable Answer	Additional Guidance	Mark
(b)(i)	• use of v = s/t (1) • t = 5.05 × 10^{-5} s (1)	Example of calculation: $t = \frac{s}{v} = \frac{15\times10^{3}\,\text{m}}{0.99\times3\times10^{8}\,\text{ms}^{-1}} = 5.05\times10^{-5}\text{s}$	**(2)**
(b)(ii)	• use of $\lambda t_{1/2} = 0.693$ (1) • λ = 3.15 × 10^{5} s^{-1} (1) • use of $N = N_0 e^{-\lambda t}$ (1) • $\frac{N}{N_0} = 1.23\times10^{-7}$ (1)	Example of calculation: $\lambda = \frac{\ln 2}{t_{1/2}} = \frac{0.693}{2.2\times10^{-6}\text{s}} = 3.15\times10^{5}\text{s}^{-1}$ $\frac{N}{N_0} = e^{-\lambda t} = e^{-3.15\times10^{5}\text{s}^{-1}\times5.05\times10^{-5}\text{s}} = 1.23\times10^{-7}$ $\frac{N}{N_0} = 1.1\times10^{-7}$ if "show that" value used	**(4)**
(b)(iii)	• This is much smaller than 10% indicating the muon lifetime is much greater than the expected value (1) • The high speed of the muon has led to relativistic effects (1)		**(2)**

Q7.

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

Question Number	Acceptable answers	Additional guidance	Mark
*(iv)	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	<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 = $10000(m)/0.99 \times 3 \times 10^{8}(ms^{-1})$	(6)

Q8.

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 $s = ut + \frac{1}{2}at^2$ (1) with $u = 0$ and vertical acceleration to find s • $s = 3.3 \times 10^{-4}$ m (1)	Example of calculation: $t = \frac{0.02\text{ m}}{2.3 \times 10^7\text{ m s}^{-1}} = 8.7 \times 10^{-10}$ 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)**

Q9.

Question Number	Acceptable Answers		Additional guidance	Mark
a	• fundamental – quarks and leptons	(1)	MP2 and 3 could be given for a named particle and its quark composition Can be inferred if either set named	5
	• 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)		

Question Number	Acceptable Answers		Additional guidance	Mark
b	• Use of $\Delta E = \Delta mc^2$	(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
	• Conversion of J to eV	(1)		
	• mass = 120 GeV/c^2	(1)		

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	(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
	• Reference to $E = mc^2$ (can be written in any form)	(1)		
	• 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)		
c(ii)	• Use of circumference = $2\pi r$	(1)	Example of calculation: $r = 27000\div2\pi$ $r = 4300\text{ m}$ $p = 8.3\text{T}\times1.6\times10^{-19}\text{C}\times4300\text{m}$ $p = 5.7\times10^{-15}\text{Ns}$	3
	• Use of $p = Bqr$	(1)		
	• $p = 5.7\times10^{-15}$ Ns	(1)		
ciii	0	(1)	zero	1

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