PEARSON EDEXCEL A-LEVEL PHYSICS · 9PH0

PHYSICS



MARK SCHEME

TOPIC 8: NUCLEAR AND PARTICLE PHYSICS

PARTICLE PHYSICS AND THE STANDARD MODEL

SCORE	PERCENTAGE
/431	%

STEMUP

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Mark Scheme

Q1.

Question Number	Answer	Mark
	C	1

Q2.

Question Number	Acceptable answers		Additional guidance	Mark
	• converts eV using 1.6×10^{-19}	(1)	Example of calculation	
	• divides by c^2 i.e. $(3 \times 10^8)^2$	(1)	$m = \frac{1116\text{V} \times 10^6 \times 1.6 \times 10^{-19}\text{C}}{(3 \times 10^8\,\text{m s}^{-1})^2}$	
	• mass = 2.0×10^{-27} kg	(1)	$m = 2.0 \times 10^{-27}$ kg	3

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	Acceptable answers	Additional guidance	Mark
	• Energy of cosmic ray could be turned into matter/mass (1) • According to $\Delta E = c^2 \Delta m$ (1)		2

Q6.

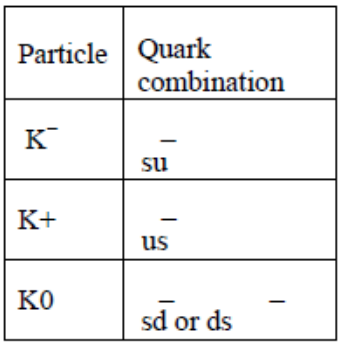
Question Number	Acceptable answers	Additional guidance	Mark
(i)	• Converts eV to J **(1)** • use of $\Delta m = \Delta E / c^2$ **(1)** • mass = 1.98×10^{-27} (kg) **(1)**	Example of calculation $m = \frac{1115\ \text{V} \times 1.6 \times 10^{-19}\text{C} \times 10^6}{(3 \times 10^8)^2 (\text{ms}^{-1})^2}$ $m = 1.98 \times 10^{-27}\ \text{kg}$	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

Q7.

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

Q8.

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})/1.6×10^{-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 $E = mc^2$ 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

Q9.

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	IC points / IC mark / Max linkage mark / 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** 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)/0.99×3×10^8(ms^{-1})	(6)

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Q10.

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	5
	• Baryons made of 3 q	(1)		
	• Mesons made of quark and antiquark	(1)	Can be inferred if either set named	
	• 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)		
	• $p = 5.7\times10^{-15}\text{Ns}$	(1)		
ciii	0	(1)	zero	1

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

Mark Scheme

Q1.

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 $\times$ 1.6×10^{-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**

Q2.

Question Number	Acceptable answers		Additional guidance	Mark
	• converts eV using 1.6×10^{-19}	(1)	Example of calculation $m = \frac{1116\text{V} \times 10^6 \times 1.6 \times 10^{-19}\text{C}}{(3 \times 10^8\,\text{m s}^{-1})^2}$	
	• divides by c^2 i.e. $(3 \times 10^8)^2$	(1)		
	• mass = 2.0×10^{-27} kg	(1)	$m = 2.0 \times 10^{-27}$ kg	3

Q3.

Question Number	Answer		Mark
	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)	3
	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		

Q4.

Question Number	Acceptable answers	Additional guidance	Mark
	The only correct answer is C $\frac{1.67 \times 10^{-27} \times (3.00 \times 10^8)^2}{1.60 \times 10^{-10}}$	A,B and D all contain numerical errors	1

Q5.

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)**

Q6.

Question Number	Acceptable answers	Additional guidance	Mark
	• attempt to determine mass difference between radium and radon-plus-alpha (1) • conversion to kg (1) • Use of $\Delta E = c^2\Delta m$ (1) • Use of 1.6×10^{-19} factor (1) • Answer = 4.87 (MeV) (1)	$\Delta m = 225.97713\text{u} - (221.97040\text{u} + 4.00151\text{ u})$ $= 5.22 \times 10^{-3}\text{ u} = 5.22 \times 10^{-3} \times 1.66 \times 10^{-27}\text{ kg} = 8.67 \times 10^{-30}\text{ kg}$ $\Delta E = c^2\Delta m = (3 \times 10^8\text{ m s}^{-1})^2 \times 8.67 \times 10^{-30}\text{ kg} = 7.80 \times 10^{-13}\text{ J}$ ΔE in MeV $= 7.80 \times 10^{-13}\text{ J} \div 1.6 \times 10^{-19}\text{ C}$ $= 4.87$ MeV	**5**

Q7.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	• units eV (energy) base units: kg m^2 s^{-2} **Or** base units of momentum: kg m s^{-1} **(1)** • divide energy by units of speed (c) m s^{-1} gives kg m s^{-1} which are units of momentum Or multiply units of momentum by speed (c) m s^{-1} to give units of energy kg m^2 s^{-2} **(1)**		**2**
(ii)	• resolves a y-component or x-component of electron momentum **(1)** • applies momentum conservation in x-direction or y-direction **(1)** • comparison of total momentum after **Or** momentum of proton after plus comment **(1)** Alternative: • draws a vector triangle	Example of calculation $p_y = 9.1\ (\text{GeV/c})\sin 20 = 3.1\ \text{GeV/c}$ $p_x = 9.1\ (\text{GeV/c})\cos 20 = 8.55\ \text{GeV/c}$ p_x of proton = 20 (GeV/c) - 8.55 (GeV/c) = 11.45 G $p_{\text{proton}} = \sqrt{3.1^2 + 11.45^2}$ = 11.86 GeV/c Alternative: p_y = 9.1 (GeV/c)sin20 = 3.1 GeV/c=11.9($\emptyset = 15.2$ So total p after = 11.9 GeV/c cos 15.2 + 9.1 (GeV/c)cos20	**3**
	• Uses cosine rule • Calculates angle from three sides = 20.4°	= 11.5 + 8.55 = 20.05 GeV/c	
(iii)	• (total) kinetic energy not conserved **(1)**		**1**

Q8.

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

Q9.

Question Number	Answer		Mark
(a)	The magnetic field (must be) at right angles to the current	(1)	1
(b)	All three units for force, length and current clearly identified (The unit of force is kg m s^{-2} , the unit of current is A, the unit of length is m)	(1)	
	T = kg A^{-1} s^{-2}	(1)	2
(c)	*Use* of $\rho = m/V$ Use of $mg = BIl$ B = 0.53 (T) (no u.e. as given in question for part (b)) Example of calculation $m = 2.7 \times 10^3\ \text{kg m}^{-3} \times 10 \times 10^{-3}\ \text{m} \times 10 \times 10^{-3}\ \text{m} \times l$ $m = 0.27 \times l$ $B = (0.27 \times l \times 9.81\ \text{m s}^{-2}) / (5\ \text{A} \times l)$ B = 0.53 T	(1) (1) (1)	3
(d)	(Magnetic field is) into paper/page	(1)	1
	Total for question		7

Q10.

Question Number	Acceptable answers		Additional guidance	Mark
	• converts eV to J	(1)	Example of calculation: $m = \frac{106\,\text{V} \times 1.6 \times 10^{-19}\,\text{C} \times 10^{6}}{(3 \times 10^{8})^{2}\,(\text{ms}^{-1})^{2}}$	
	• use of $\Delta m = \Delta E / c^2$	(1)		
	• mass = 1.9×10^{-28} (kg)	(1)	$m = 1.88 \times 10^{-28}\,\text{kg}$	(3)

Q11.

Question Number	Answer		Mark
(a)(i)	Three quarks **Or** three antiquarks (accept the letter q to represent quarks)	**(1)**	**1**
(a)(ii)	Quark and an antiquark (accept the letter q to represent quarks)	**(1)**	**1**
(b)	Similarity: they have the same mass **Or** same magnitude of charge Difference: opposite charge	**(1)** **(1)**	**2**
(c)(i)	Up and antistrange (in words or symbols, and can be in either order)	**(1)**	**1**
(c)(ii)	μ^- $+\square_\mu$ $K^- \rightarrow \mu^- + \square_\mu$	**(1)** **(1)**	**2**
(c)(iii)	Energy = 2×494 MeV eV to J conversion Energy = 1.58×10^{-10} (J) (division by c^2 and subsequent multiplication by c^2 is not penalised) <u>Example of calculation</u>	**(1)** **(1)** **(1)**	**3**
	Energy = $2 \times 494 \times 10^{6}$ eV $\times$ 1.6×10^{-19} J eV^{-1} Energy = 1.58×10^{-10} J		
	Total for question		**10**

Q12.

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

Q13.

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Question Number	Answer	Mark
	C	**1**

Q14.

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)**

<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>
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<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)	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**

Q16.

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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 $\Delta E = \Delta mc^2$ (1) • Conversion of J to eV (1) • mass = 120 GeV/c^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

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) • 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)	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 = $2\pi r$ (1) • Use of $p = Bqr$ (1) • $p = 5.7\times10^{-15}$ Ns (1)	Example of calculation: $r = 27000\div2\pi$ $r = 4300$ m $p = 8.3\text{T}\times1.6\times10^{-19}\text{C}\times4300\text{m}$ $p = 5.7\times10^{-15}\text{Ns}$	3
ciii	0 (1)	zero	1

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

Q17.

Question Number	Acceptable answers	Additional guidance	Mark
	• extra mass after collision is the mass of pion **Or** energy must be conserved so E_k is required for pion **(1)** • According to $\Delta E = c^2\Delta m$ (if extra mass is pion) then ΔE required is 140 MeV **Or** extra mass is 140 MeV/c^2 so E required is 140 MeV **(1)** • Momentum conservation means that the (three) resulting particles after the collision must have some momentum/E_k **(1)** • The incoming proton needs 140 MeV plus the E_k of the product particles so statement is inaccurate **(1)**		**4**

Q18.

Question Number	Acceptable answers	Additional guidance	Mark
	• Convert eV to J **(1)** • Convert J to kg **(1)** • mass = 2.5 ×10^{-28} (kg) **(1)**	Example of calculation: $m = \frac{140\ (\text{MeV/c}^2) \times 1.6 \times 10^{-13}\text{J MeV}^{-1}}{(3 \times 10^8)^2\ (\text{m s}^{-1})^2}$ $m = 2.49 \times 10^{-28}$ (kg)	**3**

Q19.

Question Number	Answer	Mark
	C	1

Q20.

Question Number	Answer	Mark
	B	1

Mark Scheme

Q1.

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) OR 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)**

Q2.

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)

<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>

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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(Total for question = 1 mark)

Mark Scheme

Q1.

Question Number	Acceptable answers	Additional guidance	Mark
	B		1

Q2.

Question Number	Acceptable answers	Additional guidance	Mark
	The only correct answer is C A is not correct as the particle is a meson B is not correct as the particle is a meson D is not correct as the mass cannot be negative		**1**

Q3.

Question Number	Acceptable answers	Additional guidance	Mark
	• Muon is a lepton (1) • Muons / leptons are fundamental particles (1) • Pion is a meson (1) • Pions / mesons consist of a quark and antiquark (1)		4

Q4.

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

Q5.

Question Number	Answer		Mark
(a)	<table><tr><th>Meson</th><th>Charge/*e*</th><th>Strangeness</th></tr><tr><td>$\bar{u}s$</td><td>+1</td><td>+1</td></tr><tr><td>$\bar{d}s$</td><td>0</td><td>+1</td></tr><tr><td>$\bar{s}u$</td><td>-1</td><td>-1</td></tr><tr><td>$\bar{s}d$</td><td>0</td><td>-1</td></tr></table> 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.)	**(1)** **(1)** **(1)** **(1)**	**4**
(b)	(Different) masses/lifetimes/stabilities/decay products (accept mass-energy but not energy or weight)	**(1)**	**1**
	Total for question		**5**

Q6.

Question Number	Answer		Mark
(a)(i)	Three quarks **Or** three antiquarks (accept the letter q to represent quarks)	**(1)**	**1**
(a)(ii)	Quark and an antiquark (accept the letter q to represent quarks)	**(1)**	**1**
(b)	Similarity: they have the same mass **Or** same magnitude of charge Difference: opposite charge	**(1)** **(1)**	**2**
(c)(i)	Up and antistrange (in words or symbols, and can be in either order)	**(1)**	**1**
(c)(ii)	μ^- $+\square_\mu$ $K^- \rightarrow \mu^- + \square_\mu$	**(1)** **(1)**	**2**
(c)(iii)	Energy = 2×494 MeV eV to J conversion Energy = 1.58×10^{-10} (J) (division by c^2 and subsequent multiplication by c^2 is not penalised) <u>Example of calculation</u>	**(1)** **(1)** **(1)**	**3**

	Energy = $2 \times 494 \times 10^{6}$ eV $\times 1.6 \times 10^{-19}$ J eV^{-1} Energy = 1.58×10^{-10} J	
	Total for question	**10**

Q7.

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**

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(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 $E = mc^2$ 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**

Q8.

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) OR 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)**

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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)**

Q9.

Question Number	Answer	Mark
	$\bar{u}d$ (1)	1

Q10.

Question number	Acceptable answers	Additional guidance	Mark
	C		1

Mark Scheme

Q1.

Question Number	Acceptable answers	Additional guidance	Mark
	The only correct answer is A *B is not correct because an electron has a much smaller mass* *C is not correct because a neutron has no charge* *D is not correct because a positron has a much smaller mass and is positive*		**1**

Q2.

Question Number	Answer	Mark
	C	**1**

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	Additional guidance	Mark
	The only correct answer is C **1** **0**	A and B are incorrect as a neutron has mass D is incorrect as a neutron is neutral	**1**

Q5.

Question Number	Acceptable answers	Additional guidance	Mark
	The only correct answer is C A is not correct as the particle is a meson B is not correct as the particle is a meson D is not correct as the mass cannot be negative		**1**

Q6.

Question Number	Answer		Mark
(a)	$\bar{u}d$ (allow $\bar{c}d$ $\bar{c}s$ $\bar{u}s$)	(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

Q7.

Question Number	Acceptable answers		Additional guidance	Mark
	$\Lambda^0 \rightarrow e^+ + e^-$ (no 2) baryon number not conserved $\Lambda^0 \rightarrow$ n only (no 4) momentum **or** energy cannot be conserved $\Lambda^0 \rightarrow$ p and π^0 (no 5) charge not conserved	(1) (1) (1) (1) (1) (1)	More than 3 decays identified as not possible max 2 marks for the decays.	6

Q8.

Question number	Acceptable answers	Additional guidance	Mark
	An explanation that makes reference to the following points: • Resistance increases with decreasing intensity **(1)** • As distance increases light intensity decreases so resistance increases **(1)**		**2**

Q9.

Question Number	Answer	Mark
	C	1

Mark Scheme

Q1.

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

Q2.

Question Number	Acceptable answers	Additional guidance	Mark
	The only correct answer is C A *is not correct because lepton number is not conserved* B *is not correct because charge conservation is not obeyed* D *is not correct because charge conservation is not obeyed*	$p \rightarrow n + \beta^+ + \nu$	1

Q3.

Question Number	Acceptable answers	Additional guidance	Mark
	The only correct answer is B $n + \pi^+$	A, C and D do not follow conservation laws	1

Q4.

Question Number	Acceptable answers	Additional guidance	Mark
	An explanation that makes reference to the following points: • charge: 0 = +1 identified as proton (1) −1 identified as pion • Baryon number: 1 = 1 identified as proton (1) + 0 identified as pion • Lepton number: 0 = 0 + 0 (1) **Or** there are no leptons involved		3

Q5.

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)

<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.

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• Uses velocity = distance/time
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Or mentions time dilation
• So increase in muon lifetime
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<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>
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</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>

Q6.

Question Number	Acceptable Answer	Additional guidance	Mark
(i)	charge not conserved		**(1)**

Question Number	Acceptable Answer	Additional guidance	Mark
(ii)	• both radial fields OR (1) the magnitude of the fields is the same (at a given distance) • different directions (1)		**(2)**

Q7.

Question Number	Acceptable answers	Additional guidance	Mark
	$\Lambda^0 \rightarrow e^+ + e^-$ (no 2) (1) baryon number not conserved (1) $\Lambda^0 \rightarrow$ n only (no 4) momentum **or** energy cannot be conserved (1) (1) $\Lambda^0 \rightarrow$ p and π^0 (no 5) (1) charge not conserved (1)	More than 3 decays identified as not possible max 2 marks for the decays.	**6**

Mark Scheme

Q1.

Question Number	Acceptable answers	Additional guidance	Mark
	• Correct equation ignoring charges **(1)** Charge on pion + (1) **(1)**	$p + p \rightarrow p + n + \pi^+$	**2**

Q2.

Question Number	Acceptable answers	Additional guidance	Mark
	The only correct answer is C A *is not correct because lepton number is not conserved* B *is not correct because charge conservation is not obeyed* D *is not correct because charge conservation is not obeyed*	$p \rightarrow n + \beta^+ + \nu$	**1**

Q3.

Question Number	Acceptable answers	Additional guidance	Mark
	• Use of $\Delta E = mc\Delta\theta$ with a temperature change of 80°C **(1)** • $c = 3.94 \times 10^3\,\text{J kg}^{-1}\,\text{C}^{-1}$ **(1)**	Example of calculation: Temperature rise $= (101 - 21)^\circ\text{C}$ $175000\,\text{J} = 0.444\,\text{kg} \times c \times (101 - 21)\,\text{C}$ $c = 3.94 \times 10^3\,\text{J kg}^{-1}\,\text{C}^{-1}$	**2**

Q4.

Question Number	Acceptable answers	Additional guidance	Mark
	• $(\Lambda^0) \rightarrow p^{(1)} + \pi^{-1}$ **(1)**		**1**

Q5.

Question Number	Acceptable answers	Additional guidance	Mark
	• $\pi^- \rightarrow \mu(^-) + \overline{\nu_{(\mu)}}$ **(1)**	Any symbol allowed for the muon	1

Q6.

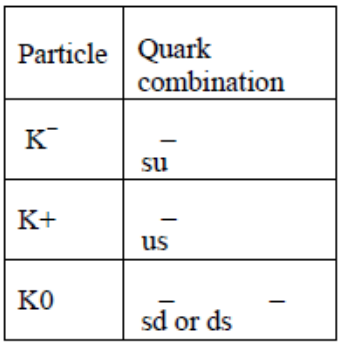
Question Number	Answer		Mark
(a)	$\overline{u}d$ (allow $\overline{c}d$ $\overline{c}s$ $\overline{u}s$)	(1)	1
(b)	π^0	(1)	1
(c)	Use of $v = s/t$ $t = 2.6 \times 10^{-8}$ s Example of answer $t = 5.9\text{ m} / 2.3 \times 10^{8}\text{ m s}^{-1}$ $t = 2.57 \times 10^{-8}$ s	(1) (1)	2
*(d)	(QWC – Work 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

Q7.

Question Number	Answer		Mark
(a)(i)	Three quarks **Or** three antiquarks (accept the letter q to represent quarks)	**(1)**	**1**
(a)(ii)	Quark and an antiquark (accept the letter q to represent quarks)	**(1)**	**1**
(b)	Similarity: they have the same mass **Or** same magnitude of charge Difference: opposite charge	**(1)** **(1)**	**2**
(c)(i)	Up and antistrange (in words or symbols, and can be in either order)	**(1)**	**1**
(c)(ii)	μ^- $+\square_\mu$ $K^- \rightarrow \mu^- + \square_\mu$	**(1)** **(1)**	**2**
(c)(iii)	Energy = 2×494 MeV eV to J conversion Energy = 1.58×10^{-10} (J) (division by c^2 and subsequent multiplication by c^2 is not penalised) <u>Example of calculation</u>	**(1)** **(1)** **(1)**	**3**
	Energy = $2 \times 494 \times 10^6$ eV $\times$ 1.6×10^{-19} J eV^{-1} Energy = 1.58×10^{-10} J		
	Total for question		**10**

Q8.

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})/1.6×10^{-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 $E = mc^2$ 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

Q9.

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	IC points / IC mark / Max linkage mark / 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** 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)/0.99×3×10^8(ms^{-1})	(6)

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Q10.

Question Number	Acceptable answers		Additional guidance	Mark
	$\Lambda^0 \rightarrow e^+ + e^-$ (no 2) baryon number not conserved	(1) (1)	More than 3 decays identified as not possible max 2 marks for the decays.	6
	$\Lambda^0 \rightarrow$ n only (no 4) momentum **or** energy cannot be conserved	(1) (1)		
	$\Lambda^0 \rightarrow$ p and π^0 (no 5) charge not conserved	(1) (1)		