The Standard Model 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 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

Q3.

Question Number	Acceptable answers	Additional guidance	Mark
	The only correct answer is C A is not the correct answer, as a baryon has three quarks. B is not the correct answer, as leptons are fundamental particles D is not the correct answer, as a nucleon is a proton or neutron		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
	$\bar{u}d$ (1)	**1**

Q7.

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

Q8.

Question Number	Acceptable answers	Additional guidance	Mark
	Any **two** from: • Each lepton has an antiparticle **(1)** • Baryon number = 0 **(1)** • Leptons are fundamental particles **(1)** • Leptons interact via the weak force **(1)** • Leptons have a lepton number which isn't zero **(1)**		**2**

Q9.

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

Q10.

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

Q11.

<table>
<tr><th>Question Number</th><th>Answer</th><th>Mark</th></tr>
<tr><td>(a)</td><td>
<table>
<tr><th>Meson</th><th>Charge/e</th><th>Strangeness</th></tr>
<tr><td>$u\bar{s}$</td><td>+1</td><td>+1</td></tr>
<tr><td>$d\bar{s}$</td><td>0</td><td>+1</td></tr>
<tr><td>$s\bar{u}$</td><td>-1</td><td>-1</td></tr>
<tr><td>$s\bar{d}$</td><td>0</td><td>-1</td></tr>
</table>
(1)
(1)
(1)
(1)

1 mark for each correct row. Antiquark can be before quark.

(If the + are missing. e or 1.6×10^{-19} appears in charge column apply a 1 mark total penalty.)
</td><td>4</td></tr>
<tr><td>(b)</td><td>(Different) masses/lifetimes/stabilities/decay products (1)
(accept mass-energy but not energy or weight)</td><td>1</td></tr>
<tr><td></td><td>Total for question</td><td>5</td></tr>
</table>

Q12.

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) Example of calculation	**(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**

Q13.

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) <u>Example of calculation</u> 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 <u>positive</u> 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 $d\bar{s}$</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**

Q14.

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: $t = \frac{s}{v} = \frac{15\times10^{3}\,\text{m}}{0.99\times3\times10^{8}\,\text{m s}^{-1}} = 5.05\times10^{-5}\,\text{s}$	**(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)**

Q15.

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

Q16.

Question Number	Acceptable answers	Additional guidance	Mark
	• See u d s (1) • Comment that charge is zero (1)	If a meson or an incorrect baryon is given which has zero charge, MP2 can be awarded for comment of zero charge.	2

Q17.

Question Number	Acceptable answers	Additional guidance	Mark
	• **p** : u u d (1) • **n** : u d d (1) • π : u $\bar{d}$ (1)	Accept labelled π^- : $\bar{u}$ d	3

Q18.

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