M1.(a) (i) X must have a negative charge ✓
to conserve charge ✓

second mark dependent on first i.e. conserve charge alone scores nothing

can gain second mark by showing balanced equation

2

(ii) X must be a baryon ✓
to conserve baryon number ✓

here two marks are independent i.e. conserve baryon number alone scores 1 mark

can gain second mark by showing balanced equation

2

(iii) K^-: s $\bar{u}$ OR strange anti-up ✓
K^+: u $\bar{s}$ OR up anti-strange ✓
K^0: d $\bar{s}$ OR s $\bar{d}$ OR down anti-strange OR strange anti–down ✓

in each case the symbols or words can be in either order

must be a bar over anti – quark
can be upper case letters e.g. U

3

(iv) (strangeness on LHS is -1)
strangeness on RHS without X is +2 / strangeness of X is -3 ✓
thus sss
OR
strangeness on RHS without X is +2 / strangeness of X is -1 ✓
thus sdd ✓ ✓

correct strangeness without X on RHS is minimum working needed for first mark
next two marks awarded for correct quark structure

3

[10]

M2.(a) (i) $u\bar{s}$ / up and anti-strange ✓

In any order
Bar must be over s only

1

(ii) 0 / zero / nothing ✓

1

(iii) K^- / negative kaon / $\bar{u}s$ ✓

1

(b) (i)

classification	K^+	ν_μ	μ^+
lepton	×	✓	✓
charged particle	✓	×	✓
hadron	✓	×	×
meson	✓	×	×

1 mark for each correct row

3

(ii) conserved: baryon number OR lepton number ✓
not conserved: strangeness / kinetic energy ✓
Mass in either loses mark

2

(c) (i) neutral pion ✓
Indicated clearly in table in any way e.g. circled or cross. If more than one box used then must be a tick with neutral pion only

1

(ii) must be neutral / no charge / 0 charge to obey charge conservation
OR
cannot be baryon to obey conservation of baryon number
OR

cannot be lepton to obey conservation of lepton number ✓

Can show by using equation and appropriate quantum numbers

1

[10]

M3.(a) Photon

(right-hand box) TO for listing
Must state name

Weak (nuclear) / weak interaction / weak nuclear interaction / weak force

B1

(left-hand box) TO for listing

2

(b) Charge / (electric) charge

B1

TO for listing any other physical quantity
Must be word; do not accept symbol

1

(c) Higgs (boson) / Higgs (particle) / Higgs (boson particle)

Not graviton

Accept Higg / Higs / Hig

B1

TO for listing

1

[4]

M4.(a) pair production ✓

1

(b) (energy = 2 × rest mass energy)
energy = 2 × 0.510999 = 1.021998 (MeV) ✓
energy = $1.021998 \times 1.60 \times 10^{-13} = 1.64 \times 10^{-13}$ J ✓

(3 sig figs ✓)

If miss out 2 factor can get CE
Can use $E=2mc^2$
First mark for full substitution and second mark for answer

3

(c) kinetic energy (of electron and positron) ✓

KE of photon gets zero

1

(d) (meet an electron and) annihilate ✓
(converting into two or more) photons ✓ OR gamma rays

2

[7]

M5. (a)

particle	quark structure	charge	strangeness	baryon number
proton ✓	uud	+ 1 ✓	0	1 ✓
sigma$^+$	uus	+1	-1 ✓	1 ✓
π^+ ✓	ud	+1 ✓	0	0

7

(b) (i) examples:
proton, antiquarks ✓

1

(ii) consists of 3 antiquarks ✓

1

(iii) same (rest) mass (energy) ✓

difference eg baryon number/charge ✓

2

[11]

M6. (a) photon interacts with (orbital) electron/nucleus/atom ✓

energy of photon used to create particle antiparticle pair ✓

to conserve momentum photon needs to interact with interacting particle ✓

2

(b) energy of photon depends on frequency ✓

if energy/frequency is below a certain value there is not enough energy ✓

to provide mass/rest energy of particles ✓

3

(c) any two ✓ ✓

eg charge

lepton number

baryon number

strangeness

2

[7]