M1.(a)　(i)　X must have a <u>negative charge</u>✓
　　　　　　　　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✓
　　　　　　　K⁰: 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)　$\overline{us}$ / up and anti-strange　✓

　　　　　　　　In any order
　　　　　　　　Bar must be over s only

(ii)   0 / zero / nothing ✓

(iii)   K⁻ / negative kaon / $\overline{us}$ ✓

(b)   (i)

classification	K⁺	ν_μ	μ⁺
lepton	✗	✓	✓
charged particle	✓	✗	✓
hadron	✓	✗	✗
meson	✓	✗	✗

1 mark for each correct row

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

(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

(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 × 1.60 × 10⁻¹³ = 1.64 × 10⁻¹³ J ✓

(3 sig figs ✓)

If miss out 2 factor can get CE
Can use E=2mc²
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) photon<u>s</u> ✓ 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

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]