1)

<table>
<tr><td>(a) (i)</td><td>particles that experience the strong (nuclear) force/interaction ✓</td><td>1</td></tr>
<tr><td>(a) (ii)</td><td>particles composed of three quarks ✓</td><td>1</td></tr>
<tr><td>(a) (iii)</td><td>particles composed of a quark and an antiquark ✓</td><td>1</td></tr>
<tr><td>(b)</td><td>similarity: but the same (rest) mass or rest energy ✓
difference: opposite quantum states eg charge ✓</td><td>2</td></tr>
<tr><td>(c)</td><td><table><tr><td></td><td>charge/C</td><td>baryon number</td><td>quark structure</td></tr><tr><td>antiproton</td><td>-1.6×10^{-19}</td><td>–1</td><td>$\overline{u}\overline{u}\overline{d}$</td></tr></table>-1 for each error</td><td>2</td></tr>
<tr><td>(d) (i)</td><td>weak interaction ✓
strange not conserved or there is a change/decay of quark (flavour) ✓</td><td>2</td></tr>
<tr><td>(d) (ii)</td><td>any two
eg charge
baryon number
(muon) lepton number</td><td>2</td></tr>
<tr><td></td><td>Total</td><td>11</td></tr>
</table>

2)

<table>
<tr><td>(a) (i)</td><td>leptons do not experience the strong interaction but hadrons do
or hadrons not fundamental/made of quarks and leptons are not ✓</td><td>1</td></tr>
<tr><td>(a) (ii)</td><td>hadron eg proton, neutron, pion ✓
lepton eg electron, neutrino ✓</td><td>2</td></tr>
<tr><td>(a) (iii)</td><td>baryons ✓
mesons ✓
baryons made from three quarks (or 3 antiquarks), mesons a quark, antiquark pair or baryons, baryon number is +1 or –1 mesons 0 ✓</td><td>3</td></tr>
<tr><td>(b)</td><td>baryon number, lepton number, charge, strangeness, energy or momentum ✓
demonstration of conservation (before and after considered and number appropriate to particle quoted) ✓</td><td>2</td></tr>
<tr><td></td><td>Total</td><td>8</td></tr>
</table>

3)

	(i)	pair production ✓	**1**
	(ii)	conservation law stated (charge or lepton number) ✓ shown to be true eg lepton number +1–1 = 0 ✓	**2**
	(iii)	energy = 2 × 0.510 (ignore sfs) ✓	**1**
	(iv)	$E = (1.02 \times 1.6 \times 10^{-13}) = 1.63 \times 10^{-13}$ ✓ $1.63 \times 10^{-3} = 6.63 \times 10^{-34} \times 3.00 \times 10^{8}/\lambda$ ✓ $\lambda = 6.63 \times 10^{-34} \times 3.00 \times 10^{8}/1.63 \times 10^{-13} = 1.22 \times 10^{-12}$ m ✓ 3 significant figures ✓	**4**
	(v)	will encounter an **electron** and the two particles will annihilate ✓ releasing (two high energy/gamma) **photons/quanta** ✓	**2**
		Total	**10**

4)

a		<table><tr><th>particle</th><th>quark structure</th><th>charge</th><th>strangeness</th><th>baryon number</th></tr><tr><td>proton ✓</td><td>uud</td><td>+ 1 ✓</td><td>0</td><td>1 ✓</td></tr><tr><td>sigma^{+}</td><td>uus</td><td>+ 1</td><td>– 1 ✓</td><td>1 ✓</td></tr><tr><td>π^{+} ✓</td><td>$u\bar{d}$</td><td>+ 1 ✓</td><td>0</td><td>0</td></tr></table>	**7**
b	i	examples: proton, antiquarks ✓	**1**
b	ii	consists of 3 antiquarks ✓	**1**
b	iii	same (rest) mass (energy) ✓ difference eg baryon number/charge ✓	**2**
		Total	**11**

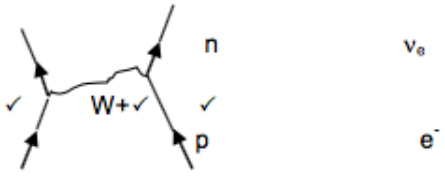
5)

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 ✓	**max 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**
	Total	**7**

6)

(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✓)	3	If miss out 2 factor can get CE Can use $E=2mc^2$ First mark for full substitution and second mark for answer
(c)	kinetic energy (of electron and positron) ✓	1	KE of photon gets zero
(d)	(meet an electron and) annihilate✓ (converting into two or more) photons✓ OR gamma rays	2	

7)

a	(i)	three✓ OR qqq	1	
a	(ii)	mesons✓	1	
a	(iii)	experience the strong interaction ✓ made up of quarks OR not fundamental✓ (eventually) decay to proton✓	2_{max}	
b		interaction: exchange particle electromagnetic: (virtual)photon✓OR γ weak: W+ or W-or $Z^{(0)}$ ✓	2	W must have superscript
c	(i)		3	If no arrow on W boson line then must be clearly slanting in correct direction for second mark e must have - superscript If no clear junctions lose second mark If no arrows on sides -1
c	(ii)	lepton number must be conserved ✓ (+1 on lhs must be +1 on rhs)	1	

8)

(a)	(i)	three ✓	**2**
	(ii)	one ✓	
(b)	(i)	charge ✓ baryon number ✓ lepton number ✓ mass ✓ energy ✓ momentum ✓ **max 2**	**5**
	(ii)	strangeness ✓	
	(iii)	weak interaction/(nuclear) force ✓	
	(iv)	proton ✓	
		Total	**7**

9)

a	i	any two eg proton, neutron ✓✓	**2**
a	ii	$u\bar{d}$ ✓	**1**
b	i	contains a strange quark **or** longer half life than expected **or** decays by weak interaction ✓	**1**
b	ii	the second one is not possible ✓ because lepton number is not conserved ✓	**2**
c	i	weak (interaction) ✓	**1**
c	ii	mention of charge conservation **or** charge conservation demonstrated by numbers ✓	**1**
c	iii	X must be a baryon ✓ baryon number on right hand side is +1 ✓	**2**
c	iv	proton/p ✓	**1**
		Total	**11**

10)

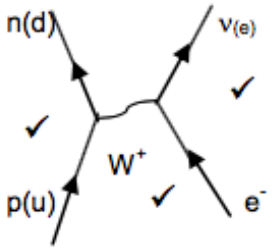
a	i	quark antiquark pair OR $\overline{qq}$ OR named quark antiquark pair ✓	1
a	ii	0 ✓	1
a	iii	$\bar{u}s$ ✓	1
b	i	Weak ✓ any of the following also score 1 mark: weak interaction weak interaction force weak nuclear weak nuclear interaction weak decay weak force weak nuclear force	1
b	ii	conserved: baryon number, charge, lepton number, spin ✓✓ not conserved: strangeness ✓	3
b	iii	$K^- \rightarrow \pi^0 + e^- + \overline{\nu_{(e)}}$ ✓✓ OR $K^- \rightarrow \pi^0 + \mu^- + \overline{\nu_{(\mu)}}$	2

11)

a		<table><tr><td>interaction</td><td>exchange particle</td></tr><tr><td>weak</td><td>W^+ OR W^- OR Z^0 ✓</td></tr><tr><td>electromagnetic</td><td>photon OR γ ✓</td></tr></table>	2

b		*uud* ✓	1

c	i	an **atomic/orbital/shell** electron ✓ interacts with a proton in the **nucleus** (via the weak interaction) ✓ neutron formed **or** u quark changes to d quark(and neutrino released) ✓	3

c	ii		3

12)

(a)		A = down✓ B = W^+✓ C = positron and D= (electron) neutrino✓	3	symbols OK NOT neutron C and D either way round

(b)	(i)	weak✓	1	

(b)	(ii)	B/$W^{(+)}$✓	1	

(b)	(iii)	W^+/B/exchange particle is charged/γ no charge OR W^+/B/exchange particle has (rest) mass/γ has zero (rest) mass OR photon has infinite range✓	1	exchange particle must be clearly identified don't accept W^+ more mass or shorter range

(c)		Any two pairs Quantity: lepton number✓ $e^+(-1) + \nu_{(e)}(1) = 0$ after same as before✓ Quantity: charge✓u(+2/3) before 1-d(1/3) = +2/3 after decay✓ Quantity: baryon number✓ proton 1 and neutron 1 (can be shown through quarks) ✓	4	can use p(+1) and $e^+(+1)$to show charge conserved Each number must be correctly linked to a particle at least once for second mark Strangeness not allowed

13)

a	(i)	$\bar{u}s$ / up and anti-strange✓	1		In any order Bar must only be over s only
a	(ii)	0 / zero/nothing✓	1		
a	(iii)	K^- / negative kaon / $\bar{u}s$ ✓	1		
b	(i)	classification: K^+ ×, ✓, ✓ / lepton: ×, ✓, ✓ / charged particle: ✓, ×, ✓ / hadron: ✓, ×, × / meson: ✓, ×, ×	3		1 mark for each correct row
b	(ii)	conserved: baryon number OR lepton number ✓ not conserved: strangeness/kinetic energy✓	2		Mass in either loses mark
c	(i)	neutral pion✓	1		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
c	(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✓	1		Can show by using equation and appropriate quantum numbers

14)

ai	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
aii	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
aiii	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
aiv	(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

15)

(a)		**The candidate's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.** The candidate's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria. **High Level (Good to excellent): 5 or 6 marks** The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question. *Candidate gives correct examples of hadrons and leptons. Identifies the differences between hadrons and leptons (hadrons affected by strong nuclear reaction and are made of quarks). Leptons are fundamental and do not experience the strong nuclear reaction. Hadrons are divided into baryons and mesons. Baryons three quarks, mesons quark anti-quark pair. Similarities between groups all experience weak interaction and if charged the electromagnetic interaction. All have rest mass.* **Intermediate Level (Modest to adequate): 3 or 4 marks** The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate. *Candidate gives correct examples of hadrons and leptons. Identifies one difference between hadrons and leptons (e.g. hadrons affected by strong nuclear reaction or are made of quarks). Leptons are fundamental Hadrons are divided into baryons and mesons.* **Low Level (Poor to limited): 1 or 2 marks** The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate. *Identifies two correct properties of hadrons and leptons.*	6	**Lower band** 1 or 2 correct facts about hadrons leptons eg Leptons are fundamental/hadrons made of quarks **Middle band** Only hadrons experience strong nuclear interaction (need this to get in middle band) Hadrons are mesons or baryons Examples of each **Top Band** Both have rest mass Mention electromagnetic interaction Correct quark structure of mesons and baryons Both hadrons and leptons interact/decay through weak interaction For 6 marks must have last <u>two</u> points

		The explanation expected in a competent answer should include a coherent selection of the following points concerning the physical principles involved and their consequences in this case. example of hadron and lepton mention of strong interaction mention of quark structure hadrons leptons are fundamental identify baryons and mesons gives quark structure of baryons and mesons similarities e.g. all have rest mass all affected by weak interaction if charged both experience electromagnetic interaction		

(b)	(i)	a correct example of particle e.g. electron and correct example of antiparticle e.g. positron✓	1	Allow correct symbols Allow antielectron for positron Also allow pi zero and gamma

(b)	(ii)	correct difference e.g. <u>opposite</u> charge/other named quantum number✓	1	must be consistent with (i)

16)

a	**The student's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.** The student's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria. **High Level (Good to excellent): 5 or 6 marks** The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question. *Student names strong, weak and electromagnetic interactions. Identifies that only hadrons experience the strong interaction but hadrons and leptons experience weak interaction. Charged particles experience electromagnetic interaction. Is able to identify all exchange particles such as gluons, W+ and W- and virtual photons. Gives examples of two of the interactions i.e. electrons repelling, electron capture, beta decay.* **Intermediate Level (Modest to adequate): 3 or 4 marks** The information conveyed by the answer may be less well organised and not fully coherent. There is less use of	ignore any reference to gravity ignore any Feynman diagrams electrostatic not allowed as alternative for electromagnetic Properties of interactions • correct exchange particle($W^{(+/-)}$boson/Z_0 boson, (virtual) photon, gluon/pion) NB sign on W not required • correct group of particles affected (strong: baryons and mesons, weak: baryons, mesons and leptons, electromagnetic: charged particles) • example of the interaction Lower band 1 mark – two interactions OR one interaction and one property for that interaction 2 marks – two interactions and one property for one interaction Middle band	6

specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate.	3 marks - two interactions plus two properties 4 marks – two interactions plus minimum of four properties (e.g. 3 props plus 1 OR 2 props plus 2), if three interactions quoted then properties can be spread between the 3 e.g. one property for each (3) plus one additional Top band 5 marks – 3 interactions plus two properties for each 6 marks – must give first two properties for all three interactions AND correctly state two examples of interactions e.g. electron capture example of weak, strong nuclear responsible for binding protons/neutrons/baryons together

Student names strong, weak and electromagnetic interactions. Identifies that only hadrons experience the strong interaction but hadrons and leptons experience weak interaction. Charged particles experience electromagnetic interaction. Is able to identify some exchange particles such as gluons, W and W and virtual photons. **Low Level (Poor to limited): 1 or 2 marks** The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate. *Student names strong, weak and electromagnetic interactions.*	A table may help: |	strong	weak	EM | |---|---|---|---| | property 1 | | | | | property 2 | | | | | property 3 | | | |

	Identifies that only hadrons experience the strong interaction. *Identifies one exchange particle.* **The explanation expected in a competent answer should include a coherent selection of the following points concerning the physical principles involved and their consequences in this case.** *names of interactions – strong, weak and electromagnetic* *hadrons experience strong* *hadrons and leptons experience weak* *charged particles experience electromagnetic* *identify exchange particles* *give examples of various interactions e.g. electron capture*		

b	(either weak interaction or electromagnetic or strong interaction) first mark conservation at left hand junction of charge, baryon and lepton number✓ second mark conservation at right hand junction of charge, baryon and lepton number✓ third mark for correct exchange particle✓	if exchange particle not identified but baryon and lepton numbers conserved on both sides – 1 mark ignore orientation of line showing exchange particle or any arrows on exchange particle line when awarding first two marks if arrows on incoming and outgoing interacting particles in wrong direction then lose mark if lines do not meet at a junction lose 1 mark **with third mark** orientation of exchange particle line must be consistent with exchange particle shown and no arrow required	3
		if exchange particle line is horizontal (for weak) then must be a correct arrow arrow overrides slope	