1. (a) Identify the number of neutrons in a nucleus of polonium-210 $\left({}^{210}_{84}\mathrm{Po}\right)$.

Tick (✓) **one** box.

84 ☐

126 ☐

210 ☐

294 ☐

(1)

(b) A polonium-210 nucleus is formed when a stationary nucleus of bismuth-210 decays. A beta-minus (β^-) particle is emitted in this decay.

Outline, with reference to β^- decay, why bismuth-210 and polonium-210 have different proton numbers.

_____

_____

_____

_____

_____

_____

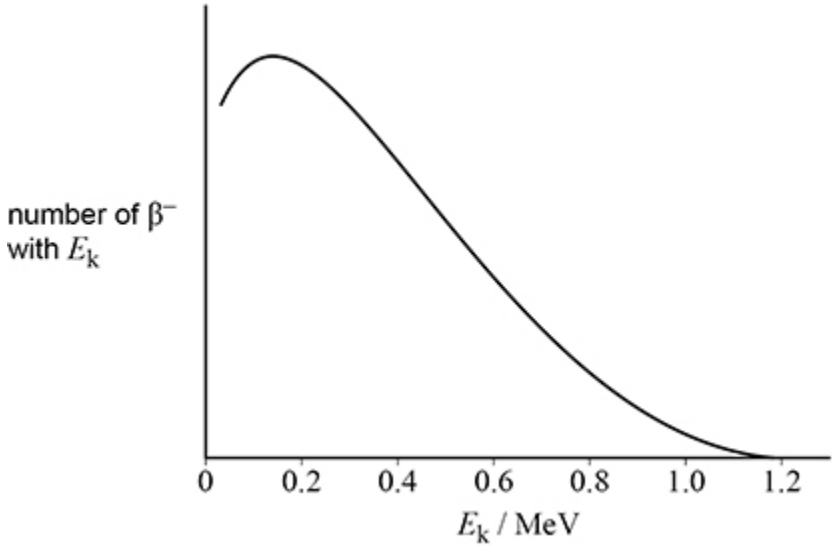
(2)

The kinetic energies of β^- particles emitted from a sample of bismuth-210 are analysed. These β^- particles have a range of kinetic energies.

The total energy released when each nucleus of bismuth-210 decays to a nucleus of polonium-210 is 1.2 MeV.

Figure 1 shows the variation with E_k of the number of β^- particles that have the kinetic energy E_k.

Figure 1



(c) Explain how the data in **Figure 1** support the hypothesis that a third particle is produced during β^- decay.

(2)

(d) This third particle is an electron antineutrino.

Explain why an electron antineutrino, rather than an electron neutrino, is produced during β^- decay.

_____

_____

_____

_____

_____

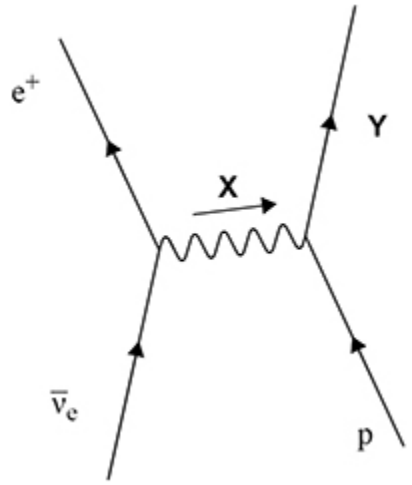
_____

(2)

(e) A large tank of water is used as part of an electron antineutrino detector. An electron antineutrino $\bar{\nu}_e$ enters the tank and interacts with a proton (p).

Figure 2 represents this interaction.

Figure 2



Identify **X** and **Y**.

X = _____

Y = _____

(2)

(f) The positron produced in the interaction in **Figure 2** slows down and collides with a lepton in a molecule of water.

Describe the process that occurs when the positron collides with this lepton. In your answer you should identify the lepton in the molecule of water.

(3)

(g) The range of the electromagnetic interaction is infinite.
The table below gives the range of the strong nuclear interaction and the range of the weak nuclear interaction.

Interaction	Range / m
strong nuclear	10^{-15}
weak nuclear	10^{-18}

Deduce whether the positron or the electron antineutrino is likely to travel the shorter distance in the tank of water before interacting.

(3)

(Total 15 marks)

2. An atom of oxygen-15 $\left({}^{15}_{8}\mathrm{O}\right)$ gains two electrons to form an ion.

What is the specific charge of the ion?

A -1.3×10^{7} C kg^{-1} ⬭

B -2.4×10^{7} C kg^{-1} ⬭

C -5.1×10^{7} C kg^{-1} ⬭

D -6.4×10^{7} C kg^{-1} ⬭

(Total 1 mark)

3. Which is an exchange particle for the weak interaction?

A lepton ⬭

B photon ⬭

C pion ⬭

D W^{+} ⬭

(Total 1 mark)

4. A particular baryon has a quark structure dss and decays by the weak interaction.

What are possible decay products of this baryon?

The quark structure of Λ^{0} is uds.

A $\Lambda^{0} + \pi^{-}$ ⬭

B $n + \pi^{-}$ ⬭

C $\Lambda^{0} + e^{-}$ ⬭

D $K^{+} + K^{0}$ ⬭

(Total 1 mark)

5. A muon and an antimuon annihilate to produce the minimum number of photons.

What is the maximum wavelength of the photons?

A 5.9×10^{-15} m ⬭

B 1.2×10^{-14} m ⬭

C 5.9×10^{-9} m ⬭

D 1.2×10^{-8} m ⬭

(Total 1 mark)

6. Which row describes the nature of the strong nuclear force between two nucleons at separations of 0.25 fm, 2.0 fm and 8.0 fm?

	At a separation of 0.25 fm	**At a separation of 2.0 fm**	**At a separation of 8.0 fm**	
A	attractive	repulsive	negligible	⬭
B	repulsive	attractive	attractive	⬭
C	negligible	repulsive	attractive	⬭
D	repulsive	attractive	negligible	⬭

(Total 1 mark)

7. What are the products when a free neutron decays?

A $p + e^- + \nu_e$ ⬭

B $p + e^+ + \bar{\nu}_e$ ⬭

C $p + e^- + \bar{\nu}_e$ ⬭

D $p + e^+ + \nu_e$ ⬭

(Total 1 mark)

8. In a Young's double-slit experiment, monochromatic light is incident on two narrow slits and the resulting interference pattern is observed on a screen.

Which change **decreases** the fringe separation?

A decreasing the separation between the two slits ⬭

B increasing the distance between the slits and the screen ⬭

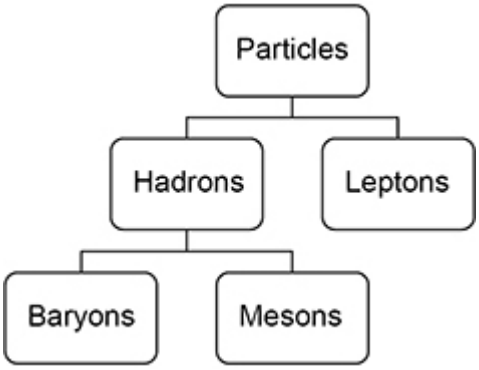
C using monochromatic light of higher frequency ⬭

D using monochromatic light of longer wavelength ⬭

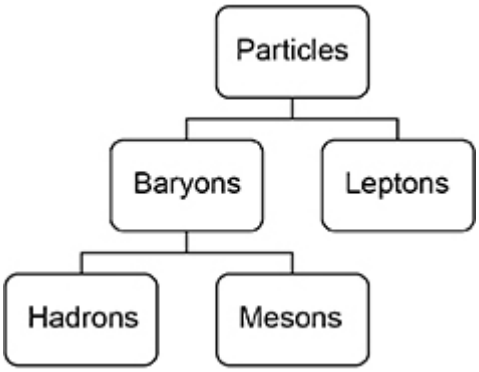
(Total 1 mark)

9. Which shows the classification of particles?

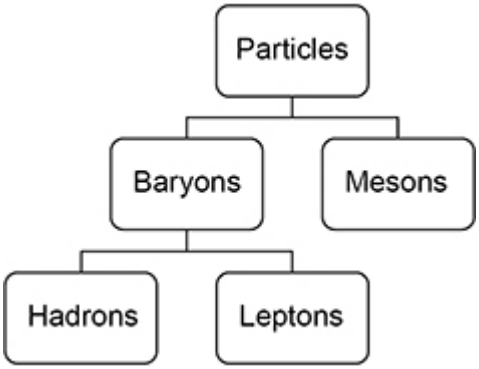
A



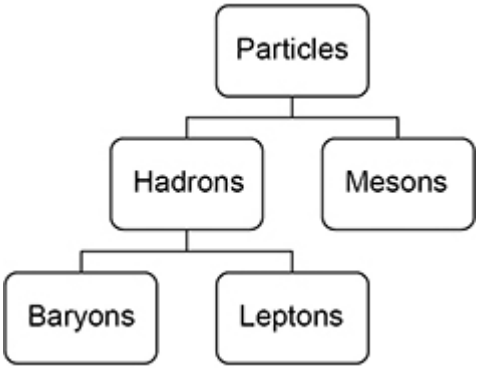
B



C



D



A ⬭

B ⬭

C ⬭

D ⬭

(Total 1 mark)

10. Cosmic rays are high-energy particles that come from space. Most of these particles are protons. There are other particles in cosmic rays, including atomic nuclei.

The table below gives the data for one particular nucleus **X**.

Mass / kg	8.02×10^{-26}
Specific charge / C kg^{-1}	4.39×10^{7}
Kinetic energy / MeV	215

(a) Determine the number of neutrons in nucleus **X**.

number of neutrons = _____

(3)

(b) Calculate the speed of **X**.
Ignore relativistic effects.

speed = _____ m s^{-1}

(3)

A pion (π^+) and a kaon (K^+) are produced when cosmic rays interact with the upper atmosphere.

(c) The π^+ decays to produce a positron and an electron neutrino.

Show how the conservation laws apply to this decay.

_____

_____

_____

_____

_____

(2)

(d) The K^+ decays to produce an anti-muon and a muon neutrino.

Explain how strangeness applies in this decay.

_____

_____

_____

_____

(2)

(e) Write an equation for a K^+ decay that involves only hadrons.

_____

(2)

(Total 12 marks)

11. The gravitational force is one of the four fundamental forces.
The ticks in the table match particles with the other fundamental forces.

In which row is the particle matched to the only other fundamental forces it experiences?

	Particle	Electromagnetic force	Weak nuclear force	Strong nuclear force	
A	μ^+	✓	✓		⬭
B	$\overline{p}$	✓		✓	⬭
C	π^0	✓	✓	✓	⬭
D	ν_e		✓	✓	⬭

(Total 1 mark)

12. The proton number of uranium is 92 and the proton number of radon is 88

Which series of decays turns a uranium nucleus into a radon nucleus?

A $\alpha + \beta^- + \beta^- + \alpha + \alpha$ ⬭

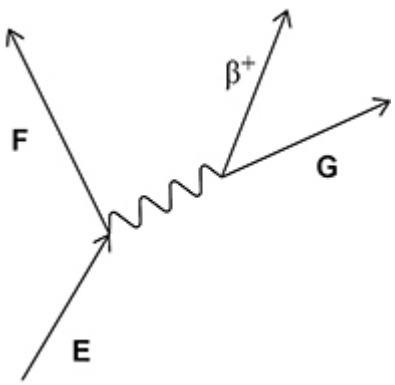
B $\beta^- + \beta^- + \alpha + \beta^- + \alpha$ ⬭

C $\alpha + \alpha + \alpha + \alpha + \beta^-$ ⬭

D $\beta^- + \beta^- + \beta^- + \beta^- + \alpha$ ⬭

(Total 1 mark)

13. The diagram represents a particle interaction.



Which row identifies particles **E**, **F** and **G**?

	E	F	G	
A	up quark	down quark	neutrino	⬭
B	down quark	up quark	neutrino	⬭
C	up quark	down quark	antineutrino	⬭
D	down quark	up quark	antineutrino	⬭

(Total 1 mark)

14. The quark combination of a particle is sū.

Which is true for this particle?

A It has a baryon number of 1 ⬭

B It has a charge of -1.6×10^{-19} C. ⬭

C It is a pion. ⬭

D It has a strangeness of $-\frac{1}{3}$ ⬭

(Total 1 mark)

15. One strong interaction that occurs when two high-energy protons collide is

$$p + p \rightarrow p + \pi^+ + \pi^- + \mathbf{X}$$

(a) Determine the lepton number, strangeness and charge of particle **X**.

lepton number = _____

strangeness = _____

charge = _____

(2)

(b) Identify particle **X**.

_____

(1)

(c) A possible decay of a negative pion is

$$\pi^- \rightarrow e^- + \mathbf{Y}$$

What is particle **Y**?
Tick (✓) **one** box.

- $\bar{\nu}_e$ ☐
- ν_e ☐
- π^0 ☐
- ${}^{1}_{0}n$ ☐

(1)

(d) Some subatomic particles are classified as hadrons. There are two classes of hadrons.

Discuss the nature of hadrons.
Your answer should include:

- the identifying properties of hadrons
- the structure of a hadron in each class
- a discussion of the stability of free hadrons.

(6)

(Total 10 marks)

16. A sample of pure boron contains only isotope **X** and isotope **Y**.
A nucleus of **X** has more mass than a nucleus of **Y**.

(a) The sample is ionised, producing ions each with a charge of $+1.6 \times 10^{-19}$ C.
The specific charge of an ion of **X** is 8.7×10^{6} C kg^{-1}.

Calculate the mass of an ion of **X**.

mass of ion = _____ kg

(1)

(b) Determine the number of nucleons in a nucleus of **X**.

mass of a nucleon = 1.7×10^{-27} kg

number of nucleons = _____

(2)

(c) Compare the nuclear compositions of **X** and **Y**.

_____

_____

_____

_____

_____

_____

(2)

(d) Ions of **Y** have the same charge as ions of **X**.

State and explain how the specific charge of an ion of **X** compares with that of an ion of **Y**.

(2)

(e) The table contains data about two completely ionised samples of pure boron. Each sample contains only isotopes **X** and **Y**.

Sample number	Number of ions in sample	Mass of sample / kg	Charge on each ion / C
1	3.50×10^{16}	6.31×10^{-10}	$+1.60 \times 10^{-19}$
2	3.50×10^{7}	6.20×10^{-19}	$+1.60 \times 10^{-19}$

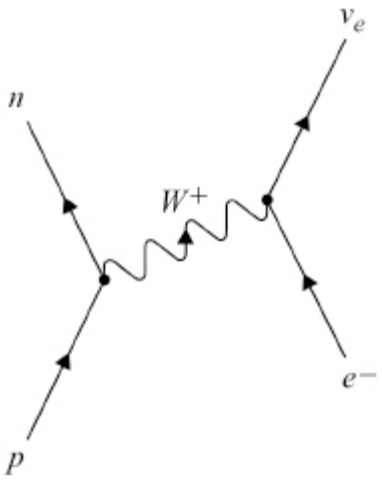
Deduce which sample, **1** or **2**, contains a greater percentage of isotope **Y**.

(3)

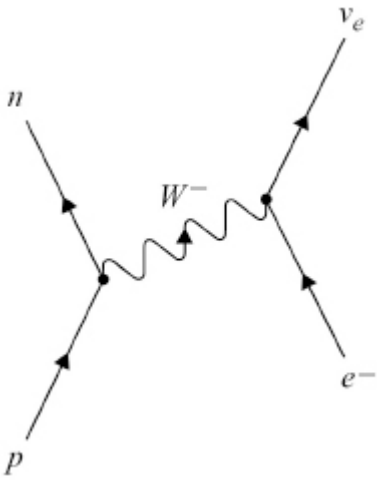
(Total 10 marks)

17. Which diagram represents electron capture?

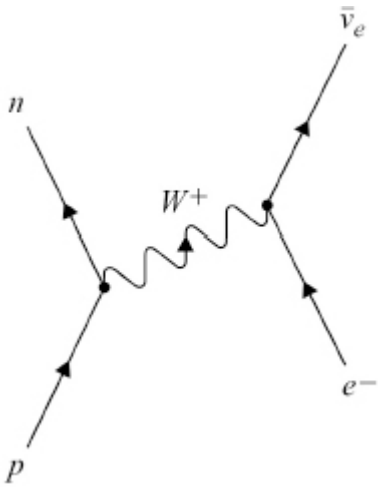
A



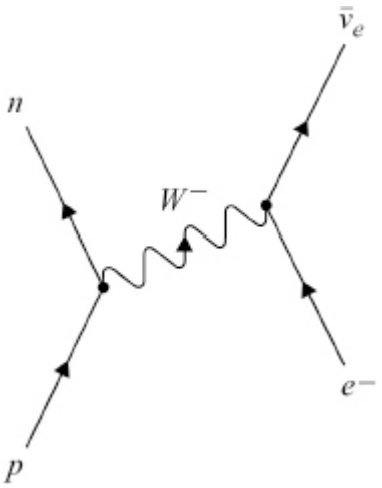
B



C



D



A ⬭

B ⬭

C ⬭

D ⬭

(Total 1 mark)

18. $^{x}_{81}Tl$ decays to $^{206}_{82}Pb$ by a series of four radioactive decays.

Each decay involves the emission of either a single α particle or a single β^- particle.

What is *x*?

A 207 ⬭

B 209 ⬭

C 210 ⬭

D 212 ⬭

(Total 1 mark)

19. What is the number of up quarks and down quarks in a $^{9}_{4}Be$ nucleus?

	Number of up quarks	Number of down quarks	
A	11	16	⬭
B	13	14	⬭
C	14	13	⬭
D	16	11	⬭

(Total 1 mark)

20. Which decay of a positive kaon (K^+) particle is possible?

A $K^+ \rightarrow \pi^0 + e^+ + \bar{\nu}_e$ ⬭

B $K^+ \rightarrow p + \nu_\mu$ ⬭

C $K^+ \rightarrow \pi^+ + \pi^+ + \pi^0$ ⬭

D $K^+ \rightarrow \mu^+ + \nu_\mu$ ⬭

(Total 1 mark)

21. (a) Determine whether the following reaction is a possible decay for the neutral pion π^0.

$$\pi^0 \rightarrow e^- + \mu^+ + \bar{\nu}_e$$

(2)

(b) State the **two** possible quark configurations of a π^0.

1. _____

2. _____

(1)

(c) A student suggests that the kaon K^0 and the anti-kaon $\overline{K^0}$ are the same particle.

Discuss whether this suggestion is correct.

(2)

(d) The nucleus is held together by a force. It was predicted that a particle exists that is responsible for this force. The particle itself must experience this force.

The particle would have a rest energy between that of an electron and half that of a nucleon.

Discuss whether a kaon, a muon and a pion **each** have the properties of the predicted particle.

Information about these three particles is in the Data and Formulae Booklet.

(4)

(Total 9 marks)

22. A deuterium nucleus and a tritium nucleus fuse together to produce a helium nucleus and particle **X**.

$$^{2}_{1}\mathrm{H} + ^{3}_{1}\mathrm{H} \rightarrow ^{4}_{2}\mathrm{He} + \mathbf{X}$$

What is **X**?

A an electron ⬭

B a neutron ⬭

C a positron ⬭

D a proton ⬭

(Total 1 mark)

23. Which row gives a particle with its quark combination and category?

	Particle	Quark combination	Category	
A	Negative pion	$d\bar{u}$	baryon	⬭
B	Positive pion	$u\bar{d}$	hadron	⬭
C	Negative pion	$u\bar{d}$	meson	⬭
D	Positive pion	$d\bar{u}$	hadron	⬭

(Total 1 mark)

24. Which row gives the numbers of baryons and leptons in an atom of $^{12}_{6}C$?

	Number of baryons	Number of leptons	
A	6	6	⬭
B	12	6	⬭
C	6	12	⬭
D	18	0	⬭

(Total 1 mark)

25. A muon

A is subject to the strong interaction. ⬭

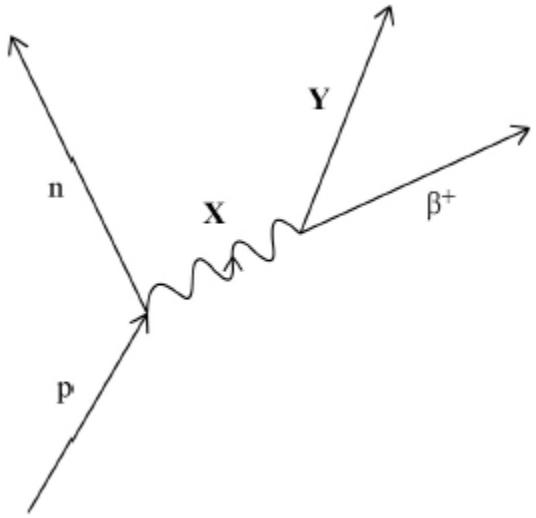
B can decay into an electron only. ⬭

C is a stable particle. ⬭

D is subject to the weak interaction. ⬭

(Total 1 mark)

26. The process of beta plus (β^+) decay can be represented by

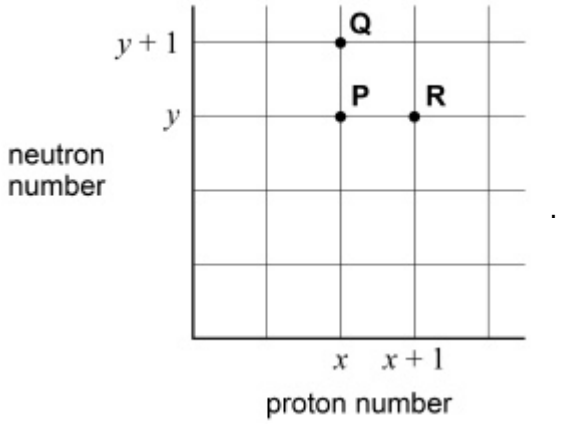


Which row identifies particles **X** and **Y**?

	X	Y	
A	W^+	ν_e	⬭
B	W^+	$\overline{\nu_e}$	⬭
C	W^-	ν_e	⬭
D	W^-	$\overline{\nu_e}$	⬭

(Total 1 mark)

27. The graph of neutron number against proton number shows three nuclei **P**, **Q** and **R**.



Which row identifies an isotope of **P** and the nucleon number of this isotope of **P**?

	Isotope of P	Nucleon number of isotope of P	
A	**Q**	$y + 1$	⬭
B	**Q**	$x + y + 1$	⬭
C	**R**	$x + y + 1$	⬭
D	**R**	$x + 1$	⬭

(Total 1 mark)

28. $^{236}_{92}U$ undergoes a series of decays to produce $^{204}_{82}Pb$.

How many alpha decays are involved in this decay series?

A 5 ⬭

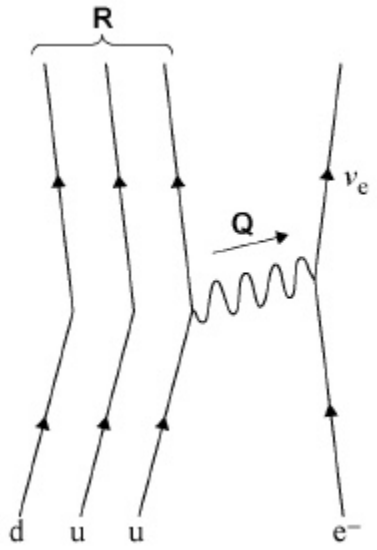
B 6 ⬭

C 8 ⬭

D 10 ⬭

(Total 1 mark)

29. The partially completed diagram represents electron capture.



Which row identifies the exchange particle **Q** and the quark structure of particle **R**?

	Particle Q	Quark structure of particle R	
A	W^-	uuu	⬭
B	W^+	dud	⬭
C	W^+	uuu	⬭
D	W^-	dud	⬭

(Total 1 mark)

30. The decay of a neutral kaon K^0 is given by the equation

$$K^0 \rightarrow X + Y + \bar{\nu}_e$$

What are X and Y?

	X and Y	
A	e^+ and e^-	⬭
B	μ^+ and e^-	⬭
C	π^+ and e^-	⬭
D	π^- and e^+	⬭

(Total 1 mark)

31. Fluoride ions are produced by the addition of a single electron to an atom of fluorine $^{19}_{9}\text{F}$.

What is the magnitude of specific charge of the fluoride ion?

A 3.2×10^{-26} C kg^{-1} ⬭

B 8.4×10^{-21} C kg^{-1} ⬭

C 5.0×10^{6} C kg^{-1} ⬭

D 4.5×10^{7} C kg^{-1} ⬭

(Total 1 mark)

32. The $\sum^0$ baryon, composed of the quark combination uds, is produced through the strong interaction between a π^+ meson and a neutron.

$$\pi^+ + \text{n} \rightarrow \sum^0 + \text{X}$$

What is the quark composition of X?

A $u\bar{s}$ ⬭

B ud ⬭

C $u\bar{d}$ ⬭

D $ud\bar{s}$ ⬭

(Total 1 mark)

33. An iodine nucleus decays into a nucleus of Xe−131, a beta-minus particle and particle Y.

$$^{131}_{53}\text{I} \rightarrow ^{131}_{54}\text{Xe} + ^{0}_{-1}\text{e} + \text{Y}$$

Which is a property of particle Y?

A It has a lepton number of +1 ⬭

B It is an antiparticle ⬭

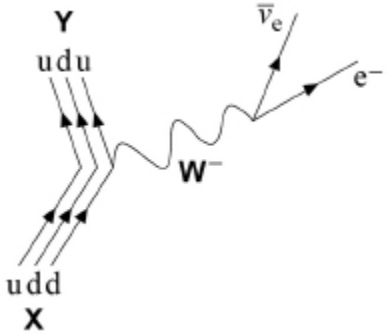
C It is negatively charged ⬭

D It experiences the strong interaction ⬭

(Total 1 mark)

34. The diagram below represents the decay of a particle **X** into a particle **Y** and two other particles.

The quark structure of particles **X** and **Y** are shown in the diagram.



(a) Deduce the name of particle **X**.

_____

(1)

(b) State the type of interaction that occurs in this decay.

_____

(1)

(c) State the class of particles to which the $\mathbf{W^-}$ belongs.

_____

(1)

(d) Show clearly how charge and baryon number are conserved in this interaction.

You should include reference to all the particles, including the quarks, in your answer.

_____

_____

_____

_____

_____

(2)

(e) Name the only stable baryon.

_____

(1)

(f) A muon is an unstable particle.

State the names of the particles that are produced when a muon decays.

_____

(1)

(Total 7 marks)

35. Which row shows the correct interactions experienced by a hadron or a lepton?

	Particle	Strong interaction	Weak interaction	
A	Hadron	Yes	Yes	⬭
B	Lepton	Yes	Yes	⬭
C	Hadron	Yes	No	⬭
D	Lepton	Yes	No	⬭

(Total 1 mark)

36. When a nucleus of the radioactive isotope $^{65}_{28}Ni$ decays, a β^- particle and an electron antineutrino are emitted.

How many protons and neutrons are there in the resulting daughter nucleus?

	Number of protons	Number of neutons	
A	28	65	⬭
B	29	65	⬭
C	29	36	⬭
D	30	35	⬭

(Total 1 mark)

37. What interactions are involved in the production of a strange particle and its decay into non-strange particles?

	Production	Decay	
A	strong	weak	⬭
B	strong	strong	⬭
C	weak	strong	⬭
D	weak	weak	⬭

(Total 1 mark)

38. An atom of $^{16}_{7}N$ gains 3 electrons.

What is the specific charge of the ion?

A 1.80×10^{7} C kg^{-1} ⬭

B -1.80×10^{7} C kg^{-1} ⬭

C 4.19×10^{7} C kg^{-1} ⬭

D -4.19×10^{7} C kg^{-1} ⬭

(Total 1 mark)

39. The positive kaon (K^{+}) has a strangeness of +1.

(a) Which of the following is the quark composition of the positive kaon?
Tick (✓) the correct answer.

	✓ if correct
$\bar{u}s$	
$u\bar{u}\bar{s}$	
$u\bar{s}$	
$\bar{d}\bar{d}s$	

(1)

(b) The equation shows a possible decay of the positive kaon.

$$K^+ \longrightarrow \mu^+ + \nu_\mu$$

(i) Show that lepton number is conserved in this decay.

(1)

(ii) State a quantity that is not conserved in this decay.

_____

(1)

(iii) Complete the following table using ticks to indicate correct classifications for each particle. The first column has been completed for you.

	Charged	**Hadron**	**Meson**	**Baryon**	**Lepton**
K^+	✓				
μ^+	✓				
ν_μ					

(3)

(c) The positive kaon can also decay to form a π^+ and one other particle X.
Deduce the identity of X.

_____

_____

_____

_____

_____

_____

(3)

(Total 9 marks)

40. Under certain conditions a photon may be converted into an electron and a positron.

(a) State the name of this process.

_____

(1)

(b) For the conversion to take place the photon has to have an energy equal to or greater than a certain minimum energy.

(i) Explain why there is a minimum energy.

_____

_____

(2)

(ii) Show that this minimum energy is about 1 MeV.

(1)

(iii) Explain what happens to the excess energy when the photon energy is greater than the minimum energy.

_____

_____

(1)

(iv) A photon has an energy of 1.0 MeV.

Calculate the frequency associated with this photon energy.
State an appropriate unit in your answer.

frequency = _____ unit = _____

(4)

(Total 9 marks)