

1.

1. (a) Mesons, leptons and quarks are three groups of particles. State which of these groups are affected by:

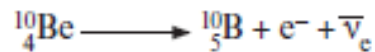
(i) the weak nuclear force; [1]

.....

(ii) the strong nuclear force. [1]

.....

- (b) The following interaction shows a β^- decay for a beryllium nucleus.



(i) State the name of the $\bar{\nu}_e$ particle. [1]

.....

(ii) Explain how lepton number and charge are conserved in this interaction. [2]

.....

.....

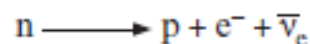
.....

.....

- (c) (i) Write down the number of neutrons in:

I. ${}_{4}^{10}\text{Be}$ II. ${}_{5}^{10}\text{B}$ [1]

- (ii) On the level of baryons the interaction can be written as:



Show clearly that there is a change in quark flavour in this interaction. [2]

.....

.....

.....

.....

2.

7. (a) Quarks and electron neutrinos are fundamental particles whereas protons and neutrons are not. Explain this statement. [2]

.....

.....

.....

.....

- (b) (i) State why it is that electron neutrinos are very difficult to detect. [2]

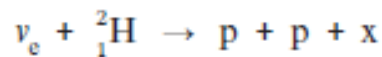
.....

.....

.....

.....

- (ii) Electron neutrinos can be detected when they interact with deuterium nuclei, ${}^2_1\text{H}$, that are present in heavy water. The following reaction is observed.



- Identify particle x and justify your answer using the conservation laws. [3]

.....

.....

.....

.....

.....

- (c) When a positron and an electron meet they annihilate to produce two gamma ray photons.



- State which force is responsible for this interaction, giving your reasoning. [2]

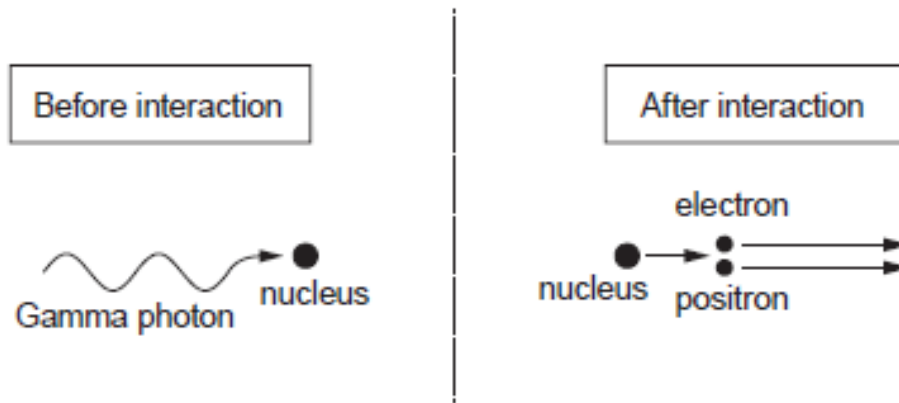
.....

.....

.....

3.

5. The following interaction can take place when a gamma photon encounters a stationary nucleus.



The energy of the gamma photon "creates" a positron-electron pair and the nucleus gains some momentum in the direction of the original gamma photon.

- (a) Show that this interaction can only take place if the energy of the gamma photon is greater than 1.02 MeV. [3]

.....

.....

.....

.....

.....

.....

- (b) The actual energy of the incident gamma photon is 1.03 MeV. Assuming that the kinetic energy of the nucleus after the interaction is negligible, explain briefly why the kinetic energies of the positron and electron are approximately 0.005 MeV each. [2]

.....

.....

.....

.....

- (c) Use the kinetic energies of 0.005 MeV and conservation of momentum to show that the speeds of the positron and electron are $4.2 \times 10^7\text{ ms}^{-1}$ and that the momentum of the nucleus after the collision is $4.7 \times 10^{-22}\text{ kg ms}^{-1}$. [4]

- (d) The momentum of the nucleus ($4.7 \times 10^{-22}\text{ kg ms}^{-1}$) is essential otherwise conservation of momentum would be impossible. Deduce whether or not the assumption in part (b) is valid (the mass of the nucleus is $3.3 \times 10^{-25}\text{ kg}$). [2]

4.

4. (a) The table shows information about some sub-atomic particles.

Particle	Symbol	Quark combination	Charge / e	Baryon number
proton	p	uud	+1	1
delta particle	Δ^{++}	uuu		
electron	e^{-}	no quarks present		
pion	π^{-}		-1	

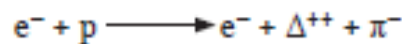
(i) Complete the table.

[3]

(ii) Identify the lepton in the table.

[1]

(b) JJ Thomson, when studying the properties of cathode rays in 1897, discovered the electron. In the early 20th century, Ernest Rutherford, carrying out a series of experiments on radioactive substances, discovered the proton. The following interaction between protons and electrons has been observed by using high energy particle accelerators.



Show how charge and lepton number are conserved in the above interaction.

[2]

.....

.....

.....

.....

(c) The Δ^{++} decays in about 6×10^{-24} s as shown below.



- (i) Show clearly that both up-quark number and down-quark number are conserved in this decay. [2]

.....

.....

.....

- (ii) Give two reasons for believing that this decay is a strong force interaction. [2]

.....

.....

.....

(d) During a press conference, the spokesman for a nuclear research centre was asked the question:

'You have discovered many new particles, none of which have had any discernible impact on society. How do you justify the huge expense of continuing with these experiments?'

In response, the spokesman referred to the work of JJ Thomson and Ernest Rutherford. Suggest why the spokesman responded in this way. [2]

.....

.....

.....

.....

.....

- [illegible]

- (b) Electron capture occurs when an electron interacts with a proton in the nucleus of an atom. The following interaction occurs:



- (i) Identify the particle, x , explaining how you used the relevant conservation laws. [3]

.....

.....

.....

.....

.....

.....

- (ii) Describe the change in quark flavour during electron capture. [1]

.....

.....

.....

- (iii) State and explain which interaction is responsible for this decay. [1]

.....

.....

.....

6. (a) The anti- Δ^{++} is an anti-baryon and a first-generation particle which has a charge of $-2e$. Explain why the only possible quark make-up of the anti- Δ^{++} is $\bar{u}\bar{u}\bar{u}$. [1]

.....

.....

- (b) The anti- Δ^{++} has a lifetime of approximately 6×10^{-24} s and decays into a π meson and another anti-baryon. Deduce the quark make-up of the π meson and the anti-baryon and name them. [2]

.....

.....

.....

- (c) State which force is responsible for the decay of the anti- Δ^{++} into a π meson and anti-baryon, giving a reason for your answer. [2]

.....

.....

.....

- (d) In 2011, a highly respected international research collaboration reported that they had measured neutrinos travelling at speeds greater than that of light. This report was met by caution from the scientific community and then the result was disproved. Explain briefly why the result was met with caution and how the results might have been disproved. [3]

.....

.....

.....

.....

.....

.....

.....

.....

7. (a) Explain briefly what is meant by conservation of mass-energy.

[2]

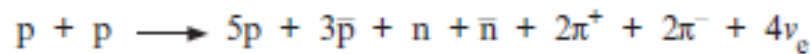
.....

.....

.....

.....

(b) It is suggested that a collision between two protons, each of kinetic energy 3 GeV produces the following interaction:



Determine which, if any, of the conservation laws are violated (the rest mass-energy of a proton or a neutron ≈ 1 GeV).

[4]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....