3.11 Physics: Nuclear and Particle Physics: 10-minute Pack

AQA 7408 · Calculator allowed · about 10 minutes

Total Marks

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

1 Before the neutrino was proposed, physicists observed that β particles emitted from a given radioactive source did not all have the same, fixed kinetic energy, but instead showed a continuous range (spectrum) of energies up to a single maximum value.

(a) State the change in proton number Z and nucleon number A of a nucleus undergoing β-minus decay. **(2)**

(b) Discuss how the observation of a continuous range of β particle energies, rather than a single fixed energy, led physicists to propose the existence of the neutrino, referring to the conservation of energy and momentum. **(6)**

(Total for Question 1 is 8 marks)

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Mark scheme · 3.11 Physics: Nuclear and Particle Physics: 10-minute Pack

Question 1

(a) proton number Z increases by 1 **B1**

(a) nucleon number A stays the same (unchanged) **B1**

(a) Answer: Z increases by 1; A is unchanged.

(b) **L3** A coherent, logically structured account that explains why a genuine two-body decay (nucleus -> nucleus + beta particle only) would give the beta particle a single, fixed kinetic energy, contrasts this with the observed continuous spectrum up to a maximum, and explains how introducing a third particle (the neutrino), sharing the released energy and momentum with the beta particle in varying proportions from decay to decay, resolves the discrepancy while conserving both energy and momentum in every individual decay. **5-6**

(b) **L2** Some relevant, largely correct physics is given, such as recognising that a two-body decay would predict a fixed beta particle energy and that the observed continuous spectrum was therefore unexpected, and/or that a third, unseen particle carrying away a variable share of energy and momentum was proposed, but the explanation is incomplete, lacks detail on momentum conservation, or is not fully coherent. **3-4**

(b) **L1** Basic, largely isolated relevant statements are made, such as noting that beta particles have a range of energies or that a neutrino is emitted, with little or no explanation of why this observation implies a third particle or which conservation principle is involved. **1-2**

(b) **L0** No creditable response, or the answer does not relate to the question. **0**

(b) Indicative content:

- If beta decay were a genuine two-body process (parent nucleus -> daughter nucleus + beta particle only), conservation of energy and momentum would require the beta particle to be emitted with one single, fixed kinetic energy for a given parent and daughter pair, as is observed for alpha decay.
- Experimentally, however, beta particles from a given source were observed to have a continuous range of kinetic energies, from zero up to a single maximum value, not one fixed energy.
- This appeared to violate conservation of energy (individual decays seemed to 'lose' varying amounts of energy) and, when momenta were considered, conservation of momentum too.
- Pauli proposed that a third, initially unseen particle, later named the neutrino, is also emitted in every beta decay.
- The total energy and momentum released in the decay is shared, in varying proportions from decay to decay, between the beta particle, the neutrino and the recoiling nucleus, so the beta particle's individual energy can vary continuously up to a maximum (when the neutrino carries away almost none of the energy), while total energy and momentum are always conserved in each individual decay.
- Because the neutrino has negligible mass, no charge, and interacts extremely weakly with matter, it was not directly detected in these early experiments, which explains why its existence had to be inferred indirectly from the shape of the beta energy spectrum rather than being observed directly.

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