AQA AS Particle Classification, Quarks and Conservation Laws solutions

Matching solutions and teaching prompts for the class review

Specification points covered

• 3.2.1.5(a) Hadrons and the strong interaction.	• 3.2.1.5(m) Strangeness conservation in strong interactions.
• 3.2.1.5(b) Baryons and antibaryons.	• 3.2.1.5(n) Strangeness change in weak interactions.
• 3.2.1.5(c) Mesons, including pions and kaons.	• 3.2.1.5(o) Collaboration in particle physics.
• 3.2.1.5(d) Conservation of baryon number.	• 3.2.1.6(a) Quark and antiquark properties.
• 3.2.1.5(e) Proton stability and baryon decay.	• 3.2.1.6(b) Quark combinations in hadrons.
• 3.2.1.5(f) Pion exchange and the strong nuclear force.	• 3.2.1.6(c) Use of u, d, s and their antiquarks.
• 3.2.1.5(g) Kaon decay into pions.	• 3.2.1.6(d) Quark compositions of nucleons and antinucleons.
• 3.2.1.5(h) Leptons, neutrinos and antiparticles.	• 3.2.1.6(e) Quark compositions of specified pions and kaons.
• 3.2.1.5(i) Electron and muon lepton-number conservation.	• 3.2.1.6(f) Neutron decay.
• 3.2.1.5(j) Muon decay into an electron.	• 3.2.1.7(a) Quark changes in beta decay.
• 3.2.1.5(k) Strong production and weak decay of strange particles.	• 3.2.1.7(b) Conservation of charge, baryon number, lepton numbers and strangeness.
• 3.2.1.5(l) Strangeness and pair production.	• 3.2.1.7(c) Conservation of energy and momentum.

Teaching focus

Insist on precise particle, wave and energy language as well as correct calculations.
Use each common-error prompt to correct the pupil's model or reasoning, not only the final answer.

1. Reading the event display

1. The array identifies four particles in one cosmic-ray shower: a proton, a positive pion, a negative muon and a muon neutrino. Classify each particle as a baryon, meson or lepton. [4 marks]

Answer / mark points: Proton: baryon. Positive pion: meson. Negative muon: lepton. Muon neutrino: lepton. One mark for each.

Teacher prompt / common error: Hadrons are baryons or mesons; leptons are not hadrons.

2. The event display shows a proton track continuing through the detector, while a neutron, a kaon and a muon later decay. State which named particle is the only stable baryon and explain why the other tracks may end in decays. [3 marks]

Answer / mark points: The proton is the only stable baryon. The neutron is unstable when free and decays by the weak interaction. Kaons are unstable mesons and muons are unstable leptons, so their tracks can terminate at decay vertices.

Teacher prompt / common error: Do not call every long track stable. The specification identifies only the proton as a stable baryon.

2. Reconstructing particles

3. Complete the particle-property audit: state (a) the charge of u; (b) the charge of d; (c) the baryon number of any quark; (d) the strangeness of s; and (e) the strangeness of $\bar{s}$. [5 marks]

Answer / mark points: (a) u has charge +2/3 e. (b) d has charge -1/3 e. (c) a quark has baryon number +1/3. (d) s has strangeness -1. (e) $\bar{s}$ has strangeness +1.	
Teacher prompt / common error: Use fractions of e for quark charge and distinguish a quark from an antiquark.	

4. State the quark composition of a proton, a neutron, π^+ and K^0. Use only u, d, s and their antiquarks. [4 marks]

Answer / mark points: p = uud; n = udd; π^+ = u $\bar{d}$; K^0 = d $\bar{s}$.	
Teacher prompt / common error: A meson must contain one quark and one antiquark. Check the total charge after writing each composition.	

5. A proposed strong-interaction event is $\pi^- + p \rightarrow K^0 + X$. The candidates for X are n (Q = 0, B = 1, S = 0), Λ^0 (Q = 0, B = 1, S = -1) and $\bar{K}^0$ (Q = 0, B = 0, S = -1). Identify X by applying charge, baryon number and strangeness conservation. [3 marks]

Answer / mark points: Initial totals are Q = 0, B = 1 and S = 0. K^0 has Q = 0, B = 0 and S = +1, so X must have Q = 0, B = 1 and S = -1. Therefore X is Λ^0.	
Teacher prompt / common error: Apply all three quantum numbers. Charge alone does not distinguish n from Λ^0.	

3. Strange-particle evidence

6. Explain why the simultaneous production of K^0 and Λ^0 in Question 5 is described as production of strange particles in a pair. [2 marks]

Answer / mark points: The initial particles have total strangeness zero. The K^0 has $S = +1$ and the Λ^0 has $S = -1$, so the strange and antistrange content is created together and total strangeness remains zero.	
Teacher prompt / common error: Pair production here means opposite strangeness, not necessarily a particle and its own antiparticle.	

7. A K^+ later decays by $K^+ \rightarrow \pi^+ + \pi^0$. Show how strangeness changes and state which fundamental interaction causes this decay. [2 marks]

Answer / mark points: K^+ has $S = +1$, while both pions have $S = 0$, so $\Delta S = -1$. This is a weak-interaction decay.	
Teacher prompt / common error: A change in strangeness identifies the weak interaction; strong interactions conserve strangeness.	

8. The software tests three proposed decays: A $\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$; B $n \rightarrow p + e^- + \bar{\nu}_e$; C $p \rightarrow e^+ + \pi^0$. Decide which are allowed. For each decision, name a relevant conserved quantity. [4 marks]

Answer / mark points: A is allowed: charge is conserved; electron lepton number is +1 - 1 = 0 and muon lepton number remains +1. B is allowed: charge, baryon number and electron lepton number are conserved. C is forbidden because baryon number changes from 1 to 0, even though charge is conserved.	
Teacher prompt / common error: Conservation is tested across the complete event, including neutrinos and antineutrinos.	

4. Quark changes and event totals

9. State the quark change in (a) beta-minus decay of a neutron and (b) beta-plus decay of a proton. Name the nucleon produced in each case. [3 marks]

Answer / mark points: (a) In beta-minus decay d → u; a neutron becomes a proton. (b) In beta-plus decay u → d; a proton becomes a neutron. Credit the two quark changes and both resulting nucleons together for the final mark.

Teacher prompt / common error: The particle changes are opposite: d → u for beta-minus and u → d for beta-plus.

10. A fluorine-19 nucleus contains 9 protons and 10 neutrons. Calculate the total number of up quarks and the total number of down quarks in the nucleus. [2 marks]

Answer / mark points: Up quarks = (9 × 2) + (10 × 1) = 28. Down quarks = (9 × 1) + (10 × 2) = 29.

Teacher prompt / common error: Count quarks inside every nucleon; do not count only the valence quarks of one proton and one neutron.

11. Before one collision the total energy is 6.20 GeV and the total momentum is zero. The visible products carry 4.90 GeV and a total momentum of 1.10 GeV c^{-1} east. State the energy and momentum that an undetected product must carry. [3 marks]

Answer / mark points: Missing energy = 6.20 - 4.90 = 1.30 GeV. To conserve momentum, the product carries 1.10 GeV c^{-1} west. It must carry the momentum opposite to the visible products.

Teacher prompt / common error: Energy is a scalar difference; momentum needs both magnitude and direction.

5. Scientific case

12. Write a structured explanation of how the array team can identify a strange-particle event. Include hadron families, quark content, conservation at production, decay by the weak interaction and why independent collaboration is needed before a new event is accepted. [5 marks]

Answer / mark points: A high-level response should state that baryons contain three quarks and mesons contain a quark-antiquark pair; identify strange content using s or $\bar{s}$; test charge, baryon number and strangeness at a strong-production vertex; explain that strange particles are produced in pairs so total strangeness is conserved; identify a later decay with $\Delta S = 0$, $+1$ or -1 as weak; and explain that large teams independently calibrate detectors, analyse data and validate or peer-review the claim. Award any five distinct, linked points.

Teacher prompt / common error: Precise answers separate strong production from weak decay and say what collaboration contributes to validation.

Language and method check

Award independent, creditworthy physics steps; do not award extra marks for repeated statements.
Accept equivalent methods when the physical reasoning, units and final precision remain consistent.