Level 3 Physics: Atoms – The Nucleus - Answers

In 2013, **AS 91525** replaced **AS 90522.** Prior to 2013, this was an external standard - AS90522 Atoms, Photons and Nuclei.

It is likely to be assessed using an internal test from 2013 onwards (although teachers can select from a range of assessment techniques). There were only minor changes to this existing material in the standard when it became AS91525 but also a number of additions including Relativity and some material on fundamental particles. The old external examinations may be useful revision for an internal test.

However, the mess that is NCEA Assessment Schedules….

For 90522 there was an Evidence column with the correct answer and Achieved, Merit and Excellence columns explaining the required level of performance to get that grade. Each part of the question (row in the Assessment Schedule) contributed a single grade in either Criteria 1 (Explain stuff) or Criteria 2 (Solve stuff). From 2003 to 2008, the NCEA shaded columns that were not relevant to that question (Sorry haven't had time to do 2004 yet).

Question	Evidence	Achievement	Merit	Excellence
2012(1) (a)(i)	Because it has most nucleons, ^{238}U has the highest total binding energy. Even though it has a smaller BE / n than Ca, Mn, Fe, Ni, Pb, the difference in BE / n is SMALL compared to the increase in number of nucleons.	[1] ^{238}U OR ^{62}Ni with indication of comparison to Fe. OR As Nickel has more nucleons / larger mass number (allow largest atomic mass / largest nucleus).	[1] As for achievement AND EITHER: As Uranium has the largest / most number of nucleons / largest mass number (allow largest atomic mass / largest nucleus. OR As Nickel has more nucleons / larger mass number than Fe. OR Shows calculations to support choice).	

(ii)	^{1}H has zero binding energy as it is a single proton When protons fuse to form larger nuclei, energy is released, as the strong force overcomes the electromagnetic repulsion between the protons (^{1}H nuclei). This releases energy as the fused nucleus is at a lower energy state (and therefore has less mass). This can be seen by the larger binding energy per nucleon of the fused nuclei. As seen in the diagram, there is a big difference in BE / n between small nuclei (left hand side), so an increase in mass number due to fusion will release a large amount of energy per nucleon involved in the fusion process. Since stars have a large amount of hydrogen and conditions (high temperature and pressure) which allow hydrogen fusion to occur, stars are able to produce a large amount of energy.	[1]Fusion releases energy OR H has zero BE / n. OR Stars produce energy by fusion. OR High BE / n means lower energy nucleons. OR Compares energy / BE / BE per nucleon or mass of products and reactants without link to fusion.	[1]Compares energy of products and reactants of fusion (accept combine / joining nuclei / nucleons): (Fused products have **higher** BE / n or BE, so energy is released. OR Fused products have **lower** mass / **lower** average mass per nucleon so energy is released. OR Fused products have higher BE / n or BE and so have moved to a lower energy state). OR Comments on size of energy released by fusion: (Difference in BE / n is **large** therefore **large** amount of energy released in fusion. OR Difference in mass per nucleon is **large** so **large** amount of energy released in fusion. OR **Large** amount of hydrogen / large number of reactions / fast rate of reactions therefore large amount of energy released in fusion).	

(iii)	Iron cannot release energy by fusion (or fission), because larger atoms have lower binding energy per nucleon and so energy is required to fuse Fe / Ni (or split Fe / Ni).	[1]Fe and Ni have **highest** BE / n. OR Fe and Ni have the **lowest** mass per nucleon. OR Energy **needed** for fusion / fission of Fe / Ni. OR Fe / Ni will not release energy during fission / fusion. OR Fe and Ni nuclei / nucleons in **lowest** energy state. OR Fe and Ni are the most stable nucleus / have most stable nucleons.	[1]LINKS Fe and Ni have **highest** BE / n. OR Fe and Ni have the **lowest** mass per nucleon. OR Fe and Ni nuclei in **lowest** energy state). AND (Energy **needed** for fusion / fission of Fe / Ni. OR Fe and Ni will not release energy during fission / fusion.	
(b)	$^{12}_{6}C + ^{12}_{6}C \rightarrow ^{20}_{10}Ne + ^{4}_{2}Ne$ $(12 \times 12.29 \times 10^{-13}\ J \times 2) \rightarrow$ $(20 \times 12.85 \times 10^{-13}\ J) + (4 \times 11.32 \times 10^{-13}\ J)$ $(294.96 \times 10^{-13}\ J) \rightarrow (302.28 \times 10^{-13}\ J)$ difference $= 7.28 \times 10^{-13}$ J = energy released $E = \Delta mc^2$ $\Delta m = \frac{E}{c^2} = \frac{7.32 \times 10^{-13}}{(3.0 \times 10^8)^2} = 8.13 \times 10^{-30}$ kg NOTE: missing $\times 10^{-13}$ is not a transcription error.	[2]Correct calculation of binding energy of 2 nuclides. OR Energy difference calculated without multiplying by number of nucleons (0.41×10^{-13}). OR Correct working for mass deficit for any energy difference	[2]Correct energy released OR Correct working for mass deficit but multiplying BE / n by number of protons or omitting $\times 10^{-13}$ OR Correct working with minor error (eg c instead of c^2, ONE incorrect rearranging)	

2011(1) (a)	$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{92}_{36}\mathrm{Kr} + {}^{141}_{56}\mathrm{Ba} + 3\,{}^{1}_{0}\mathrm{n}$ OR $^{235}_{92}\mathrm{U} \rightarrow {}^{92}_{36}\mathrm{Kr} + {}^{141}_{56}\mathrm{Ba} + 2\,{}^{1}_{0}\mathrm{n}$ 3 neutrons	[2]Equation with correct major products and reactants with mass numbers and atomic numbers balanced – mass # and atomic # is shown for all particles. [1]Neutron(s) or ${}^{1}_{0}$n and no other incorrect particle – allow γ – must be product side of the equation Allow incorrect name as long as symbol (including mass and atomic number) is correct		
(b)	$E = mc^2$ $\Rightarrow m = \dfrac{7.45\times10^{-16}}{(3.00\times10^{8})^2} = 8.28 \times 10^{-33}$ kg If this mass value is added to the rest mass of a neutron, the answer (to the same number of sf) does not change. OR The energy of the neutron's rest mass is $E = mc^2 = 1.6749\times10^{-27}\times\left(3\times10^{8}\right)^2 = 1.50741\times10^{-10}\,\mathrm{J}$ If this energy is added to the kinetic energy of the neutron, the answer doesn't change (to the same number of sf). OR The speed of the moving neutron is given by: $v = \sqrt{\dfrac{2E_K}{m_n}} = \sqrt{\dfrac{2\times7.45\times10^{-16}}{1.6749\times10^{-27}}} = 943189\ \mathrm{m\,s^{-1}}$ The speed is extremely low compared to the speed of light and only at speeds close to the speed of light does mass of the neutron become significant.	[2]Correct mass value (8.28×10^{-33} kg). OR Calculates the energy of the neutron's rest mass (1.507×10^{-10} J). OR Calculates speed (943 189 m s^{-1}).	[1] Correct reasoning.	

(c)	$E = hf$ and $E = \Delta mc^2$ $\Delta m = m_{reactants} - m_{products}$ $m_{reactants} = (390.2182 + 1.67\underline{\mathbf{49}}) \times 10^{-27}$ $m_{products} = (152.6167 + 233.9450 + 3 \times 1.67\underline{\mathbf{49}}) \times 10^{-27}$ $\Delta m = 3.067 \times 10^{-28}$ kg $E = \Delta mc^2 = 2.7603 \times 10^{-11}$ J $f = \frac{E}{h} = 4.1633 \times 10^{22} = 4.16 \times 10^{22}$ Hz	[2]Correct Δm OR Calculates E using correct method with incorrect mass.	[2]Correct E. OR Correct method with incorrect mass **deficit**, i.e. some attempt at subtraction of **products/reactants**. OR Correct method but doesn't multiply mass by c^2 to get Energy ($f = 4.63 \times 10^5$ Hz)	[2]Correct answer and working, e.g. missing neutrons etc. accepted.
(d)	total $p + n$ $= 92 \times 1.67\underline{\mathbf{26}} \times 10^{-27} + 143 \times 1.67\underline{\mathbf{49}} \times 10^{-27}$ $= 393.3899 \times 10^{-27}$ total mass deficit: $= 393.3899 \times 10^{-27} - 390.2182 \times 10^{-27}$ $= 3.1717 \times 10^{-27}$ kg $E = mc^2 = 3.1717 \times 10^{-27} \times (3.00 \times 10^8)^2$ $= 2.85453 \times 10^{-10} = 2.85 \times 10^{-10}$ J	[2]Correct mass deficit OR Energy calculated with incorrect mass deficit, ie some attempt at subtraction of masses.	[2]Correct answer and working Inclusion of the kinetic energy of the moving electron(s) accepted.	

(e)	**Binding energy** is the energy which must be supplied to separate the nucleus into its constituent nucleons (or is the energy released when the constituent nucleons are brought close enough together to form a nucleus). As work has to be done to separate the nucleons, their total energy increases and, accordingly, their mass will increase due to mass-energy equivalence. Therefore the combined mass of the nucleons in the nucleus is less than their combined mass when they are acting as separate particles.	[1] Answer shows understanding of binding energy OR mass equivalence.	[1] Answer shows understanding of binding energy AND mass equivalence.	
2010(3) (a)	$\Delta m = 66.34446 \times 10^{-27}$ $- 66.34121 \times 10^{-27}$ $- 0.000911 \times 10^{-27}$ $= 2.339 \times 10^{-30}$ kg $E = \Delta mc^2$ $E = 2.339 \times 10^{-30}\left(3.00 \times 10^8\right)^2$ $= 2.1 \times 10^{-13}$ J	[2]Correct mass deficit. $= 2.339 \times 10^{-30}$ kg	[2]Correct answer. $= 2.1 \times 10^{-13}$ J	

(b)	Binding energy is the energy required to completely separate the nucleons in a nucleus. Ca must be at a lower energy, because energy was given off when the reaction happened. So Ca must have a **greater** binding energy. Both nuclei have the same number of nucleons, so the Ca has the greater binding energy per nucleon. OR Fe is the most stable nucleus (A), and an excellence level explanation to compliment answer can gain full marks	[1]Recognition that Ca has a greater binding energy. OR correct definition of binding energy. OR that the nuclei have the same number of nucleons. OR Fe	[1]Correct definition of Binding energy + Recognition that Ca has the greater binding energy per nucleon because • more mass deficit • Ca has less mass • Ca is formed spontaneously • energy is given out.	[1]Ca has more binding energy, but same number of nucleons, so **more binding energy per nucleon.**
(c)	$E = \frac{hc}{\lambda} = \frac{6.626 \times 10^{-34} \times 3.00 \times 10^{8}}{8.5 \times 10^{-13}}$ $= 2.339 \times 10^{-13}$ J This is more than the energy release in the reaction so it can't have come from it. OR using Energy from part (a) to find λ (9.45×10^{-13}), and comparing λ (8.5×10^{-13})	[2]Correct calculation. [1]Correct answer can be used to demonstrate concept knowledge		
2009(3) (a)	When two or more nuclei join together to become a larger nucleus.	[1] Two nuclei join/fuse/bond/bind		

(b)	He-4 has a binding energy of 7.0 MeV per nucleon from the graph. He-4 has 4 nucleons. Binding energy of the nucleus = 4 × 7 = 28 MeV	[2] Shows 7 MeV per nucleon and 4 nucleons/2 protons and 2 neutrons		
(c)	Mass deficit = mass of constituent nucleons – mass of nuclei $= 1.672621 \times 10^{-27} + 1.674927 \times 10^{-27} - 3.343583 \times 10^{-27}$ $= 3.965 \times 10^{-30}$ kg	[2] Correct calculation shown		
(d)	$\Delta E = \Delta m c^2$ $\Delta E = 3.965 \times 10^{-30} \times (3 \times 10^8)^2$ $= 3.5685 \times 10^{-13}$ J BE per nucleon $= 3.57 \times 10^{-13} / 2$ $= 1.784 \times 10^{-13}$ J = 1.11 MeV so it matches the 1.1 on the graph.	[2] Correct binding energy with working (3.5685×10^{-13} J or 2230000 eV or 2.23 MeV)	[2] Correct binding energy per nucleon. (1.784×10^{-13} J or 1.11 MeV)	[2] Correct binding energy per nucleon in eV or MeV plus statement that it matches the graph.
2008(1) (a)	This is a **SHOW** question Total be $= [\Sigma m_{nucleons} - m_{nucleus}] \times c^2$ $= [61 \times m_p + (147 - 61) \times m_n - m_{Pm}] \times c^2$	[2] Correct Mass defect $= 2.167786 \times 10^{-27}$ kg [1] Correct answer shows concept knowledge.	[2] Correct binding energy $= 1.951007 \times 10^{-10}$ J.	[2] Correct binding energy per nucleon
(b)	mass deficit / defect	[1] Correct answer.		

(c)	This is a **SHOW** question $\Delta m = m_{\text{Nd-146}} + m_n - m_{\text{Nd-147}}$ $= (242.243122 + 1.674929 - 243.908613) \times 10^{-27}$ kg	[2]Complete valid method.		
(d)	$\Delta m = (243.908613 - 243.906111 - 0.000911939) \times 10^{-27}$ $= \mathbf{1.590061 \times 10^{-30}}$ $E = \Delta mc^2 = \mathbf{1.43105 \times 10^{-13}\ J}$ $E/e = 8.93293 \times 10^5 \quad = \mathbf{8.93 \times 10^5\ eV}$	[2]Correct Δm [1]*Correct answer (eV or J) shows concept knowledge.*	[2]*Correct energy in J.*	[2]Correct answer.
(e)	The decay products have less mass because energy has been released ($E = \Delta mc^2$). Pm-147 has a greater binding energy per nucleon than Nd-147, hence the decay leads to loss of energy.	[1]Energy has been released so mass is lost.	[1]Pm-147 has a greater binding energy per nucleon than Nd-147.	[1]Complete answer showing understanding and linkage of both concepts.
2007(1) (a)	$E = 4.78 \times 10^6 \times 1.6 \times 10^{-19}$ $= 7.648 \times 10^{-13}$ $\mathbf{= 7.6 \times 10^{-13}\ J}$	[2]Correct answer (working must be shown because they could work backwards from Δm in next question).		
(b)	$\Delta E = mc^2 \quad \Rightarrow m = \dfrac{7.648 \times 10^{-13}}{(3.00 \times 10^8)^2}$ $= 8.49778 \times 10^{-30} \quad = \mathbf{8.5 \times 10^{-30}}$	[2] Correct working [1] Answer rounded to 2sf, plus THREE answers given with a correct unit. (not including 1 (a) or (b))		

(c)	The nucleons in the product nuclei have lower energy than the nucleons in the reactant nuclei, which means that energy must be released. This energy is given off (in the form of heat and electromagnetic energy). As mass includes energy, a reduction of energy means a reduction of mass.	[1]Mass loss due to energy being released. (Do **not** accept mass is **changed** into energy.)	[1]Some idea of the lower energy of the nucleons meaning a lower mass. OR higher binding energy per nucleon means lower mass per nucleon.	[1]Explanation is clear and complete.
(d)	$8.49778 \times 10^{-30} =$ $2 \times m_C - (33.197 + 6.6465) \times 10^{-27}$ $\Rightarrow m_C = ½ \times (8.49778 \times 10^{-30} + 39.844 \times 10^{-27})$ $= 19.9260 \times 10^{-27}$ = **19.926×10^{-27} kg**		[2] Correct answer (Look out for 19.922 – Δm has not been included and 19.918 -Δm has been subtracted)	
(e)	Nuclear stability relates to how much energy (per nucleon) would be required to split a nucleus into its individual nucleons. The greater the energy needed, the more stable the nucleus. OR Nuclear stability relates to the binding energy per nucleon. The greater the binding energy per nucleon, the more stable the nucleus.	[1] Links nuclear stability to energy needed to split the nucleus **OR** to binding energy.	[1] Links nuclear stability to energy to remove nucleon from the nucleus **OR** to binding energy per nucleon.	
2006(1) (a)	$\Delta m = 3 \times p + 3 \times n - Li$ $= 3 \times 1.67353 \times 10^{-27} + 3 \times 1.67492 \times 10^{-27}$ $- 9.98835 \times 10^{-27} = 5.700 \times 10^{-29}$ kg	[2]Correct working.		

(b)	Total binding energy $E = \Delta mc^2$ $E = 5.700 \times 10^{-29} \times (3.00 \times 10^8)^2$ $= 5.13 \times 10^{-12}$ J Li has 6 nucleons so, per nucleon => $\frac{5.13 \times 10^{-12}}{6} = 8.55 \times 10^{-13}$ J	[2]Correct total binding energy.	[2]Correct answer.	
(c)	A higher binding energy per nucleon indicates a more stable nucleus.	[1]Correct idea.		
(d)	Mass of reactants = $3.34449 \times 10^{-27} + 5.00827 \times 10^{-27} = 8.35276 \times 10^{-27}$ kg Mass of products = $1.67492 \times 10^{-27} + 6.64648 \times 10^{-27} = 8.32140 \times 10^{-27}$ kg Mass deficit = $8.35276 \times 10^{-27} - 8.32140 \times 10^{-27} = 3.136 \times 10^{-29}$ kg $E = mc^2 = 3.136 \times 10^{-29} \times (3.00 \times 10^8)^2$ $= 2.82 \times 10^{-12}$ J		[2]Correct answer.	
(e)	Fusion requires two nuclei to combine. For this to happen they have to overcome the net repulsion between two nuclei. It is only at very high temperatures that the nuclei have enough energy to do this.	[1]Recognition that: high temperature produces high energy for nuclei to collide / net repulsion between nuclei must be overcome during fusion.	[1]High speed gives the large amount of energy required to overcome repulsion.	

2005(3) (a)	$396.92935 + 1.67493 = 398.60428$ $154.27837 + 235.64216 + 5 \times 1.67493$ $= 398.29468$ difference $= 0.3091 \times 10^{-27}$ kg $E = mc^2 = 0.3091 \times 10^{-27} \times 9.00 \times 10^{16}$ $= 2.7819 \times 10^{-11}$ J $= 1.74 \times 10^{8}$ eV		Correct mass difference or correct answer consistent with incorrect method of calculating mass difference.	Correct answer.
(b)	Total binding energy $= 1.4567 \times 10^{-29} \times 142$ $= 2.0685 \times 10^{-27}$ J	Correct answer.		
(c)	The binding energy per nucleon for plutonium is less than that for strontium and barium. This means that the nucleons in the plutonium nucleus are at higher energy levels than those in the nuclei of strontium and barium. This extra energy must be lost when the strontium and barium nuclei are formed. **OR** The binding energy per nucleon is the cause of the mass deficit per nucleon. As the number of nucleons is conserved and the products have a higher binding energy per nucleon, they also have greater mass deficit. The overall loss in mass is converted to kinetic energy and radiation.	*ONE correct and relevant statement:* nucleons in the plutonium nucleus have more energy than those in strontium and barium nuclei / higher binding energy per nucleon – less mass per nucleon.	Link made between the greater energy of the plutonium nucleons and the need to lose energy when barium and strontium are formed / link between binding energy per nucleon, mass deficit and energy change when Ba and Sr are formed.	Explanation is clear, concise and accurate. Ba and Sr higher binding energy nucleon – lower energy level nucleons – energy difference released on formation / Ba and Sr higher binding energy per nucleon – greater mass deficit hence mass lost on formation – mass loss converted to energy.