Name	Date started	Target end date

GCE A LEVEL — MASS-ENERGY & BINDING ENERGY QUESTION PACK

Legacy PH5 · New spec Unit 3 Topic 6a · A2 unit, 25% of A-level

REVISE
.wales

PHYSICS — UNIT 3 · MASS-ENERGY & BINDING ENERGY

3.6 Nuclear energy — mass-energy equivalence and binding energy

Einstein's $\Delta E = \Delta mc^2$, the atomic mass unit u, mass defect $\Delta m = Zm_p + Nm_n - M_{nuc}$, binding energy per nucleon, and the BE/A curve with its iron-56 peak.

NEW 2015 SPEC · UNIT 3 TOPIC 6A

Estimated time for entire question pack: ~56m

Derived from the legacy PH5 paper's pace of 120 marks in 1h 45m.

*You are advised to **not** attempt to complete all of this in one sitting.*

ABOUT THIS QUESTION PACK

This is a **comprehensive practice question pack**, not a single mock paper. It contains every question from the legacy WJEC PH5 papers (2008 modular spec) that maps onto new-spec Unit 3 Topic 6a (3.6).

Questions are ordered chronologically within each section.

INSTRUCTIONS

Use black ink or black ball-point pen. Answer all questions in the spaces provided.

The number of marks is given in brackets at the end of each question or part-question. A calculator is required. The Data Booklet is allowed.

For Examiner's use only

Q	Source	Max	Mark
1	WJEC PH5 June 2010 · A1	10	
2	PH5 Jun 11 Q5	9	
3	PH5 Jun 13 Q2	8	
4	PH5 Jun 16 Q2	13	
	Total	**40**	

Mass-Energy & Binding Energy — what the new spec asks

WJEC GCE A Level Physics (from 2015) · Unit 3: Oscillations & Nuclei · Topic 3.6.

Mass-energy equivalence A

- Einstein: $\Delta E = \Delta m\, c^2$ relates any mass change to its energy equivalent.
- Atomic mass unit: 1 u = 1.661×10^{-27} kg ≡ 931 MeV.

Mass defect A

- $\Delta m = Z\, m_p + N\, m_n - M_{nucleus}$.
- Always > 0 for a bound nucleus — energy must be supplied to disassemble it.

Binding energy A

- Total BE = $\Delta m\, c^2$; the energy needed to split a nucleus into separate nucleons.
- BE / nucleon = total BE / A — the headline stability indicator.

BE/A curve A

- Peaks near ^{56}Fe at ~8.8 MeV / nucleon.
- Energy is released whenever a reaction moves products closer to the iron peak.
- Compare BE/A before and after to find the Q-value.

Mass-Energy & Binding Energy in one page

Quick-reference notes — revisit before each section.

Mass-energy

Einstein's relation between energy and mass change.

1 u ≡ 931 MeV (one atomic mass unit's energy equivalent).

Atomic mass unit

1 u = &frac1;$_{12}$ mass of a ^{12}C atom.

1 u = 1.661×10^{-27} kg.

Mass defect

$\Delta m = Zm_p + Nm_n - M_{nucleus}$.

Always positive for a bound nucleus.

Binding energy

$BE = \Delta m\, c^2$.

BE / A = BE per nucleon.

Use BE / A to compare nuclear stabilities.

BE/A curve

Peaks near ^{56}Fe at ~8.8 MeV / nucleon.

Light nuclei: low BE/A ⇒ can fuse and release energy.

Heavy nuclei: lower BE/A than Fe ⇒ can split.

Q-value

Q = (sum of initial masses − sum of final masses) × c^2.

$Q > 0$ ⇒ energy released; $Q < 0$ ⇒ energy must be supplied.

Units of choice

Multiply mass-defect in u by 931 MeV to get energy.

Or convert to kg and multiply by c^2 in $m^2\, s^{-2}$.

Strategy

1. Add up nucleon masses ($Zm_p + Nm_n$).
2. Subtract nucleus mass.
3. Multiply × c^2 (or 931 MeV/u).
4. Divide by A for BE/nucleon.

Section index

Use this index to jump straight to the section you need.

End of cover material.

SECTION A

A1. *(a)* Calculate the binding energy **per nucleon** of ${}^{14}_{6}C$. [4]

(1u = 931MeV, $m_{neutron}$ = 1.008665u, m_{proton} = 1.007276u, mass of ${}^{14}_{6}C$ nucleus = 13.999950u).

....

....

....

....

The following reaction can be regarded as evidence for the existence of neutrinos (or an anti-neutrino in this case).

$$ {}^{14}_{6}C \longrightarrow {}^{14}_{7}N + {}^{0}_{-1}\beta^{-} + \overline{\nu}_e $$

The mass of the ${}^{14}_{6}C$ nucleus is 13.999950u and the mass of the ${}^{14}_{7}N$ nucleus is 13.999234u. The mass of the β^{-} particle is 0.000549u and the anti-neutrino ($\overline{\nu}_e$) has negligible mass.

(b) Calculate the energy released in this reaction (1u = 931MeV). [3]

....

....

....

....

The evidence for the existence of the anti-neutrino came from the (unexpected) wide variation of the energies of the β^{-} particles emitted. However, you should now ignore the existence of the anti-neutrino.

(c) Explain briefly, using conservation of momentum, which particle (${}^{14}_{7}N$ or β^{-}) receives most of the energy of the reaction. [3]

Before the reaction (stationary ${}^{14}_{6}C$) After the reaction

....

....

....

5. Americium-241($^{241}_{95}$Am) is an artificially made radioactive isotope and is commonly used in smoke detectors. It decays through emission of an α particle to neptunium (Np).

(a) Complete the following reaction equation by entering the appropriate numbers on the dotted lines. [2]

$$^{241}_{95}\text{Am} \longrightarrow \;^{\cdots\cdots}_{\cdots\cdots}\text{Np} \quad + \quad ^{\cdots\cdots}_{\cdots\cdots}\alpha$$

(b) Use the following data to calculate the energy released in the above reaction. [3]

mass of americium 241 nucleus = 241.00471 u mass of α particle = 4.00151 u,
mass of neptunium nucleus = 236.99712 u 1u = 931 MeV

....

....

....

....

....

(c) (i) Calculate the binding energy per nucleon of americium-241. [4]

mass of proton = 1.00728 u, mass of americium nucleus = 241.00471 u,
mass of neutron = 1.00866 u, 1u = 931 MeV

....

....

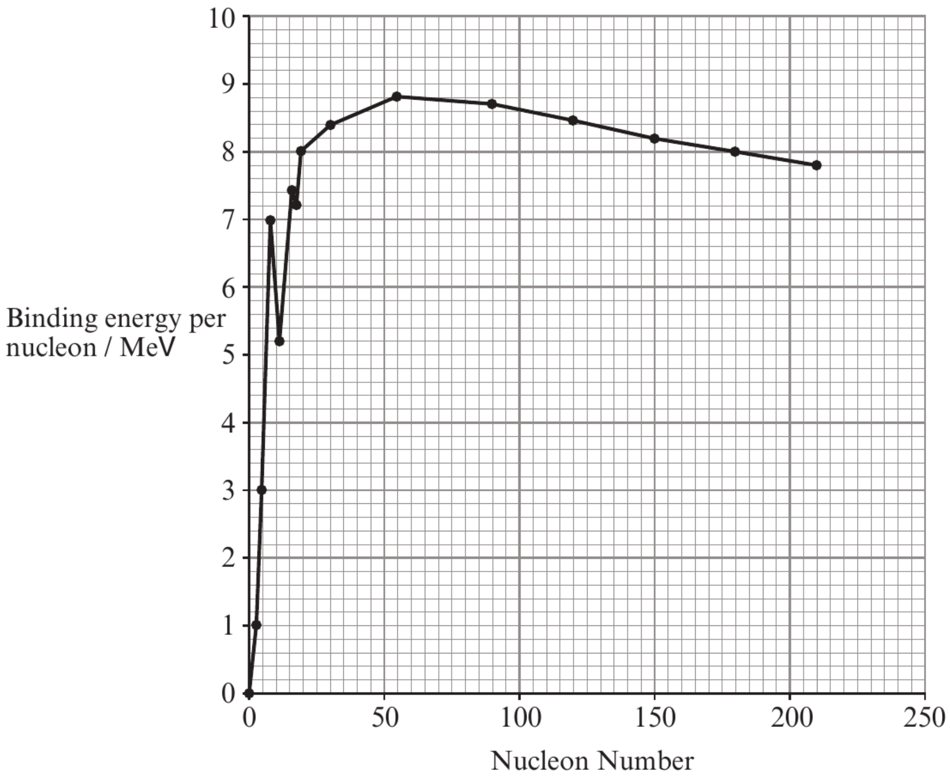
....

....

....

....

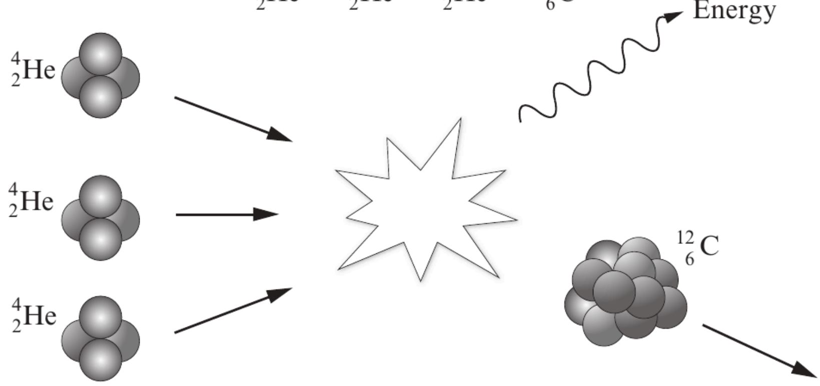
(ii) Plot your answer from *(c)*(i) on the graph below. [1]



Examiner only

2. The following fusion reaction can occur inside stars with core temperatures of around 100 million kelvin.

$${}^{4}_{2}He + {}^{4}_{2}He + {}^{4}_{2}He \rightarrow {}^{12}_{6}C$$



(a) Calculate the energy released in the above reaction from the following data. [3]

Mass of ${}^{4}_{2}He$ = 4.0026 u   Mass of ${}^{12}_{6}C$ = 12.0000 u   1 u = 931 MeV

....

....

....

....

....

....

Examiner only

(b) The isotope $^{62}_{28}Ni$ has a binding energy per nucleon of 8.795 MeV/nucleon and this is the highest known binding energy per nucleon.
Calculate the mass of a $^{62}_{28}Ni$ nucleus in unified atomic mass units (u) and give your answer to 5 significant figures. [5]

mass of proton = 1.00728 u, mass of neutron = 1.00866 u, 1u = 931 MeV

Examiner only

2. An oxygen fusion reaction that occurs in red supergiants is given below.

$$^{16}_{8}\mathrm{O} + ^{16}_{8}\mathrm{O} \rightarrow ^{28}_{14}\mathrm{Si} + ^{4}_{2}\mathrm{He} + 9.594\ \mathrm{MeV}$$

mass of $^{16}_{8}\mathrm{O}$ = 15.9905 u, mass of $^{4}_{2}\mathrm{He}$ = 4.0015 u

(a) Calculate the binding energy **per nucleon** of a $^{16}_{8}\mathrm{O}$ nucleus. [3]

mass of neutron = 1.0087 u, mass of proton = 1.0073 u, 1 u = 931 MeV

(b) Taking account of the energy released in the reaction, calculate the mass of a $^{28}_{14}\mathrm{Si}$ nucleus to 6 significant figures. [4]

Examiner only

(c) Explain without calculation, whether the total binding energy of $^{28}_{14}\mathrm{Si}$ and $^{4}_{2}\mathrm{He}$ is greater or less than that of two $^{16}_{8}\mathrm{O}$ nuclei. [3]

(d) The following nuclear reaction would release considerably more energy but cannot occur.

$$^{16}_{8}\mathrm{O} + {}^{16}_{8}\mathrm{O} \rightarrow {}^{32}_{16}\mathrm{S} + 16.5\ \mathrm{MeV}$$

Explain why this is impossible in terms of **simple conservation laws**. (Hint: consider the following set up.) [3]

END OF QUESTION PACK

4 questions · 40 marks · ~56m

Source: WJEC PH5 (2008 modular spec)

Curated for WJEC Physics 2015 spec A2 Unit 3 — Topic 6a (3.6)