Assessor's use only

QUESTION THREE: NUCLEAR REACTIONS IN THE SUN

Inside large stars, two carbon nuclei can fuse together to form magnesium.

$$^{12}_{6}C + ^{12}_{6}C \rightarrow ^{24}_{12}Mg$$

Information: Rest mass of a carbon–12 nucleus: $1.9921157 \times 10^{-26}$ kg
Rest mass of a magnesium nucleus: $3.9817469 \times 10^{-26}$ kg
Rest mass of a proton: 1.67353×10^{-27} kg
Rest mass of a neutron: 1.67492×10^{-27} kg

(a) Calculate the mass deficit when two carbon nuclei fuse together to make magnesium.

$\Delta m = 2m_c - m_{Mg}$

$= 2(1.9921157 \times 10^{-26} kg) - (3.9817469 \times 10^{-26} kg)$

$= 2.4845 \times 10^{-29} kg$

A/ correct value

if wrong possible replacement evidence calculating Δm in part (d).

A 2

(b) Explain why this reaction can occur in the centre of large stars, but does not occur with carbon atoms on earth.

Both carbon nuclei are positively charged, so they will electrically repel each other. To fuse them together, they need to be hit at high speed to overcome this repulsion. Therefore, for this reaction to occur, high temperatures are needed. These conditions occur inside stars, but not on Earth.

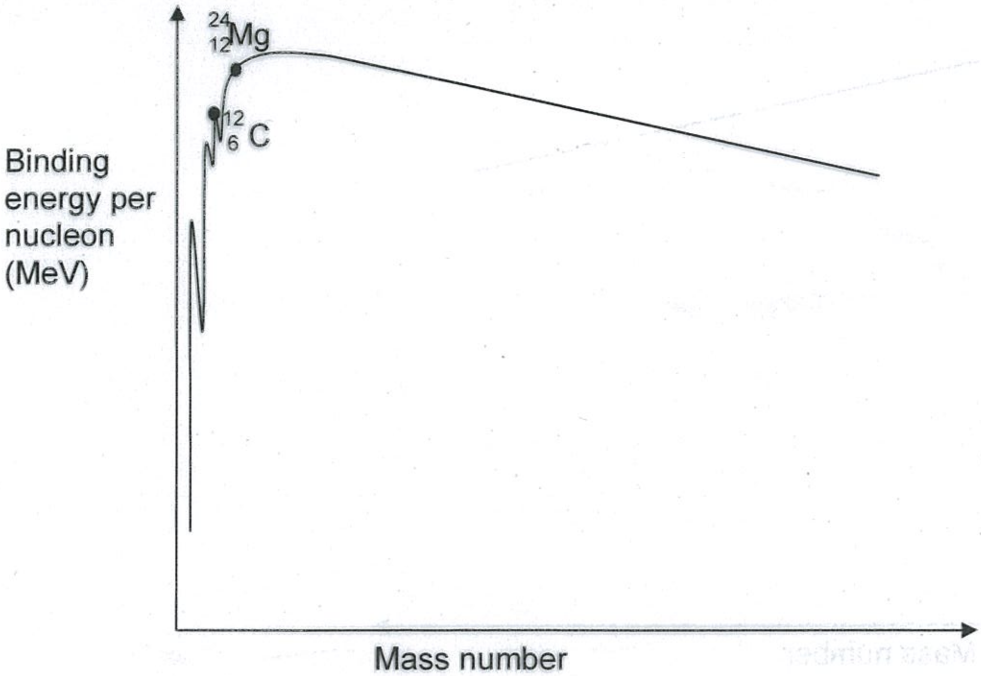
AME, 1

A/ IDEA of need to overcome repulsion, or need to hit at 'high speed'/'large E_K' to fuse

M/ Need to overcome repulsion linked to the need for high energy (OR) High energy/speed linked to the high temperature inside stars

E/ ... (AND) ...

The following sketch graph shows the binding energy per nucleon for the most common isotopes, with magnesium–24 and carbon–12 marked.



(c) Define binding energy.

The energy required to pull a nucleus apart into its nucleons

A/ (OR)

The energy released when a nucleus is formed by its nucleons

A₁

(d) Use the information at the start of this question to calculate the binding energy **per nucleon** of magnesium–24.

$\Delta m = 12m_p + 12m_n - m_{Mg}$

$\Delta m = 12(1.67353 + 1.67492) \times 10^{-27} kg - (3.9817469 \times 10^{-26} kg)$

$\Delta m = 3.63931 \times 10^{-28} kg$ A/ Δm (OR) BE correct

Binding Energy $= \Delta mc^2 = (3.63931 \times 10^{-28} kg)(3.00 \times 10^{8} ms^{-1})^2$

$BE = 3.27538 \times 10^{-11} J$

$BE/nucleon = \frac{(3.27538 \times 10^{-11} J)}{24 \text{ nucleons}} = 1.36474 \times 10^{-12} J$

$= 1.36 \times 10^{-12} J$ (3 s.f.)

M/ valid working and value

AM_2

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(e) Use the graph to decide which nucleus is the more stable, carbon–12 or magnesium–24. State why you made this choice.

A/ Binding energy per nucleon is a measure of the stability of the nucleus. Magnesium-24 has a higher binding energy per nucleon than carbon-12 (as shown on the graph), so magnesium-24 is more stable.

A₁

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NZIP 2009

QUESTION TWO: SOLAR ENERGY (THE MIGHTY ATOM)

The sun may be producing energy by what is termed the proton – proton cycle. Four hydrogen nuclei combine in a series of nuclear reactions to ultimately produce a helium nucleus (an α particle).

(a) What name describes the energy holding the nucleons together in a nucleus?

A/ Nuclear binding energy

A₁

The mass of a proton is 1.00753u and the mass of a helium nucleus is 4.00380u. (Atomic mass unit, u = 1.66×10^{-27} kg).

(b) Calculate the energy equivalent of a proton. Give your answer to the correct number of significant figures.

$E = mc^2$

$= (1.00753u \times 1.66 \times 10^{-27} \text{ kg/u})(3.00 \times 10^{8} \text{ ms}^{-1})^2$

$= 1.50525 \times 10^{-10}$ J A/ correct value

$= 1.51 \times 10^{-10}$ J ✓ (3 s.f.)

A/ 3 sig. fig. (and) correct units in two other questions

A₂ A₁

(c) Calculate the mass of hydrogen that must be converted to helium per second in the sun, if the energy radiated from it is 3.820×10^{26} J s^{-1}.

mass deficit = [mass nucleons] – [mass of helium]

$\Delta m = [4 \times 1.00753u] - [4.00380u]$

$\Delta m = 0.02632u$ A/ correct Δm

Energy released per four proton (hydrogen) conversion

$\Delta E = mc^2$

$= (0.02632u \times 1.66 \times 10^{-27} \text{ kg/u})(3.00 \times 10^{8} \text{ ms}^{-1})^2$

$= 3.932208 \times 10^{-12}$ J

M/ correct number of 4 proton events

Total energy radiated = (Energy released converting four hydrogen) × (No. of four hydrogen events)

Each second, 3.820×10^{26} J $= (3.932208 \times 10^{-12}$ J$) \times$ (number of protons in sets of four)

number of protons $= 4 \times 9.71464 \times 10^{37}$

total mass of protons (hydrogen) $= (4 \times 9.71464 \times 10^{37}$ protons$) \times (1.00753u \times 1.66 \times 10^{-27}$ kg/u$)$

$= 6.49910 \times 10^{11}$

$= 6.50 \times 10^{11}$ kg ✓ (3 s.f.) E/ correct value

AME₂

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In a reaction similar to that in a hydrogen bomb a deuterium atom with kinetic energy of 3.525×10^{-12}J collides with a tritium atom at rest. The reaction produces a neutron with kinetic energy of 4.200×10^{-13} J and an atom of helium with kinetic energy of 5.895×10^{-12}J.

(d) What principle other than mass number and atomic number conservation, governs this reaction?

A/ 'mass - energy' conservation

A1

kinetic contribution — rest mass

(e) The rest masses of an atom of deuterium, helium and tritium are 3.3434×10^{-27}, 6.6443×10^{-27} and 5.0066×10^{-27} kg respectively. Calculate the rest mass of the neutron. The particle speeds are such that you can ignore any relativistic effects.

rest mass

$$[\text{deuterium } {}^2_1H] + [\text{tritium } {}^3_1H] \rightarrow [\text{helium } {}^4_2He] + [\text{neutron } {}^1_0n]$$

$$\left[3.3434\times10^{-27}\text{kg} + \left(\frac{3.525\times10^{-12}\text{J}}{(3.00\times10^{8}\text{ms}^{-1})^2}\right)\right] + \left[5.0066\times10^{-27}\text{kg}\right] \rightarrow$$

A/ correct reactant (or) product masses.

$$\left[6.6443\times10^{-27}\text{kg} + \left(\frac{5.895\times10^{-12}\text{J}}{3.00\times10^{8}\text{ms}^{-1\,2}}\right)\right] + \left[m_{neutron} + \left(\frac{4.200\times10^{-13}\text{J}}{3.00\times10^{8}\text{ms}^{-1\,2}}\right)\right]$$

solve for, $m = 1.6747\times10^{-27}$ kg or 1.67×10^{-27} kg (3 s.f.) ✓ M/ correct value

AM2

(f) Explain why large nuclei with high mass numbers are likely to be less stable than relatively smaller nuclei.

A/ The stability of a nuclei depends on its binding energy.

M/ So nuclei that have higher 'binding energy per nucleon' are more stable.

E/ The binding energy per nucleon of a nuclei is a measure of the amount of energy required per nucleon to break the nucleus apart. This means that the greater the binding energy the greater the energy needed to break it up and hence the more stable the nucleus. So large nuclei with high mass numbers will have lower binding energy and be less stable.

AME1

NZIP 2008

QUESTION THREE: NUCLEAR PHYSICS

The nucleus of a bromine atom is $^{81}_{35}\mathrm{Br}$

Mass of a proton = 1.0073 u
Mass of a neutron = 1.0087 u
Mass of a bromine nucleus = 80.8971 u
1 u = 1.660×10^{-27} kg.
Speed of electromagnetic energy = 3.00×10^{8} m s^{-1}.

(a) Show that the mass deficit in forming the bromine nucleus from its component particles is 1.259×10^{-27} kg.

mass deficit, Δm = [components: protons + neutrons] − [nucleus]

$\Delta m = [(35 \times 1.0073u) + (46 \times 1.0087u)] - [80.8971u]$

$= 81.6557 - 80.8971$

A✓ $= 0.7586\,u$ correct Δm in a.m.u.'s

$\Delta m = (0.7586u) \times (1.660 \times 10^{-27}\,kg/u)$

M✓ $= 1.259 \times 10^{-27}$ kg (4 s.f.) valid working ANSWER given in question AM₂

(b) Calculate the binding energy per nucleon for a bromine nucleus.

$E_{total} = \Delta mc^2$

$= (1.259 \times 10^{-27}\,kg)(3.00 \times 10^{8}\,ms^{-1})^2$

A✓ $= 1.1331 \times 10^{-10}$ J correct total binding energy

Energy per nucleon $= (1.1331 \times 10^{-10}\,J)/(81\text{ nucleons})$

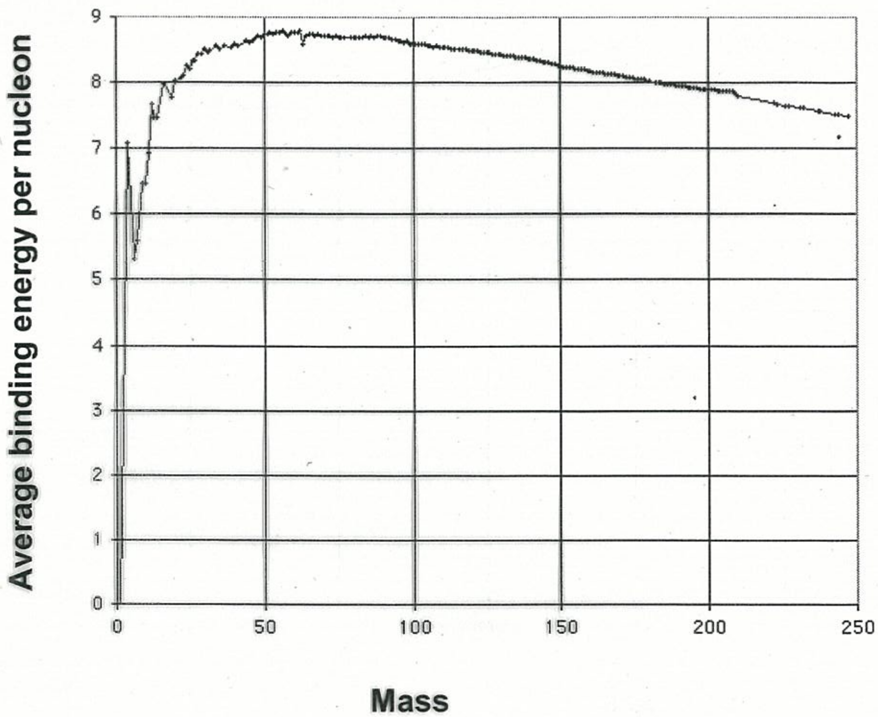
M✓ $= 1.3988 \times 10^{-12}$ J correct value

binding energy per nucleon = ____________________

Assessor's use only

The graph below shows the binding energy per nucleon of nuclei against their mass numbers.

A tin nucleus is ${}^{120}_{50}\mathrm{Sn}$ and the bromine nucleus is ${}^{81}_{35}\mathrm{Br}$.



(c) Use information from the above graph to explain the relative stability of a tin nucleus compared with a bromine nucleus.

A/ The stability of a nucleus is related to the 'binding energy per nucleon'.

M/ The mass number of tin is 120 and that of Bromine is 81. From the graph, the nucleus of Sn has a lower value for the binding energy per nucleon than that of Br. A nucleus of lower value binding energy per nucleon needs less energy to separate it nucleons. So Sn nucleus needs less energy and so is less stable than a Br nucleus.

E/ Clear correct explanation

AME,