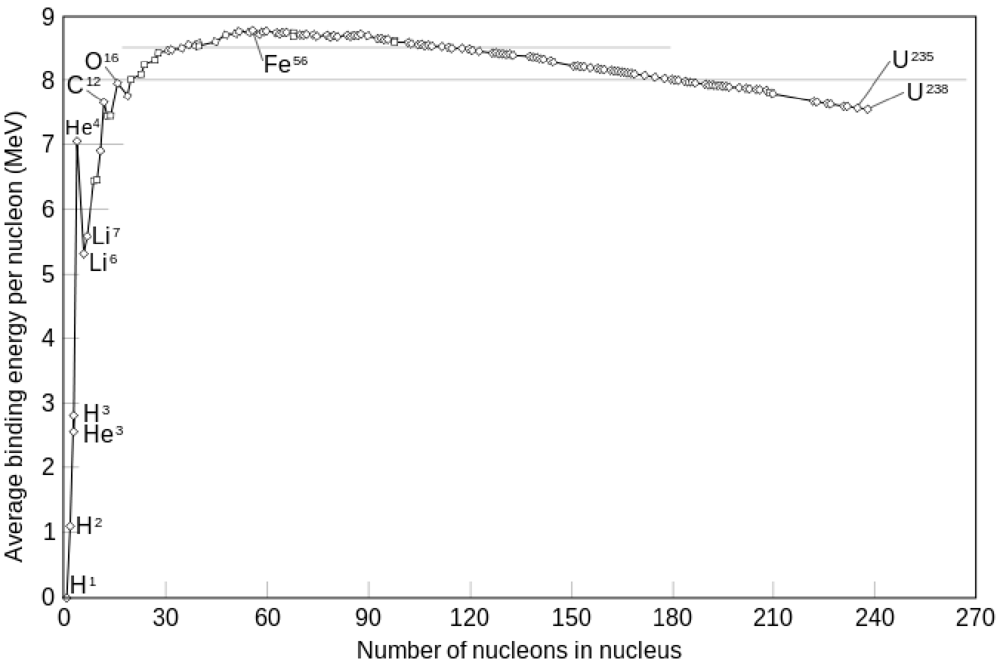
ATOMS: NUCLEUS QUESTIONS

ENERGY FROM STARS (2012;1)

Nuclide	Binding energy per nucleon ($\times 10^{-13}$ J)
^{2}H	1.78
^{4}He	11.32
^{12}C	12.29
^{14}N	11.96
^{16}O	12.76
^{19}F	12.45
^{20}Ne	12.85
^{23}Na	12.98
^{40}Ca	13.68
^{55}Mn	14.02
^{58}Fe	14.07
^{62}Ni	14.07
^{206}Pb	12.60
^{238}U	12.25



(a) Use the information in the table and the graph to answer the following questions.

i. In the above list, nickel and iron have the highest binding energy *per nucleon*. Explain which nuclide on the list has the highest total binding energy.

ii. Explain how stars, which are composed mostly of ^{1}H, can release huge amounts of energy.

iii. If a star reaches a stage where it has formed a core rich in iron and nickel, it suddenly stops 'burning'. Explain why this happens.

(b) When a star has used up much of its 1H and 4He, it begins 'carbon burning'. One of the reactions to occur is

$$^{12}_{6}\text{C} + {}^{12}_{6}\text{C} \rightarrow {}^{20}_{10}\text{Ne} + {}^{4}_{2}\text{He}$$

Calculate the energy released in this reaction, and hence determine the mass deficit in the reaction.

NUCLEAR PHYSICS (2011;1)

Rest mass values:

Neutron	1.6749×10^{-27} kg
Proton	1.6726×10^{-27} kg
Uranium-235 nucleus	390.2182×10^{-27} kg
Krypton-92 nucleus	152.6167×10^{-27} kg
Barium-141 nucleus	233.9450×10^{-27} kg

Fission reactions take place in a nuclear reactor when moving neutrons hit Uranium-235 nuclei.

In one of the possible fission reactions, one neutron hits a nucleus and breaks it into Krypton-92 and Barium-141.

(a) Write a nuclear equation for the reaction, and name the other particles produced during the reaction.
(b) If the moving neutron has kinetic energy 7.45×10^{-16} J, show that this energy contributes negligible mass to the mass of the moving neutron.
(c) If all the energy released from the fission of one U-235 nucleus is converted to a single photon, calculate the frequency of the photon produced.
(d) Calculate the total binding energy of a uranium-235 nucleus
(e) Explain, in terms of binding energy, why the mass of a uranium-235 nucleus is less than the total mass of its constituent nucleons.

RADIOACTIVE DECAY (2010;3)

The Earth's interior is heated by radioactive decay. One of the nuclei which is responsible is a potassium isotope, K-40. This has several possible decay routes, one of which is:

$$^{40}_{19}\text{K} \rightarrow \, ^{40}_{20}\text{Ca} + \, ^{0}_{-1}e + \bar{\nu}_e$$

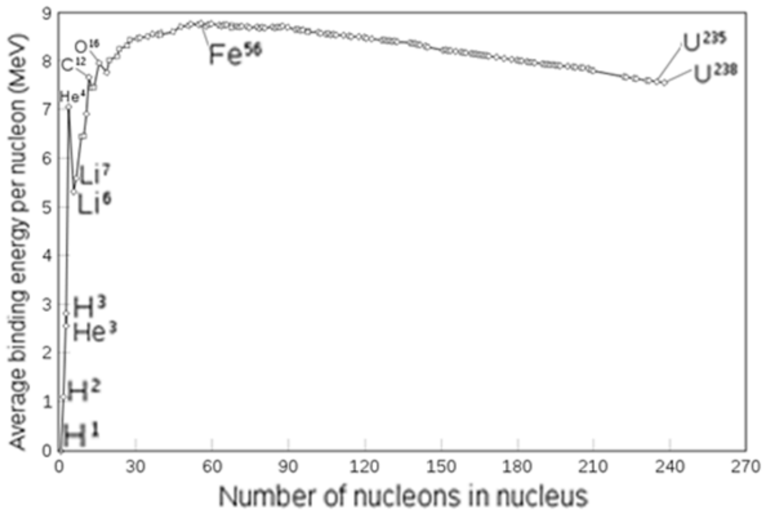
This reaction occurs spontaneously in the K-40. The energy released by the mass deficit in one event is 2.1×10^{-13} J. Masses are as follows:

Nucleus of K-40	$^{40}_{19}\text{K}$	66.34446×10^{-27} kg
Nucleus of Ca-40	$^{40}_{20}\text{Ca}$	66.34121×10^{-27} kg
electron	$^{0}_{-1}e$	0.000911×10^{-27} kg
antineutrino	$\bar{\nu}_e$	zero

(a) Use the information above to calculate the mass deficit for the nuclear reaction shown, and hence show that the energy released by this mass is 2.1×10^{-13} J.
(b) Explain which nucleus has the greatest binding energy per nucleon. Your answer should include an explanation of the term binding energy.
(c) Gamma rays with a wavelength of 8.5×10^{-13} m are also emitted from K-40. Show that they cannot come from this reaction.

ENERGY FROM STARS (2009;3)

Speed of light = 3.00×10^{8} ms^{-1}



Stars emit a huge amount of energy from nuclear fusion reactions.

(a) State the meaning of the term nuclear fusion.

When stars first form, they are composed almost entirely of hydrogen.'Hydrogen burning' converts hydrogen-1 (H^1_1) into helium-4 (He^4_2) in a complex series of reactions.

(b) Using the information from the graph, show that 28 MeV is released when one nucleus forms from its constituent nucleons. Explain your reasoning.

(c) Using the table below, show that the mass deficit when hydrogen-2 (H^2_1) is formed from its constituent nucleons, is 3.965×10^{-30} kg.

Mass of a proton	1.672621×10^{-27} kg
Mass of a neutron	1.674927×10^{-27} kg
Mass of a nucleus of hydrogen-2	3.343583×10^{-27} kg

(d) Calculate the binding energy per nucleon for hydrogen-2 and compare your answer with the value from the graph above.

NUCLEAR REACTIONS (2008;1)

Nuclear rest mass data	
Electron:	$9.11\,939 \times 10^{-31}$ kg
Proton:	$1.672\,623 \times 10^{-27}$ kg
Neutron:	$1.674\,929 \times 10^{-27}$ kg
Promethium-147:	$243.906\,111 \times 10^{-27}$ kg
Neodymium-146:	$242.243\,122 \times 10^{-27}$ kg
Neodymium-147:	$243.908\,613 \times 10^{-27}$ kg
Speed of light	3.00×10^{8} m s^{-1}
Charge on an electron	1.602×10^{-19} C

The radiated energy of the substance promethium-147 can be used on the hands of luminous watches to produce light. Promethium-147 is not a naturally occurring substance. It is made by bombarding neodymium-146 with neutrons to produce neodymium-147, which then decays to promethium-147.

(a) Show that the binding energy per nucleon of promethium-147 ($^{147}_{61}\mathrm{Pm}$) is 1.3 x 10^{-12} J.

The nuclear equation for the bombardment of a neodymium-146 nucleus with a neutron is:

$$^{146}_{60}\mathrm{Nd} + {}^{1}_{0}n \rightarrow {}^{147}_{60}\mathrm{Nd}$$

(b) The mass of a nucleus of Nd-147 is less than the total mass of a Nd-146 nucleus plus a neutron.

(c) State the term to describe this apparent loss of mass.

(d) Show that the 'missing mass' in this reaction is 9.438 x 10^{-30} kg.

The second reaction is the radioactive decay of $^{147}_{60}\mathrm{Nd}$ (neodymium-147) to $^{147}_{61}\mathrm{Pm}$ (promethium-147)

$$^{147}_{60}\mathrm{Nd} \rightarrow {}^{147}_{61}\mathrm{Pm} + {}^{0}_{-1}e$$

(e) Calculate the energy released during this reaction. Express your answer in electron volts.

(f) By considering both energy and binding energy per nucleon of Nd-147 and Pm-147, explain why a neodymium-147 nucleus has more mass than its decay products.

STELLAR NUCLEO-SYNTHESIS (2007;1)

The nuclei of many heavy elements are produced in stars in a process called stellar nucleo-synthesis.

Speed of light	$= 3.00 \times 10^{8}$ m s^{-1}
Charge on the electron	$= 1.6 \times 10^{-19}$ C
Nuclear rest masses	
Neon-20	$= 33.197 \times 10^{-27}$ kg
Helium-4	$= 6.6465 \times 10^{-27}$ kg

In one reaction in the carbon-fusion stage, two carbon-12 nuclei fuse to create neon. This is shown below.

$$\mathrm{C}^{12} + \mathrm{C}^{12} \rightarrow \mathrm{Ne}^{20} + \mathrm{He}^{4}$$

(a) Approximately 4.78 MeV of energy is released. Convert 4.78 MeV into joules. Show your working. in this reaction.

(b)

(i) Show that the mass lost during this reaction has an unrounded value of 8.4978×10^{-30} kg.

(ii) Round this answer to the correct number of significant figures.

(c) Explain why mass is lost during this reaction.

(d) Calculate the mass of a carbon-12 nucleus.

(e) Oxygen-16 is also produced in fusion reactions. The oxygen-16 nucleus is more stable than the carbon-12 nucleus. What is meant by nuclear stability?

NUCLEAR REACTIONS (2006;1)

Mass of nuclei:

neutron:	1.67492×10^{-27} kg
proton:	1.67353×10^{-27} kg
deuterium:	3.34449×10^{-27} kg
tritium:	5.00827×10^{-27} kg
helium-4:	6.64648×10^{-27} kg
lithium-6:	9.98835×10^{-27} kg

Speed of light = 3.00×10^{8} m s^{-1}

Three bottles of water and some rocks can provide, in theory, enough energy for a family for one year.

The water and rocks can be used to obtain the raw materials for a thermonuclear reaction that can take place between deuterium and tritium.

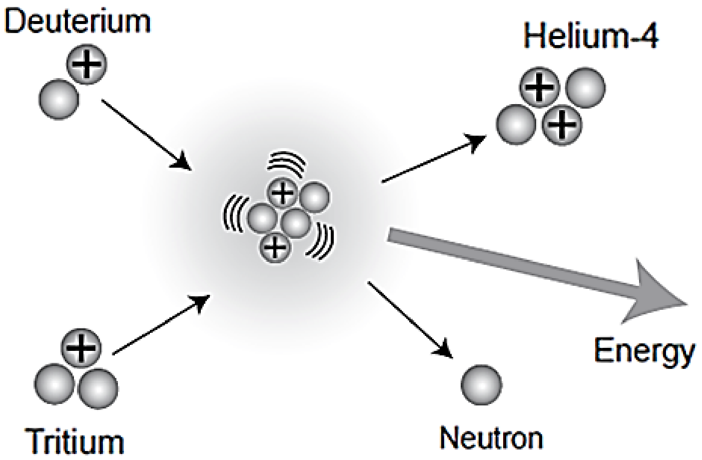
Tritium can be made from lithium $^{6}_{3}Li$, which can be extracted from the rocks'

(a) Show that the mass deficit of a lithium nucleus is 5.700×10^{-29} kg.

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

(c) State how the binding energy per nucleon can indicate the stability of a nucleus.

Deuterium (hydrogen-2) can be extracted from the water. Thermonuclear reactors heat a mixture of deuterium and tritium to 100 million degrees Celsius to produce the reaction illustrated below.



(d) Calculate the amount of energy produced in this reaction.
(e) Explain why it is necessary for the temperature to be so high for this reaction to occur.

ENERGY FROM A NUCLEAR REACTOR (2005;3)

Plutonium (Pu) is used as a fuel in a nuclear reactor to generate large amounts of energy. The following equation shows a fission reaction of plutonium that releases energy.

$$^{239}_{94}Pu + ^{1}_{0}n \rightarrow ^{142}_{56}Ba + ^{93}_{38}Sr + 5\,^{1}_{0}n$$

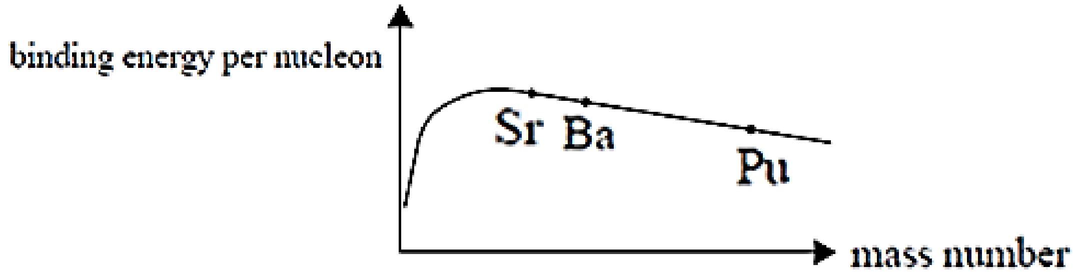
The rest masses of the particles involved are:

239 plutonium:	$396.92935 \times 10^{-27}$ kg
142 barium:	$235.64216 \times 10^{-27}$ kg
93 strontium:	$154.27837 \times 10^{-27}$ kg
neutron:	1.67493×10^{-27} kg

(a) Calculate the amount of energy, in electron volts (eV), generated in this reaction.

(b) If the binding energy per nucleon of the barium isotope $^{142}_{56}Ba$ is 1.4567×10^{-29} J, calculate the total binding energy of this nucleus.

The diagram below shows a sketch graph of average binding energy per nucleon against mass number for the elements in the nuclear reaction given.



(c) Using the graph, explain why energy is generated in this nuclear reaction.

QUESTION ONE (2004;1)

Use the following information when answering this question:

Nuclear rest masses:	deuteron	$^{2}_{1}H$	is 3.3436×10^{-27} kg
	helion	$^{3}_{2}He$	is 5.0064×10^{-27} kg
	alpha particle	$^{4}_{2}He$	is 6.6447×10^{-27} kg
	proton	$^{1}_{1}p$	is 1.6726×10^{-27} kg
	neutron	$^{1}_{0}n$	is 1.6749×10^{-27} kg
	electron	e^{-1}	is 0.000911×10^{-27} kg

Speed of light = 3.00×10^{8} m s^{-1}
The size of the charge on an electron = 1.60×10^{-19} C
Planck's constant = 6.63×10^{-34} J s

(a) Name the type of nuclear reaction that takes place in the Sun.

The reaction is a multi-step process. One of these steps is: $^{2}_{1}H + ^{1}_{1}p \rightarrow ^{3}_{2}He + \gamma$

(b) Show that the mass equivalent of the gamma photon is 9.8 x 10^{-30} kg.
(c) Calculate the energy of the gamma photon in electron volts.

The multi-step process is equivalent to the following single process:

$$4^{1}_{1}p + 2e^{-} \rightarrow ^{4}_{2}He + 2v + 6\gamma$$

v is a neutrino and each one carries 4.005 x 10^{-14} J of energy.

(d) Calculate the average frequency of the gamma radiation produced.

(e) The deuteron $^{2}_{1}H$ comprises one proton and one neutron

(i) Calculate the mass deficit of the deuteron.
(ii) Explain why there is a mass deficit.