Worksheet answers

- The questions on this worksheet involve the calculation of mass defect, binding energy and binding energy per nucleon.

1. Complete the following calculations to find the mass defect, binding energy and binding energy per nucleon of helium.

mass of a neutral helium atom	4.002 604 u
mass of a proton	1.007 276 u
mass of a neutron	1.008 665 u
mass of an electron	0.000 549 u

Start by totalling the individual masses of protons, neutrons and electrons in a neutral helium atom that contains two protons, two neutrons and two electrons.

particle	mass (u) x number		
protons	1.007 276 x 2	=	2.014 552
neutrons	1.008 665 x 2	=	2.017 330
electrons	0.000 549 x 2	=	0.001 098
total mass		=	4.032 980 u

The mass of the neutral helium atom = 4.002 604 u

- Calculate the mass defect by subtracting the mass of neutral helium atom from the total mass of the individual particles.

Mass defect (u) = 4.032 980 – 4.002 604 = 0.030 376 u

- Convert the mass defect into kilograms using the conversion factor 1 u = 1.6605×10^{-27} kg.

Mass defect (kg) = $0.030\,376 \times (1.6605 \times 10^{-27})$ = 5.044×10^{-29} kg

- Using Einstein's famous equation $E = m\,c^2$, convert this mass into binding energy.

Binding energy (J) = $5.044 \times 10^{-29} \times (3.00 \times 10^{8})^2$ = 4.54×10^{-12} J

- Helium has four nucleons (two protons and two neutrons). Calculate the binding energy per nucleon.

Binding energy per nucleon = $4.54 \times 10^{-12} / 4$ = 1.14×10^{-12} J per nucleon

- Convert this to MeV per nucleon using the conversion: 1MeV = 1.6×10^{-13} J

For helium:

Binding energy (MeV) = $4.54 \times 10^{-12} / 1.6 \times 10^{-13}$ = 28.4 MeV

Binding energy per nucleon = 28.4 / 4 = 7.1 MeV per nucleon

2. When the nucleus of a uranium-235 atom is divided into two smaller nuclei, mass is converted into energy. Where does this energy originate?

   The energy originates from the difference in binding energy between a uranium-235 nucleus and its fission products.

3. Boron undergoes fission via thermal neutron capture to produce lithium-7, an alpha particle and energy in the reaction $n + {}^{10}_{5}B \rightarrow {}^{7}_{3}Li + {}^{4}_{2}He$. Using the data below, calculate the mass defect (in u and kg) and binding energy (in J and MeV) for this reaction.

mass of a neutral boron-10 atom	10.012 939 u
mass of a neutral lithium-7 atom	7.016 005 u
mass of a neutral helium-4 atom	4.002 603 u
mass of a neutron	1.008 665 u

Mass of $n + {}^{10}_{5}B$	= 1.008 665 + 10.012 939	= 11.021 604 u
Mass of ${}^{7}_{3}Li + {}^{4}_{2}He$	= 7.016 005 + 4.002 603	= 11.018 608 u
Mass defect	= 11.021 604 – 11.018 608	= 0.002 996 u
	= 0.002 996 x (1.6605 x 10^{-27})	= 4.975 x 10^{-30} kg
Binding energy	= 4.975 x 10^{-30} x (3.00 x 10^{8})^{2}	= 4.478 x 10^{-13} J
	= 4.478 x 10^{-13} / 1.6 x 10^{-13}	= 2.80 MeV

4. Thorium-228 undergoes fission according to the equation ${}^{228}_{90}Th \rightarrow {}^{224}_{88}Ra + {}^{4}_{2}He$. Use the data below to calculate the mass defect and binding energy for this reaction.

mass of a neutral thorium-228 atom	228.028 73 u
mass of a neutral radium-224 atom	224.020 20 u
mass of a neutral helium-4 atom	4.002 60 u
mass of an electron	0.000 55 u

Mass of neutral ${}^{228}_{90}Th$ atom		= 228.028 73 u
Mass of ${}^{224}_{88}Ra + {}^{4}_{2}He$ nuclei	= 224.020 20 + 4.002 60	= 228.022 80 u
Mass defect	= 228.028 73 – 228.022 80	= 0.005 93 u
	= 0.005 93 x (1.6605 x 10^{-27})	= 9.847 x 10^{-30} kg
Binding energy	= 9.847 x 10^{-30} x (3.00 x 10^{8})^{2}	= 8.862 x 10^{-13} J
	= 8.862 x 10^{-13} / 1.6 x 10^{-13}	= 5.54 MeV