CHEM1612 Worksheet 13: The Nuclear Atom

Model 1: The Atomic Symbol

The atomic symbol, *X*, is used to identify the element to which an atom belongs and the number of electrons, protons and neutrons it contains:

$$^{A}_{Z}X$$

number of protons = number of electrons = atomic number = Z

number of neutrons = mass number - number of protons = A - Z

Critical thinking questions

1. How many electrons, protons and neutrons are there in each of the species below?

	species	number of electrons	number of protons	number of neutrons
(a)	$^{24}_{12}Mg$			
(b)	$^{26}_{12}Mg$			
(c)	$^{79}_{35}Br$			

2. Alpha and beta particles and gamma rays are important in radioactive decay. What are the charges and masses of the species below?

	species	charge	mass
(a)	alpha particle: α or $^{4}_{2}He$		
(b)	high speed electron $^{0}_{-1}\beta$		
(c)	positron β or $^{0}_{+1}\beta$		
(d)	gamma rays: $^{0}_{0}\gamma$		

3. The three subatomic particles (the electron, proton and neutron) contain only one type of particle so the overall charge is not added to the symbol. What are the masses and charges of these particles?

	species	charge	mass
(a)	$^{0}_{-1}e$ (electron)		
(b)	$^{1}_{1}p$ (proton)		
(c)	$^{1}_{0}n$ (neutron)		

Model 2: Radioactive Decay

A nuclide is a particular nuclear species with a specified number of protons and neutrons. The 6 most important ways in which radioactive nuclides decay are:

(a) α decay: the nucleus loses an α particle ($^{4}_{2}He^{2+}$)
(b) $_{-1}\beta$ decay: a neutron in the nucleus is converted into a proton and an electron. The electron is ejected from the nucleus.
(c) Positron or β emission: a proton in the nucleus is converted into a neutron and a positron. The positron is ejected from the nucleus.
(d) Electron capture: the nucleus captures an electron. This reacts with a proton in the nucleus to produce a neutron.
(e) Neutron emission: loss of a neutron.
(f) Gamma or γ decay: emission of high energy photons. This often accompanies the other decay mechanisms.

Critical thinking questions

1. For each of the decay routes, complete the table below showing the effect on the nucleus.

	type of decay	change in number of neutrons (N)	change in number of protons (Z)
(a)	α decay	*reduced by 2*	*reduced by 2*
(b)	$_{-1}\beta$ decay		
(c)	β emission		
(d)	electron capture		
(e)	neutron emission		
(f)	γ decay		

2. What nucleus is produced when the following nuclear decays occur?

   (a) $^{238}_{92}U$ undergoes α decay:

   (b) $^{14}_{6}C$ undergoes $_{-1}\beta$ decay:

   (c) $^{11}_{6}C$ undergoes β emission:

   (d) $^{55}_{26}Fe$ undergoes electron capture:

   (e) $^{13}_{4}Be$ emits a neutron:

   (f) $^{99m}_{43}Tc$ undergoes γ decay:

3. By first working out the number of neutrons (N) and the number of protons (Z) before and after the nuclear decays in question 2, what is the effect of the decay on the mass number and on the ratio N / Z?

	type of decay	change in mass number	change in N / Z
(a)	α decay		
(b)	$_{-1}\beta$ decay		
(c)	β emission		
(d)	electron capture		
(e)	neutron emission		
(f)	γ decay		

Model 3: Predicting the Mode of Decay

The figure on the next page shows a plot of the number of neutrons (N) *vs* the number of protons (Z) for *stable* nuclides. A key factor in determining stability is the N / Z ratio. The nuclides form a narrow **band of stability**:

- very few stable nuclides exist with $N / Z < 1$
- for light nuclide ($Z \leq 20$), $N / Z \approx 1$
- The N / Z ratio of stable nuclides gradually increases as Z increases with $N / Z = 1.15$ for $^{56}_{26}Fe$, $N / Z = 1.28$ for $^{107}_{47}Ag$ and $N / Z = 1.49$ for $^{184}_{74}W$.
- All nuclides with $Z > 83$ are unstable.

An unstable nuclide generally decays in a mode that shifts its N / Z ratio towards the band of stability.

Critical thinking questions

1. Why is $^{75}_{33}As$ much more stable than $^{66}_{33}As$?

2. Nuclides *above* the band of stability in the figure have a N / Z ratio which is too high. Using your answer to question 3 in Model 2, which of the 6 modes of decay might such a nuclide undergo? Fill in your answer in the box on the figure below.

3. Nuclides *below* the band of stability in the figure have a N / Z ratio which is too low. Using your answer to question 3 in Model 2, which of the 6 modes of decay might such a nuclide undergo? Fill in your answer in the box on the figure below.

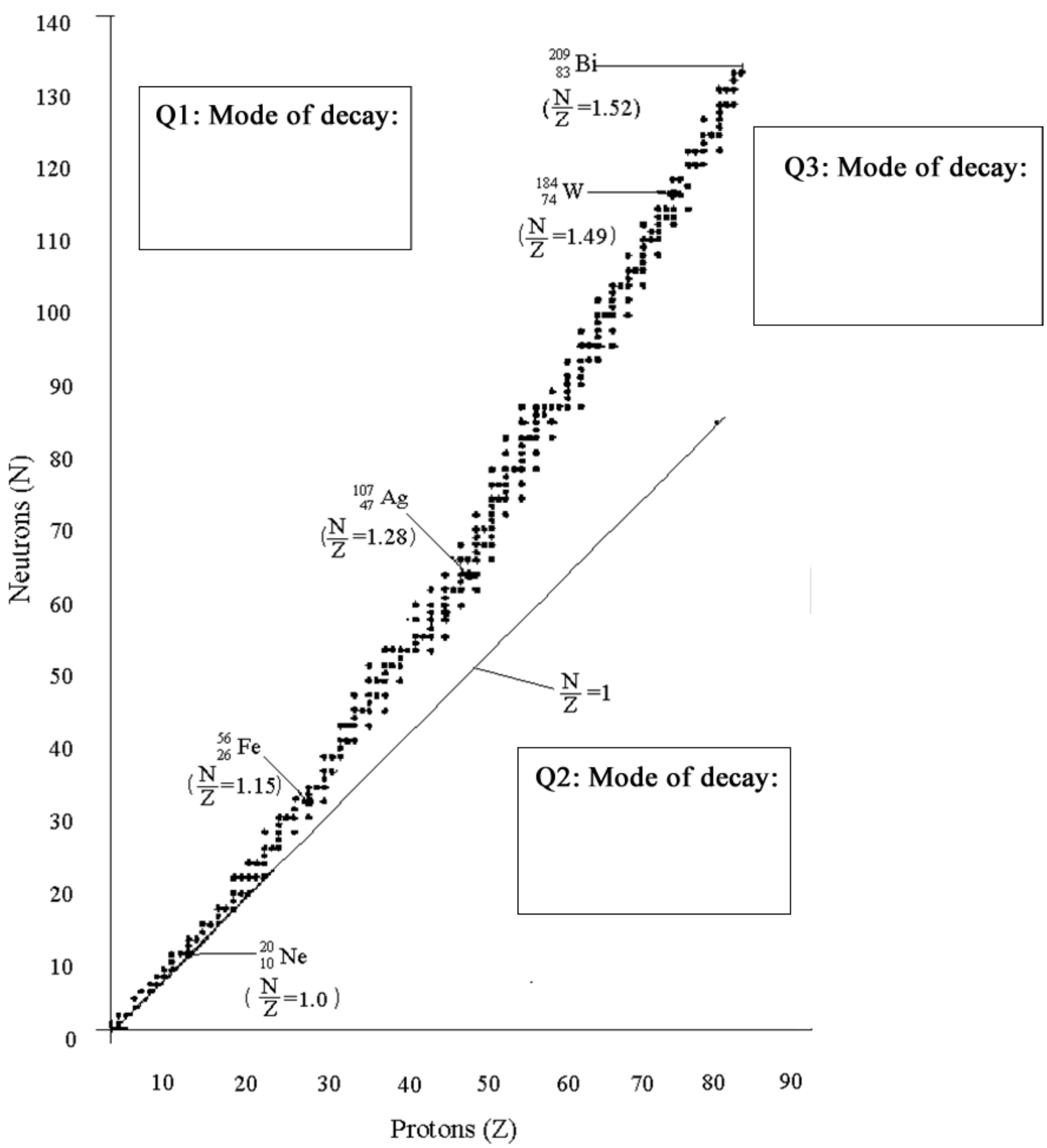
4. Nuclides with $Z > 83$ are beyond the band of stability and are unstable. Using your answer to question 3 in Model 2, which of the 6 modes of decay might such a nuclide undergo? Fill in your answer in the box on the figure below.

5. For each of the following radioactive nuclides, calculate their N / Z ratios and hence predict the mode(s) of nuclear decay they are likely to undergo.

   (a) $^{12}_{5}B$

   (b) $^{234}_{92}U$

   (c) $^{127}_{57}La$



Model 4: The Rate of Radioactive Decay

The number of radioactive nuclei decaying per unit time is proportional to the number present. If the initial number present is N_0 and the the number remaining at time t is N_t then:

$$\ln\frac{N_t}{N_o} = -\lambda t \qquad \text{where } \lambda \text{ is the decay constant (units s}^{-1}\text{).}$$

Critical thinking questions

1. The half life, $t_{1/2}$, is the time taken for the number of radioactive nuclei to halve. By setting $N_t = N_0 / 2$, express $t_{1/2}$ in terms of λ.

2. Lucas Heights in Sydney makes many radioactive isotopes for medical applications in Australia and overseas. ^{131}I is used in treating thyroid cancers and in imaging. It has a half life of 8.02 days.

   (a) What is the decay constant for ^{131}I?

   (b) If 2.0 mg of ^{131}I is needed for a medical procedure, what mass of the isotope would be required to be able to use it exactly 2 days later?

3. On the 6th April 2011, after the earthquake and tsunami in Japan, levels of ^{131}I in seawater were recorded as 2.5×10^6 times the legal limit.

   How long will it take the initially sampled seawater to fall back to its legal limit?