Unit 3 Atomic Theory
Nuclear Chemistry Worksheet

Name ___________________
Block ____

Model 1: 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) β^- 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)	β^- 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 β^- 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 1, 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)	β^- decay		
(c)	β^+ emission		
(d)	electron capture		
(e)	neutron emission		
(f)	γ decay		

Model 2: Predicting the Mode of Decay

Figure 1 on the next page shows a plot of the number of neutrons (*N*) *vs* the number of protons (*Z*) for *stable* nuclides. Clearly, 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 ($Z \leq 10$), $N / Z \approx 1$
- 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 $Z > 82$ are unstable.

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

Critical thinking questions

4. Why is $^{31}_{15}$P much more stable than $^{30}_{15}$P ?

5. Nuclides *above* the band of stability in the figure 1 have a *N* / *Z* ratio which is too high. Using your answer to question 3, which of the 6 modes of decay might such a nuclide undergo to approach the band of stability? Fill in your answer in the box on the figure overleaf.

6. Nuclides *below* the band of stability in the figure 1 have a *N* / *Z* ratio which is too low. Using your answer to question 3, which of the 6 modes of decay might such a nuclide undergo to approach the band of stability? Fill in your answer in the box on the figure overleaf.

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

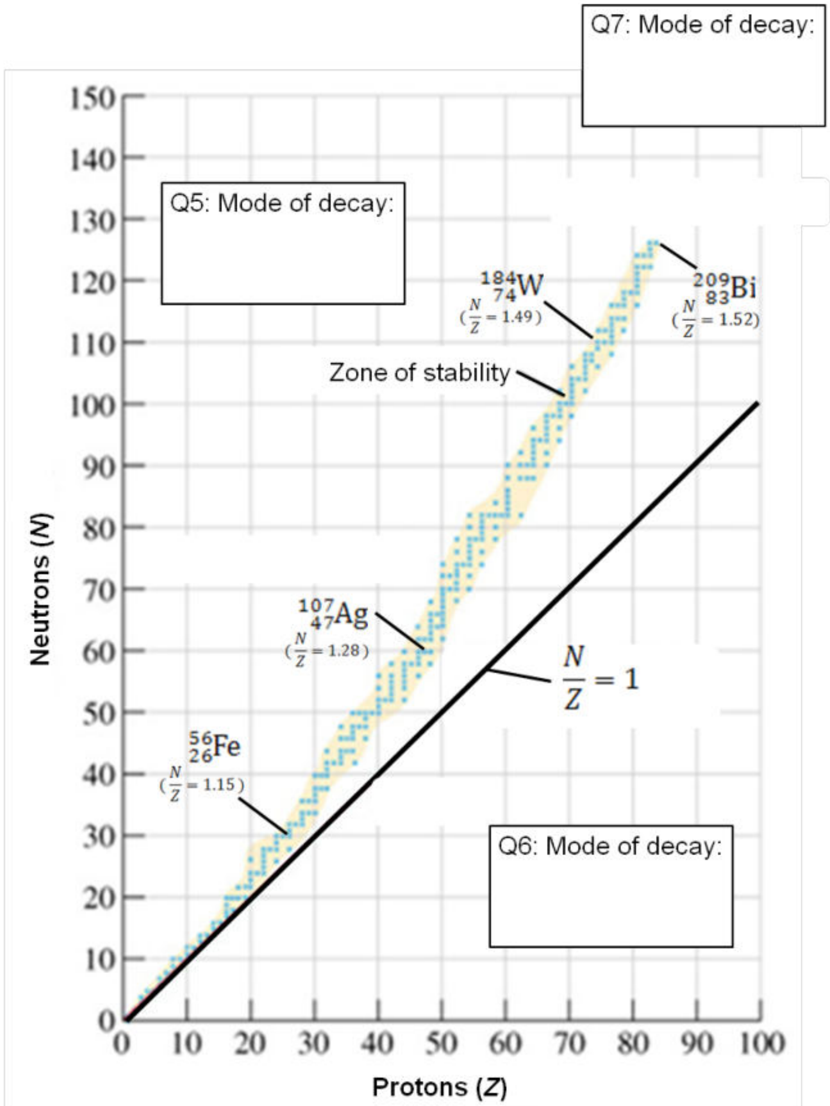


Figure 1. Plot of the number of neutrons (*N*) *vs* the number of protons (*Z*) for the stable nuclides.

8. Sketch each of the following nuclides on figure 1, calculate their N / Z ratios and hence predict their stability. For the unstable (radioactive) nuclides, predict the mode(s) of nuclear decay they are likely to undergo.

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

(b) $^{153}_{63}Eu$

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

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

Model 3: Calculating radioactive decay and half life, $t_{1/2}$ and activity

Radioactive isotopes undergo exponential decay as described by the following equation:

$$N_{(t)} = N_0 e^{-kt} \qquad (1)$$

The half life of a given radioisotope is the time required for half of the original number of nuclei (N_0) to decay (i.e. the time after which half of the original sample remains). Half-life can be described by the following equation:

$$t_{1/2} = \frac{ln2}{k} \qquad (2)$$

The activity of a radioactive sample is the number of disintegrations it undergoes per second. It depends on the number of particles present.

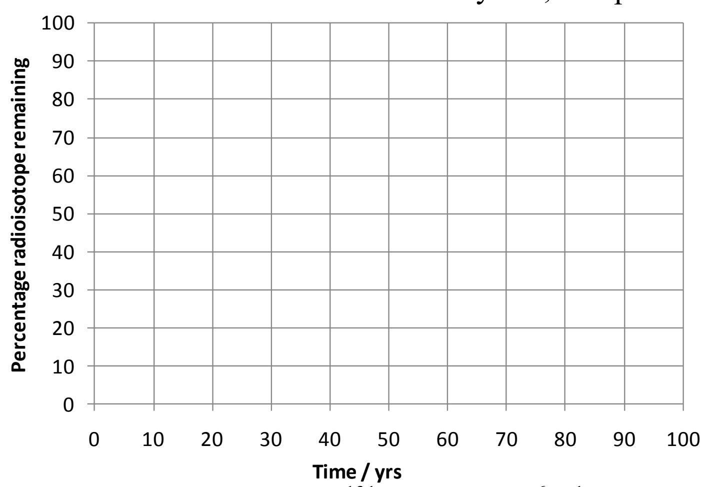
$$A = \mathrm{k}\,N \qquad (3)$$

Critical thinking questions

9. What does each symbol in equation 1 mean? What are the SI units of each symbol?

10. What does each symbol in equation 2 mean? What are the SI units of each symbol?

11. If a radionuclide has a half life of 10 years, complete the graph below:



12. The decay constant (k) for ^{131}I is $1.0 \times 10^{-6}\ s^{-1}$. Calculate the half-life of ^{131}I in seconds, and in days.

13. What does each symbol in equation 3 mean? What are the SI units of each symbol?

14. What is the value of N when calculating molar activity, A_M?

15. A 10.0 mg sample of ^{201}Tl has an activity of 7.9×10^{13} Bq. What is the decay constant for ^{201}Tl? What is the half-life of ^{201}Tl, in seconds?