Welcome to our module on Nuclear Chemistry

In this module, we will explore the changes that nuclei undergo and its chemical consequences. You will learn how to balance nuclear equations in compliance with conservation rules, and be able to differentiate modes of nuclear decay. Furthermore, you will solve problems involving binding enegies and you should be able to relate it to its possibility of being an energy source. Lastly, this module classified remarkable radiosiotopes and how it transformed medical diagnosis, treatment, and research.

Learning Outcomes:

At the end of the module, you should be able to:

1. write, balance, and interpret equations for nuclear reactions;
2. distinguish among various modes of nuclear decay, including alpha decay, beta decay, positron emission, and electron capture.;
3. solve the binding energies of nuclei and the energy changes of nuclear reactions using Einstein's equation;
4. explain how both nuclear fission and fusion processes can be highly exothermic and their potential as energy sources; and
5. discuss how radioisotopes can be used in medical imaging techniques and other fields.

In this module, you are recommended to have:

- Desktop, laptop or mobile phone to view this file; and
- Steady internet access to participate in our online class discussion through Google Meet (this will be streamed through Facebook Live so you'll be able to watch it for future reference).

You are also expected to:

- Read the entire module as it may help you to answer several self-assessments, activities or quizzes at the end of this lesson.
- Accomplish the self-assessments on your own. It is designed to gauge your understanding of the lesson and it will not be recorded. If you have any clarifications, you may contact me through our Google Classroom.

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Content:

Nuclear Reactions

If changes occur within atomic nuclei, nuclear reaction takes place. Just like in the previous lesson, nuclear reactions should be written in an equation to better understand how it works. The target nucleus and bombarding particle are represented on the left side of the equation, and the product nucleus and ejected particle on the right side. Certain rules may also apply in writing nuclear equations:

Balancing Nuclear Reactions

1. Conservation of mass number (A)

The quanitity of protons and neutrons in the product must be equal to the amount of protons and neutrons in the reactant.

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{138}_{55}\text{Cs} + ^{96}_{37}\text{Rb} + 2\,^{1}_{0}\text{n}$$

$$235 + 1 = 138 + 96 + (2 \times 1)$$

2. Conservation of atomic number (Z)

The amount of atomic number in the product must equate to the quanitity of atomic number in the reactant.

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{138}_{55}\text{Cs} + ^{96}_{37}\text{Rb} + 2\,^{1}_{0}\text{n}$$

$$92 + 0 = 55 + 37 + (2 \times 0)$$

Radioactivity

A nuclei which changes in structure and emits radiation is known as radioactive. The process in which unstable isotopes decay is called radioactivity. To predict the identity of the product nucleus, you should take note how the atomic number and mass number change when the target nucleus ejects a particle. An illustration below summarizes the various decay types and its corresponding radiation emitted. It also shows how to use nuclear equations to identify 'daughter' nuclei and the figure which represents it.

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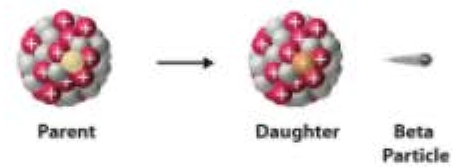
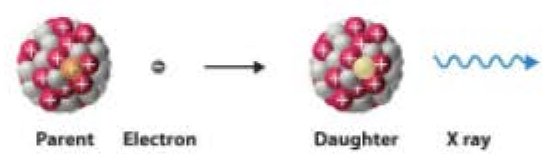
Decay Type	Radiation Emitted	Generic Equation	Model
Alpha decay	${}^{4}_{2}\alpha$	${}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}X' + {}^{4}_{2}\alpha$	
Beta decay	${}^{0}_{-1}\beta$	${}^{A}_{Z}X \longrightarrow {}_{Z+1}^{A}X' + {}^{0}_{-1}\beta$	
Positron emission	${}^{0}_{+1}\beta$	${}^{A}_{Z}X \longrightarrow {}_{Z-1}^{A}X' + {}^{0}_{+1}\beta$	
Electron capture	X rays	${}^{A}_{Z}X + {}^{0}_{-1}e \longrightarrow {}_{Z-1}^{A}X' + \text{X ray}$	

Source: chemwiki.ucdavis.edu

Nuclear Binding Energy

The energy needed to separate a nucleus into its constituent particles is called binding energy. Alternately, it can also be described as the energy that would be released when individual protons and neutrons form into a nucleus. More stable nuclei tend to have higher binding energy.

Let's have ${}^{4}_{2}$He (Helium-4) as an example:

Mass of Helium-4 atom (experimentally observed)	**Mass of individual atoms which constitutes Helium-4**
4.002603 u	p = 1.007825 u p = 1.007825 u n= 1.008665 u n= 1.008665 u 4.032980 u

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$$\begin{array}{r} 4.032980 \text{ u} \\ \underline{-\ 4.002603 \text{ u}} \\ 0.030377 \text{ u} \end{array}$$

The difference (Δm) of 0.030377 u is called mass defect. According to Einstein's equation, $E=mc^2$, the calculated missing mass has been converted into binding energy. By substituting the mass defect (convert atomic mass unit to kilograms, 1u = 1.66054 x 10^{-27} kg) and speed of light (c) in the equation, we'll get:

$$E=\Delta mc^2$$

$$E=0.030377u\left(\frac{1.66054\,x\,10^{-27}\,kg}{u}\right)\left(\frac{2.99792\,x\,10^8\,m}{s}\right)^2$$

$$E=4.5335\,x\,10^{-12}\frac{kg\cdot m^2}{s^2}$$

$$E = 4.5335 \times 10^{-12} \text{ Joules}$$

But we have to compute for the energy released per Helium-4 atom, therefore:

$$E = (4.5335 \times 10^{-12} \text{ Joules})\left(\frac{6.02214\,x\,10^{23}}{mole}\right)$$

$$E = \frac{2.7301\,x\,10^9\,J}{mole}$$

This value is slightly less than the energy released by a 1-ton TNT explosion. This energy is far more greater than burning the same amount of fuel that is why it is considered as an alternative source of energy by some.

Radioisotopes

Some of the most beneficial results of utilizing radioactive nuclei is in the field of industry and many areas of basic and applied research. A table below provides a list of the radioisotopes and their corresponding uses.

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Isotope	Use (diagnostic purposes)	Isotope	Use
$^{11}_{6}C$	Brain scan (Positron Emission Tomography)	$^{133}_{54}Xe$	Lung imaging
$^{24}_{11}Na$	Circulatory disorders	$^{201}_{81}Tl$	Heart disorders
$^{32}_{15}P$	Detection of eye tumors	Strontium-87	Study of bone growth
$^{59}_{26}Fe$	Anemia	Cobalt-60	Destroy tumors
$^{67}_{31}Ga$	Scan for lung tumors, abscesses	Neutron bombardment (induced radioactivity)	Archaeology
$^{75}_{34}Se$	Pancreas scan	Americium-241	Used in smoke alarms
$^{99}_{43}Tc$	Imaging of brain, liver, kidneys, bone marrow		

References:

Brown, L. & Holme T. (2011). *Chemistry for Engineering Students (2nd ed.).* Belmont, CA: Brooks/Cole.

Masterton, W.L., Hurley, C.N. & Neth, E.J. (2012). Chemistry: Principles and Reactions (7th ed.). Belmont, CA: Brooks/Cole.

Atkins, P. & Jones, L. (2010). *Chemical Principles: The Quest for Insight. 5th Ed.* W.H. Freeman and Company. New York

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