Unit 10: Nuclear Chemistry

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Honors Chemistry

Unit Learning Objectives: By the end of the unit students will be able to…

(1) Write the nuclide symbol for a given isotope.
(2) Describe alpha, beta, and gamma radiation and give the appropriate symbol for each
(3) Define a transmutation and state what types of radiation can lead to a transmutation.
(4) Define penetrating power and rank alpha, beta, and gamma radiation according to their strength.
(5) Complete nuclear reactions including those involving alpha, beta, or gamma radiations as well as neutrons and protons.
(6) Define half life.
(7) Perform calculations involving half-life in order to solve for mass, time, original mass, and half life.
(8) Describe the factors effecting nuclear stability including binding energy, band of stability, and magic numbers.
(9) Calculate the binding energy for a given isotope. Name the isotope with the highest binding energy. Define fission and fusion and classify a nuclear reaction as either a fission or fusion reaction.
(10) Determine if a given isotope is found on the band of stability and use this to predict if it will be stable/non radioactive or unstable/radioactive.
(11) Describe some of the main applications of nuclear chemistry including nuclear energy, nuclear medicine, and radioactive data.

Monday	Tuesday	Wednesday	Thursday	Friday
Mar 7 What's going on in a nucleus? Nuclear Radiation	**8** Nuclear Reactions	**9** Half-Life	**10** Half-Life **OPEN HOUSE!**	**11** Radioisotope Dating and Half Life Lab
14 Nuclear Stability	**15** Applications of Nuclear Chemistry Nuclear Power Plants	**16** Applications of Nuclear Chemistry Nuclear Bombs	**17** **Unit 10 Test** **HW packet Due**	**18** Spring Rally Finish Nuclear Videos

Happy Spring Break!

Nuclear Chemistry: ____

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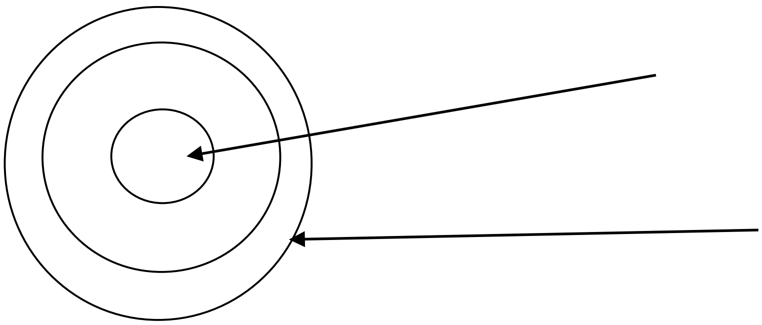
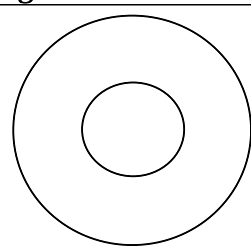
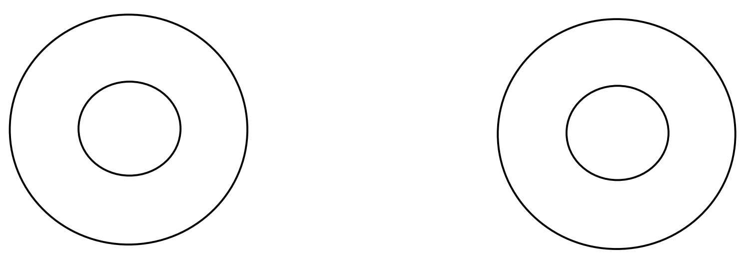
What is going on in the nucleus of an atom?
Review: Parts of an atom



Did you notice that even though the protons in the nucleus have the same charge(positive) and it is known that like charges repel each other, that the protons are able to be crammed together into the nucleus! How is this possible?

	What's happening?	**Diagram**
1.	Proton has 2 force fields	
2.	When 2 protons come within the proximity of each other they REPEL!	 Protons repel each other due to what force? _______________
3.	But if 2 protons can be accelerated toward each other at high speeds then…	Then the nuclear force over powers the repulsive magnetic fields and allows the protons to stick together! This process occurs naturally in stars.

		We can also do this in labs with machines called ____________ ____________.
4.	Neutrons have no magnetic field but they do have a nuclear force field.	This allows neutrons to stick together and to not repel each other! Neutrons stabilize the nucleus by spreading the protons apart—magnetic repulsion decreases exponentially with distance! But--- there is still repulsion because there is a lot of energy stored in the nucleus, where the protons are constantly battling these two forces.

Nuclear Radiation
The nucleus of certain isotopes is unstable. These isotopes are called ____________________________.
These isotopes can emit RADIATION!

Nuclide Symbol- A nuclide symbol gives the mass and the number of protons for a given isotope of an atom.

Ex**.** The nuclide symbol for radium-228 is

Ex. Write the nuclide symbol for chlorine-37

There are three main types of Radiation.

Type of Radiation	Symbol	Notes	Example
Alpha		Alpha radiation produces an alpha particle, which has the same structure as a helium nucleus	
Beta		Beta radiation produces a beta particle, which has the same structure as an electron. In the nucleus, a neutron changes into a proton and an electron	
Gamma		Gamma radiation does not give off a particle, instead high energy radiation is given off in the form of electromagnetic waves. An “excited” element gives off gamma radiation and returns to the “ground” state.	

Video: Acute Radiation Syndrome

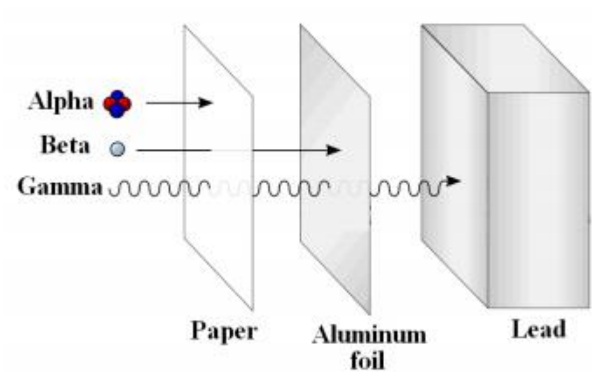
1. What is a rad?

2. What is acute radiation syndrome?

3. What are some effects of ARS on the body? (List three)

Penetrating Power: describes the strength of each form of nuclear radiation.

- Alpha particles: ____
- Beta Particles: ____
- Gamma Rays: ____



Other subatomic particles can also be involved in nuclear reactions.

Proton = $^{1}_{1}H$ Neutron = $^{1}_{0}n$

Nuclear Reactions: Nuclear reactions affect the nucleus of an atom. <u>In a nuclear reaction, the mass and the number of protons must be equal on both sides of the reaction.</u>

Transmutation: ____

____

Types of Nuclear Reactions:

1. **Alpha Decay:**

2. **Beta Decay**

3. **Fusion**: This is what happens in stars and particle accelerators! Two smaller Nuclei will collide with enough energy to stick together and form a larger nucleus.

4. **Fission**: This is what happens in bombs and nuclear power plants. A large nucleus splits into two smaller "daughter nucleus" and 1-5 neutrons.

Chain Reaction: ____

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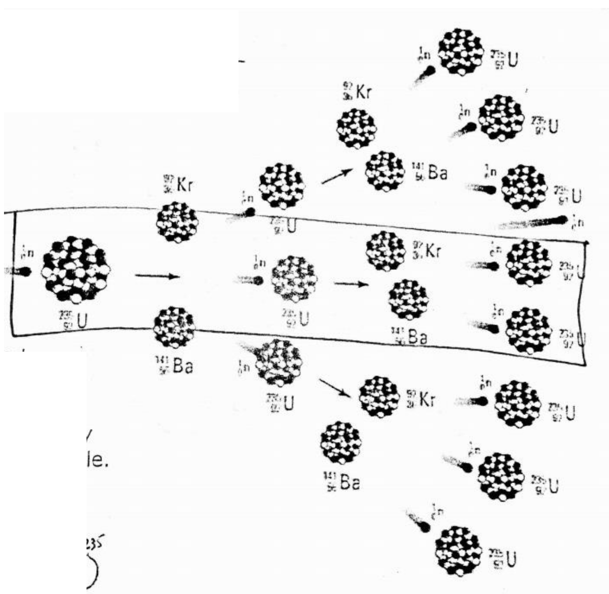


An ________________________________ fission chain reaction will create a __________.
The chain reaction can be controlled by various substances that are cable of absorbing some of the neutrons release by fission. This causes the fissioning to proceed in a linear fashion instead of exponentially increasing. Therefore a controlled fission reaction can be found in the production of __________________

Video: A chain Reaction

1. What happens when an atoms is hit with a neutron? Explain this process.

Ex. complete the following nuclear reactions and state what type of nuclear reaction is taking place.

1. $\frac{222}{86}Rn \rightarrow \frac{218}{84}Po + \_\_\_\_$

2. $\frac{99}{43}Tc \rightarrow \_\_\_ + \frac{0}{-1}e$

3. $\frac{111}{49}In \rightarrow \frac{111}{49}In + \_\_\_\_\_$

4. $\frac{63}{29}Cu + \frac{2}{1}H \rightarrow \frac{64}{30}Zn + \_\_\_\_$

5. $\frac{235}{92}U + \frac{1}{0}n \rightarrow \frac{137}{52}Te + \_\_\_\_\_ + 2\frac{1}{0}n$

Half-Life

Half-life: The amount of time required for the mass of a radioactive element to decay to half of the original amount. Different radioactive isotopes decay at very different rates.

Isotope	Half Life
Carbon-14	5730 years
Uranium-238	4.46×10^9 years
Cobalt-60	10.47 minutes
Astatine-218	1.6 s
Phosphorus-32	14.28 days
Polonium-214	1.64×10^{-4} seconds
Potassium-40	1.3×10^9 years

Carbon Dating Videos:

1. Why is the carbon atom unique?

2. What is carbon-14? What is unique about carbon-14?

3. What happens to the amount of carbon-14 in an organism after the organism dies?

4. How can scientists determine when an organism died using carbon-14? Explain this process.

Half Life Equation:

$$A = I(0.5)^{t/h}$$

A = amount remaining
I = initial amount
t = time
h = half life

1. Carbon-14 has a half-life of 5730 years
   a. A. What mass of a 100 g sample would remain after 22920 years?

   b. How long would it take for a 256.0 g sample to decay to 8.000 g?

   c. How long would it take for a sample to decay to 12.5 % of the original amount?

   d. If 3.00 g of sample remain after 34380 years, what was the mass of the original sample?

2. A 50 g sample of cesium-137 decays to 12.5 g in 180 years. What is the half life of cesium-137

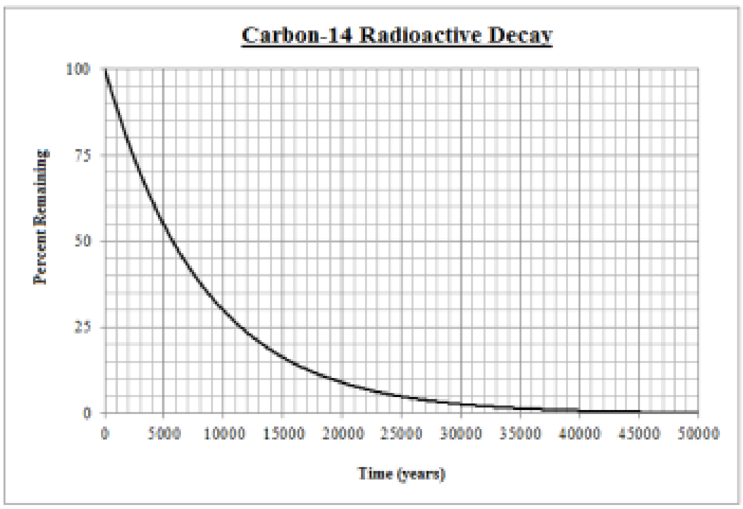
Radioactive Dating

Carbon Dating

All organisms take in carbon (plants by photosynthesis and animals by ingestion). The percentage of carbon-14 in the atmosphere is constant and a living organism will have the same percentage. When an organism dies it no longer takes in new carbon-14. Carbon-14 has a half-life of 5730 years, so as time passes the carbon-14 in the tissue decays. Carbon-14 decays by emission of beta particles.

$$\frac{14}{6}C \rightarrow \frac{14}{7}N + \frac{0}{-1}e$$

The percentage of carbon-14 remaining in an organism can be used to determine its age. Carbon dating is best for dating organic materials younger than 50,000 years.



Ex. What would be the age of a sample with 25 % of the carbon-14 remaining?

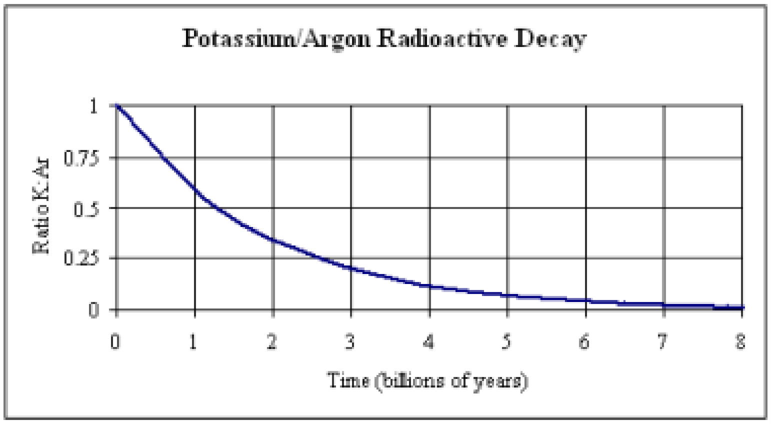
Ex. What percentage of carbon-14 would remain in a 2000 year sample?

Potassium/Argon (K/Ar) Dating

Potassium is found in rocks produced during volcanic eruptions. Potassium-40 has a half-life of 1.3 x 10^9 years. As time passes, the potassium undergoes beta capture to become argon gas.

$$\frac{40}{19}K + \frac{0}{-1}e \rightarrow \frac{40}{18}Ar$$

The argon becomes trapped in air bubbles in the rock. The ration of K:Ar in an object can be used to determine its age. K/Ar dating is best for inorganic materials older than 100,000 years.



Ex. How old is a rock with a K:Ar ration of 0.40?

More on Nuclear Stability

- The stability of the nucleus of an atom is a combination of several factors
    1. ______________________________
    2. ______________________________
    3. ______________________________
- Nuclei that are unstable are radioactive, and nuclei that are stable are not radioactive.

1. **Binding Energy**

- When the nucleus of an atom is formed, some of the mass of the protons and neutrons is converted into binding energy which holds the nucleus together (strong force)
- The higher the binding energy, the more stable the nucleus.

Albert Einstein (1879-1955): Mass can be converted into energy according to the following equation:

$$E = mc^2$$

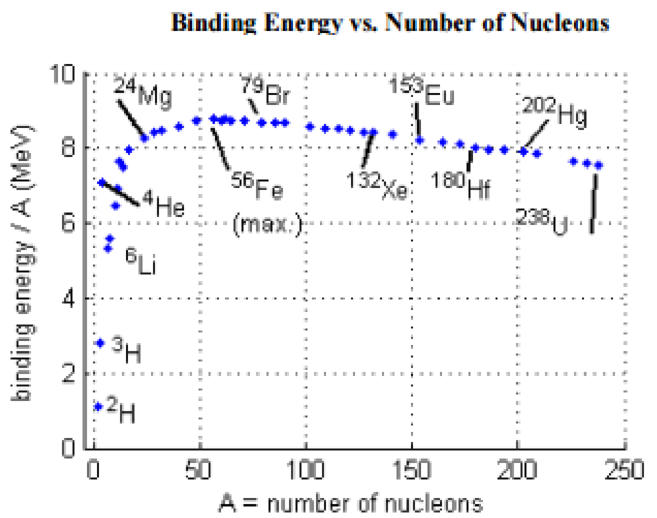
E = energy (Joules)
m = mass (kg)
c = speed of light (3.00×10^8 m/s)

Ex. The mass lost when a helium-4 nucleus is formed in 5.05 x 10^{-29} kg. Determine the binding energy.

- Binding energy is given in units called Mega electron Volts (MeV). 1 MeV= 1.602 x 10^{-13} J
- Binding energy is then calculated as energy per nucleon (protons and neutrons are both called nucleons, ie. Helium-4 has two protons and two neutrons, and therefore has four nucleons).

Ex. Convert the binding energy of helium-4 in MeV/nucleon.

The binding energy for different isotopes is show below.



- The isotope with the highest binding energy and therefore the most stable nucleus is iron-56.
- Atoms with smaller atomic numbers undergo **fusion** to increase atomic number and increase binding energy and atoms with larger atomic numbers undergo **fission** (splitting of nuclei) to decrease atomic number and increase binding energy.

  Fusion takes place in starts to produce helium and energy.

$$\frac{2}{1}H + \frac{3}{1}H \rightarrow \frac{4}{2}He + \frac{1}{0}n$$

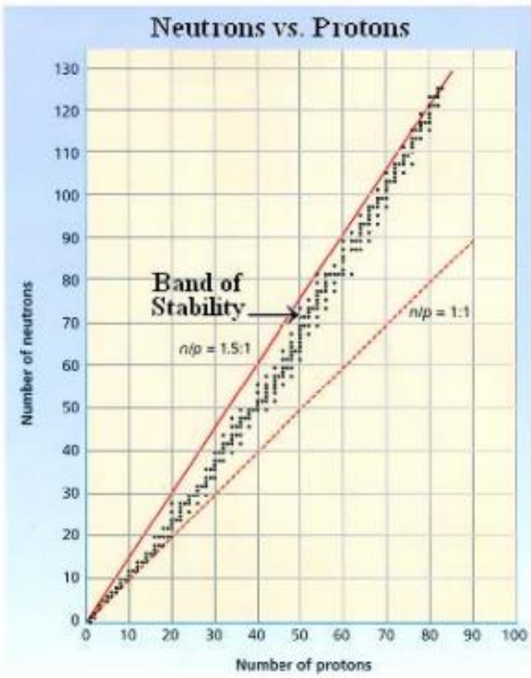
  Fission takes place in nuclear reactors to release energy.

$$\frac{235}{92}U + \frac{1}{0}n \rightarrow \frac{141}{56}Ba + \frac{92}{36}Kr + 3\frac{1}{0}n$$

- Fusion actually release more energy than fission, but requires a high temperature to initiate the process and is therefore impractical to supply energy commercially.

2. Band of Stability

- The stability of the nucleus also depends on the ratio of neutrons to protons
- Since protons are positively charged, they will repel one another in the nucleus.
- Neutrons act to decrease (or "buffer") the repulsive forces and stabilize the nucleus.
- If the number of neutrons vs. the number of protons for stable isotopes is graphed, it can be seen that stable nuclei fit into the "band of stability". Each point on the group represents a stable/non radioactive isotope.



n/p is the ratio of neutrons to protons

ex. Calculate the number of protons and neutrons for each isotope. Use the graph to determine if each of the isotopes are stable/non radioactive or unstable/radioactive.

neon-20 ___ p ___ n

neon-30 ___ p ___ n

lead-206 ___ p ___ n

lead-182 ___ p ___ n

- Note: the ratio of neutrons to protons increases with an increasing number of protons because additional neutrons are required to reduce proton-proton repulsion (initially, nuclei are stable with a n/p ratio close to one, but as the number of protons increases, the n/p ratio for stable nuclei becomes closer to 1.5).
- There are no stable nuclei with more than 83 protons (ie. the elements Polonium and above are all radioactive) because the proton-proton repulsion is too great to be overcome.

(3) Magic Numbers: 2, 8, 20, 28, 50, 82, 126

- Some nuclei are unusually stable because the number of protons, neutrons, and/or mass is equal to a "magic number".
- It is suggested that protons/neutrons are found in "shells" or energy levels in the nucleus (similar to the electron shells)
- As with electrons, it is thought that full shells result in stability. A stable nucleus results in a non-radioactive isotope.

Examples of isotopes that are particularly stable as a result of" magic numbers":

$^{4}_{2}He$ $^{16}_{8}O$ $^{40}_{20}Ca$

Applications of Nuclear Chemistry

Nuclear Medicine

1. **Radiation Therapy**- Radioactive isotopes can also be used in medical treatments. In radiation therapy, a patient is given a specific dose of radioactive medicine. Radiation therapy is frequently

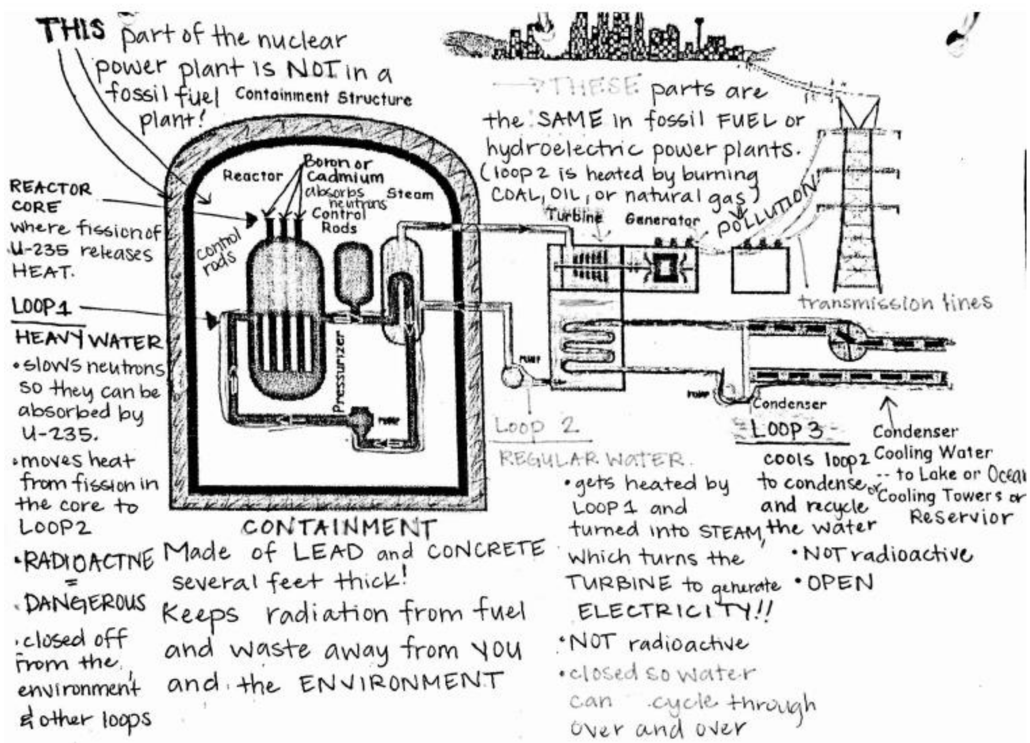
used to treat cancer because fast growing cancer cells are more susceptible to damage by high-energy radiation than are healthy cells.

2. **PET scans-** In a PET scan, a patient is given a radioactive form of a chemical required in metabolism. Fluorine-18 is one of the most common radioisotopes used in PET scans. The decay of fluorine-18 produces a positron. A positron is the antimatter counterpart of an electron/beta particle and has the symbol $^{0}_{+1}e$. When the positron that is produced encounters an electron, the matter-antimatter pair annihilate one another and produce gamma rays. The position of the gamma rays is determined by a computer in order to create a three dimensional picture of a patients organs. PET scans are used in diagnosing cancer, detecting heart diseases, and analyzing brain disorders.

3. Bone Scans- For a bone scan, a patient is administered technetium-99. The body will take up technetium-99 with other minerals required in metabolism. Areas of higher than normal uptake will generally be indicative of fractures, infections, or tumors. Technetium-99 emits gamma rays which can be detected by cameras to create a detailed picture of the body.

Nuclear Energy (See Videos- Chernobyl and)

4. **Nuclear Power Plants**- can be used to harness energy produced in nuclear reactions. In a reactor the energy from the reactions used to heat large quantities of water to produce steam. The energy from this process is harness using a generator and then converted into electricity. The main component of nuclear fuel is uranium-235.



5. **Nuclear Bombs-** Unlike a nuclear power plan which has a controlled chain reaction, a nuclear bomb is an uncontrolled chain reaction that releases a lot of energy!