Chapter 28: Nuclear Chemistry
Part 1: Notes – The Basics of Nuclear Radiation and Nuclear Decay

Objectives: Differentiate between nuclear and chemical reactions.
Define: spontaneous nuclear decay, nuclear reaction, parent nuclide, daughter nuclide, decay series, & radioisotope.
For alpha, beta, and gamma radiation, list its Greek symbol, its nuclear symbol, its constituent particles, its charge, and its penetrating power.
Balance spontaneous nuclear decay equations and explain how to balance them.
List the products of a spontaneous nuclear decay.
Explain how an electron can be emitted in a spontaneous nuclear decay reaction.

Text Reference: Section 28.1 – pages 841-844

Chemical Reactions versus Nuclear Reactions

NUCLIDE – the nucleus of a radioactive isotope
Isotopes have different numbers of neutrons so they have different nuclides.
Some nuclides are less stable than other nuclides.

SPONTANEOUS NUCLEAR DECAY

Three types of energy released: alpha radiation, beta radiation, and gamma radiation

PARENT NUCLIDE – initial nucleus in a nuclear reaction or spontaneous nuclear decay
DAUGHTER NUCLIDE – resulting nuclide in a nuclear reaction or spontaneous nuclear decay

DECAY SERIES – series of spontaneous radioactive decays that ultimately result in a stable nuclide

- An unstable parent decays to form an unstable daughter – which becomes the unstable parent in the next decay where the parent decays into the daughter – which, if it is unstable – will turn into the parent and the process will repeat.
- The decay pattern repeats until the formation of a stable daughter nuclide.

Name of Radiation	*Alpha radiation*	*Beta Radiation*	*Gamma Radiation*
Greek symbol			
What is it?			
Nuclear Symbol			
Constituent particles			
Charge			
Common source			
Penetrating Power			
Shielding			
Extras…			

Also, *POSITIVE BETA RADIATION* – it is symbolized β+ - it is a stream of high-speed positrons – nuclear symbol: ${}^{0}_{+1}e^{+1}$ – same mass as beta particle – it is the antiparticle of the electron

Examples of Spontaneous Nuclear Decay Reactions:

Recall: in a spontaneous nuclear decay – a energy/a particle is emitted and a new particle is formed

Question: How are these nuclear reactions "balanced"?

ALPHA DECAY – an alpha particle is emitted and a new daughter particle is formed

$^{238}_{92}U \rightarrow {}^{4}_{2}He + {}^{234}_{90}{}^{Th}$ + energy usually excess energy is not written but it is understood to be there

BETA DECAY – a beta particle is emitted and a new daughter particle is formed

$^{238}_{92}U \rightarrow {}^{0}_{-1}e^{-} + {}^{238}_{93}Np$ + energy usually excess energy is not written but it is understood to be there

Sample Problems:

The beta decay of Pa-234

The alpha decay of Po-218

The beta decay of Pb-214

Nuclear reactions involve the nucleus of the atoms and the subatomic particles in the nucleus. Those particles are the PROTONS and NEUTRONS.

Isotope versus Radioisotope:

Key Question: *Since the subatomic particles in the nucleus are protons and neutrons, how is it possible for a beta particle (an electron) to be emitted during a spontaneous nuclear decay reaction?*

Chapter 28: Nuclear Chemistry
Part 1: Assignment – Spontaneous Nuclear Decay

Fill in the blanks with the appropriate answer to complete the nuclear decay equations. Classify as alpha or beta decay.

1. $^{231}_{91}\text{Pa} \rightarrow {}^{4}_{2}\text{He} +$ ________________ ________________

2. $^{233}_{90}\text{Th} \rightarrow$ ________________ $+ {}^{0}_{-1}\text{e}^{-}$ ________________

3. $^{210}_{84}\text{Po} \rightarrow {}^{0}_{-1}\text{e}^{-} +$ ________________ ________________

4. $^{210}_{82}\text{Pb} \rightarrow$ ________________ $+ {}^{4}_{2}\text{He}$ ________________

5. $^{75}_{33}\text{As} \rightarrow {}^{75}_{34}$________________ + ________________ ________________

6. $^{235}_{90}\text{Th} \rightarrow$ ________________ $+ {}^{231}_{88}$________________ ________________

7. $^{235}_{92}\text{U} \rightarrow {}^{231}_{90}$________________ + ________________ ________________

8. $^{245}_{94}\text{Pu} \rightarrow$ ________________ $+ {}^{245}_{95}$________________ ________________

For 9 – 14, complete the nuclear equations in this *decay series*. Use the product of the one reaction as the reactant in the next reaction.

9. $^{235}_{92}\text{U} \rightarrow {}^{4}_{2}\text{He} +$ ________________

10. ________________ $\rightarrow {}^{0}_{-1}\text{e}^{-} +$ ________________

11. ________________ $\rightarrow {}^{4}_{2}\text{He} +$ ________________

12. ________________ $\rightarrow {}^{0}_{-1}\text{e}^{-} +$ ________________

13. ________________ $\rightarrow {}^{4}_{2}\text{He} +$ ________________

14. ________________ $\rightarrow {}^{4}_{2}\text{He} +$ ________________

15. How are the mass number and the atomic number affected by the loss of a:
    a. beta particle?

    b. alpha particle?

    c. gamma ray?

16. Write the equation for the radioactive decay of fluorine-17 by positron emission.

17. Why does the relatively large mass and charge of an alpha particle limit its penetrating ability?

18. Bismuth-211 is a radioisotope. It decays by alpha emission to yield yet another radioisotope, which emits beta radiation as it decays to a stable isotope. Write equations for the nuclear reactions and name the decay products.

Chapter 28: Nuclear Chemistry
Part 2: Notes – Ionizing and Nonionizing Radiation and Initiated Nuclear Radiation

Objectives: Differentiate between ionizing and nonionizing radiation, list examples of both and list what cells they most affect.
Explain how to initiate a nuclear reaction and state why it may be done.
Write and balance initiated nuclear reactions and explain the rule used in balancing.
Define, explain, and identify: ionizing and nonionizing radiation, transmutation, electromagnetic radiation, transuranium element, and band of stability.
Explain why it is impossible to get rid of all radiation.
Text Reference: Section 28.2 (Part) pages 845-846 and 850-851

Recap Question: *If a nuclear reaction occurs in the nucleus, how can there be beta emission?*

Spontaneous nuclear decay is a reaction that happens without any prompting. Tremendous amounts of energy are released.
Sometimes, we want to take a large nuclide and break it into smaller parts.
Why?

Question: *How is it possible to cause a stable nuclide to undergo nuclear decay?*
Answer:

Transmutation: the process of changing one element into another element
(Recall, the identity of an element is determined by the number of protons contained in the nucleus.)

Radiation: general term for energy or particles that are emitted from a source and travel through the intervening medium of space
Example of radiation: light, heat (thermal radiation), alpha, beta, gamma

Ionizing Radiation: radiation of sufficient energy to create ions from the atoms and molecules in matter
Examples of ionizing radiation: x-rays, gamma rays
When ionizing radiation encounters matter, it leaves it different than it was before.
Examples: $H_2O + \gamma \rightarrow H^+ + OH^-$
$H_2O + \gamma \rightarrow H_2O^+ + e^-$

Ionizing radiation causes changes in living cells. Some of these changes in living cells may have no overall effect on the life of the organism; other changes may affect the life of the organism. Radiation may strike the chromosomes in the ovum or sperm – the organism produced from than irradiated cell may be affected in some way that may not be noticed until birth.

Examples of cells most sensitive to ionizing radiation: bone marrow, reproductive organs, and the cells in the linings of intestines.

Nonionizing Radiation: radiation that is not energetic enough to create ions in molecules of matter

You cannot get rid of all radiation. Everything emits some sort of radiation.
Everything emits ***ELECTROMAGNETIC RADIATION***.

OTHER NUCLEAR SYMBOLS

The neutron: The proton:

Chapter 28: Nuclear Chemistry

Part 2: Assignment - Initiated Nuclear Reactions

Fill in the blanks with the appropriate information to complete the nuclear reactions.

1. $^{1}_{1}H$ + ________________ → $^{1}_{0}n$ + $^{54}_{25}Mn$

2. $^{23}_{11}Na$ + $^{4}_{2}He$ → ________________ + $^{25}_{12}Mg$

3. $^{30}_{15}P$ + ________________ → $^{30}_{14}Si$ + $^{1}_{1}H$

4. $^{235}_{92}U$ + $^{1}_{0}n$ → $^{95}_{42}Mo$ + 2 $^{1}_{0}n$ + ________________

5. $^{14}_{7}N$ + $^{4}_{2}He$ → $^{17}_{8}O$ + ________________

6. $^{9}_{4}Be$ + ________________ → $^{12}_{6}C$ + $^{1}_{0}n$

7. $^{11}_{5}B$ + $^{4}_{2}He$ → $^{14}_{7}N$ + ________________

8. $^{245}_{94}Pu$ → $^{0}_{-1}e^{-}$ + ________________

9. $^{63}_{29}Cu$ + $^{2}_{1}H$ → $^{64}_{30}Zn$ + ________________

10. ________________ + $^{4}_{2}He$ → $^{14}_{7}N$ + $^{1}_{0}n$

11. $^{31}_{15}$________ + $^{1}_{1}H$ → $^{28}_{14}$________ + ________________

12. $^{63}_{29}$________ + $^{2}_{1}H$ → 2 $^{1}_{0}n$ + ________________

13. $^{9}_{4}$________ + $^{4}_{2}He$ → ________________ + $^{1}_{0}n$

14. $^{235}_{92}$________ + $^{1}_{0}n$ → $^{95}_{42}$________ + 2 $^{1}_{0}n$ + ________________

15. $^{63}_{29}$________ + $^{2}_{1}H$ → ________________ + $^{61}_{28}$________

16. $^{63}_{29}$________ + $^{1}_{1}H$ → $^{1}_{0}n$ + ________________ + $^{38}_{17}$________

17. $^{6}_{3}$________ + $^{2}_{1}H$ → $^{1}_{0}n$ + $^{4}_{2}He$ + ________________

18. $^{37}_{17}$________ + ________________ → $^{35}_{16}$________ + $^{4}_{2}He$

19. $^{239}_{94}$________ + $^{4}_{2}He$ → $^{1}_{0}n$ + ________________

20. $^{28}_{14}$________ + $^{2}_{1}H$ → ________________ + $^{29}_{14}$________

21. What happens to an atom with a nucleus that falls outside the band of stability?

22. Identify the more stable isotope in each pair: C-12 or C-13 O-16 or O-18

    H-3 or H-1 N-14 or N-15

23. What are the transuranium elements and why are they unusual?

Chapter 28: Nuclear Chemistry
Part 3: Notes – Introduction to Half-Life and Half-Life Problems

Objectives: Define half-life and list its common units.
Solve basic half life problems and list the steps required to solve such problems.
Explain why size has no effect on the time for half-life but it does for the number of decays.
Text Reference: Section 28.2 (Part) pages 847-849

Radioactive isotopes have widely different stabilities. They disintegrate in times ranging from fractions of a second to billions of years. The atoms of a sample of a given isotope do not disintegrate all at once; rather they undergo their particle emissions in a pattern that is statistically predictable. In other words, scientists cannot predict exactly when a given atom of an isotope will decay, but they can predict what fraction of atoms in any given sample of the isotope will decay during s given period of time. (Think – Life Insurance Companies. They cannot predict exactly who will die in a given year, but they can predict about how many people in the various age and health brackets will die during a given year.)

The number of decays that will occur in a given amount of time depends on the relative instability of the isotope and the number of atoms in the sample. As a sample decays, the number of atoms in the isotope sample gets smaller. As the number of atoms gets smaller, the number of decays gets smaller.

HALF-LIFE – the length of time it takes for a sample of radioactive material to decay to half its original amount – abbreviated as $t_{1/2}$.
The size of the original sample does not affect the length of the half-life, just the number of decays that occur.

1 000 000 atoms $\xrightarrow{\text{10 days}}$ 500 000 atoms (500 000 decays)

500 000 atoms $\xrightarrow{\text{10 days}}$ 250 000 atoms (250 000 decays)

Calculations and Half-Life

$q_i \text{ x } 1/2^n = q_f$

q_1 = initial quantity
q_f = final quantity
n = number of half-lives that have passed
n = total time ÷ length of one half-life

Example 1: Rh-111 has a half-life of 25.0 minutes. You have a sample of Rh-111 with a mass of 150.0 g. The Rh-111 undergoes alpha decay. (a) Write a balanced nuclear equation. (b) How many grams of Rh-111 will remain after 6.25 half-lives have passed? (c) How much total time has passed?

Example 2: A sample of a radioactive isotope has a half-life of 14.6 days. (a) If your sample has a mass of 4.75 g, how much would remain after 82.4 days? (b) How many half-lives have passed?

Example 3: Pt-206 undergoes beta decay with a half-life of 38.0 minutes. (a) Write a balanced nuclear equation. (b) If you start with 250.0 g of Pt-206, how much will remain after 228.6 minutes?

Example 4: A sample has a mass of 125 g. The sample decayed and its mass decreased to 15.625 g. How many half-lives have passed

Example 5: A sample of a radioactive isotope has a mass of 75.0 g. The sample decayed and after 62.25 days, its mass was 22.42 g. (a) How many half-lives have passed? (b) Calculate the length of the half-life of this isotope.

Example 6: A sample contains 1/12 the original amount of radioactive material as it contained when you began your research. The half-life of this substance is 13.56 days. (a) How many half-lives have passed? (b) How old is the sample?

Chapter 28: Nuclear Chemistry

Part 3: Assignment – Half-Life Problems

Solve the following problems using the formula, as illustrated in class. Show your set-up, units, etc. Be neat and clearly indicate your final answer(s).

1. Nitrogen-13 decays by beta emission and has a half-life of 10.0 minutes. Assume you start with a 12.87 g sample.
   (a) How long is 4.26 half-lives?
   (b) How much of your sample will remain after 4.26 half-lives have passed?

2. Manganese-56 decays by beta emission and has a half-life of 2.60 hours.
   (a) How many half-lives is 18.56 hours?
   (b) If your sample has an initial mass of 23.45 g, what will be its mass after 18.56 hours?

3. Iron-59 has a half-life of 45.1 days.
   (a) How many half-lives will Fe-59 undergo in 186.95 days?
   (b) How much of a sample will remain after 186.95 days if you start with 0.400 g Fe-59?

4. You start with a sample that has a mass of 0.879 g of X-60. After 13.45 years, all but 0.170 g have undergone nuclear decay.
   (a) How many half-lives have passed?
   (b) What is the half-life of X-60?

5. Iodine-131 has a half-life of 8.05 days. A patient is given a dose of 20.0 mg of this isotope to study a possible thyroid condition. How many milligrams of this isotope remain in the body after 42.3 days?

6. The half-life of Xe-133 is 5.02 days. If you start with 2,510,000 atoms of the isotope, how many atoms will remain after exactly 5 weeks?

7. An isotope has a half-life of 0.475 days. If 36.78 g of this isotope were shipped by train from NYC to California, how many grams of the isotope would be available for use if the trip took 4.93 days?

8. The half-life of an isotope is 15.75 minutes. If you start with 1.63 mol of the isotope, how much of the isotope remains after 119.23 minutes?

9. If you start with 125 000 atoms of Cs-129, how much time must pass until you have only 312 atoms remaining? The half-life of Cs-129 is 32,0 hours.

10. The half-life of iodine-125 is 60.0 days. If you had 132 768 atoms of I-125, how many atoms remain after 865 days?

Text – Page 865 – Question #49. Answer the question here.

Chapter 28: Nuclear Chemistry
Part 4: Notes – Carbon-14 and Radioactive Carbon Dating

Objectives: List why carbon-14 is useful for dating ages of artifacts and how it is used..
Explain and write the equations for the formation-decay cycle of carbon-14.
State the half-life of carbon-14 and its rate of decay in a living object.
Solve various carbon-dating problems related to carbon-14.
Text Reference: Section 28.2 (Part) pages 847-849

In a sample of radioactive nuclides, the decay of an individual nuclide is a random event. It is impossible to predict which nuclide will be the next one to undergo a nuclear change. However, you can determine the amount of time it takes for one-half of a radioactive sample to decay; it is the substance's half-life. One useful application of half-life is in the determination of the ages of fossils, rocks, and other artifacts.

Carbon-14 is a radioactive nuclide constantly produced in the atmosphere. It has a half-life of 5730 years, and it undergoes beta emission, decaying into nitrogen-14.

During photosynthesis, green plants absorb carbon-14 in the form of carbon dioxide. A percentage of this carbon is made from radioactive carbon-14. Once the plant dies, photosynthesis stops, and no more radioactive carbon dioxide is absorbed. However, the decay of C-14 continues. Careful measurements of the amount of C-14 remaining in a once living plant yield the approximate time in history when the plant died.

NOTE: Radioactive carbon-14 is formed when neutrons in space collide with nitrogen-14 in the atmosphere, creating carbon-14 and a released neutron. This carbon forms carbon dioxide. The carbon in the carbon dioxide then decays through beta emission.

The radioactivity may then be measured as the number of disintegrations that occur per minute per gram of substance. The rate changes as the amount of radioactive material decreases with time. Measurements show that a living plant gives off 15.3 ± 0.1 decays/minute/gram of material containing carbon-14. a plant that was living 5730 years ago (the half-life of C-14) will have a rate of decay that is half as large as a living plant: 1/2 x 15.3 decays/minute/gram = 7.65 decay/minute/gram.

The time a plant or animal lived and died may be determined by finding the decay rate of the carbon-14 in the earthly remains, calculating the number of half-lives that it has undergone, and then using the half-life of C-14 to determine the length of time it has been dead.

Example 1: A fossil was found to undergo C-14 decay at a rate of 3.825 decays/minute/g of C-14. Determine the age of the fossil.

Example 2: A sample of an artifact has a decay rate of 157 decays/minute. The mass of the sample is 55.0 g. Determine the age of the artifact.

Chapter 28: Nuclear Chemistry
Part 4: Assignment – Carbon Dating and Half-Life Problems

Solve the following problems. Show all work, units, set-ups, etc.

1. A fossil was found to undergo C-14 decay at a rate of 5.867 decay/min/g. What is the age of the fossil?

2. You start with 7.00×10^9 atoms of an isotope. After 1.36 years, all but 5.78×10^3 have undergone nuclear decay. (a) How many half-lives have passed? (b) How long is the half-life of this isotope?

3. A wooden artifact was found to undergo carbon-14 decay at a rate of 8.956 decay/min/g. What is the age of the fossil?

4. A set of mummified bones was unearthed in an Egyptian desert. The bones were tested and found to undergo carbon-14 decay at a rate of 12.098 decay/min/g. What is the age of the mummy?

5. Only one-fourth of the radioactive atoms of a certain isotope are present 20.0 minutes after original measurements. How many atoms will be present after another 10.0 minutes have passed?

6. A meteorite was found to contain 1/10 of the original amount of K-40, the other 9/10 have decayed to non-radioactive Ar-40. Since the $t_{1/2}$ for K-40 is 1.3×10^9 years, how old is the meteorite?

7. The half-life of Fr-220 is 30.0 seconds. If, at exactly 12:00 noon, there is 1.00 g of this isotope, what time will it be when only 4.75×10^{-3} g remains?

8. (a) Calculate the half-life of an isotope if you start with 2.50 g of the isotope and 0.954 g of this isotope disintegrates in 2.38 hours.
(b) Calculate the half-life of an isotope is you start with 2.50 g of the isotope and it disintegrates to 0.954 g in 2.38 hours.

9. Why might radioisotopes of C, N, and O be especially harmful to living creatures?

Chapter 28: Nuclear Chemistry
Part 5: Notes – Relationship Between Energy and Mass (Says Einstein)

Objectives: Relate thermodynamic stability of a nucleus to change in potential energy related to the formation of the nucleus.
Calculate mass defect, binding energies and energies of formation.
Explain the relationship between mass and energy.
Define: nucleon, binding energy, mass defect, joule, and energy of formation.

Key information: mass of proton = 1.0078 g/mol = 1.67262×10^{-24} g
mass of neutron = 1.0087 g/mol = 1.67493×10^{-24} g
mass of alpha particle = 4.0026 g/mol = 6.64884×10^{-24} g
mass of electron = 5.48580×10^{-4} g/mol = 9.10939×10^{-28} g

We can determine the thermodynamic stability of a nucleus by calculating the change in potential energy that would occur if that nucleus were formed from its constituent particles and comparing that mass to its actual mass.

For example, write the equation that represents the formation of the O-16 nucleus:

Calculate the hypothetical mass of the O-16 nucleus as it is formed from its constituent ***nucleons***:

Now the energy change associated with this process may be calculated by comparing the theoretical mass with the actual mass of the nucleus.

The actual mass of the O-16 nucleus is 2.65535×10^{-23} g. Find the difference between these two masses (the actual mass of the nucleus and the theoretical mass of its constituent particles). *This is products – reactants of the formation equation, above.*

So, _______________ g of mass would be lost when 1 nucleus of O-16 was formed from its constituent nucleons.

> NOTE: There is a loss of mass during normal chemical changes. The energy changes are small enough during these chemical changes that the corresponding mass changes are not detectable, due in large part to the negligible mass of the electron.

Now, how is this information used to determine the energy change that accompanies this process?

The answer is found in the work of Albert Einstein. *Einstein's Theory of Relativity* showed that energy and matter are interconnected. **Energy may be considered a form of matter.** His famous equation, $E = mc^2$, give the relationship between a quantity of energy and the mass associated with it. When a system gains or loses energy, it also gains or loses a quantity of mass. Thus, **the mass of a nucleus is less than that of its component nucleons** because the process is so very **exothermic**.

MASS DEFECT – **difference in mass between the nucleus and its component.** It equals the **products – reactants.**

$E = mc^2$ E = _________________________ with a unit of _________________________.

m = _________________________ with a unit of _________________________.

c = _________________________ with a value and unit of _________________________.

A negative sign for the value of E indicates that the process is **exothermic**. Energy, and mass, is lost from the system.

The energy change observed for nuclear processes are extremely large compared to those observed for chemical and physical changes. The nuclear processes constitute a potentially valuable energy resource.

Example 1: Calculate the energy released when 1 mole of O-16 nuclei is formed from constituent particles.

Frequently, the thermodynamic stability of a particular nucleus is represented as **energy released per nucleon**. Calculate the energy per nucleon for the formation of 1 mole of O-16.

The negative sign indicates that the process is exothermic. This makes sense since putting nucleons together is less energetic than when they are free. They are more stable together than when they are running free.

In a similar sense, the process of decomposing a nuclei into its components would require energy be taken in, an **endothermic process**. The difference between the formation and the breaking down of a nucleus is just the sign of the energy associated with it. Formation is exothermic (negative sign) while breaking it down is endothermic (positive sign). The numeric value of the energy is the same.

BINDING ENERGY – energy required to decompose a nucleus into its components – generally endothermic

The more stable the nuclei, the more energy per nucleon would be required to decompose it. The most stable nuclei known is Fe-56.

Energy absorbed to decompose a nucleus may also be found using $E = mc^2$. Just remember to write the equation correctly and that mass defect = products – reactants.

Example 2: A nuclide of Po-211 decays spontaneously through alpha emission. (a) Write the nuclear decay equation. (b) Calculate the mass defect. (c) Calculate the energy for the decay of a Po-211 nuclide. (d) Calculate the energy for the decay of 1 mole of Po-211. (e) Calculate the energy per nucleon for the decay of a nuclide of Po-211. (f) Calculate the energy in kilojoules for the formation of this Po-211 nuclide from the daughter nuclide by the capture of 1 alpha particle.

Mass of Po-211 = 3.50476×10^{-22} g; Mass of daughter nuclide = 3.43812×10^{-22} g.

Chapter 28: Nuclear Chemistry
Part 5: Assignment – Relationship Between Energy and Mass (says Einstein)

On a separate sheet of paper, answer the following questions. Show ALL work, units, set-ups, and everything you know you need. Be NEAT!!!

Key information: mass of proton = 1.0078 g/mol = 1.67262×10^{-24} g
mass of neutron = 1.0087 g/mol = 1.67493×10^{-24} g
mass of alpha particle = 4.0026 g/mol = 6.64884×10^{-24} g
mass of electron = 5.48580×10^{-4} g/mol = 9.10939×10^{-28} g

1. The sun radiated 3.90×10^{23} joules of energy into space every second. What is the rate at which mass is lost from the sun?

2. (a) The earth receives 1.80×10^{14} kJ/second of solar energy. What mass of solar material is converted to energy over a 24-hour period to provide the daily amount of solar energy to earth?
(b) How much coal would have to be burned to provide the same amount of energy? (Coal releases 32 kJ of energy per gram when combusted.)

3. Calculate the binding energy per nucleon for Mg-24. The mass of Mg-24 is 23.9850 g/mol.

4. Consider the reaction: $^{2}_{1}\text{H} + {}^{3}_{1}\text{H} \rightarrow {}^{4}_{2}\text{He} + {}^{1}_{0}\text{n}$.
Calculate the energy released per mol of $^{4}_{2}\text{He}$ produced.
Mass of H-2 = 2.01410 g/mol; Mass H-3 = 3.01605 g/mol

5. A nuclide of $^{67}_{31}\text{X}$ has a mass of 67.4352 g/mol. How much energy is released during the formation of this nuclide from its nucleons? Calculate (a) energy per mole, (b) energy per nuclei, and (c) energy per nucleon.

6. Consider the reaction: $2\,{}^{3}_{2}\text{He} \rightarrow {}^{4}_{2}\text{He} + 2\,{}^{1}_{1}\text{H}$
Mass of $^{3}_{2}\text{He} = 5.01002 \times 10^{-24}$g
(a) Calculate the mass defect.
(b) Calculate the energy produced per nuclide of $^{4}_{2}\text{He}$ produced.
(c) Calculate the energy produced per nucleon of $^{4}_{2}\text{He}$ produced.

7. Isotope X has 197 neutrons and 135 protons.
(a) Write the equation for the formation of the isotope from its constituent particles.
(b) Calculate the hypothetical mass of X-332 formed from protons and neutrons.
(c) The actual mass of X-332 nuclide is 5.51591×10^{-22} g. Calculate the mass defect for the formation of X-332.
(d) Calculate the energy formed when 1 nuclide of X-332 is produced.
(e) Calculate the energy formed when 1 mole of X-332 is produced.
(f) Calculate the energy formed from the formation of 1 mole of X-332 in J/nucleon.