1. Calculate the neutron-proton ratios for the following nuclides:

   a. carbon-12 \( \frac{6 \text{ neutrons}}{6 \text{ protons}} = 1:1 \)

   b. oxygen-14 \( \frac{6 \text{ neutrons}}{8 \text{ protons}} = 0.75:1 \)

   c. radon-222 \( \frac{136 \text{ neutrons}}{86 \text{ protons}} = 1.58:1 \)

   d. calcium-52 \( \frac{32 \text{ neutrons}}{20 \text{ protons}} = 1.6:1 \)

2. Locate the nuclides in the previous problem on the neutron-to-proton ratio graph in the notes. Which ones lie within the band of stability?
   Carbon – 12

3. For the stable nuclides, which ones tend toward 1:1? Which ones tend toward 1.5:1?
   The smaller, stable nuclides tend to have a 1:1 ratio of neutrons to protons, whereas the larger nuclides tend toward a 1.5:1 ratio of neutrons to protons as the atomic numbers approach 83.

4. Balance the following nuclear equations.

   a. \( \frac{43}{19}K \rightarrow \frac{43}{20}Ca + \frac{0}{-1}\beta \)

   b. \( \frac{233}{92}U \rightarrow \frac{229}{90}Th + \frac{4}{2}He \)

   c. \( \frac{12}{6}C + \frac{0}{-1}e \rightarrow \frac{11}{-1}B \)

   d. \( \frac{13}{7}N \rightarrow \frac{0}{+1}\beta + \frac{13}{6}C \)
5. Write a hypothetical decay series for uranium-238 that involves alpha and/or beta decay reactions. Flip a coin to determine which type of decay occurs. Heads is alpha decay and tails is beta decay. Repeat this process 15 times. At the end of your decay series calculate the neutron to proton ratio and predict if your final isotope is stable or unstable.

heads
a. \( ^{238}_{92}\text{U} \rightarrow ^{4}_{2}\text{He} + ^{234}_{90}\text{Th} \)

tails
b. \( ^{234}_{90}\text{Th} \rightarrow ^{0}_{-1}\beta + ^{234}_{91}\text{Pa} \)

c. \( ^{234}_{91}\text{Pa} \rightarrow ^{4}_{2}\text{He} + ^{230}_{89}\text{Ac} \)

d. \( ^{230}_{89}\text{Ac} \rightarrow ^{4}_{2}\text{He} + ^{226}_{87}\text{Fr} \)

e. \( ^{226}_{87}\text{Fr} \rightarrow ^{0}_{-1}\beta + ^{226}_{86}\text{Rn} \)

heads
f. \( ^{226}_{86}\text{Rn} \rightarrow ^{4}_{2}\text{He} + ^{222}_{84}\text{Po} \)

g. \( ^{222}_{84}\text{Po} \rightarrow ^{0}_{-1}\beta + ^{222}_{85}\text{At} \)

tails
h. \( ^{222}_{85}\text{At} \rightarrow ^{0}_{-1}\beta + ^{222}_{86}\text{Rn} \)

heads
i. \( ^{222}_{86}\text{Rn} \rightarrow ^{4}_{2}\text{He} + ^{218}_{84}\text{Po} \)

heads
j. \( ^{218}_{84}\text{Po} \rightarrow ^{4}_{2}\text{He} + ^{214}_{82}\text{Pb} \)

\[ \text{neutrons} = \frac{214-82}{82} = \frac{132}{82} = 1.61 \]

Still unstable

6. Where on the periodic table are most of the natural radioactive nuclides located?
Periods 6 and 7; atomic numbers 84 through 92; exception is technetium, which is atomic number 45 in period 5.

7. What changes in atomic number and mass number occur in each of the following types of radioactive decay?
   a. alpha emission
      The mass number decreases by 4 and the atomic number decreases by 2.
   b. beta emission
      The mass number doesn’t change, but the atomic number increases by 1.
   c. positron emission
      The mass number doesn’t change, but the atomic number decreases by 1.
   d. electron capture
      The mass number doesn’t change, but the atomic number decreases by 1.

8. Explain how beta emission, positron emission, and electron capture affect the neutron-proton ratio.
Beta emission decreases the neutron-proton ratio; positron emission increases the neutron-proton ratio; and electron capture increases the neutron-proton ratio.
   All have the same mass, 0.0005486 amu, and mass number, 0. Electrons and beta particles have a 1- charge, while positrons have a 1+ charge.

10. What are gamma rays?
    Gamma rays are the highest energy waves in the electromagnetic radiation spectrum. They are the most dangerous type of nuclear radiation because of their high energy and penetrating ability. They are photons with no mass.

11. How does the half-life of a nuclide relate to the stability of the nuclide?
    All nuclides with a half-life are unstable, BUT the longer a nuclide’s half-life the more stable it is. Stable nuclides have no half-life, because they don’t decay.

12. How are artificial radioactive isotopes produced?
    Artificial radioactive isotopes are produced by bombarding a natural isotope with positively or neutrally charged particles, such as alpha particles, protons and neutrons.

13. Why are neutrons more effective for bombarding atomic nuclei than protons or alpha particles?
    Because they are neutral and can penetrate the positively-charge nuclei, which will try to repel the positively-charge protons and alpha particles.

14. Why are all of the trans-uranium elements radioactive?
    They are unstable because all nuclides with an atomic number greater than 83 are unstable, and all trans-uranium elements have an atomic number greater than 92.

15. The half-life of plutonium-239 is 24,110 years. Of an original mass of 100.0 g, how much plutonium-239 remains after 90,015 years? (Hint: See notes.)
    \[ N_t = N_0 \left( \frac{1}{2} \right)^{t_1/2} = 100.0 \text{ g} \left( \frac{1}{2} \right)^{90,015 \text{ yrs}/24,110 \text{ years}} = 7.52 \text{ g} \]

16. The half-life of thorium-227 is 18.72 days. How many days are required for three-fourths of a given amount of thorium-227 to decay?
    If three-fourths of the thorium decays, then one-fourth will remain. It takes two half-lives for an element to decay to one-fourth its original amount. Therefore,
    \[ \text{time} = 2 \text{ half-lives} \times \frac{18.72 \text{ days}}{\text{half-life}} = 37.44 \text{ days} \]

17. Exactly 1/16 of a given amount of protactinium-234 remains after 26.76 hours. What is the half-life of protactinium-234?
    It takes 4 half-lives for an element to decay to one-sixteenth of its original amount,
    \[ \text{half-life} = \frac{26.76 \text{ hours}}{4 \text{ half-lives}} = 6.690 \text{ days} \]
18. How many milligrams of a 15.0 mg sample of radium-226 remain after 6002 years? The half-life of radium-226 is 1599 years.

\[ N_t = N_0 \left( \frac{1}{2} \right)^{t/t_{1/2}} = 15.0 \text{ mg} \left( \frac{1}{2} \right)^{6022 \text{ yrs}/1599 \text{ yrs}} = 1.11 \text{ mg} \]

19. Archeologists found an artifact that has 10.5% of its original carbon-14 content. The half-life of carbon-14 is 5730 years. How old is the artifact?

\[ t = \frac{\ln \frac{N_t}{N_0}}{\ln \frac{1}{2}} = \frac{5730 \text{ years}}{\ln \frac{1}{2}} \ln 0.105 = 18,600 \text{ years} \]

20. Why can a radioactive material affect photographic film even though the film is well wrapped in black paper? Gamma rays and beta particles "expose" the film and paper cannot block these two types of nuclear radiation.

21. How does the penetrating ability of gamma rays compare with that of alpha particles and beta particles? Gamma rays have more penetrating ability than alpha and beta particles, because of it has high energy and no mass. Alpha particles can be blocked by skin and paper. Beta particles can be blocked by wood. Concrete and lead are needed to block gamma rays.

22. How does nuclear radiation damage biological tissue? Nuclear radiation has ionizing energy, which can mutate biological tissue or make it dysfunctional.

23. How is the fission of a uranium-235 nucleus induced? The uranium-235 atom is bombarded with a neutron.

24. How does the fission of uranium-235 produce a chain reaction? One of the reactants, a neutron, is also one of the products. When one uranium-235 atom decays it produces 3 neutrons, which then cause 3 additional uranium atoms to decay. They in turn produce 9 neutrons, cause 9 additional uranium atoms to decay. The rate of the reaction increases exponentially.

25. Describe the reaction that produces the sun’s energy. Fusion produces the sun’s energy: \[ \text{energy} + 4 \, ^{1}\text{H} \rightarrow ^{3}\text{He} + 2 \, ^{0}\beta + \text{energy} \]

26. What is one problem that must be overcome before controlled fusion reactions that produce energy are a reality? Because fusion occurs at high temperatures we need to find materials that can hold the reactants and products at temperatures of about withstand temperatures of around 1x10^8 degrees Kelvin.