HW 5-8: REVIEW – Honors
Nuclear Chemistry

Name Answer Key
Period ______ ***Date*** ________

Topics:

- No questions on alpha, beta and gamma radiation properties or reactions, except anything given on this review
- Radioactive decay half-life problems; nuclear decay series.
- Fission, fusion-- equations, definitions and examples of each. Forces at work during the processes. Why are both fission and fusion favorable?
- Nuclear power plants-- fuel, control rods, moderator, meltdowns, basics of nuclear reactor accidents
- E= mc^2 calculations. Interpretation of Mass Defect graph. Understand that energy-mass is always conserved, but mass is converted to energy in nuclear reactions
- General sources, effects, measurement, and uses of radiation.
- C-14 Dating article: Concept of formation, carbon cycled, decay in steady state; why C-14 ratio decreases after death of organism; Limits; Don't memorize exact reactions, but know concepts.
- Star Born Article: how were elements besides hydrogen formed? Balance of gravity and expanding radiation.
- Other Articles/Videos (Alchemist's Dream, Fusion Energy)

Sample Problems:

1) Complete these nuclear equations and indicate if they are fission or fusion.

a) $\underline{{}^{239}_{94}\text{Pu}} + {}^{1}_{0}\text{n} \rightarrow {}^{88}_{37}\text{Rb} + {}^{149}_{57}\text{La} + 3\,{}^{1}_{0}\text{n}$ type of process? Fission

b) ${}^{9}_{4}\text{Be} + {}^{4}_{2}\text{He} \longrightarrow \underline{{}^{12}_{6}\text{C}} + {}^{1}_{0}\text{n}$ type of process? Fusion

c) ${}^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \longrightarrow {}^{95}_{36}\text{Kr} + {}^{139}_{56}\text{Ba} + \underline{2\,{}^{1}_{0}\text{n}}$ type of process? Fission

d) ${}^{238}_{92}\text{U} + {}^{4}_{2}\text{He} \longrightarrow \underline{{}^{241}_{94}\text{Pu}} + {}^{1}_{0}\text{n}$ type of process? Fusion

2) The earliest artificial transmutation reaction-- performed by Rutherford in 1911 in his discovery that the proton was a hydrogen atom, involved bombarding nitrogen-14 with an alpha particle, producing a proton (hydrogen-1). Write out the reaction and determine the other product.

$${}^{14}_{7}\text{N} + {}^{4}_{2}\text{He} \longrightarrow {}^{1}_{1}\text{H} + {}^{17}_{8}\text{O} \text{ --or-- } {}^{14}_{7}\text{N} + {}^{4}_{2}\text{He} \longrightarrow {}^{1}_{1}\text{p} + {}^{17}_{8}\text{O}$$

3) An isotope of one particular actinoid undergoes fission when struck with a neutron and produces the daughter nuclei strontium-93 and cerium-148 plus 3 neutrons. Write out the equation and determine the identity of the parent nucleus.

$${}^{243}_{96}\text{Cm} + {}^{1}_{0}\text{n} \longrightarrow {}^{93}_{38}\text{Sr} + {}^{148}_{58}\text{Ce} + 3\,{}^{1}_{0}\text{n}$$

4) Strontium-90 decays through beta decay. If it has a half-life of 29 years, how long does it take until 75% has decayed? *(How much remains radioactive?)*

100% – 75% = 25% remaining

$$25\% = (100\%)\left(\frac{1}{2}\right)^n; \frac{25\%}{100\%} = \frac{1}{4} = \left(\frac{1}{2}\right)^n; n = 2; time = 2(29\text{ yrs}) = \boxed{58\text{ yrs}}$$

5) After 12.5 hours, 96 μg of a particular isotope has decayed to 3.0 μg. What is its half-life?

$$3\mu g = 96\mu g\left(\frac{1}{2}\right)^n; \frac{3\mu g}{96\mu g} = \frac{1}{32} = \left(\frac{1}{2}\right)^5; n = 2; t_{1/2} = \frac{12.5\text{ hr}}{5} = \boxed{2.5\text{ hr}}$$

6) Why is the equation $E = mc^2$ significant in a nuclear reaction, but not in a chemical reaction?
In nuclear reactions, the Δm is significant enough that E is measurable (and large); in chemical reactions, E is too small for Δm to be significant or measurable.

7) Describe the basic processes in fusion and fission (no forces). How is energy released during these processes? How does Mass Defect relate to the stability of a nucleus?
In fusion, two lighter nuclei form a more stable, heavier nucleus with a larger mass defect. The extra mass defect is converted to energy by $E = mc^2$. In fission, a large nucleus is split into two smaller nuclei with larger mass defects. As above, the extra mass defect is converted to energy. The larger the mass defect, the more stable the nucleus.

8) a) How much energy (in pJ) is released when this alpha decay takes place? ${}^{226}_{88}\text{Ra} \longrightarrow {}^{222}_{86}\text{Rn} + {}^{4}_{2}\text{He}$
mass of ^{226}Ra = 226.025360 amu; mass of ^{222}Rn = 222.017530 amu; mass of ^{4}He = 4.00260361 amu
(*See reference charts for formulas and more constants.)*

$$\Delta m = 226.025360 \text{ amu} - (222.017530 \text{ amu} + 4.00260361 \text{ amu}) = 0.00522639 \text{ amu}$$

$$E = \underbrace{\left(0.00522639 \text{ amu} \times \frac{1.6605\times10^{-27} \text{ kg}}{1 \text{ amu}}\right)}_{8.67842\times10^{-30} \text{ kg}} \underbrace{\left(3.00\times10^{8} \text{ m/s}\right)^2}_{7.81\times10^{-13} \text{ J}} \left(\frac{1 \text{ pJ}}{1\times10^{-12} \text{ J}}\right) = \boxed{0.781 \text{ pJ}}$$

b) Convert this to MJ/mol

$$E_{mol} = \underbrace{\frac{0.781 \text{ pJ}}{1 \text{ atom}} \times \frac{6.022\times10^{23} \text{ atoms}}{1 \text{ mol}}}_{4.70\times10^{23} \text{ pJ/mol}} \times \underbrace{\frac{1\times10^{-12} \text{ J}}{1 \text{ pJ}}}_{4.70\times10^{11} \text{ J/mol}} \times \frac{1 \text{ MJ}}{1\times10^{6} \text{ J}} = \boxed{4.70\times10^{5} \text{ MJ/mol}}$$

9) The mass of one atom of ${}^{17}_{8}$O is 16.9991315 amu.

a) Determine the mass defect for the formation of one atom of ${}^{17}_{8}$O, in amu (write out the "reaction" to form ${}^{17}_{8}$O from its individual particles). $8p^{+} + 9n^{0} + 8e^{-} \rightarrow {}^{17}_{8}\text{O}$

$$\Delta m = \left[8(1.007276 \; amu) + 9(1.008665 \; amu) + 8(0.0005486 \; amu)\right] - 16.9991315 \; amu$$

$$= 17.1405818 \; amu - 16.9991315 \; amu = \boxed{0.1414503 \; amu}$$ note: this is per atom

b) Determine the energy released by the formation of one mol of ${}^{17}_{8}$O, in J/mol

$$E = \underbrace{\left(\frac{0.1414503 \; amu}{1 \text{ atom}}\right)\left(\frac{1.6605\times10^{-27} \text{ kg}}{1 \; amu}\right)}_{2.348782\times10^{-28} \text{ kg/atom}} \underbrace{\left(3.00\times10^{8} \text{ m/s}\right)^2}_{2.114\times10^{-11} \text{ J/atom}} \times \frac{6.022\times10^{23} \text{ atoms}}{1 \text{ mol}} = \boxed{1.27\times10^{13} \text{ J/mol}}$$

c) Determine the energy released (mass defect) by formation of ${}^{17}_{8}$O, in MeV/nucleon (1 MeV = 9.6483×10^{10} J/mol)

$$E = \left(1.27\times10^{13} \text{ J/mol} \times \frac{1 \text{ MeV}}{9.6483\times10^{10} \text{ J/mol}}\right) \Big/ 17 \text{ nucleons} = \boxed{7.76 \text{ MeV/nucleon}}$$

10) Referring to the Mass Defect chart in your notes, explain why fusion of element up through Fe releases energy (i.e. products are more stable), but fusing elements above Fe requires energy.
As lighter elements are fused, the mass defect (stability) increases, and this mass is converted into energy. Beyond Fe, fusion results in products with a lower mass defect (more mass), which requires energy to be converted to mass.

11) Why does the fission of U-235 produce a nuclear chain reaction?
When U-235 is split, it emits several neutrons. These neutrons can initiate further fission reactions that themselves release several neutrons each, in a cascading chain reaction.

12) Explain why atomic bombs explode and nuclear power plants produce a steady amount of heat. *(Include & explain the concepts of enrichment and critical mass).*
Atomic bombs can explode because their uranium is enriched (concentrated) and contains greater than the critical (minimum) mass needed for a run-away chain reaction. In nuclear power plants, the uranium is less enriched and contains less than the necessary critical mass, so although energy is released, the chain reaction never goes out of control.

13) What is the purpose of control rods in a nuclear power plant?
The control rods absorb neutrons to slow/stop the fission chain reaction.

14) What is the purpose of a moderator in a nuclear power plant?
The moderator slows the neutrons so they can initiate fission in fissile isotopes.

15) Why is it safer to use water as a moderator instead of graphite?
Since water also acts as the coolant, any drop in the level of water that would reduce the ability of the reactor to stay cool would also reduce the heat output of the reactions. With graphite as the moderator, reduction in the coolant level has no accompanying reduction in the output of the reactor since the neutrons are still capable of initiating fission.

16) Why is fusion not currently used in nuclear power plants?
We have not yet achieved sustained fusion reactions that produce more energy than they consume. The technological difficulties in initiating and confining the plasma in which fusion occurs are currently unsolved.

17) Why do stars contract after the supply of hydrogen starts to run low?
When the hydrogen fuel runs low, fusion stops and the outward pressure is not large enough to counter the inward pull of gravitational attraction.

18) Why is it more difficult to fuse two helium nuclei together than to fuse two hydrogen nuclei together? *Discuss the forces involved.*
Helium nuclei have twice the charge of each hydrogen nucleus. The coulombic (electrical) repulsion of two 2+ atoms is four time greater than for the two 1+ H atoms, requiring greater energy to push them close enough together for the strong nuclear force to fuse the nuclei.

19) What happens within the contracting star to enable and initiate fusion of helium? Describe the forces between the nuclei.
As the star collapses, friction heat up the particles and the density increases, providing the conditions needed for the two He^{2+} nuclei to overcome coulombic (electrical) repulsion and get close enough for the strong nuclear force to pull them together.

20) Under what conditions will a supernova occur? What happens when a supernova does occur?
When a star whose mass is greater than 1.44× that of our sun reaches the stage at which its Fe core can no longer sustain fusion, it will collapse under its gravity. As it collapses, so much energy is released that the star explodes, providing enough energy to fuse elements heavier than Fe.

21) Why do C-14 levels stay constant when an organism is alive, but C-14 levels decrease when the organism dies? *(You don't need to know the specific reactions involved, just know the basic concepts.)*
When alive, the level of C-14 in an organism stays constant because as it decays it is replenished from the carbon cycle as the organism eats and respires. This occurs in a steady-state process in which the amount of C-14 that decays is exactly equal to the amount that comes in. After death, the organism no longer takes in C-14, but it still decays, so without replenishment the level of C-14 decreases.

22) Why is nuclear radiation called "ionizing" radiation? What other radiation is also ionizing?
Nuclear radiation is ionizing because it can strip electrons off of atoms, making them reactive. X-rays and UV light are also ionizing.

23) Why is ionizing radiation dangerous to living organisms? What are the two kinds of damage that can result?
The reactive ions formed can damage tissue. Somatic damage causes immediate damage to the cell itself and can kill the cell or cause cancer to form. Genetic damage occurs in reproductive cells and can lead to mutations.

24) List and explain the three methods discussed for detection of nuclear radiation.
- A Geiger Counter—Ar gas in the detector is ionized by radiation & produces a current
- Scintillation Counter—phosphors emit light when struck by radiation & a detector registers the flash
- Photographic film—radioactivity exposes the film and the exposures can be counted after the film is developed.

25) ___F___ T or F? The majority of radiation that a typical human receives is man-made.
26) ___F___ T or F? Eating bananas should be avoided because they contain potassium-40.
27) ___T___ T or F? Radiation can be beneficial and harmful. Give examples. Beneficial: cancer radiation treatments, radiotracers, radioisotopic dating, PET scans; harmful: cell damage and death.