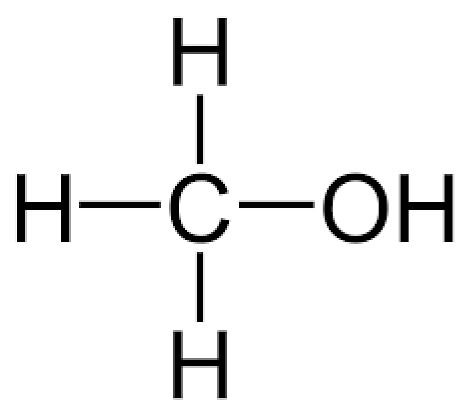
2023 WUCT: Chemistry of Astronomy ANSWER KEY

This exam consists of 7 questions and is worth 100 points. You will work together with a partner to answer the questions. You will have 1 hour to take the exam. The only allowed resources for this exam are a calculator and the provided equation sheet. You may NOT use any other notes or books. You must show your work and box your final answer to receive credit for a problem. NOTE: If you get the answer to an early part of a question incorrect but later use that answer for a subsequent part of the question, you can still earn full credit for those subsequent parts. Please write your answer in the designated space on the answer sheet. If you need additional space for a problem, you may use scratch paper, but make sure to clearly indicate in the problem's designated space where the rest of your work can be found. Dark pencil or pen is preferred.

Problem #1: ***(14 points)***

Astrochemists use methanol to measure magnetic fields. By measuring the radio signals from methanol molecules, they can better understand the magnetic fields that play a vital role in determining where enormous stars are born.

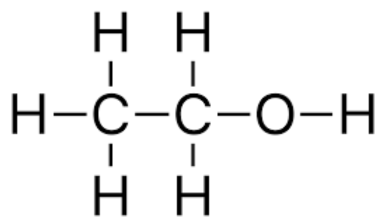
a. Methanol has the molecular formula CH_3OH. Draw the viable Lewis structure(s) and label any non-zero formal charges. If any valid resonance forms exist, draw them and circle the major contributor. ***(2 points)***



There are no non-zero formal charges and there are no resonance structures.

+2 points for correct structure

Sagittarius B2 is a massive molecular cloud of gas and dust located almost 390 lightyears away from Earth. It contains methanol, ethanol, and vinyl alcohol. The Lewis structure for ethanol is provided below.



b. Using the provided structure for ethanol, as well as the Lewis structure(s) you drew for methanol in part (a), determine which has the larger vapor pressure based on the strength of their intermolecular forces and molecular sizes. Explain your ranking. Assume both compounds exist in a liquid state at the same temperature. ***(3 points)***

(Key Concept 1) Methanol has a higher vapor pressure than ethanol.
(Key Concept 2) The molecule that has the weakest intermolecular forces will have the higher vapor pressure.
(Key Concept 3) Methanol is smaller than ethanol, which means it has weaker London Dispersion Forces and thus a higher vapor pressure.

+1 point for correct answer (stating that methanol > ethanol)
+1 point for each Key Concept 2 and 3

Over the past 20 years, researchers have discovered that interstellar clouds contain methanol. To better understand the organic compound, they have devised an experiment in which a 5.48 mol sample of methanol is placed in a 13.5 L evacuated rigid tank before being heated to 333˚C. Since methanol's boiling point is 64.7˚C, all of the methanol in the tank is vaporized at 333˚C and the methanol decomposes to form carbon monoxide and hydrogen gas.

c. Write the balanced molecular equation for this decomposition process. ***(1 point)***

$$CH_3OH\ (g) \rightarrow CO\ (g) + 2H_2\ (g)$$

+1 point for correct equation

d. The reaction mixture has 4.58 mol of H_2(g) at 333˚C. Calculate the number of moles of CO(g) in the tank. ***(2 points)***

$$4.58\ mol\ H_2 \times \frac{1\ mol\ CO}{2\ mol\ H_2} = 2.29\ mol\ CO\ (g)$$

+2 points for correct final answer

e. At 333˚C, rank the three gases (CH_3OH, CO, and H_2) based on increasing average molecular speed, then rank them based on increasing kinetic energy. Note: You should have two separate rankings. ***(2 points)***

Average Kinetic Energy:

This is the same for all three gases because they are all in the tank at the same temperature (333˚C).

Average Molecular Speed:

Kinetic Energy = $\frac{1}{2}mv^2$

Since their kinetic energies are the same, the species with the lowest mass will have the highest average molecular speed.

$CH_3OH\ (g) < CO\ (g) < H_2\ (g)$

+1 point for correct ranking of average molecular speed
+1 point for correct ranking of kinetic energy

Now consider the reverse reaction of the one you provided in part (c). This combination reaction was studied at 29˚C and the following results were obtained.

Experiment	$[CO]_0$ (mol/L)	$[H_2]_0$ (mol/L)	Initial Rate (mol/L*s)
1	0.070	0.035	13.0×10^{-6}
2	0.035	0.035	6.5×10^{-6}
3	0.070	0.0175	6.5×10^{-6}
4	0.030	0.035	5.57×10^{-6}
5	0.050	0.030	7.5×10^{-6}

f. Determine the rate law with correct orders for each species. Based on the order of the reaction with respect to each species, what is the overall order? ***(3 points)***

Rate = $k[CO]^x[H_2]^y$

First, compare experiments 1 and 2:

Rate 2/Rate 1 = $k[CO]_2^x[H_2]_2^y / k[CO]_1^x[H_2]_1^y$

$6.5 \times 10^{-6} / 13.0 \times 10^{-6} = k(0.035)^x(0.035)^y / k(0.070)^x(0.035)^y$

$0.5 = (0.5)^x$ so $x = 1$

Next, compare experiments 1 and 3:

Rate 3/Rate 1 = $k[CO]_3^x[H_2]_3^y / k[CO]_1^x[H_2]_1^y$

$6.5 \times 10^{-6} / 13.0 \times 10^{-6} = k(0.070)^x(0.0175)^y / k(0.070)^x(0.035)^y$

$0.5 = (0.5)^y$ so $y = 1$

Rate = $k[CO][H_2]$, Overall order: 2

+2 points for correct rate law expression

+1 point for correct overall order

g. Assume the reaction was a fourth order reaction. If the concentration of one of the reactants doubles, the rate increases by a factor of 2. How will the rate of the reaction change if the concentration of the other reactant is halved? Explain. ***(1 point)***

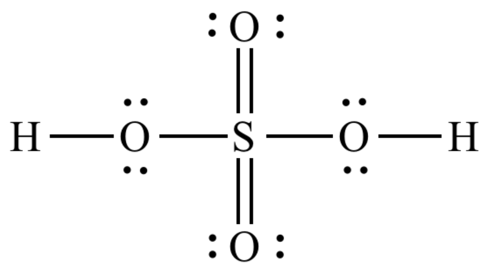
With respect to the first reactant, the rate is first order since the rate increases by a factor of 2 as the concentration of the reaction doubles. Since the reaction is fourth-order overall, the exponents of the individual reactant orders must sum to 4. Thus, **the second reactant has an order of 3. If the concentration of the second reactant is halved, the rate will decrease by a factor of 8**.

+1 point for correctly stating that the rate will decrease by a factor of 8 because the other reactant must be third order

Problem #2: ***(12 points)***

The majority of Venus's atmosphere is made up of carbon dioxide gas, $CO_2(g)$. Thick clouds of gaseous sulfuric acid, $H_2SO_4(g)$, trap heat and cause a runaway greenhouse gas effect.

a. Draw the most preferred Lewis structure of H_2SO_4 with minimized formal charges. ***(1 point)***



+1 point for correct Lewis structure

b. Name the geometry of the central S atom. ***(1 point)***

Tetrahedral

+1 point for correct answer

c. A sample of a cloud in the atmosphere of Venus is collected in an evacuated, heat-resistant 10.0 L container. The total pressure inside the container is 7,220 torr. 85% of that pressure is due to CO_2. The temperature inside the container is measured to be 37 °C. How many moles of H_2SO_4 are in the sample? Assume the gases are behaving ideally. ***(3 points)***

Dalton's Law of Partial Pressures:

$P_{total} = P_{CO2} + P_{H2SO4}$

7,220 torr = 0.85(7,220 torr) + P_{H2SO4} torr

P_{H2SO4} = 1,083 torr

Unit Conversions:

$P_{H2SO4} = 1,083\ torr \times \frac{1\ atm}{760\ torr} = 1.425\ atm$

V = 10.0 L

$R = 0.08206\ \frac{L\ atm}{mol\ K}$

$T = 37°C + 273.15\ K = 310.15\ K$

Ideal Gas Law:

$PV = nRT$

$(1.425\ atm)(10.0\ L) \ = \ n\ (0.08206 \frac{L\ atm}{mol\ K})(310.15\ K)$

n_{H2SO4} = 0.5599 mol

+1 point for correct substitution into Dalton's Law of Partial Pressure equation
+1 point for correct substitution into Ideal gas law equation
+1 point for correct final answer

d. If all of the H_2SO_4 gas collected in part (c) was distilled into liquid, what would the mass of this liquid be? ***(2 points)***

$0.5599\ mol\ H_2SO_4 \ \times \ \frac{98.079\ g}{1\ mol} \ = \ 54.91\ g\ H_2SO_4$

+2 points for correct answer

One common reaction that occurs in Venus's atmosphere is the synthesis of H_2SO_4 from sulfur dioxide, oxygen, and water.

e. Balance the following equation: ***(2 points)***

____2____SO_2 + ____1____O_2 + ____2____H_2O → ____2____H_2SO_4

+2 points for correctly balancing the equation

f. Recreating this synthesis in a lab back on Earth, chemists combine 17 mol of SO_2 and 20 mol of O_2 with an excess of water vapor. How many mL of H_2SO_4 are produced if the density of H_2SO_4 is 1.83 g/mL? ***(3 points)***

Limiting Reactant:

$17\ mol\ SO_2 \ \times \ \frac{2\ mol\ H_2SO_4}{2\ mol\ SO_2} \ = \ 17\ mol\ H_2SO_4$

$20\ mol\ O_2 \ \times \ \frac{2\ mol\ H_2SO_4}{1\ mol\ O_2} \ = \ 40\ mol\ H_2SO_4$

Limiting reactant is SO_2.

$17\ mol\ H_2SO_4 \ \times \ \frac{98.079\ g\ H_2SO_4}{1\ mol\ H_2SO_4} \ \times \ \frac{1\ mL}{1.83\ g} \ = \ 911.11\ mL\ H_2SO_4$

+1 point for solving for limiting reactant (SO_2)
+2 points for correct final answer

Problem #3: ***(17 points)***

The greatest amount of sunlight is emitted in waves with wavelengths around 500 nm, which is why the sun appears yellow. However, the sun also emits wavelengths of light in many other regions of the electromagnetic spectrum, such as the infrared, ultraviolet, and radio regions.

a. A wave of light with a frequency of $1.038 \times 10^{15}\ Hz$ is emitted from the Sun. What is the wavelength of this wave **in nanometers**? ***(2 points)***

$c = \lambda f$

$\lambda = \frac{c}{f}$

$\lambda = \frac{3.0 \times 10^{8}\ m/s}{1.038 \times 10^{15}\ Hz}$

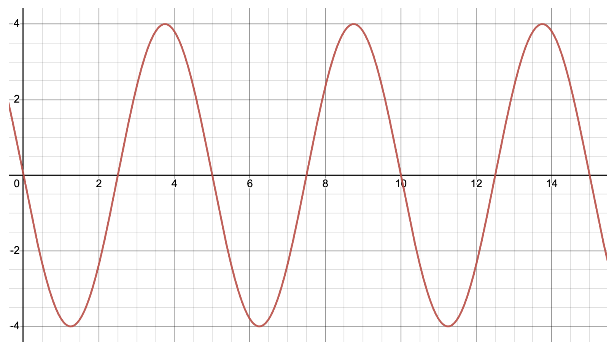
$\lambda = 2.89 \times 10^{-7}\ m$

$\lambda = 289\ nm$

+1 point for using $c = \lambda f$ equation

+1 point for correct final answer

b. The graph below plots the position of a point on a radio wave over time in picoseconds. Answer the following questions.



i. What is the wavelength of this photon? ***(3 points)***

Period of the wave (from the graph): 5 ps

Frequency of the wave: $\frac{1}{5\ ps} = \frac{1}{5 \times 10^{-12}\ s} = 2 \times 10^{11}\ Hz$

Wavelength:

$\lambda = \frac{c}{f} = \frac{3.0 \times 10^{8}\ m/s}{2 \times 10^{11}\ Hz} = 1.5 \times 10^{-3}\ m$

+1 point for reading the period of the wave off the graph (NOT frequency!)

+1 point for correct calculations of frequency of the wave

+1 point for correct final answer

ii. What is the energy of this radio wave? ***(2 points)***

$$E = hf = (6.626 \times 10^{-34} Js)(2 \times 10^{11} \frac{1}{s}) = 1.3252 \times 10^{-22} J$$

+2 point for correct final answer

c. A UV light wave with a wavelength of 259 nm emitted from the sun zooms through space and strikes a large piece of aluminum metal on Earth. Electrons are ejected with a maximum speed of $4.97 \times 10^{5} m/s$. Answer the following questions.

i. What is the work function of the aluminum metal in **electron volts (eV)**? ***(3 points)***

$$E = KE_{max} + \phi$$

$$hf = \frac{1}{2}mv_{max}^{2} + \phi$$

Finding frequency:

$$f = \frac{c}{\lambda} = \frac{3.0 \times 10^{8} m/s}{259\, nm \times \frac{1\, m}{10^{9}\, nm}} = 1.158 \times 10^{15} Hz$$

Finding KE_{max}:

$$KE_{max} = \frac{1}{2}(9.11 \times 10^{-31} kg)(4.97 \times 10^{5} m/s)^{2} = 1.125 \times 10^{-19} J$$

Finding ϕ:

$$\phi = hf - KE_{max} = (6.626 \times 10^{-34} Js)(1.158 \times 10^{15} \frac{1}{s}) - (1.125 \times 10^{-19} J)$$

$$\phi = 6.5479 \times 10^{-19} J \times \frac{1\, eV}{1.602 \times 10^{-19} J} = 4.087 \text{ eV}$$

+1 point for using $E = KE_{max} + \phi$ equation
+1 point for correct calculation of KE_{max}
+1 point for correct final answer

ii. If the electrons on the piece of aluminum metal absorbed 2.5 eV of energy, what speed would they be ejected with? Explain in 1-2 sentences. ***(2 points)***

The electrons would not be ejected at all because the electrons require at least 4.087 eV of energy to be removed from the aluminum atoms.

+1 point for stating that no electrons will be ejected
+1 point for stating that at least 4.087 eV of energy is required (2.5 eV is not enough)

d. The amount of energy it takes to remove an electron from an atom or ion is called an ionization energy. Rank the following atoms from lowest first ionization energy to highest. ***(1 point)***

Cl, As, N, S

(lowest) _____As_____ < _____S_____ < _____Cl_____ < _____N_____ (highest)

+1 point for correct ranking

e. After having been hit by a beam of UV light from the sun, a barium (Ba) atom's valence electrons are ejected. Name the ion and write out the complete ground state electron configuration for it, listing each orbital and the number of electrons present. ***(2 points)***

Ion: Ba^{2+}
Number of electrons: 54
Same electron configuration as the noble gas xenon

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^6$
Also acceptable: $[Kr]\ 5s^2 4d^{10} 5p^6$

+1 point for correct ion
+1 point for correct electron configuration

f. Another beam of UV light strikes a zirconium (Zr) atom, and electrons are ejected until there are 38 remaining. Name the ion and write out the ground state noble gas electron configuration for it. ***(2 points)***

Ion: Zr^{2+}
Number of electrons: 38
Noble gas: Kr (krypton)

$[Kr]4d^2$

Note: electrons are removed from the s-orbital of a transition metal before they are removed from the d-orbital

+1 point for correct ion
+1 point for correct electron configuration

<u>Problem #4</u>: *(12 points)*

Hydrogen is the most abundant element in stars. The light and heat produced in stars is from a process called Nuclear Fusion, in which two nuclei collide into each other in order to form a heavier new atom with a heavier nucleus.

a. Using the information above, what other element besides hydrogen is abundant in stars? Please explain your answer. ***(2 points)***

Helium

If two hydrogen nuclei collide together, the new element will have two protons. Therefore, helium is made.

+1 point for correct answer (stating helium)
+1 point for correct justificatio

b. Please write a possible equation of the process illustrated above and explain your reasoning. (Hint: Use "Energy" somewhere in the equation and use your answer to part (a)) ***(2 points)***

$H + H \rightarrow He + Energy$

When two elements add together, energy is released (exothermic) as a product with helium.

+1 point for correct equation
+1 point for correct justification

c. It is hypothesized that some redox reactions on interstellar dust grains have the ability to create various polyatomic species. Consider the redox equation below. Find the oxidation and reduction half reaction as well as the fully balanced redox reaction. ***(6 points)***

$$NiO_2 + Fe \Rightarrow Ni(OH)_2 + Fe(OH)_2 \text{ in basic solution}$$

Oxidation half reaction:

$$Fe \ + \ 2\,OH^- \ \rightarrow \ Fe(OH)_2 \ + \ 2e^-$$

+2 points for correct oxidation half reaction

Reduction half reaction:

$$NiO_2 \ + \ 2e^- \ + \ 2H_2O \ \rightarrow \ Ni(OH)_2 \ + \ 2OH^-$$

+2 points for correct reduction half reaction

Fully balanced equation:

$$NiO_2 \ + 2H_2O \ + \ Fe \ \rightarrow \ Ni(OH)_2 \ + \ Fe(OH)_2$$

+2 points for correct fully balanced reaction

+1 point if the reduction and oxidation half reactions are switched (first 4 points are not possible)

d. Spectroscopy is a technique used by astronomers to measure electromagnetic radiation from celestial objects. A spectrum of colors can be displayed and allow astronomers to predict what kinds of elements are in that celestial object. Suppose you had a wavelength that measured 560 nm. How much energy is released **in joules**? ***(2 points)***

$$E \ = \ \frac{hc}{\lambda} \ = \ \frac{(6.626 \times 10^{-34})(3.0 \times 10^{8})}{560 \ nm \times \frac{1\ m}{1 \times 10^{9}\ nm}} \ = \ 3.54964286 \ \times 10^{-19}\ \text{J}$$

+1 point for correct answer
+1 point for correct units

Problem #5: ***(14 points)***

On Earth, sulfur dioxide (SO_2) is naturally produced by volcanoes. This also happens to be the case on other terrestrial planets, such as Venus, and even Jupiter's moon Io. The story is completely different on gas giants such as WASP-39b, an exoplanet in the WASP-39 system with an equilibrium temperature of approximately 1100 K. The James Webb Space Telescope observed WASP-39b using its NIRSpec instrumentation and found an unexplained peak with a wavelength of 4.05 μm. The researchers working on this project were interested in determining if SO_2 was responsible for this peak and how it could be generated in WASP-39b's atmosphere.

a. In an H_2 rich atmosphere, the primary sulfur species is H_2S.

i. What is the oxidation state of sulfur in H_2S? ***(2 points)***

-2

+2 points for correct oxidation state

ii. What is the oxidation state of sulfur in SO_2? ***(2 points)***

+4

+2 points for correct oxidation state

iii. Can redox chemistry explain the generation of SO_2? Explain in one sentence. ***(2 points)***

Yes, the oxidation state of the sulfur changes when it goes from H_2S to SO_2, meaning redox chemistry occurred.

+1 point for correct answer (stating yes, with some kind of justification attempt)

+1 point for correct justification

b. The researchers studying the WASP-39b atmosphere proposed a free-radical based mechanism to explain their observations.

i. Define "free-radical." ***(2 points)***

A chemical species with unpaired electrons

+2 points for correct answer ("unpaired electrons" must be stated)

ii. The first step of the researchers' proposed mechanism generates a hydrogen and a hydroxyl radicals through photolysis according to the equation shown below:

$$H_2O \xrightarrow{hv} HO\cdot + H\cdot$$

Given the starting materials of 2 equivalents of H_2O and 1 equivalent of H_2S, propose a series of reactions using free-radical intermediates to yield 1 equivalent of SO_2 and 3 equivalents of H_2. (hint: one of the key intermediates in the process include the $S^{-\cdot}$ radical) ***(6 points)***

$$H_2O \xrightarrow{hv} HO^{\cdot} + H^{\cdot}$$

$$H_2O + H^{\cdot} \longrightarrow HO^{\cdot} + H_2$$

$$H_2S + H^{\cdot} \longrightarrow HS^{\cdot} + H_2$$

$$HS^{\cdot} + H^{\cdot} \longrightarrow \bar{S}^{\cdot} + H_2$$

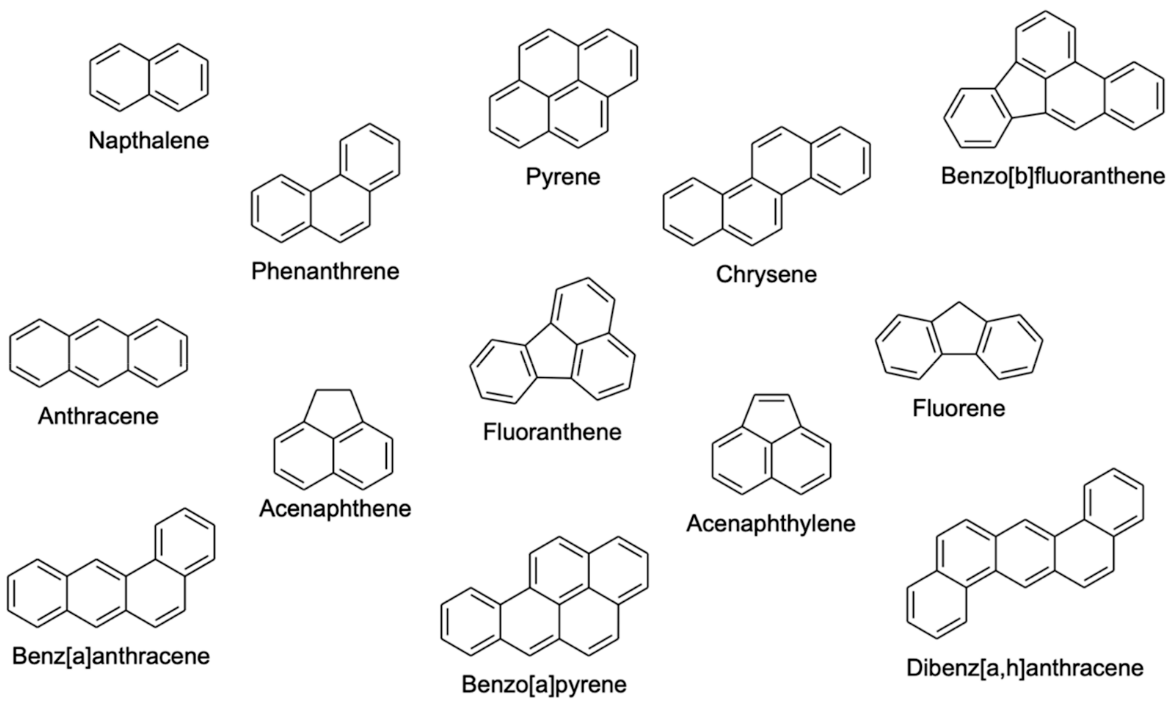
$$\bar{S}^{\cdot} + HO^{\cdot} \longrightarrow SO + H^{\cdot}$$

$$SO + HO^{\cdot} \longrightarrow SO_2 + H^{\cdot}$$

+1 point for each line of the reaction (maximum of 6 points)

Problem #6: ***(15 points)***

Most of the carbon in space is thought to exist in a form of molecules called polycyclic aromatic hydrocarbons (PAHs). Since the 1980s, evidence has shown that these molecules are abundant in space. However, they have not yet been directly observed. This speculative hypothesis, called the PAH World Hypothesis, proposes that polycyclic aromatic hydrocarbons are abundant in our universe today.



a. Explain why PAHs show low solubility in water. ***(2 points)***

Many correct answers: presence of aromatic rings, nonpolar molecules, nonpolar C-H bonds
**** Note: any reasonable answers will be accepted*

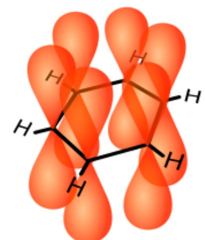
+2 points for at least one correct reason

b. Of the molecules that are shown above, which one has the lowest boiling point? ***(2 points)***

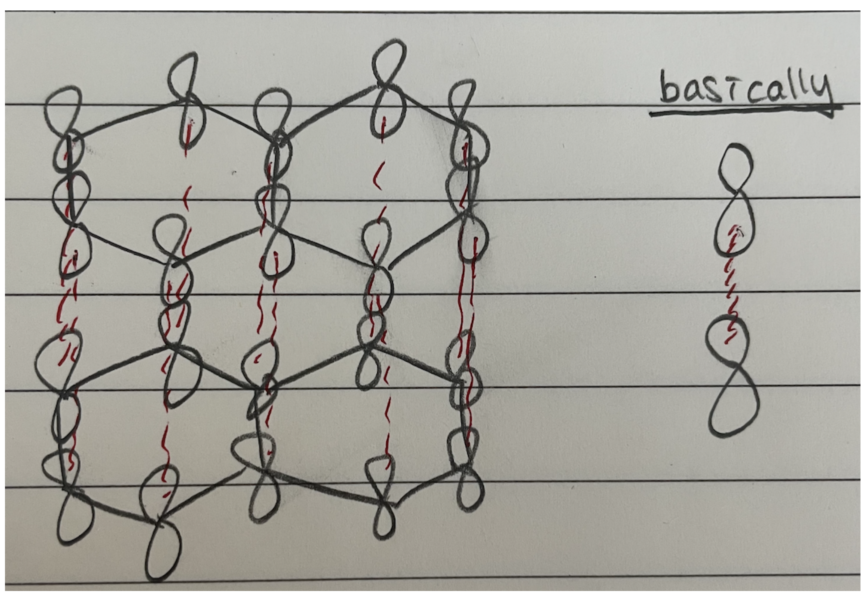
Naphthalene (smallest London Dispersion Forces)
**** Note: no explanation required for full-credit*

+2 points for correct answer

c. Aromatic molecules show π–π stacking (pi-pi stacking) interactions. π–π stacking refers to the attractive, noncovalent interactions (orbital overlap) between the p-orbitals of aromatic rings. The 6 p-orbitals of benzene are shown below. In the π–π stacking interaction for 2 benzene molecules, the 6 p-orbitals of one benzene molecule perfectly stack on top of the 6 p-orbitals of the other benzene molecule. Draw the full π–π stacking interaction between 2 anthracene molecules. ***(4 points)***

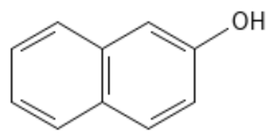


6 p-orbitals



+2 points for drawing 2 molecules of anthracene
+2 points for stacking the 2 anthracenes perfectly on top of each other with p-orbitals in the correct orientation shown

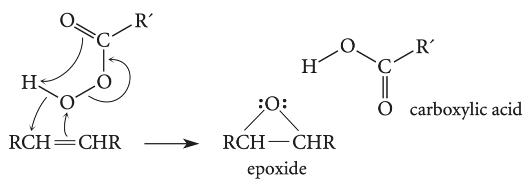
d. When PAHs are subject to ionizing radiation like solar UV light, one of the outer hydrogens can get stripped off and get replaced by a hydroxyl (an -OH) group. If naphthalene is exposed to solar UV light, draw what the final molecule would look like. ***(2 points)***

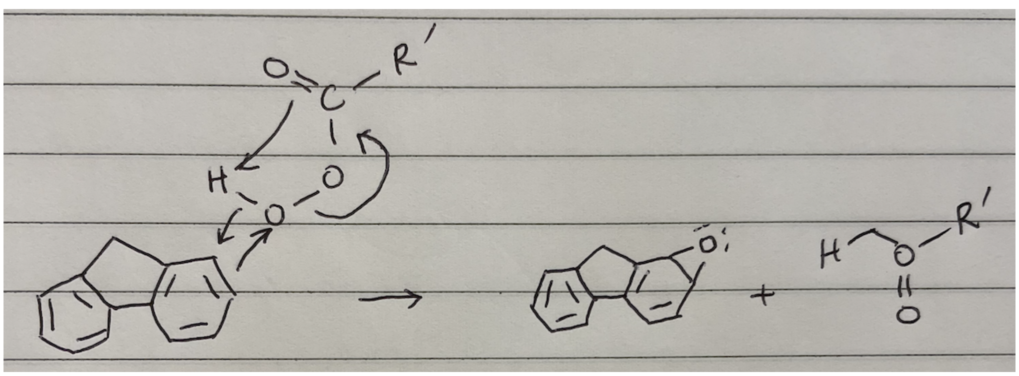


***Note: Although the molecule above is the most favorable product, the hydroxyl group can be added anywhere in the molecule.*

+2 points for correct answer

e. One common modification that occurs on PAH molecules is epoxidation, which will make PAHs more reactive. Peroxycarboxylic acids are commonly used in epoxidation reactions. The full mechanism of epoxidation by peroxycarboxylic acids is shown below. Draw out the mechanism of epoxidation on fluorene in the presence of peroxycarboxylic acid. ***(3 points)***





*** Note: The epoxide can be formed on any double bond*

+1 point for drawing fluorene and peroxycarboxylic acid

+1 point for showing the arrow pushing mechanism

+1 point for correct final drawing

f. Looking at the structure of epoxides, why are epoxides such reactive molecules? ***(2 points)***

The molecule is locked into place in a highly unfavorable ring. There is a huge amount of ring strain, making the molecules very unstable and highly reactive.

+1 point for mentioning ring strain

+1 point for stating that because of the ring strain, the molecule is unstable and reactive

Problem #7: ***(16 points)***

During the Big Bang, only the lightest elements were formed. The rest of the elements were formed through nuclear reactions. An example of an element formed in the Big Bang is hydrogen. Hydrogen has some stable isotopes. Deuterium, also called a heavy hydrogen, is an isotope of hydrogen with a nucleus that contains 1 proton and 1 neutron. The amount of deuterium made in Big Bang is about 10^{-5} of the amount of hydrogen produced. However, in recent years, observational results reveal that many interstellar molecules contain many deuterium atoms. These species have an abundance ratio compared to their fully hydrogenated forms. This enhancement in the ratio of D/H is due to a process called fractionation.

a. One of the important reactions involved in fractionation is:

$$H_3^+ + HD \rightleftarrows H_2D^+ + H_2$$

i. Assume that the left-to-right reaction is exothermic with $\Delta H = -230kJ$ and the reaction happens at a temperature of 10K, calculate the entropy of the surroundings. ***(2 points)***

$$\Delta S_{surr} = -\frac{\Delta H}{T} = -\frac{-230kJ}{10K} = 23,000 J/K = 23\ kJ/K$$

+1 point for using the entropy equation
+1 point for correct final answer

ii. Assuming that this reaction involves only gaseous molecules, predict the change in positional entropy in this reaction. Does it increase, decrease or stay the same? Justify your answer. ***(2 points)***

In general, when a reaction involves gaseous molecules, the change in positional entropy is dominated by the relative numbers of molecules of gaseous reactants and products. Therefore, since in this reaction, the number of molecules of gaseous products and reactants are the same, the positional entropy in this reaction is expected to stay the same.

+1 point for correct answer (stating that positional entropy stays the same)
+1 point for stating that the number of molecules of products and reactants are the same

iii. At temperatures of cold interstellar clouds of 10K, the reverse reaction is inhibited. Explain why this happens in terms of Le Chatelier's Principle. ***(2 points)***

Since the reaction is exothermic, the reverse reaction is endothermic. A cold temperature will cause the equilibrium to favor the direction of the exothermic reaction. Therefore, the reverse reaction is unfavorable, and this explains why the reverse reaction is inhibited.

+1 point for stating that the reverse reaction is endothermic
+1 point for stating that this makes the reaction shift to the right (forward)

Deuterium can participate in a nuclear fusion reaction called deuterium-tritium fusion, which is one of the most efficient types of fusion for fusion devices used in power generation. (Tritium is an isotope of hydrogen with a nucleus that contains 1 proton and 2 neutrons).

b. Given that in deuterium-tritium fusion, one deuterium atom fuses with one tritium atom to produce a helium atom with 1 neutron and 17.59 MeV of energy, write down the balanced equation for this nuclear reaction. ***(1 point)***

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n + 17.59\,MeV$$

+1 point for correct balanced equation

c. Since large quantities of energy are produced in nuclear fusion, scientists are trying to develop a feasible fusion process for energy generation. However, a major obstacle is that high temperatures are needed to initiate nuclear fusion. Explain why high temperature is necessary to initiate this reaction. ***(3 points)***

Since the forces that bind the nucleons only act at very short differences, in order for nuclear fusion to occur, **(Key Concept 1)** the two atoms have to get very close together to fuse and release energy. However, **(Key Concept 2)** since protons in both atoms are positively charged, there will be large electrostatic repulsive force between the two atoms. Therefore, **(Key Concept 3)** to counteract the effect of electrostatic repulsive force, a high temperature is needed to give the two atoms a large enough velocity to collide with enough energy to let the nuclear forces bind the two atoms together and cause fusion.

**** Note: other reasonable justifications will also be accepted*

+1 point for Key Concept 1: atoms have to get very close to fuse
+1 point for Key Concept 2: positively charged protons exert large electrostatic repulsive forces on each other
+1 point for Key Concept 3: high temperature is needed to get the two atoms moving fast enough to collide

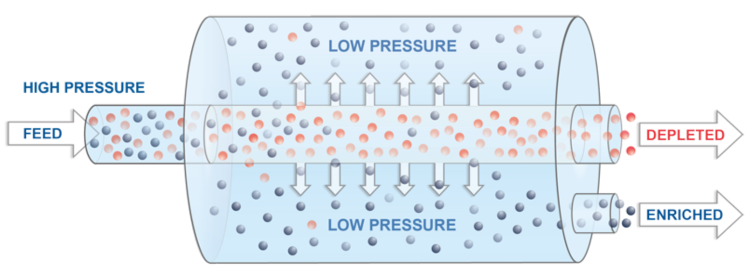
Another type of nuclear reaction process is nuclear fission, which is more stable than nuclear fusion and is used in all nuclear power plants. The most common substance used in the nuclear fission process is uranium-235. However, most of the natural uranium is uranium-238, which is non-fissionable, and there's only about 0.72% of uranium-235 by mass. In order to conduct nuclear fission, the amount of uranium-235 needs to be increased to about 3%. To enrich uranium-235, a process called gaseous diffusion is used.

d. In the diffusion process, natural uranium reacts with fluorine to form UF_6, and the gaseous diffusion process is based on Graham's law, which is an empirical law that states that the rate of effusion of a gas is inversely proportional to the square root of the mass of its particles ($\frac{Rate\ of\ effusion\ for\ gas\ 1}{Rate\ of\ effusion\ for\ gas\ 2} = \frac{\sqrt{M_2}}{\sqrt{M_1}}$). Given that fluorine only has one natural and common isotope, explain its significance in relation to Graham's law. ***(3 points)***

Graham's law states that the rate of diffusion of a gas is inversely proportional to the square root of its molar mass. Therefore, the difference in the rate of diffusion between $^{235}UF_6$ and $^{238}UF_6$ is solely due to the difference in mass between ^{235}U and ^{238}U, since fluorine has only one isotope which wouldn't cause any difference in molar mass.
**** Note: other reasonable justifications will also be accepted*

+3 points for reasonable justification

e. Using the given image below, explain the process of enrichment through the concepts in Graham's law. ***(3 points)***



According to Graham's law, the lighter $^{235}UF_6$ gas molecules have a faster rate of diffusion than the heavier $^{238}UF_6$ gas molecules. Therefore, the lighter $^{235}UF_6$ gas molecules will be moving at higher speed, and therefore create lower pressure. According to the image above, the gas molecules with average higher speed and lower pressure will pass through a separate stream, and this stream will contain enriched uranium gas which contains more $^{235}UF_6$ gas molecules.
**** Note: other reasonable justifications will also be accepted*

+3 points for reasonable justification