HARD PACKET 1

Team ID Number: ________________________

Physical Properties

The Clausius Clapeyron Equation describes the relationship between vapor pressure and temperature:

$$ln(P) = -\frac{\Delta H_{vap}}{RT} + C$$

where C is constant at all temperatures; ΔH_{vap} = 40.65kJ/mol.

Suppose there is a closed container of water at an external pressure of 1.0 atm. *What is the vapor pressure of water at 90 ℃?*

HARD PACKET 1

Team ID Number: ________________________

Equilibrium

A scientist is performing an experiment an unknown metal hydroxide, $X(OH)_{3,}$ where X is an unknown metal. He finds that when $X(OH)_3$ is completely dissolved in 0.010 M NaOH, the pH of the solution is 12.74. *What is the molar solubility of $X(OH)_3$ in pure water*?

HARD PACKET 1

Team ID Number: ______________________

Electrochemistry

A Galvanic cell Cu (s), CuBr (s)| Br^- (1.0 M) || Cu^+ (0.10 M) | Cu (s) at 298 K has a measured cell potential of 0.377 V. Given that the half-reaction:

$$Cu^+ (aq) + e^- \rightarrow Cu (s) \qquad \varepsilon^\circ_{red} = 0.522V$$

Calculate K_{sp} for CuBr(s) at 298 K.

HARD PACKET 2

Team ID Number: ________________________

Physical Properties

Some scientists attempt to build a weather balloon filled with CO_2 and O_2. They fill the balloon with 11.5 L of CO_2 gas at an initial pressure of 60.0 torr and 21.5 L of O_2 gas at an initial pressure of 50.0 torr. Once fully expanded, the balloon occupies 33.0L of volume. Assuming that the temperature of the gases remains constant and that the two gases behave ideally, *what is the expected final pressure of the CO_2 gas in this mixture?*

HARD PACKET 2

Team ID Number: ________________________

Thermodynamics

On Planet Laberstros, the chemicals Ờ and Ự can combine into $Ờ_2Ự$ by the following equilibrium process:

Reaction 1: $2Ờ(aq) + Ự(aq) \rightleftarrows Ờ_2Ự(aq)$

Scientists on Earth have compiled a table of useful information regarding these elements:

ΔG^o	-16.5 kJ/mol
Specific heat capacity of Ờ	$C_{Ờ}$=4.0 J℃$^{-1}$g^{-1}
Specific heat capacity of Ự	$C_{Ự}$=4.32 J℃$^{-1}$g^{-1}
Specific heat capacity of $Ờ_2Ự$	$C_{Ờ_2Ự}$=4.3 J℃$^{-1}$g^{-1}
Heat capacity of water between 0℃ and 100℃, assume constant for all concentrations of solutes	C_w=4.184 J℃$^{-1}$g^{-1}

The ΔG value can be determined for any temperature using the following equation:

$$\Delta G(kJ/mol) = 0.00072T^2 - 0.008T - 78.05$$

All of the chemicals are completely soluble in water. The solvation of all these chemicals is a very exothermic process. Below is a table of the enthalpy of solvation and molar mass for the chemicals:

Chemical	H_{solv} (kJ/mol)	Molar Mass (g/mol)
Ờ	-8.87	73.6
Ự	-7.32	145.6
$Ờ_2Ự$	-10.68	292.8

An Earth scientist adds 50.0 g of Ờ, 50.0 g of Ự, and 50.0 g of $Ờ_2Ự$, to 500.0 mL of water at 298 K and 1.0 atm. The chemicals dissolve completely in water. The scientist observes that the final volume of water is 600.0 mL. Assume that the density of the solution is approximately 1.0 g/mL. *What are the concentrations of each chemical when the solution reaches equilibrium?*

HARD PACKET 2

Team ID Number: ________________________

Chemical Reactions

The sequential redox reductions of vanadium are given below:

$$2\ VO_2^+\ (aq) + 4\ H^+\ (aq) + Zn\ (s) \rightarrow 2VO^{2+}\ (aq) + Zn^{2+}\ (aq) + 2H_2O\ (l)$$
$$2VO^{2+}\ (aq) + 4\ H^+\ (aq) + Zn\ (s) \rightarrow 2V^{3+}\ (aq) + Zn^{2+}\ (aq) + 2H_2O\ (l)$$

A bunch of scientists has a supply of 11.1 mL of a 0.0035 M solution of VO_2^+ and 0.0020 g of Zinc metal on hand. *Determine if this amount of Zinc metal is enough to fully reduce all the* VO_2^+*. If it is not enough, how many more grams of zinc metal are required?*

HARD PACKET 3

Team ID Number: ________________________

Acid/Base

Phosphoric Acid, H_3PO_4, is a triprotic acid, which means that it can lose all three of its hydrogens. High school students perform a titration experiment, titrating 55.0 mL of 2.0 M H_3PO_4 with 1.0M NaOH. *Calculate the pH of the solution when 188.0 mL of NaOH is added.*

$$K_{a1} = 7.5 \times 10^{-3}$$
$$K_{a2} = 6.2 \times 10^{-8}$$
$$K_{a3} = 4.8 \times 10^{-13}$$

HARD PACKET 3

Team ID Number: ______________________

Thermodynamics

Spaceships can use potassium superoxide to convert carbon dioxide into oxygen during long voyages. The balanced equation is given below:

$$2KO_2\,(s) + CO_2\,(g) \rightarrow K_2CO_3\,(s) + 1.5O_2\,(g) \qquad \Delta G° = -30 \text{ kJ/mol}$$

NASA wants to use the energy generated by this exothermic reaction to help power the journey of the spacecraft. A grown adult creates about 1.0 kg of carbon dioxide a day, while a spacecraft needs about 55.24 W to maintain operation of electrical equipment in deep space. *How many astronauts are needed to provide enough carbon dioxide to power the spaceship?*

HARD PACKET 3

Team ID Number: ________________________

Kinetics

In an iodine clock experiment, students measure the time required for a mixture of two 0.080 M solutions, solution A and solution B, to change colors. In the first trial, the mixture had a total of 20.0 mL, composed of an equal mixture of solution A and solution B, and took 10 minutes to change colors. In the second trial, the mixture also had a total volume of 20.0 mL but was composed of 10.0 mL of solution B, 8.0 mL of solution A, and 2.0 mL of distilled water. Assuming that the speed of the reaction follows the formula rate of reaction = $k[A]^2[B]$, *how long does it take for the second trial to change colors?*

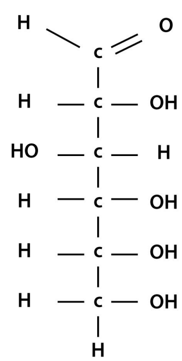
HARD PACKET 4 Team ID Number: ________________________

Thermodynamics

Recently, your friend Daniel has decided to gain a lot of muscle. However, he has resorted to fixing up his diet rather than exercising and is currently deciding what type of sweetener to place in his morning coffee. *How much energy, in kJ/g, does the lowest calorie sweetener offer to Daniel's body?* Assume Daniel's body is perfectly efficient and metabolizes everything into the component molecules' standard state without any loss of energy.

Sweetener	**Chemical Formula**
1. Glucose	$C_6H_{12}O_6$
2. Pyruvate	$C_3H_4O_3$
3. Aspartic Acid	$C_4H_7NO_4$

1.



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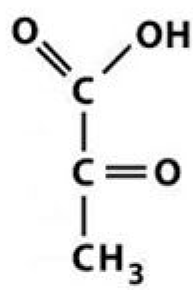

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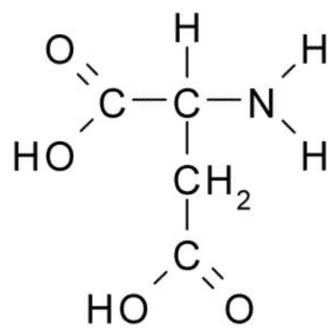


2.

Use the following table to help answer this question:

Bond	**Energy (kJ/mol)**	**Bond**	**Energy (kJ/mol)**
C-O	358	C-H	413
C=O	745	N-H	391
C-N	293	O-H	463
C-C	348		

HARD PACKET 4

Team ID Number: ________________________

Chemical Reactions

The Ostwald process is used to make nitric acid (HNO_3) from ammonia (NH_3). The first step produces one of the precursor reactants, nitric oxide (NO) and typically involves a metal catalyst. The first step of the unbalanced reaction is shown below:

$$NH_3\ (g) + O_2\ (g) \rightarrow NO\ (g) + H_2O\ (g) \text{ (for the balanced reaction, } \Delta H = -905.2\text{kJ)}$$

This reaction occurs only at a pressure between 4.0 atm to 10.0 atm and a temperature of 500 K. A 2.0 L rigid container is heated to 500 K. In the container, the partial pressure of both ammonia and oxygen is 1.5 atm while the partial pressure of an inert gas is 1.0 atm. *When the reaction is complete, how much energy is evolved as heat? How much energy is evolved as work?*

HARD PACKET 4

Team ID Number: ________________________

Electrochemistry

WUCT, the Washington University Chemistry Tournament, is petitioning WashU to cut the entire landscaping budget and delegate all horticulture duties to WUCT. Because WUCT cannot afford to buy water for the grass, the following half reaction will be used to generate water instead:

$$4H^+ + O_2 + 4e^- \rightarrow 2H_2O.$$

To facilitate this reaction, liquid mercury (which for some reason is cheaper than water) is loaded into the sprinkler system and sprinkled onto the grass, providing the electron source for the water generating reaction using this half reaction below:

$$Hg \rightarrow Hg^{2+} + 2e^-$$

Assume the concentration of mercury ions in WashU soil is at 1.0 M and that the temperature is 298 K. *What is the highest pH WashU soil can have before this method is no longer a feasible way to produce any water?*

HARD PACKET 5

Team ID Number: ________________________

Equilibrium

8.67 g of calcium oxide (CaO), a white powder, is dissolved in 500.0 mL of water under a certain condition. 6.48 g of a white precipitate form in the solution. *What is the K_{sp} of the white precipitate under these conditions?*

HARD PACKET 5

Team ID Number: ________________________

Electrochemistry

You've run out of aluminum foil while camping, but luckily you have a solution of aluminum nitrate and the supplies to set up an electrochemical cell (aren't camping chemists just the best?). *Calculate the current (in Amps) you should use in your cell if you want to plate 100.0 g of Al in 210 minutes, so you can make dinner before the sun goes down.*

HARD PACKET 5

Team ID Number: ________________________

Acid/Base

Hexaflurosilicic acid (H_2SiF_6) is often added to water as a way to fluorinate the American water supply. This acid is very strong, and the first deprotonation goes to completion. The second deprotonation has a pKa of -0.45. The salt of hexafluorisilic acid (e.g. Na_2SiF_6) will dissociate into 6 free fluoride ions, resulting in the fluoridation of the water. However, this reaction only occurs near neutral pH. If WUCT wishes to have 1.0ppm fluoride ions in its 500.0L drinking water (which they still can't afford) in environmentally friendly water bottles*, how many grams of hexaflurosilicic acid should be added? What volume of 1.0M NaOH should be added?* (Note that 1.0M = 3.55×10^4ppm)

HARD PACKET 6

Team ID Number: ________________________

Physical Properties

Excess BaF_2 was placed in 250.0 mL of 0.50 M NaF and heavy water solution with a density of 1.11 g/cm^3. *By how many degrees Celsius was the freezing point lowered by BaF_2?*
K_{sp} of BaF_2 is 1.84×10^{-7} Freezing point depression constant of heavy water is 1.86 ºC per molal.

HARD PACKET 6

Team ID Number: ______________________

Equilibrium

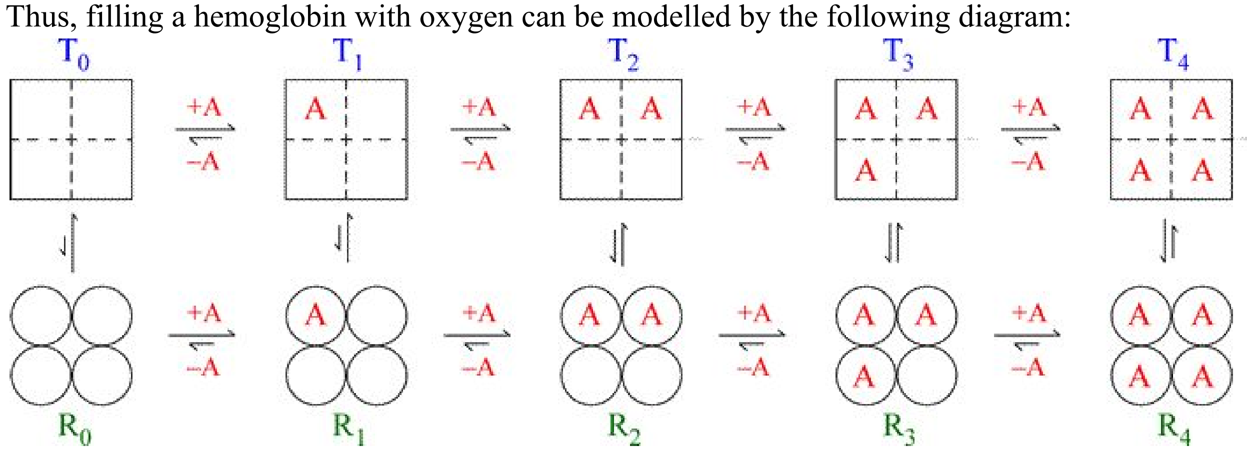
The Symmetry Model of Allosteric Behavior is a model used to describe hemoglobin. Hemoglobin is a four-subunit enzyme whose main function is to bind oxygen. It has two conformations, a low affinity state called Taut (T) and a high affinity state called Relaxed (R). At a given time, all the subunits of a single subunit are in the same conformation, but can switch between the forms as dictated by equilibrium. When no oxygen is bound, equilibrium largely favors the T form. The diagram below demonstrates the conformations of hemoglobin. This interaction is given by the following equilibrium reaction:

$$R_0 \leftrightarrows T_0 \;;\; K_0 = 1.0 \times 10^5$$

Oxygen binding can also bind and dissociate from hemoglobin in an equilibrium reaction. This is given by the following dissociation reaction:

$$RO \leftrightarrows R + O \;;\; K_R = 2.5 \times 10^{-2}$$
$$TO \leftrightarrows T + O \;;\; K_T = 1.0$$

Thus, filling a hemoglobin with oxygen can be modelled by the following diagram:



Recall that equilibrium is a state function. *What is the equilibrium constant, K_4, between T_4 and R_4? Does this favor the T conformation or the R conformation?*

HARD PACKET 6

Team ID Number: ________________________

Kinetics

Planet X, home to a dizzying number of gaseous molecules, are the subject of heavy experimentation. A common reaction in the atmosphere is shown below:

3¥ + 2§ → 2JƱ $\qquad E_a = 47.0$ kJ/mol

Another substance deep in the core of the planet, simply listed as टॆ, can reduce the activation energy of this reaction by a factor of 3. *What is the mathematical relationship between the reaction in the core with टॆ (k_2) and the reaction in the atmosphere without टॆ (k_1)?*

HARD PACKET 7

Team ID Number: ________________________

Equilibrium

A 1.0L solution consisting of 20.0% propanol (C_3H_8O, density = 0.803 g/cm^3) and 80.0% water by mass is surrounded by an atmosphere with a partial pressure of 10.0 atm O_2, and a partial pressure of 1.0 atm CO_2. *Find the reaction quotient (Q_c) for this initial mixture, considering the unbalanced chemical equation:*

$$C_3H_8O\ (aq) + O_2\ (g) \rightarrow CO_2\ (g) + H_2O\ (l)$$

(The Henry's law constant for O_2 in water is 1.28×10^{-3} mol · L^{-1} · atm^{-1}, and the Henry's law constant for CO_2 in water is 3.1×10^{-2} mol · L^{-1} · atm^{-1}.)

HARD PACKET 7

Team ID Number: ________________________

Acid/Base

0.50 M aqueous solution of $HCOO^-$ is allowed to equilibrate at 200.0 ˚C. Given that the K_a of HCOOH is 2.95×10^{-5} at 200 ˚C, K_w at 200.0 ˚C is 4.9×10^{-12}, and that the following equilibrium concentrations result, *what are the pH and pOH of a 0.15 M aqueous solution of HCOOH at 200.0 ˚C?*

HARD PACKET 7 Team ID Number: ________________________

Kinetics

PET Imaging, or Positron Emission Tomography, takes advantage of radioisotopes to image the human body to aid in medical diagnosis. One common substrate used is fludeoxyglucose (FDG), which contains an atom of fluorine-18 (^{18}F) and is an analogue of glucose (i.e. it is chemically similar to glucose, a component of sugar). The half life of fluorine-18 is 110 minutes; when the fluorine-18 decays, the FDG molecule is no longer detectable. Once FDG is in the cell, it is phosphorylated by hexokinase through an SN2-like mechanism, and therefore cannot leave the cell. Unlike glucose, however, FDG cannot be metabolized. Neuroscientists observed that glucose (and therefore FDG) is taken up by tumors more quickly than regular tissue. They observed that at some time, t = 0 minutes, there is 500.0 μM in a tumor cell and 200.0 μM in a regular cell of the same type. Then, at another time, t = 157 minutes, they observed that the tumor cell had 2.0 mM while the regular cell had 600.0 μM. *Assuming the rate of glucose and FDG uptake are the same, what is the ratio of the average rate of glucose uptake between the tumor cell and the regular cell?*

HARD PACKET 8

Team ID Number: ________________________

Physical Properties

Give the full name of the compound and the charge of the ion complexes.

a) $Li_3[CuCl_3Br_3]$
b) $Ca_2[Pt(C_2O_4)_4]$
c) $[Ag(NH_3)_4(H_2O)_2]Cl$
d) $Na[Fe(CN)_2(OH)_2]$

HARD PACKET 8

Team ID Number: ______________________

Equilibrium

The EPA has set safe levels of Ba^{2+} ions in drinking water to be 2 ppm. WUCT's backup dog trainer (Dr. Poupon DeGrasse) wisely spilled enough $BaCl_2$ into his well of initially pure water to raise the concentration to 20.0 ppm. To correct this, Dr. DeGrasse adds some ammonium sulfate to the well, such that the initial concentration of ammonium sulfate is 2.158 μM in the well. *If the K_{sp} of the precipitate is 1.1×10^{-10}, what will the resulting concentration of Ba^{2+} be, in ppm, at equilibrium?* Assume that density of solutions is 1.0g/mL.

HARD PACKET 8

Team ID Number: ________________________

Acid/Base

Phenolphthalein is a commonly used indicator in titration reactions, which works as a weak base. For phenolphthalein, pK_{ind}= 9.3. However, phenolphthalein begins changing color at a pH of 8.3. If we started with 250.0ml of pure water, *how many moles of phenolphthalein must be added to change the color of the solution?*

HARD PACKET 9

Team ID Number: ________________________

Thermodynamics

A list of reactions is provided for you:

Reaction	**ΔH° (kJ/mol)**
$2H_2 + CO \rightarrow CH_4 + \frac{1}{2} O_2$	36.0
$H_2O\ (l) \rightarrow \frac{1}{2} O_2\ (g) + H_2\ (g)$	286
$CH_4\ (g) + CO_2\ (g) \rightarrow H_2\ (g) + 2CO\ (g)$	247
$CO_2\ (g) + H_2\ (g) \rightarrow CO\ (g) + H_2O\ (g)$	41.0
$H_2O\ (l) \rightarrow H_2O\ (g)$	44.0

Determine ΔH° of the following reaction:

$$CH_4\ (g) + 2O_2\ (g) \rightarrow CO_2\ (g) + 2H_2O\ (g)$$

HARD PACKET 9

Team ID Number: ________________________

Acid/Base

Consider 50.0mL of a solution of weak acid, HA, ($K_a = 1.0\times10^{-6}$) which has a pH of 4.0. What volume of water must be added to change the pH of the solution to 5.0?

HARD PACKET 9

Team ID Number: ________________________

Kinetics

A reaction with a given rate constant occurs at room temperature, 25 °C, with an activation energy of 45.0 kJ/mol.

In experiment 1, Peeti raises the temperature of the reaction by 10.0 °C.
In experiment 2, carried out at room temperature, Peeti uses a catalyst that decreases the activation energy by 15.0 kJ.

What is the ratio of the rate constant of the reaction in experiment 2 to the rate constant of the reaction in experiment 1?