CHEMISTRY OF THE HUMAN BODY

WUCT 2018

Two students from each team will work together on this test for a total time of 60 minutes. A copy of the test will be provided to each student, but only one copy of the exam will be graded. Make sure all work and solutions are in the exam packet that you submit for grading. No work on scrap paper will be graded. Please answer the questions in the space provided, and use the back of the page if necessary. Explanations must be in complete sentences, diagrams must be labeled, and units must be shown throughout calculations for full credit. Partial credit will be awarded where appropriate. Please note that not all lone pairs are necessarily shown on every chemical structure. Proctors can answer procedural questions, but they will not answer questions about specific problems. Cheating is strictly prohibited -- please refer to our cheating policy for more information.

Student 1 ID	Student 2 ID
0 0 0 0	0 0 0 0
1 1 1 1	1 1 1 1
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3 3 3 3	3 3 3 3
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Team: ______________________________

Team ID: ___________________________

Student 1: __________________________

Student 2: __________________________

HUMAN BODY

Question 1 (10 points)

Gastric Acid, a combination of hydrochloric acid (HCl), potassium chloride (KCl), and sodium chloride (NaCl) is of vital importance in the human stomach, which must maintain specific pH values.

a. Human saliva contains sodium bicarbonate, which helps neutralize the hydrochloric acid in our stomach. Write the chemical equation for this reaction.

$HCl + NaHCO_3 \rightarrow NaCl + H_2O + CO_2$

+2 correct equation, no explanation needed, writing chemical names instead of formulae is acceptable.

b. The contents of Joey's stomach are modeled by combining 60 mL of 0.239M HCl and 40 mL of an unknown concentration of $NaHCO_3$ in a beaker. The pH of the resulting solution is 2.00. Calculate how many moles of bicarbonate are present. (K_a of sodium bicarbonate $= 4.37 \times 10^{-7}$)

Find $[H^+]$ total: 10e-2 = 0.01 M

(0.01 M)(0.1 L) = 0.001 mol H^+ final

(0.239M)(0.06 L) = 0.01434 mol H^+ from HCl

0.01434 mol H^+ - moles of bicarbonate = 0.001

Moles bicarbonate = **0.01334 mol**

+7 correct final answer with work

+1 correct units

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Question 2 (15 points)

Sweating, the human body's primary method of thermoregulation, is sometimes termed "evaporative cooling." This happens when a person experiences warm conditions such as during exercise.

a. Given that the $\Delta H_{vaporization}$ of water is relatively large, 2260 $J \cdot g^{-1}$, explain why sweating is an effective method for cooling the body.

Sweating is an effective method to cool down the body because it takes advantage of the relatively large $\Delta H_{vaporization}$ of water (+2). Heat from the body is able to be used to cause water to undergo a phase change from liquid to gas--which effectively removes heat from the body (+2). Due to this loss in heat, the body cools down, which is why sweating is often called "evaporative cooling" (+2).

b. The heat capacity (C) of the average person is 3.5 $kJ \cdot kg^{-1} \cdot °C^{-1}$. If a person with a mass of 80 kg has a body temperature of 37.5 °C, calculate how many grams (g) of *pure water* needed to have evaporate off the skin to cool to normal body temperature (37 °C).

$Q = mC\Delta t$

$(80\ kg)(\frac{3.5\ kj}{kg * °C})(37.5\ °C - 37\ °C) = 140\ kj$

140 kj of heat are required to cool to normal body temperature of 37 $°C$

$Q = m\Delta H_{vaporization}$

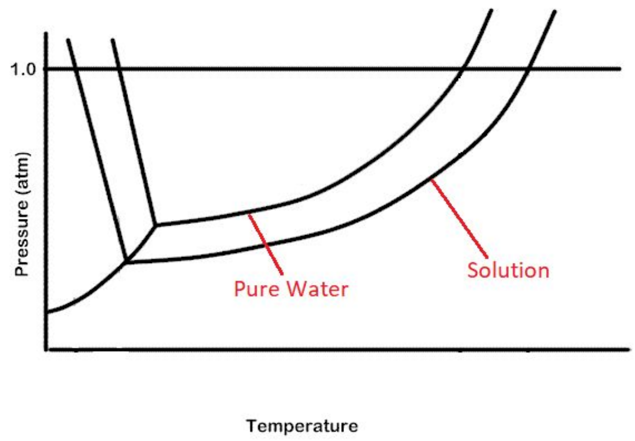
$140\ kj = m_{H2O}(\frac{2.26\ kj}{gram})$

$m_{H2O} = 61.9\ grams$

+1 correct equations
+1 correct plugging in
+1 correct answer
+1 units

HUMAN BODY

c. In reality, sweat consists of a wide variety of ions and molecules. Label the pure solvent and solution phase curves on the phase diagram below. Explain how you made your choice based on your knowledge of colligative properties, properties that depend only on the concentration of solute and not on its identity.



+2 correct labels (no partial)

Solution phase curve has the gas/liquid phase shifted towards the right to demonstrate a boiling point elevation given a constant external pressure (+3). **Or**, the examinee can argue the solid/liquid phase is shifted left, to demonstrate a freezing point depression at a given external pressure (+3).

HUMAN BODY

Question 3 (10 points)

The air that we breathe contains more than just oxygen. In fact, the majority of the air we breathe in is not oxygen. The percent composition of air by **mass** is shown in the table below.

Species	Percent by **mass**
N_2	75.52
O_2	23.14
Ar	1.29
CO_2	0.06

a. For this question, the lungs will be modeled using a balloon. Blowing air into the balloon is analogous to the lungs expanding from a breath of air. When inflated, the balloon is spherical with a diameter of 10 cm. The balloon is filled with air of temperature 291K. The total pressure exerted by the gas is 1.1×10^{-4} atm. Calculate how many moles of gas are taken into the "lungs" from this single breath.

Volume of the ballon: V = (4/3)pi(5 cm)^3= 523.6 cm^3 → 0.5236 L (standalone calculation not required)

PV = nRT → n = PV/RT

n = (1.1e-4 atm)(0.5236 L)/(0.08206 L atm K^{-1} mol^{-1})(291 K)

n = 2.41 x 10^{-6} mol

+3 correct equations and plugging in

+1 correct final answer

+1 units

b. The total pressure exerted on the lungs by a single breath is $1.1 \times 10^{-4} atm$. Calculate the partial pressure (in atm) exerted by O_2 inside the lungs.

Assume 100 total grams, $P_{total} \times \chi = P_i$

75.52g Nitrogen	/ (28g/mol) =	2.70 mol Nitrogen
23.14g Oxygen	/ (32g/mol) =	0.723 mol Oxygen
1.29g Argon	/ (40g/mol) =	0.0323 mol Argon
0.05g Carbon Dioxide	/ (44g/mol) =	0.00114 mol Carbon Dioxide
		3.46 Total moles

(0.723 mol O_2 / 3.46 total mol) * 100 = 20.9% molar composition of O_2

0.00011 atm * 0.209 = 0.000023 atm

+2 mole fraction calculation

+2 partial pressure calculation

+1 units

DO NOT WRITE BELOW THIS LINE

HUMAN BODY

Question 4 (15 points)

A research team at the Washington University School of Medicine recently developed drug A and drug B to target an area of the brain called the hypothalamus. Drugs A and B, like many drugs, operate under first order kinetics in the body.

a. Upon reading the bottle for drug A, you see that each pill contains 180 mg of active ingredient, and that the amount of active ingredient is expected to drop to 45 mg within 3 hours of ingestion.

   i. Using the information on the label of Drug A, calculate the half life (in hours) of Drug A.

$A = A_0(0.5)^{T/t}$ here T = time, and t = $t_{1/2}$

$45\ mg = 180\ mg\ (0.5)^{3\ hrs/t}$

$0.25 = (0.5)^{3\ hrs/t}$

$t = 1.5$ hours

Or: show that 180 mg → 90 mg → 45 mg is two half lives for the drug, and with the given time of 3 hours, the half life is 1.5 hours.

+4 either method

   ii. With your answer from part a.i., calculate the rate constant of Drug A, assume that it follows first order kinetics. If you were unable to answer a.i., you may use $t_{1/2} = 1.75$ hours.

If using $t_{1/2} = 1.5$ hr:

$t = \frac{ln\,2}{k}$

$k = \frac{ln\,2}{t} = \frac{ln\,2}{1.5\ hr}$

$k = 0.462\ hr^{-1}$

If using $t_{1/2} = 1.75$

$t = \frac{ln\,2}{k}$

$k = \frac{ln\,2}{t} = \frac{ln\,2}{1.75\ hr}$

$k = 0.396\ hr^{-1}$

+1 correct equation and plugging in
+1 correct final answer
+1 units

b. You learn that drugs A and B are synergistic, meaning when taken together, the overall effect is greater than the summed effects of each drug individually. A and B combine in an exothermic reaction: $A + 2B \rightleftharpoons C + Heat$. The table below shows several different experiments to determine the overall reaction rate of the drugs:

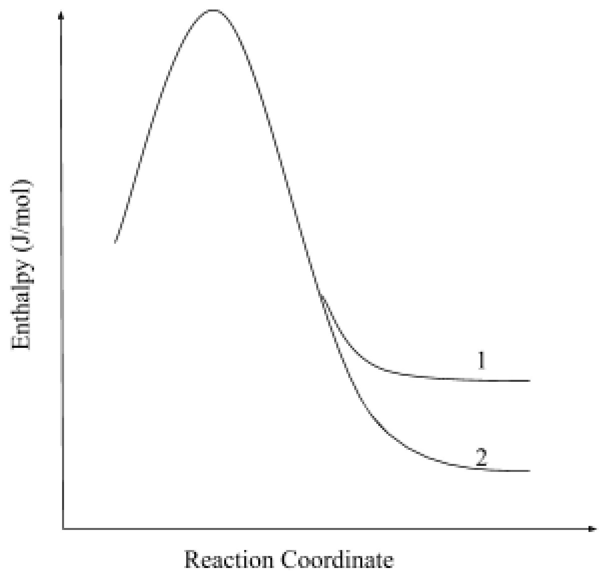
Trial	[A] (M)	[B] (M)	[C] (M)	Forward rate of reaction (M/s)
1	0.102	0.104	0.500	1.098
2	0.100	0.203	2.013	4.121
3	0.218	0.108	1.000	2.54
4	0.300	0.300	10.000	27
5	0.700	0.400	3.500	112
6	0.500	0.300	any number is possible	45

i. Based on the data above, fill in the blanks in the table and determine the rate law of the reaction. The rate law should be written in the form: rate=$k[A]^n[B]^m$.

Rate = $1000x[A][B]^2$

+1 determination that reaction is first order with respect to A
+1 determination that reaction is second order with respect to B
+1 determination of k (acceptable range: 985-1015)
+1 statement of full rate law equation
+1 filling in table

c. Refer to the reaction coordinate diagram below to answer the following question. Line 1 is the result when drug A is taken alone, and line 2 is when the drugs A and B are taken together. If the temperature of the reaction is increased, predict what would happen to the activation energy and the forward rate of reaction. Explain your reasoning. (hint: the Arrhenius equation might be helpful)



The activation energy would NOT change but forward rate of reaction would increase. Use Arrhenius equation $k = ae^{-e_A/RT}$ to find that k increases as T increases and remember that energy of activation is a constant.

+3 full answer addressing activation energy, forward rate, relevant changes

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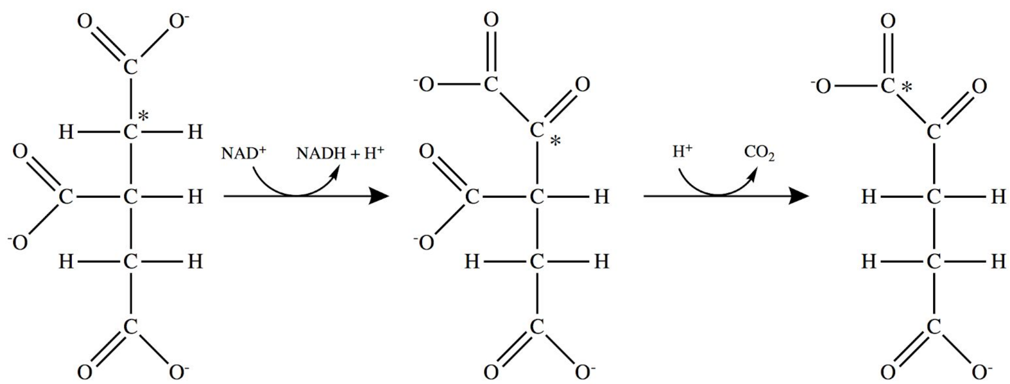
Question 5 (25 points)

The Citric Acid Cycle, an important step in cellular respiration, is responsible for the release of energy stored in carbohydrates and other molecules through a series of steps. One very important reaction in this cycle is the conversion of isocitrate to α-ketoglutarate through oxalosuccinate, an intermediate compound. This reaction is shown below as chemical structures.



Isocitrate   Oxalosuccinate   α-Ketogluterate

a. Identify the oxidizing and reducing agents in the reaction of isocitrate to oxalosuccinate, shown above.

+2 reducing agent: Isocitrate
+2 oxidizing agent: NAD^+

b. In the figure above, circle the atom on the isocitrate that is oxidized or reduced.

+2 starred carbon on structure of isocitrate

c. Calculate the oxidation number of the starred (*) carbon in each compound shown above. Assume electrons shared between two identical atoms are shared equally.

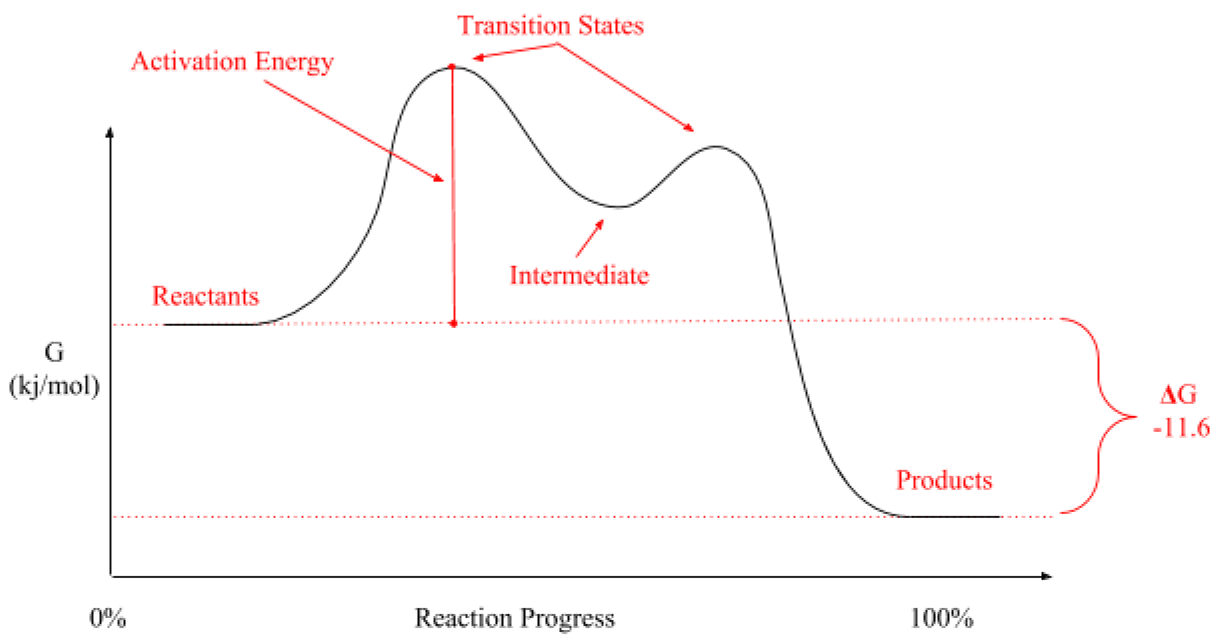
+2 Isocitrate: 4-6 = -2
+2 Oxalosuccinate: 4-2 = +2
+2 α-Ketogluterate: 4-1 = +3

d. The $\Delta G°$ of this reaction is -11.6 $kJ \cdot mol^{-1}$. Is this reaction favorable? Answer either yes or no, and include a one sentence explanation.

+1 Yes

+1 The reaction is exergonic. (or other equivalent wording)

e. Given the hypothetical reaction coordinate diagram below, label the activation energy, intermediate(s), transition state(s), reactants, products, and indicate the $\Delta G°_{rxn}$ in this graph.



+1 each feature correctly identified (7 possible)

f. Using the $\Delta G°$ value from part d, calculate the equilibrium constant, K_{eq}, for the reaction at 25° C.

$\Delta G° = -RT\,ln(Keq)$

$-11.6\ kj/mol * 1000\ j/kj = -(8.314\ j/(mol * k)(273.15 + 25\ K)\ ln(Keq)$

$k_{eq} = 108$

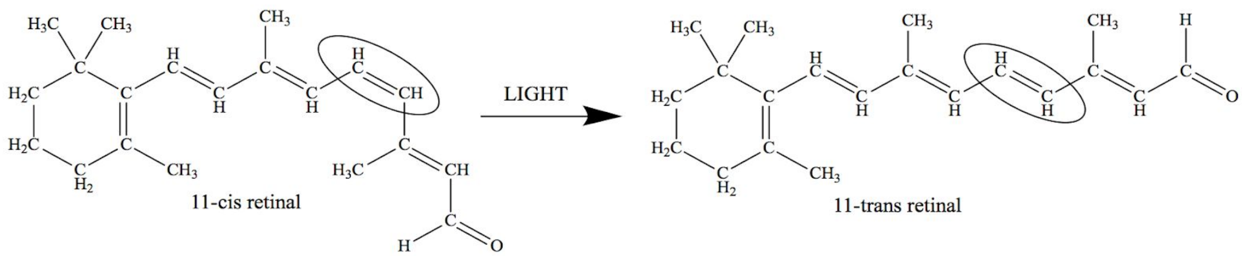
+2 plugging into correct equation with correct constant

+1 units

+1 for correct answer

HUMAN BODY

Question 6 (25 points)
George Wald received a Nobel Prize for determining the chemical process by which the light entering our eyes is converted to signals in our brain that allow us to see. For the purposes of this question we will focus on the photoisomerization, light induced change in structure, of 11-*cis* retinal to 11-*trans* retinal. The circled atoms and bonds below show this isomerization from *cis* to *trans*.



a. Using your knowledge of molecular orbitals and bonding, explain why it is difficult to rotate around a double bond. Explanations must include a diagram of a double bond.

+2 double bonds are composed of a sigma and a pi bond
+4 atoms in a sigma bond are able to rotate around their bond axis, atoms double bonded have p orbitals that are parallel and overlapping which decreases flexibility
+2 there is a high energy barrier to rotate around or break a double bond
+2 diagram showing or indicating the pi system of a double bond
+1 labels

b. Humans are able to see because our eyes can detect wavelengths of light between 400 and 700 nm. Calculate the maximum and minimum energies (in J per photon) of light that humans can detect.

Maximum: 4.97e-19 J

Minimum:2.84e-19 J

$E_{photon} = \frac{h*c}{lambda}$, plug in the upper and lower wavelengths given.
+2 plugging in correct constants and values
+1 units
+1 correct identification of minimum and maximum

DO NOT WRITE BELOW THIS LINE

c. Will a photon in the visible light range be able to dissociate one molecular carbon-carbon bond (Bond Dissociation Energy = 602 kJ · mol^{-1})? Justify your statement numerically.

+2 convert energies to same units (ex: 602 kJ/mol (mol/6.022e23)(1000 J/kJ) = 9.99e-19 J)
+2 stating this value is greater than that of the light we can detect.

d. In three sentences or less, propose an explanation that accounts for the difference between the energy required to break a carbon-carbon double bond and the energy available for the *cis*/*trans* isomerization.

+1 state that value from part C is the energy required to *break* a double bond
+3 state that in the case of retinal, the bond is broken and reformed, so the energetics will be different.

e. Humans actually have many different light sensitive molecules in their eyes, and each is able to detect light of a different wavelength. In one sentence, propose a hypothesis that explains why humans are not able to see outside of of the 400-700 nm light range.

+2 state that there are no light-sensitive molecules for wavelengths outside of this range, or light outside of that range will not be able to cause a conformational change. Other answers are possible, and will be evaluated in a case-by-case basis.

This is the end of the exam