Chemistry Lab

MIT Science Olympiad Invitational

January 24th, 2015

Team Name: ___KEY___

Time: ~50 Minutes. A 5 minute warning will be given.
Do not open the test until instructed to begin.
A periodic table and all relevant constants are included in the back.
Show all work necessary to receive credit.
Do not forget units!
If you plan on taking the pages of the test apart, make sure to label each page with your team number and restaple all the pages together (in order) before turning it in.

Team Number: ______

PROBLEM 1
10% of total

TOTAL	A	B	C	D	E	F
16	**2**	**2**	**3**	**3**	**4**	**2**

General Grading Scheme: up to ½ credit if final answer incorrent, -1 pt if no units

A strip of magnesium ribbon is dropped into hot water, and the following reaction takes place:

1 $Mg(s)$ + 2 $H_2O(l) \rightarrow$ 1 $Mg(OH)_2(s)$ + 1 $H_2(g)$ 2 pts

a. Balance the reaction by filling in the coefficients, using lowest whole numbers.

b. Why must the magnesium ribbon be dropped into hot water to induce a reaction?

1 pt Mg reacts slowly with cold water

1 pt Hot water makes reaction faster

c. After a period of time, the reaction slows and the evolution of bubbles ceases. Explain these observations. Hint: Think about solubility.

1 pt coat of $Mg(OH)_2$ forms

1 pt $Mg(OH)_2$ is insoluble

1 pt H_2 production ceases with no more reaction

d. Assuming that the magnesium reacts completely with the water, calculate the mass of H_2 formed when 0.420g of magnesium ribbon is introduced.

Mass of H_2 = 0.0346g H_2 (3 pts)

e. The hydrogen gas evolved is captured and combusted with 0.250g of oxygen. If 0.230g of water are produced, find the limiting reagent and calculate the % yield.

Limiting Reagent: O_2 (2pts) *% Yield = 81.8% (2 pts)*

f. When magnesium is reacted with hot steam, it reacts with it in a 1:1 ratio to form two products. Write the equation of the balanced reaction.

Balanced Equation: $Mg(s) + H_2O(g) \rightarrow MgO(s) + H_2(g)$ 2 pts for correct products

Team Number: ______

PROBLEM 2
11% of total

TOTAL	A	B	C	D	E	F
18	**5**	**3**	**2**	**2**	**4**	**2**

An unknown metal X from the Group 1 elements (alkali metals) burns in a pure oxygen environment with an intense red flame to form a white compound.

a. Write the product of combustion (the metal oxide) that predominates for each the alkali metals, from lithium to cesium.

Li: Li_2O
Na: Na_2O_2
K: KO_2 and K_2O_2 both accepted
Rb: RbO_2
Cs: CsO_2 (1 pt each)

b. Assuming that 0.200g of the unknown metal X forms 0.431g of the oxide, identify X.

Identity of X: Li (3 pts)

c. When X is burned in atmospheric air, the metal oxide is not the exclusive product. The metal also reacts with nitrogen to form a metal nitride product. Write down the balanced equation of this nitrogen reaction (use X in place of the metal if you could not determine its identity).

Balanced Equation: $6\ Li(s) + N_2(s) \rightarrow 2\ Li_3N\ (s)$ (2 pts for product, -1 if not balanced)

d. The metal nitride reacts with water to form a gaseous product. Identify this gas.

Identity of Gas: NH_3 (2 pts)

e. 0.300g of metal X are burned in atmospheric air to form 0.600g of a mixture of the metal oxide and nitride. Find the mass of each product formed.

Mass of Metal Oxide = 0.442g *Mass of Metal Nitride = 0.158g*
(2 pts each)

f. Metal X is treated with hydrogen gas to form an ionic compound. Identify this ionic compound.

Identity of X: LiH (2 pts)

Team Number: ______

PROBLEM 3
11% of total

TOTAL	A	B	C	D	E	F	G	H
18	**2**	**2**	**2**	**2**	**2**	**4**	**2**	**2**

Write down the net ionic equation for each question below (*does not need to be balanced).* Also classify the reactions as being combustion, acid-base, organic, decomposition, combination, precipitation, nuclear, oxidation-reduction, or complex-ion formation. Multiple reaction types may apply, but you need only write one.

0.5 pts reactant, 1 pt product, 0.5 pts reaction type

a. Solutions of sodium iodide and lead nitrate are mixed.

$Pb^{2+} + I^- \rightarrow PbI_2$

Combination, precipitation

b. Carbon dioxide is bubbled through a solution of calcium hydroxide.

$CO_2 + Ca^{+2} + OH^- \rightarrow CaCO_3 + H_2O$

Acid-base, precipitation

c. A solution of hydrofluoric acid is added to a suspension of aluminum hydroxide.

$HF + Al(OH)_3 \rightarrow Al^{+3} + F^- + H_2O$

Acid-base

d. Phosphorus is burned in excess oxygen.

$P_4 + O_2 \rightarrow P_4O_{10}$

Combustion, Oxidation-reduction

e. Uranium-238 undergoes alpha decay.

$^{238}U \rightarrow {}^{234}Th + {}^{4}_{2}\alpha$

Nuclear

f. $YBa_2Cu_3O_7$ is dissolved in aqueous HCl with excess KI in an oxygen-free atmosphere.

$YBa_2Cu_3O_7 + H^+ + I^- \rightarrow Y^{3+} + Ba^{2+} + CuI + H_2O + I_3^-$ or

$YBa_2Cu_3O_7 + H^+ + I^- \rightarrow Y^{3+} + Ba^{2+} + CuI + H_2O + I_2$

Acid-base, precipitation, oxidation-reduction (points doubled)

g. Concentrated hydrochloric acid is added to a solution of cobalt(II) chloride and heated.

$Co^{+2} + Cl^- \rightarrow CoCl_4^{2-}$

Complex-ion formation

h. Acetic acid is heated with ethanol in the presence of H^+

$CH_3COOH + CH_3CH_2OH \rightarrow CH_3COOCH_2CH_3 + H_2O$

Organic

Team Number: ______

PROBLEM 4
7% of total

TOTAL	A	B	C	D	E
12	**3**	**3**	**2**	**2**	**2**

Breathalyzers make an estimate of blood alcohol by measuring the amount of alcohol in a person's breath. Old breathalyzer models functioned by having a person breath through a solution of potassium dichromate, which oxidizes the ethanol in the person's breath into acetic acid. The dichromate changes color in the process, which is measured by a detector.

a. Balance each of the equations below for the oxidation of ethanol and reduction of dichromate.

$1\ CH_3CH_2OH + 1\ H_2O \rightarrow 1\ CH_3COOH + 4\ H^+ + 4\ e^-$

$1\ Cr_2O_7^{2-} + 14\ H^+ + 6\ e^- \rightarrow 2\ Cr^{3+} + 7\ H_2O$ (1.5 pts per correct equation)

b. Combine the two equations to write a net ionic equation.

Equation: $3\ CH_3CH_2OH + 3\ H_2O + 16\ H^+ + 2\ Cr_2O_7^{2-} \rightarrow 3\ CH_3COOH + 4\ Cr^{+3} + 14H_2O$

1 pt reactants, 1 pt products, 1 pt balancing

The concentration of ethanol in the person's blood to ethanol in the person's breath is on average 2100. Thus, this is the standard most machines are calibrated to. The current legal limit on driving in the United States is 0.08g ethanol per $1000cm^3$ of blood.

c. If a person at the limit exhales 1L of breath, how many moles of ethanol are breathed out?

Moles of Ethanol = 8.28×10^{-7} mol (2 pts)

d. If 14% of the dichromate molecules in the breathalyzer have reacted, how many molecules of dichromate does the breathalyzer in total contain?

Molecules of Dichromate = 3.324×10^{17} molecules (2 pts)

e. A person's ratio of ethanol in blood to ethanol in breath is 2300. The BAC reported by the breathalyzer will be: *Circle the correct choice*

Higher than the real BAC　　　　Lower than the real BAC (2 pts)

Team Number: ______

PROBLEM 5
11% of total

TOTAL	A	B	C	D	E	F	G
18	**2**	**2**	**3**	**3**	**4**	**2**	**2**

Consider the following reaction:

$2\ N_2O_5\ (g) \rightarrow 4\ NO_2\ (g) + O_2\ (g)$

a. If N_2O_5 is disappearing at a rate of 0.20 mol/L·sec, what is the rate of appearance of O_2?

*Rate of Appearance = 0.10 mol/L*sec (2 pts)*

b. Given that the decomposition of N_2O_5 is found to be first order, what happens to the reaction rate if $[N_2O_5]$ is tripled?

Also triples (2 pts)

c. The rate constant has been determined to be $3.20 \times 10^{-2}\ s^{-1}$ at 273K and $5.50 \times 10^{-2}\ s^{-1}$ at 298K. Find the half-life of N_2O_5 at 298K in seconds.

Half Life = 12.6 seconds (3 pts)

d. For a sample of N_2O_5 with an initial concentration of 0.340 mol/L, calculate the concentration of N_2O_5 after 60 seconds at 298K.

$[N_2O_5]$ = 0.0125 mol/L (3 pts)

e. Calculate the activation energy of the reaction (answer in J or kJ)

Activation Energy = 14.6 kJ/mol (4 pts)

f. What will be the concentration of $[N_2O_5]$ after 6 half-lives? ($[N_2O_5]_o$ = 0.340 mol/L).

$[N_2O_5]$ = 5.31×10^{-3} mol/L (2 pts)

g. Which of the following graphs give a straight line? *Circle the correct choice*

$[N_2O_5]$ vs. time   ln $[N_2O_5]$ vs. time (2pts) $1/[N_2O_5]$ vs. time

Team Number: ______

PROBLEM 6
10% of total

TOTAL	A	B	C	D
16	**8**	**2**	**4**	**2**

The reaction order of the following reaction is under investigation:

A + 2B → C + 2D + E

A series of initial rates were determined in a set of experiments below:

$[A]_o$ (mol/L)	$[B]_o$ (mol/L)	$[C]_o$ (mol/L)	$[D]_o$ (mol/L)	Initial Reaction Rate (mol/L·sec)
0.20	0.30	0.10	0.20	0.01
0.30	0.30	0.10	0.20	0.015
0.20	0.60	0.20	0.20	0.01
0.30	0.30	0.20	0.20	0.0075
0.20	0.60	0.20	0.30	0.01

a. Determine the reaction order with respect to [A], [B], [C], and [D].

(2 pts each)

A = 1 *B = 1* *C = -1* *D = 0*

b. Write the overall experimental rate equation.

Rate = k[A][B]/[C] *(2 pts)*

c. Calculate the value of k_{exp} (include its units).

k_{exp} = *0.0166* sec^{-1} *(4 pts)*

d. The reaction occurs in solution, with water taking part as a first-order catalyst. Therefore, k_{exp} can be rewritten as $k_{exp} = k_{actual} \cdot [H_2O]$. Assuming that the solution is dilute, calculate k_{actual}

k_{actual} = 3×10^{-4} *L/mol*sec (2 pts)*

Team Number: ______

PROBLEM 7
7% of total

TOTAL	A	B	C	D
12	**3**	**3**	**3**	**3**

In biochemistry, the Michaelis-Menten mechanism models the kinetics of enzymes. An enzyme E and its substrate S initially combine to form the enzyme-substrate complex ES. ES can either then separate into E and S (the original reactants), or undergo a reaction to reform the enzyme and product P.

$E + S \rightleftharpoons ES$ Forward Reaction: Rate = $k_1[E][S]$ Reverse Reaction: Rate = $k_1'[ES]$
$ES \rightarrow E + P$ Forward Reaction: Rate = $k_2[ES]$ Reverse Reaction: None

When the overall reaction rate is calculated, the rate of formation of product is $\frac{k_2[E]_o[S]}{K_M+[S]}$

Where K_M is the Michaelis constant, $K_M = (k_1' + k_2)/k_1$

a. The reaction rate equation simplifies itself in the presence of limiting cases. Write down the rate law when [S] is extremely high.

Rate = *$k_2[E]_o$ (3 pts)*

b. The rate law calculated above represents the maximum reaction rate, denoted V_{max}, when all of the enzyme is bound to substrate. Find the value of K_M when the reaction rate is half of its maximum rate, or $\frac{1}{2}V_{max}$. Express in terms of $[E]_o$ and [S] – you may only need to use one.

K_M = [S] (3 pts)

c. Find the reaction order with respect to $[E]_o$ and [S], when [S] is set to an extremely low concentration.

$[E]_o$ = 1 *[S] = 1* *(1.5 pts each)*

d. A competitive inhibitor can be added to an enzyme-substrate mix, where the inhibitor competes with the substrate for access to the enzyme. This effectively results in decreased reaction rates at identical substrate concentrations. In this case, how would you expect the values of V_{max} and K_M to change? *Answer with decrease, stay the same, or increase*

V_{max} = Same *K_M = Increase* *(1.5 pts each)*

Team Number: ______

PROBLEM 8
33% of total

TOTAL	#1	#2	#3	#4	#5	#6	#7
56	**8**	**8**	**8**	**8**	**8**	**8**	**8**

On your bench, you have been given seven pipets that contain solutions of $AgNO_3$, $BaCl_2$, $Cu(NO_3)_2$, $CuSO_4$, $Pb(NO_3)_2$, KI, and $Na_2S_2O_3$ labeled 1-7 (though not necessarily in that order). Carry out an experiment to determine the contents of each pipet. **No refills will be given**.

To receive credit, you must construct a data table and/or provide detailed observations that you can use to draw conclusions of each unknown solution. Make sure to justify each choice.

#1	#2	#3	#4
#5	#6	#7	