School/Team Name: Team #:

Student Names:

Chemistry Lab

University of Michigan Science Olympiad 2018

Tiebreakers: 7, 4c, lab, 9a

Remarks:

- You *must* have appropriate clothing, including goggles, lab aprons/lab coats, and closed-toed shoes. If you don't have these, you will not be allowed to participate in the lab portion of this test.
- Five 8.5" □ 11" cheatsheets and two calculators allowed.
- You will have 50 minutes to complete this test and the lab.
- Use appropriate units. Note: SI units are always acceptable.
- If you take apart the test, write your team number on every page in the space provided.
- Sometimes, the answers won't make sense. This is okay.
- Good luck!

Lab Portion

Before you, you have a mixture of NaCl and $CaCl_2$, as well as some other materials. Use boiling point elevation to determine the percentages of each by mass.

Fill in each of the below areas as you progress.

<u>Procedure</u>:

5 pts - clear, easy to follow

3 pts for each of the following steps, unless stated otherwise

- massing the sample mass (1pt)
- mixing in the sample to the water
- boiling the water w/ sample
- recording final temperatures
- boiling water w/o sample for a reference point (4 pt)

TOTAL: 19

Data:

5 pts - data matches procedure
3 pts - data has a reasonable number of sigfigs
4 pts - data is well organized
3 pts - all data has units

total: 15

Calculations: (Please circle or otherwise distinguish your final answer)

4 pts - usage of $\Delta T_b = K_b mi$
3 pts - setup of system of equations
3 pts - correct values of i (2 for NaCl, 3 for $CaCl_2$)
3 pts - calculations easy to follow
2 pts - calculations are accurate given data

total: 15

Written Portion

1. The process A + B → 3C has a ΔH of +142.7 J.
   a. Is the process endothermic or exothermic?

      endothermic

      Total points: 1

   b. Say A has a molar mass of 43.1 g/mol. If you react 55.0 g of A with excess B, how much heat would be transferred? Assume that the forward reaction occurs until completion.

$$55.0 \text{ g A} * \frac{\text{mol A}}{43.1 \text{ g A}} * \frac{142.7\text{J}}{1 \text{ mol A}} = 182 \text{ J}$$

(3 pt)

total points: 3

2. On Earth, a particular battery-powered balloon-blowing machine can blow up 120 balloons with 25.0 cm diameter before it runs out of power.
   a. How much work is done by the machine? Assume the balloons start out completely deflated.

$$W = -P(V_f - V_i) * n = -1 \text{ atm} * \left(\frac{4}{3}\pi(0.125 \text{ m})^3 - 0\right) * 120 = -0.982 \text{ atm} \cdot \text{m}^3$$

= -99.5 kJ

Note: n = number of balloons. since all the balloons are the same we can just multiply by n

Total Points: 3 (r = 0.25 → -1, no negative sign → -0.5)

   b. On Mars, the atmospheric pressure is approximately 600 Pa. How many balloons of similar size can be blown up on Mars if the machine does as much work as it does on Earth?

$$-0.982 \ atm\ m^3 = -P(V_f - V_i)n = -600\ Pa * \frac{1\ atm}{101325\ Pa} * \left(\frac{4}{3}\pi(0.125)^3 - 0\right) * n$$

$$\Rightarrow n = 20270$$

total points: 4 (didn't convert btw pressure units → -2)

3. Nick buys 20 Big Macs. However, instead of eating them, he manages to extract all of the energy in the Big Macs to melt some ice. How many kg of ice could Nick melt with the Big Mac energy? (One Big Mac contains 540 Calories)

$$20\ Big\ Macs * \frac{540\ Cal}{Big\ Mac} * \frac{1000\ cal}{Cal} * \frac{4.184\ J}{cal} = 4.52 * 10^7\ J$$

$$4.52 * 10^7\ J * \frac{kJ}{1000J} * \frac{mol\ H_2O}{6.01\ kJ} * \frac{18.01\ g}{mol} * \frac{kg}{1000\ g} = 135\ kg$$

Total points: 4 (didn't convert from Cal to cal → -1)

4. The density of aluminum is 2.70 g/cm^3.

a. Let's say you have a solid ball of aluminum with a diameter of 50.0 cm. Would this ball float or sink in water?

density of aluminum > density of water → sink

Total points: 1

b. You have another solid ball with diameter 50.0 cm that floats in water. You know that this ball is composed of two materials, one of which is aluminum. You also know that aluminum makes up 37.2% of the mass of the ball. What is the maximum density of the other material?

$V_{ball} = \frac{4}{3}\pi(25\ cm)^3 = 6.54 * 10^4\ cm^3$

$\rho_{ball} = \frac{m_{ball}}{V_{ball}} < \rho_{water} = 1\frac{g}{cm^3} \Rightarrow m_{ball} < 6.54 * 10^4\ g$

$m_{Al} = 37.2\% * m_{ball} = 2.43 * 10^4\ g \Rightarrow V_{Al} = 2.43 * 10^4\ g * \frac{cm^3}{2.70\ g} = 9.00 * 10^3\ cm^3$

$m_{other} = m_{ball} - m_{Al} = 4.11 * 10^4\ g\ ,\ V_{other} = V_{ball} - V_{Al} = 5.64 * 10^4\ cm^3$

$\rho_{other} = \frac{m_{other}}{V_{other}} = 0.729\frac{g}{cm^3}$

Total points: 5 (37.2% volume → -2, r=50 cm → -1)

full credit off for a density > 1, for not thinking

c. Consider a spherical shell of pure aluminum with uniform thickness that stays suspended in water. The interior of this shell is a vacuum. If the exterior diameter of this shell is 50.0 cm, what is the thickness of the shell?

$V_{shell} = 6.54 * 10^4\ cm^3$. r = radius of vacuum, thickness = $(25 - r)\ cm$

$\rho_{shell} = \rho_{water} = 1\frac{g}{cm^3} \Rightarrow m_{shell} = 6.54 * 10^4\ g = m_{Al}$

$V_{Al} = \frac{4}{3}\pi(25\ cm)^3 - \frac{4}{3}\pi r^3 = \frac{m_{Al}}{\rho_{Al}} = 6.54 * 10^4\ cm^3 * \frac{cm^3}{2.70\ g} \Rightarrow r = 21.4\ cm$

Thus thickness $= 25 - 21.4 = 3.6\ cm$

Total points: 7 (r=50 cm → -1, found inner radius but not thickness → -1)

5. A resistor with a uniform cross-section has a resistance of 100 Ω.

a. Which of the following could be done to the resistor to lower the resistance to 50 Ω? Circle all that apply. (0.5 pt per option → 2 pt total)

double the length	halve the length	double the cross-sectional area	quadruple the cross-sectional area

b. Explain the difference between resistance and resistivity.

Resistance is an extensive property as it depends on the size of the resistor/wire, while resistivity is an intensive property is the same for that material regardless of dimensions.

Total points: 3 (1 pt for each for describing difference, 0.5 pt each for using proper vocab)

6. Omar is thirsty. Instead of going to the water fountain like a normal person, he creates some water by reacting a certain amount of hydrogen gas with excess oxygen. This gives Kevin the perfect opportunity to carry out his assassination plan against Omar. While Omar isn't looking, Kevin reacts 23.1% of Omar's water with oxygen to create 48100 mg of hydrogen peroxide (H_2O_2).
   a. Find the initial amount of hydrogen gas, in moles.

Reactions: $2H_2 + O_2 \rightarrow 2H_2O$, $2H_2O + O_2 \rightarrow 2H_2O_2$

48100mg H_2O_2*(g/1000mg)*(mol/34.01 g)*(2mol H_2O/2mol H_2O_2) = 1.41 mol H_2O

initial amt H_2O = 1.41 mol / 23.1% = 6.104 mol, 6.104 mol H_2O * (2 mol H_2 / 2 mol H_2O) = 6.104 mol H_2

Total points: 3 (-1 for not considering efficiency, -0.5 for finding mass)

   b. If Omar's process released 110.3 kJ of energy, what is the standard heat of formation of water? (Note: this may not be consistent with the actual $\Delta H_f°$)

Note: because $H_2(g)$ and $O_2(g)$ are the standard states of those elements, their $\Delta H_f°$'s are 0.

So, $\Delta H_f°$ H_2O = Δenergy / amount = -110.3 kJ/6.104 mol = -18.07 kJ/mol

(Note: this is obviously not the actual value)

Total points: 5 (-2 for not dividing, -1 for sign)

if they answered 1.41 for part a, their answer should be -78.2 kJ/mol

   c. $\Delta H_f°$ for H_2O_2 is -187.8 kJ/mol. How much heat was transferred during Kevin's process? Use the true value of $\Delta H_f°$ for water, -285.8 kJ/mol.

We started with 1.41 mol H_2O and ended with 1.41 mol H_2O_2.

1.41 mol H_2O_2 * (-187.8 kJ/mol) - 1.41 mol H_2O * (-285.8 kJ/mol) = 138.18 kJ

Total points: 4

7. 90.2 g of chlorine gas are cooled from room temperature to -90.0℃. The energy released by the chlorine is collected and used to heat 10.0 mL of water, also starting at room temperature. If the energy is transferred with 78.2% efficiency, at what phase and temperature is the water now?

initial T = 25 C + 273 = 298 K. Final T = -90C + 273 = 183 K

E_{Cl} = 0.48 J/(g K) * 90.2 g * (298K - 239 K) + 20.41 kJ/mol * 90.2g * mol/70.906g * 1000J/kJ + 0.948 J/(g K) * 90.2 g * (239 K-193 K) = 3.331 * 10^4 J

$E_{transferred}$ = 3.331 * 10^4 J * 0.782 = 2.605 * 10^4 J

Guess: water is still liquid. 10.0 mL * 1g/mL = 10.0 g

2.605 * 10^4 J = 10.0 g * 4.184 J/g C * (T - 25) C ⇒ T = 647 ^{O}C… nope

2.605*10^4 J = 10.0 g * 4.184 J/g C * (100 - 25) C + 40.65 kJ/mol * 10.0g * mol/18.015 g * 1000 J/kJ + 2.08 J/(g K) * 10.0 g * (T-100)C ⇒ T = 116.5 C (NOTE: range from 110 - 125 is ok, rounding is weird)

(6 pts)

-2 if forgot to take into account the efficiency (should be 465 C)

-1 if forgot the phase

8. Explain why testing for the presence of manganese frequently involves the formation of potassium permanganate, as opposed to other variations of manganese such as manganese dioxide.

Potassium permanganate is a bright pink color, which makes it easy to see compared to other forms of manganese that are colorless. (3 pt)

9. As of now, the elements in group 18 (the rightmost row of the periodic table) are helium, neon, argon, krypton, xenon, radon, and oganesson. Below is a table of some of their properties.

Element	**Atomic Number**	**Atomic Radius**	**Ionization Energy**
Helium	2	28 pm	2372.3 kJ/mol
Neon	10	58 pm	2080.7 kJ/mol
Argon	18	106 pm	1520.6 kJ/mol
Krypton	36	116 pm	1350.8 kJ/mol
Xenon	54	140 pm	1170.4 kJ/mol
Radon	86	150 pm	1037.0 kJ/mol
Oganesson	118	157 pm	839.4 kJ/mol

Say the next element in that group was discovered. Below are several physical properties of said element. For 8a, give an exact numeric value; for 8b and 8c, give an approximate numeric value and then explain why the trend you identified occurs:

a. Atomic number

atomic number = 168 (1 pt)

Note: This is due to how orbitals work

b. Atomic radius

160-170 pm (1 pt)

(-0.5 for no unit)

Explanation:

orbitals, or

More electrons, so you need more space (general gist of it) (2 pt)

c. Ionization Energy

500-760 kJ/mol (1 pt) (-0.5 for no unit)

Explanation:

shielding electrons, or ionization energy works on the electrons that are the farthest away. Increase in atomic radius means that the force needed to remove the furthest electron is lowered (2 pt)

10. Adam has a cup with 100. mL of water at room temperature.

   a. Adam likes his water cold, so he takes three ice cubes and puts them in the cup, then waits for the temperature to stabilize. If Adam wants his water at 10.0℃, what is the mass of each of the ice cubes? Assume that the ice cubes are identical and start at 0℃ and that energy is only transferred between the ice and the water.

4.184 J/g C * 100 mL * 1 g/mL * (25-10)C = 6276 J

Let each ice cube be mass m g.

6.01 kJ/mol * 1000 J/kJ * 3m g * mol/18.02 g + 4.184 J/g C * 3m g * 10 C = 6276 J

⇒ m = 5.57 g

(4 pt. -1 if answer = 16.72 g; found total mass. -2 if found incorrect energy transfer but everything else accurate)

   a. When Adam measures the temperature of his water, he finds that the temperature of the water is actually 9.43℃. What is the calorimetry constant of the cup? Assume that there is no energy transfer with the surrounding air.

6.01 kJ/mol * 1000 J/kJ * 3 * 5.57g * mol/18.02 g + 4.184 J/g C * 3 * 5.57g * 9.43 C + c_{cal} * (25-9.43) C = 4.184 J/g C * 100 mL * 1g/mL * (25-9.81) C

then, c_{cal} = 18.02 J/C

(5 pt)

   b. Disgusted, Adam gives his cup of water to Andrea. Andrea decides to boil the water to make some ramen, so she takes a heated piece of lithium and puts it into the cup. If Andrea has 21.2 g of lithium , what temperature does it need to be to boil the water?

Note: total mass of water = 100 mL * 1 g/mL + 3 * 5.57 g (from the ice) = 116.7 g

Note: we want to get the water to boiling temp, but we don't want it to boil away completely because that's how ramen works

116.7 g * 4.184 J/g C * (100-9.43) C + 18.02 J/C * (100-9.43) C= $4.586*10^4$ J

21.2 g * 3.58 J/g C * (T-100) C = 4.586 * 10^4 J ⇒ T = 704 C

(7 pt: -2 if include water boiling energy, -2 if forgot calorimeter, -1 if forgot ice contribution)

   c. Andrea heats the lithium to the correct temperature, but is shocked to find that 1.17 g of the lithium has evaporated away. Fortunately, she has seven 3.00 g samples of metal that she keeps at a constant 310.℃, which she decides to add to the water alongside the remaining heated lithium . What does the specific heat of the metal need to be for Andrea to be successful in making ramen?

J contributed by lithium = (21.2-1.17) g * 3.58 J/g C * (704-100) C = 4.216 * 10^4 J

Remaining J needed = 2530 J

7 * 3 g * c * (310-100) C = 2530 J ⇒ c = 0.574 J/g C

(5 pt, -1 if only accounted for one sample)