Beckman Science Olympiad 2019-20 Chem Lab

Name: ANSWER KEY

Score: /121

You have an hour to finish this test. Spend your time wisely and read the instructions carefully before answering each question. A periodic table is included on the last page of this exam.

1. Acid-Base Reactions
   a. Write the molecular equation for the reaction between hydrochloric acid and sodium hydroxide in aqueous solution. (3 pts)
   
   \[
   \text{HCl(aq) + NaOH(aq)} \rightarrow \text{NaCl(aq) + H}_2\text{O(\text{l})} \\
   1 \text{ pt: coefficients, 1 pt: states of matter, 1 pt: correct chemical species}
   \]

   b. Write the complete ionic equation for the reaction between sulfuric acid and calcium hydroxide in aqueous solution. (4 pts)
   
   \[
   2\text{H}^+(\text{aq}) + \text{SO}_4^{2-} (\text{aq}) + \text{Ca}^{2+}(\text{aq}) + 2\text{OH}^-(\text{aq}) \rightarrow \text{CaSO}_4(\text{s}) + 2\text{H}_2\text{O(\text{l})} \\
   1 \text{ pt: coefficients, 1 pt: states of matter, 2 pts: correct chemical species}
   \]

   c. Write the net ionic equation for the reaction between hydrofluoric acid and sodium bicarbonate in aqueous solution. (5 pts)
   
   \[
   \text{HF(aq) + HCO}_3^-(\text{aq}) \rightarrow \text{F}^-(\text{aq}) + \text{H}_2\text{O(\text{l})} + \text{CO}_2(\text{g}) \\
   1 \text{ pt: coefficients, 1 pt: states of matter, 3 pts: correct chemical species (1 pt partial credit if left as carbonic acid H}_2\text{CO}_3)
   \]

   d. Write the net ionic equation for the reaction between nitric acid and potassium oxide in aqueous solution. (3 pts)
   
   \[
   2\text{H}^+(\text{aq}) + \text{O}_2^-(\text{aq}) \rightarrow \text{H}_2\text{O(\text{l})} \\
   1 \text{ pt: coefficients, 1 pt: states of matter, 1 pt: correct chemical species}
   \]
2. What is the difference between molarity (M) and molality (m)? (3 pts)
   a. Molarity measures the concentration of a solvent in a solution while molality measures the concentration of a solute in a solution.
   b. Molarity measures the concentration of a solute in a solution while molality measures the concentration of a solvent in a solution.
   c. In an aqueous solution, molarity is the moles of the solute over the volume of solution while molality is the moles of the solute over the mass of the solution.
   d. In an aqueous solution, molarity is the moles of the solute over the volume of solution while molality is the moles of the solute over the volume of the solvent.
   e. In an aqueous solution at standard conditions, molarity and molality are generally the same numerical value.

3. A student performing a titration between a strong acid and a weak base is trying to find the equivalence point. Which indicator should he use? (3 pts)
   a. Phenolphthalein, pKa = 9.4
   b. Methyl red, pKa = 4.95
   c. Cresol red, pKa = 1.0
   d. Phenol red, pKa = 7.9
   e. Alizarin yellow R, pKa = 11.2

4. Which one of these statements is true at 0°C (32°F)? (3 pts)
   a. $K_a = K_b$
   b. $pOH + pH = 14.00$
   c. $K_w = 14.00$
   d. $K_a \times K_b = 1.0 \times 10^{-14}$
   e. None of the above

5. If 0.520 moles of Na$^+$ are added to 10. L of water, calculate the molarity. (3 pts)

$$[Na^+] = \frac{(0.520 \text{ mol Na}^+)/(10. \text{ L H}_2\text{O})}{[Na^+] = 0.052 \text{ M}}$$

1 pt: sig figs, 1 pt: correct answer, 1 pt: correct units
6. If 32.59 grams of zinc acetate are added to 10.0 L of water, calculate the molarity. (4 pts)

\[
[Zn(C_2H_3O_2)_2] = \frac{(32.59 \text{ g Zn(C}_2\text{H}_3\text{O}_2)_2)}{(10.0 \text{ L H}_2\text{O}) \times \frac{1 \text{ mol Zn(C}_2\text{H}_3\text{O}_2)_2)}{(183.47 \text{ g Zn(C}_2\text{H}_3\text{O}_2)_2)}
\]

\[
[Zn(C_2H_3O_2)_2] = 0.0178 \text{ M}
\]

1 pt: sig figs, 2 pts: correct answer, 1 pt: correct units

7. If 10.0 moles of lithium bicarbonate are added to 10.0 L of water, calculate the mass percentage. (4 pts)

\[
\text{Mass of LiHCO}_3 = (10.0 \text{ mol LiHCO}_3) \times \frac{(67.96 \text{ g LiHCO}_3)}{(1 \text{ mol LiHCO}_3)} = 680. \text{ g LiHCO}_3
\]

\[
\text{Mass of Water} = (10.0 \text{ L H}_2\text{O}) \times \frac{(1000 \text{ g H}_2\text{O})}{(1 \text{ L H}_2\text{O})} = 1.00 \times 10^4 \text{ kg H}_2\text{O}
\]

\[
\text{Mass %} = \frac{(680. \text{ g LiHCO}_3)}{(680. \text{ g} + 1.00 \times 10^4 \text{ g})} \times 100\% = 6.36\%
\]

1 pt: sig figs, 3 pts: correct answer

8. If 2.183 grams of barium hydroxide are added to 10.00 L of water, calculate the molarity. (4 pts)

\[
[Ba(OH)_2] = \frac{(2.183 \text{ g Ba(OH)_2})}{(10.00 \text{ L H}_2\text{O}) \times \frac{1 \text{ mol Ba(OH)_2}}{(171.34 \text{ g Ba(OH)_2})}}
\]

\[
[Ba(OH)_2] = 1.274 \times 10^{-3} \text{ M}
\]

1 pt: sig figs (3-4), 2 pts: correct answer, 1 pt: correct units

9. If 15.4 grams of iodine gas are added to 23.6 grams of carbon tetrachloride, calculate the molality. (4 pts)

\[
m = \frac{(15.4 \text{ g I}_2)}{(23.6 \text{ g CCl}_4) \times \frac{1 \text{ mol I}_2}{(253.80 \text{ g I}_2) \times \frac{1 \text{ mol CCl}_4}{(1 \text{ kg CCl}_4)}}}
\]

\[
m = 2.57 \text{ molal or kg/mol or m I}_2
\]

1 pt: sig figs, 2 pts: correct answer, 1 pt: correct units
10. What is the volume of this solution (mL)? (3 pts)
   a. 51.8 mL
   b. 52.8 mL
   c. 53.5 mL
   d. 54.2 mL
   e. 55.0 mL

11. What is the pH of a strong acid-strong base titration at the equivalence point? (3 pts)
   a. 0-3
   b. 4-6
   c. 7
   d. 8-11
   e. 11-14

12. Write the correct neutralization reaction of calcium hydroxide and perchloric acid in aqueous solution. (3 pts)

   Ca(OH)$_2$(aq) + 2HClO$_4$(aq) -> Ca(ClO$_4$)$_2$(aq) + 2H$_2$O(l)

   1 pt: coefficients, 1 pt: states of matter, 1 pt: correct chemical species

13. Which of these properties is correctly associated with sulfuric acid? (3 pts)
   a. Colorless
   b. Very fluid (low viscosity)
   c. Odorless
   d. a and b
   e. a and c
   f. a, b, and c

14. Which of these lab procedures is safe? (3 pts)
   a. Measure the salt first, place it in a graduated cylinder, and add water to the salt to moisten all the solute at once when making a solution.
   b. Always remember to secure a lid on your beaker before heating it up.
   c. If your solution is too hot, drop a few ice cubes into the solution to cool it down.
   d. Remember to dispose of any leftover chemicals instead of reusing them by placing them back in the stock container.
   e. In the event of a chemical spill, take a few paper towels and wipe it up IMMEDIATELY.
   f. Always pipette by mouth. :)
15. If $2.30 \times 10^{18}$ molecules of sodium chloride are added to 10.0 L of water, calculate the parts per million of sodium chloride. (4 pts)

$$\text{ppm} = \frac{2.30 \times 10^{20} \text{ molecules NaCl}}{(10.0 \text{ L H}_2\text{O})} \times \frac{(1 \text{ mol NaCl})}{(6.022 \times 10^{23} \text{ molecules NaCl})} \times \frac{(58.44 \text{ g NaCl})}{(1 \text{ mol NaCl})} \times \frac{(1 \text{ L H}_2\text{O})}{(1 \text{ kg H}_2\text{O})} \times \frac{(1000 \text{ mg NaCl})}{(1 \text{ g NaCl})}$$

$$\text{ppm} = 2.23 \text{ mg/kg or mg/L or parts per million}$$

1 pt: sig figs, 2 pts: correct answer, 1 pt: correct units

16. Solute X has a molar mass $M$. You add 30.0 g of solute X to 0.530 M of solute X in aqueous solution. After you add the solute, the molarity of solute X rises to 0.692 M, yet the volume of the solution still stays at 10.9 L.

a. Explain why the volume of the aqueous solution stays the same as you add more solute. (5 pts)

The volume of the aqueous solution stays the same because the volume of the solute when dissolved is insignificant. As a solid even, the volume of the solute was not very large compared to the volume of the aqueous solution, and when the solute is dissolved into the solution, it dissociates into small ions that each attract many water molecules towards them.

b. Calculate the molar mass $M$ of solute X. (5 pts)

Initial Molarity = 0.530 M = $(m_1)/10.9 \text{ L}$

$m_1 = 0.530 \text{ M} \times 10.9 \text{ L} = 5.78 \text{ mol}$

Final Molarity = 0.692 M = $(m_1 + 30.0 \text{ g}/M)/10.9 \text{ L} = (5.78 \text{ mol} + 30.0 \text{ g}/M)/10.9 \text{ L}$

$5.78 \text{ mol} + 30.0 \text{ g}/M = 0.692 \text{ M} \times 10.9 \text{ L} = 7.54 \text{ mol}$

$30.0 \text{ g}/M = 1.77 \text{ mol}$

$M = 17.0 \text{ g/mol}$

1 pt: sig figs, 3 pts: correct answer, 1 pt: correct units

c. Which common weak acid would solute X most likely be? (Hint: This liquid molecule consists of a central atom surrounded by three of the same atoms and has a neutral charge.) (2 pts)

Ammonium (NH$_3$), molar mass = 17.031 g/mol

2 pts: correct answer or any other well-known molecule fitting criteria (1 pt partial credit if still has same molar mass)
17. Given that the $K_b$ of ethanol is $1.22^\circ C/m$ and the $K_f$ of ethanol is $1.99^\circ C/m$, determine by how many degrees Celsius would the melting point of 2.98 M of lithium hydroxide in ethanol solution be lower than the normal melting point of water if the density of the solution is 0.789 g/mL. (State Level) (5 pts)

\[
\frac{(2.98 \text{ mol LiOH})}{(1 \text{ L soln})} \times \frac{(23.95 \text{ g LiOH})}{(1 \text{ mol LiOH})} \times \frac{(1 \text{ L soln})}{(1000 \text{ mL soln})} = 0.0714 \text{ g LiOH/mL soln}
\]

\[
0.789 \text{ g soln/mL soln} - 0.0714 \text{ g LiOH/mL soln} = 0.718 \text{ g ethanol/mL soln}
\]

\[
m = \frac{(2.98 \text{ mol LiOH})}{(1 \text{ L soln})} \times \frac{(1 \text{ L soln})}{(1000 \text{ mL soln})} \times \frac{(1 \text{ mL soln})}{(0.718 \text{ g ethanol})} = 4.15 \text{ molal}
\]

\[
\Delta T_f = (1.99^\circ C/m) \times (4.15m)
\]

\[
\Delta T_f = 8.26^\circ C
\]

1 pt: sig figs, 3 pts: correct answer, 1 pt: correct units

18. What is defined as an unsaturated solution? (3 pts)

a. A pure liquid OR a pure liquid with the exception of insoluble precipitates lying at the bottom of the liquid
b. The presence of strictly non-electrolytes in a solution
c. A pure liquid composed of only a single type of atom or molecule
d. Any concentration of solute in a solution before solute starts precipitating out of the solution
e. The presence of strictly weak and non-electrolytes in a solution

19. How do you make a supersaturated solution? (3 pts)

a. By adding so much solute to the solution that some precipitates out of the solution
b. By adding more solute to a solution at a high temperature past its normal saturation point and slowly cooling it back down
c. By removing all the other contaminants/solutes in the solution and adding the desired solute atoms or molecules in replacement
d. By adding more solute to a solution at a low temperature past its normal saturation point and slowly heating it back up
e. By ionizing the solution with high-energy radiation, adding more solute molecules, and waiting for the electrons of the solvent molecules to revert back to ground state
20. Name 3 factors that affects the solubility of a solute in a solution and explain how they affect the solubility. (6 pts)

Naming any 3 of the below and their explanation are each worth 1 point.

Common-Ion Effect/pH – If one of the ions which the solute dissociates into is already present in the solution, the solute would dissolve less.

Temperature – higher temperatures favor endothermic reactions, lower temperatures favor exothermic reactions, in general, solids are more soluble in higher temperature solutions while solubility of gases decreases with increasing temperature.

Pressure – The solubility of gases increases in direct proportion with the partial pressure above the solute.

Formation of Complex Ions – Some metal transition ions and Lewis bases form complex ions that reduce the concentration of ions in solution, favoring solubility of the solute.

21. Calculate the pH of an aqueous solution that is 0.30M HCHO₂ and 0.25M NaCHO₂. Kₐ of HCHO₂ = 1.8 x 10⁻⁴. (4 pts)

RICE Box

<table>
<thead>
<tr>
<th>Henderson-Hasselbalch</th>
</tr>
</thead>
<tbody>
<tr>
<td>R HCHO₂(aq) ⇌ H⁺(aq) + CHO₂⁻(aq)</td>
</tr>
<tr>
<td>I 0.30 M 0 M 0.25 M</td>
</tr>
<tr>
<td>C -x +x +x</td>
</tr>
<tr>
<td>E 0.30 – x x 0.25 + x</td>
</tr>
</tbody>
</table>

1 pt: sig figs, 2 pts: correct answer, 1 pt: show correct steps (deduct quadratic formula)

22. Calculate the pKₐ of compound Y⁻ if the concentration of [Y⁻] is 5.19 M and the concentration of [HY] is 2.89 M at equilibrium. The pH of the solution is 5.25. (4 pts)

pH = 5.25  pOH = 8.75  OR  pH = 5.25  pOH = 8.75

pOH = pKₐ + log([HY]/[Y⁻])  [OH⁻] = 1.8 x 10⁻⁹ M

8.75 = pKₐ + log(2.89 M/5.19 M)  Kₐ = [OH⁻][HY]/[Y⁻]

8.75 = pKₐ – 0.254  Kₐ = (1.8 x 10⁻⁹ M)(2.89 M)/(5.19 M)

pKₐ = 9.00  Kₐ = 9.9 x 10⁻¹⁰  pKₐ = 9.00

1 pt: sig figs, 2 pts: correct answer, 1 pt: show correct steps
23. A buffer solution of 45.0 mL of 1.20 M ascorbic acid is prepared at standard conditions. (Note: neglect the second ionization of ascorbic acid.) (State Level)
   a. Draw the skeletal (shorthand) formula of ascorbic acid. (3 pts)

   \[
   \begin{align*}
   H_2C_6H_6O_6(aq) & \rightleftharpoons H^+(aq) + HC_6H_6O_6^-(aq) \\
   K_a & = \frac{[HC_6H_6O_6^-][H^+]}{[H_2C_6H_6O_6]} \\
   I & = 1.20 \text{ M} \quad 0 \text{ M} \quad 0 \text{ M} \\
   C & = -x \quad +x \quad +x \\
   E & = 1.20 - x \quad x \quad x
   \end{align*}
   \]

   \[
   \begin{align*}
   [H^+] & = 9.7 \times 10^{-3} \text{ M} \\
   \text{pH} & = 2.01 \\
   \end{align*}
   \]

   1 pt: sig figs, 2 pts: correct answer, 1 pt: show correct steps

   b. Calculate the initial pH of the solution. (4 pts)

   \[
   \begin{align*}
   [H^+] & = 9.7 \times 10^{-3} \text{ M} \\
   \text{pH} & = \frac{1}{2} \log(1.20) = 0.215 \text{ M NaOH} \\
   (34.0 \text{ mL soln})(0.500 \text{ M NaOH}) = (34.0 \text{ mL soln} + 45.0 \text{ mL soln})M
   \end{align*}
   \]

   \[
   \begin{align*}
   \text{MV} & = \text{MV} \\
   (34.0 \text{ mL soln})(0.500 \text{ M NaOH}) & = (34.0 \text{ mL soln} + 45.0 \text{ mL soln})M
   \end{align*}
   \]

   \[
   \begin{align*}
   \text{M} & = 0.215 \text{ M NaOH} \\
   (45.0 \text{ mL soln})(1.20 \text{ M } H_2C_6H_6O_6) & = (34.0 \text{ mL soln} + 45.0 \text{ mL soln})M
   \end{align*}
   \]

   \[
   \begin{align*}
   \text{M} & = 0.684 \text{ M } H_2C_6H_6O_6 \\
   \text{RICE Box or Henderson-Hasselbalch} \\
   \text{pH} & = -\log(7.9 \times 10^{-5}) + \log(0.215/0.684) = 4.10 - 0.502 = 3.60
   \end{align*}
   \]

   1 pt: sig figs, 2 pts: correct answer, 1 pt: show adequate calculations/steps

   c. What is the pH after 34.0 mL of 0.500 M sodium hydroxide is added to the solution? (4 pts)

   MV = MV

   (34.0 mL soln) (0.500 M NaOH) = (34.0 mL soln + 45.0 mL soln)M

   M = 0.215 M NaOH

   (45.0 mL soln) (1.20 M H_2C_6H_6O_6) = (34.0 mL soln + 45.0 mL soln)M

   M = 0.684 M H_2C_6H_6O_6

   \[
   \begin{align*}
   \text{RICE Box or Henderson-Hasselbalch} \\
   \text{pH} & = -\log(7.9 \times 10^{-5}) + \log(0.215/0.684) = 4.10 - 0.502 = 3.60
   \end{align*}
   \]

   1 pt: sig figs, 2 pts: correct answer, 1 pt: show adequate calculations/steps

   d. What is the pH at the half-equivalence point? (3 pts)

   \[
   \begin{align*}
   \text{pH} & = -\log(7.9 \times 10^{-5}) \\
   \text{pH} & = 4.10
   \end{align*}
   \]

   1 pt: sig figs, 2 pts: correct answer
e. What is the pH after 108 mL of 0.500 M sodium hydroxide is added to the solution? (4 pts)

108 mL soln x (1 L soln)/(1000 mL soln) x (0.500 mol NaOH)/(1 L soln) x (1 mol OH⁻)/(1 mol NaOH) = 0.0540 mol OH⁻
45.0 mL soln x (1 L soln)/(1000 mL soln) x (1.20 mol H₂C₆H₆O₆)/(1 L soln) = 0.0540 mol H₂C₆H₆O₆
[H₃C₆H₆O₆] = 0.0540 mol H₃C₆H₆O₆/[(108 mL soln + 45.0 mL soln) x (1 L soln)/(1000 mL soln)] = 0.353 M
R  H₃C₆H₆O₆(aq) + H₂O(l) ⇌ H₂C₆H₆O₆(aq) + OH⁻(aq)
I  0.353 M / 0 M 0 M
C  -x    +x  +x
E  0.353 - x  x  x
K₆ = (1.0 x 10⁻¹⁴)/(7.9 x 10⁻⁵) = 1.3 x 10⁻¹⁰
(1.3 x 10⁻¹⁰) = (x)(x)/(0.353 - x)
1.3 x 10⁻¹⁰ = x²/0.353
x = 6.7 x 10⁻⁶  % error: -2.6%
[OH⁻] = 6.7 x 10⁻⁶ M  pOH = 5.17  pH = 8.83
1 pt: sig figs, 2 pts: correct answer, 1 pt: show adequate calculations/steps

f. What is the pH after 120. mL of 0.500 M sodium hydroxide is added to the solution? (4 pts)

MV = MV
(120. mL soln)(0.500 M NaOH) = (120. mL soln + 45.0 mL soln)M
M = 0.364 M NaOH
(45.0 mL soln)(1.20 M H₂C₆H₆O₆) = (120. mL soln + 45.0 mL soln)M
M = 0.327 M H₂C₆H₆O₆
0.364 M NaOH – 0.327 M H₂C₆H₆O₆ = 0.036 M NaOH
pOH = -log(0.036) = 1.44
pH = 14.00 – 1.44 = 12.56
1 pt: sig figs, 2 pts: correct answer, 1 pt: show adequate calculations/steps

END EXAM
Periodic Table of Elements

For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.