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)

$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$
1 pt: coefficients, 1pt: 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)

$2H^+(aq) + SO_4^{2-}(aq) + Ca^{2+}(aq) + 2OH^-(aq) \rightarrow CaSO_4(s) + 2H_2O(l)$
1 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)

$HF(aq) + HCO_3^-(aq) \rightarrow F^-(aq) + H_2O(l) + CO_2(g)$
1 pt: coefficients, 1 pt: states of matter, 3 pts: correct chemical species (1 pt partial credit if left as carbonic acid H_2CO_3)

   d. Write the net ionic equation for the reaction between nitric acid and potassium oxide in aqueous solution. (3 pts)

$2H^+(aq) + O^{2-}(aq) \rightarrow H_2O(l)$
1 pt: coefficients, 1 pt: states of matter, 1 pts: 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. Phenolphtalein, 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^oC (32^oF)? (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)

$[Na^+]$ = (0.520 mol Na^+)/(10. L H_2O)
$[Na^+]$ = 0.052 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)

$[Zn(C_2H_3O_2)_2]$ = (32.59 g $Zn(C_2H_3O_2)_2$)/(10.0 L H_2O) x (1 mol $Zn(C_2H_3O_2)_2$)/(183.47 g $Zn(C_2H_3O_2)_2$)
$[Zn(C_2H_3O_2)_2]$ = 0.0178 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)

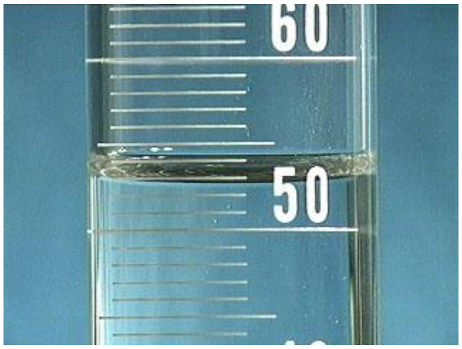
Mass of $LiHCO_3$ = (10.0 mol $LiHCO_3$) x (67.96 g $LiHCO_3$)/(1 mol $LiHCO_3$) = 680. g $LiHCO_3$
Mass of Water = (10.0 L H_2O) x (1000 g H_2O)/(1 L H_2O) = 1.00 x 10^4 kg H_2O
Mass % = (680. g $LiHCO_3$)/(680. g + 1.00 x 10^4 g) x 100% = 6.36%
1 pt: sig figs, 3 pts: correct answer

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

$[Ba(OH)_2]$ = (2.183 g $Ba(OH)_2$)/(10.00 L H_2O) x (1 mol $Ba(OH)_2$)/(171.34 g $Ba(OH)_2$)
$[Ba(OH)_2]$ = 1.274 x 10^{-3} 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 = (15.4 g I_2)/(23.6 g CCl_4) x (1 mol I_2)/(253.80 g I_2) x (1000 g CCl_4)/(1 kg CCl_4)
m = 2.57 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)

$Ca(OH)_2(aq) + 2HClO_4(aq) \rightarrow Ca(ClO_4)_2(aq) + 2H_2O(l)$
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 2.30×10^{18} molecules of sodium chloride are added to 10.0 L of water, calculate the parts per million of sodium chloride. (4 pts)

ppm = (2.30×10^{20} molecules NaCl)/(10.0 L H_2O) x (1 mol NaCl)/(6.022×10^{23} molecules NaCl) x (58.44 g NaCl)/(1 mol NaCl) x (1 L H_2O)/(1 kg H_2O) x (1000 mg NaCl)/(1 g NaCl)
ppm = 2.23 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 L
m_i = 0.530 M x 10.9 L = 5.78 mol
Final Molarity = 0.692 M = (m_1 + 30.0 g/M)/10.9 L = (5.78 mol + 30.0 g/M)/10.9 L
5.78 mol + 30.0 g/M = 0.692 M x 10.9 L = 7.54 mol
30.0 g/M = 1.77 mol
M = 17.0 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°C/*m* and the K_f of ethanol is 1.99°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)

(2.98 mol LiOH)/(1 L soln) x (23.95 g LiOH)/(1 mol LiOH) x (1 L soln)/(1000 mL soln) = 0.0714 g LiOH/mL soln
0.789 g soln/mL soln – 0.0714 g LiOH/mL soln = 0.718 g ethanol/mL soln
m = (2.98 mol LiOH)/(1 L soln) x (1 L soln)/(1000 mL soln) x (1 mL soln)/(0.718 g ethanol) x (1000 g ethanol)/(1 kg ethanol) = 4.15 molal
ΔT_f = (1.99°C/*m*) x (4.15*m*)
ΔT_f = 8.26°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 $HCHO_2$ and 0.25M $NaCHO_2$. K_a of $HCHO_2$ = 1.8×10^{-4}. (4 pts)

RICE Box

R	$HCHO_2(aq) \rightleftharpoons$	$H^+(aq)$ +	$CHO_2^-(aq)$
I	0.30 M	0 M	0.25 M
C	-x	+x	+x
E	0.30 – x	x	0.25 + x

$1.8 \times 10^{-4} = (0.25 + x)(x)/(0.30 – x)$
$1.8 \times 10^{-4} = (0.25)x/(0.30)$ Small x approx.
$x = 2.2 \times 10^{-4}$
Percent Error: 0.16%
$[H^+] = 2.2 \times 10^{-4}$ M pH = 3.67

OR

Henderson-Hasselbalch
$pH = pK_a + \log([CHO_2^-]/[HCHO_2])$
$pH = -\log(1.8 \times 10^{-4}) + \log(0.25\ M/0.30\ M)$
pH = 3.74 – 0.08
pH = 3.66

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

22. Calculate the pK_b 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
$pOH = pK_b + \log([HY]/[Y^-])$
$8.75 = pK_b + \log(2.89\ M/5.19\ M)$
$8.75 = pK_b – 0.254$
$pK_b = 9.00$

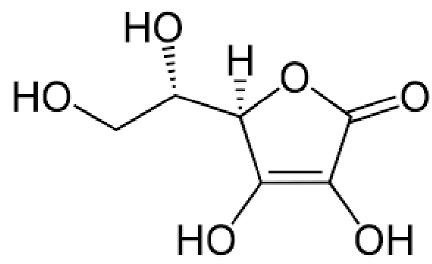
OR

pH = 5.25 pOH = 8.75
$[OH^-] = 1.8 \times 10^{-9}$ M
$K_b = [OH^-][HY]/[Y^-]$
$K_b = (1.8 \times 10^{-9}\ M)(2.89\ M)/(5.19\ M)$
$K_b = 9.9 \times 10^{-10}$ $pK_b = 9.00$

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

23. A buffer solution of 45.0mL 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)



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

R	$H_2C_6H_6O_6(aq) \rightleftharpoons$	$H^+(aq)$ +	$HC_6H_6O_6^-(aq)$	$K_a = [HC_6H_6O_6^-][H^+]/[H_2C_6H_6O_6]$
I	1.20 M	0 M	0 M	$(7.9 \times 10^{-5}) = (x)(x)/(1.20 – x)$
C	-x	+x	+x	$(7.9 \times 10^{-5}) = x^2/1.20$
E	1.20 – x	x	x	$x = 9.7 \times 10^{-3}$ % error: 0.82%

$[H^+] = 9.7 \times 10^{-3}$ M pH = 2.01

1 pt: sig figs, 2 pts: correct answer, 1 pt: show correct 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 $H_2C_6H_6O_6$

RICE Box or Henderson-Hasselbalch

$pH = pK_a + \log([OH^-]/[H_2C_6H_6O_6] = -\log(7.9 \times 10^{-5}) + \log(0.215/0.684) = 4.10 – 0.502 = 3.60$

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)

$pH = pK_a$

$pH = -\log(7.9 \times 10^{-5})$

pH = 4.10

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 $H_2C_6H_6O_6$)/(1 L soln) = 0.0540 mol $H_2C_6H_6O_6$
[$HC_6H_6O_6^-$] = 0.0540 mol $HC_6H_6O_6^-$/[(108 mL soln + 45.0 mL soln) x (1 L soln)/(1000 mL soln)] = 0.353 M

R	$HC_6H_6O_6^-(aq)$ +	$H_2O(l)$ ⇌	$H_2C_6H_6O_6(aq)$ +	$OH^-(aq)$
I	0.353 M	/	0 M	0 M
C	-x		+x	+x
E	0.353 – x		x	x

$K_b = (1.0 \times 10^{-14})/(7.9 \times 10^{-5}) = 1.3 \times 10^{-10}$
$(1.3 \times 10^{-10}) = (x)(x)/(0.353 - x)$
$1.3 \times 10^{-10} = x^2/0.353$
$x = 6.7 \times 10^{-6}$ % error: -2.6%
$[OH^-] = 6.7 \times 10^{-6}$ 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 $H_2C_6H_6O_6$) = (120. mL soln + 45.0 mL soln)M
M = 0.327 M $H_2C_6H_6O_6$
0.364 M NaOH – 0.327 M $H_2C_6H_6O_6$ = 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

Atomic #
Symbol
Name
Atomic Mass

C Solid | Hg Liquid | H Gas | Rf Unknown

Metals: Alkali metals · Alkaline earth metals · Lanthanoids · Actinoids · Transition metals · Poor metals

Nonmetals: Other nonmetals · Noble gases

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H Hydrogen 1.00794																	2 He Helium 4.002602
2	3 Li Lithium 6.941	4 Be Beryllium 9.012182											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.0067	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797
3	11 Na Sodium 22.98976928	12 Mg Magnesium 24.3050											13 Al Aluminium 26.9815386	14 Si Silicon 28.0855	15 P Phosphorus 30.973762	16 S Sulfur 32.065	17 Cl Chlorine 35.453	18 Ar Argon 39.948
4	19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955912	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938045	26 Fe Iron 55.845	27 Co Cobalt 58.933195	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.64	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.798
5	37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.96	43 Tc Technetium (97.9072)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.293
6	55 Cs Caesium 132.9054519	56 Ba Barium 137.327	57–71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.94788	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.084	79 Au Gold 196.966569	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98040	84 Po Polonium (208.9824)	85 At Astatine (209.9871)	86 Rn Radon (222.0176)
7	87 Fr Francium (223)	88 Ra Radium (226)	89–103	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (266)	107 Bh Bohrium (264)	108 Hs Hassium (277)	109 Mt Meitnerium (268)	110 Ds Darmstadtium (271)	111 Rg Roentgenium (272)	112 Uub Ununbium (285)	113 Uut Ununtrium (284)	114 Uuq Ununquadium (289)	115 Uup Ununpentium (288)	116 Uuh Ununhexium (292)	117 Uus Ununseptium	118 Uuo Ununoctium (294)

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

57 La Lanthanum 138.90547	58 Ce Cerium 140.116	59 Pr Praseodymium 140.90765	60 Nd Neodymium 144.242	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92535	66 Dy Dysprosium 162.500	67 Ho Holmium 164.93032	68 Er Erbium 167.259	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.054	71 Lu Lutetium 174.9668
89 Ac Actinium (227)	90 Th Thorium 232.03806	91 Pa Protactinium 231.03588	92 U Uranium 238.02891	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

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