2019 Academic Challenge State Chemistry Solution Set

Answer	Explanation
1. Answer is B.	Emission of alpha particles $[^4_2\mathrm{He}^{2+}]$ from the mother nucleus results in decrease of atomic number by two and mass number by 4 in the daughter nucleus.
2. Answer is D.	Chemical changes/reactions in some situations can produce heat energy.
3. Answer is E.	Out of the two 34-valence-electron systems (choices A and E) this one produces the lowest formal charges for all atoms.
4. Answer is D.	Follows the IUPAC rules of nomenclature.
5. Answer is C.	For this system the temperature above the equilibrium temperature (where $\Delta G = 0$) will cause the system to be nonspontaneous. $\Delta G = \Delta H - T\Delta S$ leading $T_{eq} = \left[\frac{\Delta H}{\Delta S}\right] = \left[\frac{-11.0 \times 10^3 \text{ J}}{-17.4 \text{ J/K}}\right] = 632 \text{ K}$
6. Answer is A.	Follows the IUPAC nomenclature rules.
7. Answer is A.	Definition of surface tension.
8. Answer is C.	$[H^+] = 10^{-pH}$ M = $10^{-6.630}$ M = 2.344×10^{-7} M; this is also the $[OH^-]$. In aqueous solution $K_w = [H^+] \times [OH^-] = [2.344 \times 10^{-7}]^2 = 5.50 \times 10^{-14}$.
9. Answer is A.	$98.7 \text{ g Fe} \times \frac{1 \text{ mol Fe}}{55.8 \text{ g Fe}} \times \frac{852 \text{ kJ}}{2 \text{ mol Fe}} = 754 \text{ kJ}$
10. Answer is C.	Drawing the Lewis structure will reveal that this species possesses dispersion and dipole forces but not hydrogen bonding.
11. Answer is B.	$HA(aq) \rightleftharpoons H^+(aq) + A^-(aq)$. At equilibrium, $[H^+] = [A^-]$ $[H^+] = 10^{-pH}$ M = $10^{-2.80}$ M = 1.58×10^{-3} M ∴ At equilibrium, [HA] = 0.294 M – 1.58×10^{-3} M = 0.292 M $\therefore K_a = \frac{[1.58 \times 10^{-3}]^2}{0.292} = 8.6 \times 10^{-6}$
12. Answer is B.	$55.0 \text{ g S} \times \frac{1 \text{ mol S}}{32.1 \text{ g S}} \times \frac{2 \text{ mol } H_2S}{3 \text{ mol S}} = 1.142 \text{ mol } H_2S.$ Plugging this value in PV = nRT will result in $V = \frac{nRT}{P} = \frac{1.142 \text{ mol} \times 0.0821 \text{ L.atm} \times \text{mol}^{-1} \text{ K}^{-1} \times 375 \text{ K}}{1.20 \text{ atm}} = 29.3 \text{ atm}$
13. Answer is D.	pOH = –log $[OH^-]$ = –log(4.15×10^{-6} M) = 5.382 pH = 14 – pOH = 8.618, the solution is basic at this pH value. $[H^+] = 10^{-pH}$ M = $10^{-8.618}$ M = 2.41×10^{-9} M
14. Answer is E.	At STP, $D_{gas} = \frac{\text{molar mass}}{\text{molar volume}} = \frac{\text{molar mass}}{22.4 \text{ L}}$ ∴ $D_{gas} \propto$ molar mass. SF_6 has the highest molar mass among the choices.
15. Answer is A.	m_{water} = 268.5 g – 143.669 g = 124.831 g $V_{water} = m_{water}/D_{water}$ = 124.831 g / 1.000 g/mL = 124.831 mL $V_{metal} = V_{total} - V_{water}$ = 126.4 mL – 124.831 mL = 1.569 mL $D_{metal} = m_{metal}/V_{metal}$ = 4.369 g/1.569 mL = 2.78 g/mL
16. Answer is A.	If an aluminum compound formula is AℓX, then X must carry a charge of 3- as Aℓ forms $A\ell^{3+}$. Nitrogen is gaseous in natural state and forms an anion of N^{3-} (nitride).

17. Answer is C.	1.043 g CO_2 x $\frac{12\text{ g C}}{44\text{ g }CO_2}$ = 0.284 g C-atom 0.567 g H_2O x $\frac{2\text{ x }1.0\text{ g H}}{18\text{ g }H_2O}$ = 0.063 g H-atom Mass of O in the sample = 0.600 – 0.284 – 0.063 = 0.253 g Atom C H O mass (g) 0.284 0.063 0.253 molar mass (g/mol) 12.0 1.0 16.0 mol 0.0237 0.063 0.0158 ratio to lowest mol 1.51 3.98 1.00 whole number ratio (multiply by 2) 3.0 7.96 2.0 Empirical formula **$C_3H_8O_2$**
18. Answer is C.	Initial moles acetic acid = 0.500 L x 0.20 M = 0.100 mol Initial moles acetate = 0.500 L x 0.30 M = 0.150 mol moles OH^- added from NaOH = 0.0200 L x 1.00 M = 0.0200 mol the reaction that occurs is $CH_3COOH + OH^- \rightarrow CH_3COO^- + H_2O$ moles acetic acid remaining at completion = 0.100 – 0.0200 = 0.0800 mol moles acetate remaining at completion = 0.150 + 0.0200=0.170 mol total volume at completion = 0.520 L [acetate] = 0.170 mol/ 0.520 L = 0.327 M [acetic acid] = 0.0800 mol/ 0.520 L= 0.154 M pKa = 4.74 pH = 4.74 + $\log\frac{0.327\text{ M}}{0.154\text{ M}} = 5.07$
19. Answer is D.	Using the integrated rate law for the first-order reaction $\ln[A]/[A_o] = -kt$ ln (75/100) = –k (60.0 min) k = 4.79X10^{-3}/min $t_{1/2} = 0.693/k$ $t_{1/2}$ = 0.693/4.79 X 10^{-3}/min = 145 minutes
20. Answer is E.	Photoelectric effect equation, $h\nu = BE + KE$ (Where BE – binding energy; KE – kinetic energy; ν – frequency) 6.626 x 10^{-34} J s x 2.50 $\times$ 10^{14}/s = BE (When KE = 0) BE for a mol of electron = 6.626x10^{-34} J s x 2.50 $\times$ 10^{14} s^{-1} x (6.022 $\times$ 10^{23} /mol)(10^{-3} kJ/1 J) = 99.75 kJ/mol
21. Answer is A.	$V_{lead} = \frac{4}{3}\pi r^3 = = \frac{4\text{ x }3.1416\text{ x }(0.050\text{ cm})^3}{3} = 5.24\text{ x }10^{-4}\text{ cm}^3$ $m_{lead} = D_{lead}$ x V_{lead} = 11.4 g/cm^3 x 5.24 x 10^{-4} cm^3 = 6.0 x 10^{-3} g
22. Answer is B.	In reaction: 2 C + $O_2 \rightarrow$ 2 CO; mole ratio of C : O_2 = 2 : 1 ; 128 g O_2 is equivalent to 4 mol, therefore, moles of C is 8. In reaction: 1 C + $O_2 \rightarrow$ 1 CO_2 ; mole ratio of C : O_2 = 1 : 1; therefore there are 8 moles of O_2 that is equivalent to 256 g.
23. Answer is B.	My approach if accepted: The reaction is 2 C_8H_{18} + 25 $O_2 \rightarrow$ 16 CO_2 + 18 H_2O 15.0 g C_8H_{18} x $\frac{1\text{ mol }C_8H_{18}}{114\text{ g }C_8H_{18}}$ x $\frac{16\text{ mol }CO_2}{1\text{ mol }C_8H_{18}}$ x $\frac{44\text{ g }CO_2}{1\text{ mol }CO_2}$ = 46.3 g CO_2 15.0 g O_2 x $\frac{1\text{ mol }O_2}{32\text{ g }O_2}$ x $\frac{16\text{ mol }CO_2}{25\text{ mol }O_2}$ x $\frac{44\text{ g }CO_2}{1\text{ mol }CO_2}$ = 13.2 g CO_2 = theoretical yield The experimental yield is 93%. ∴, the actual amount is 13.2 g x 0.93 = 12.3 g CO_2

24. Answer is C.	Consider x to be the amount, moles/L, of HCNO that dissociates $[HCNO] = 0.50 - x$; $[CNO^-] = 0.10 + x$; $[H^+] = x$ 0.10 M NaCNO completely dissociates (sodium salt) for the equilibrium: $HCNO \rightleftharpoons H^+ + CNO^-$ $K_a = [H^+][CNO^-]/[HCNO] = 2.0 \times 10^{-4} = (x)(0.10 + x) / 0.50 - x$ $x = 0.001$ M $\therefore$ 0.001 : 0.50 = x : 100 $\therefore$ x = 0.2 %
25. Answer is D.	$k = 1/t [1/a - 1/x]$ x = initial conc , a = conc after 23 sec = 0.3M $0.039 = 1/23 [1/0.3 - 1/x]$ x = 0.41 M
26. Answer is E.	$\lambda = h/mv$ (λ = wavelength; h = Planck's constant = 6.626×10^{-34} J s ; m = mass (kg) ; v = velocity) $\lambda = 6.626 \times 10^{-34}$ kg.m^2.s^{-2}.s / 9.11×10^{-31} kg x 6.00×10^6m/s $= 6.626\times10^{-34}$ J s / 9.11×10^{-31} kg x 6.00×10^6 m/s = 1.21×10^{-10} m
27. Answer is E.	$E^\circ_{cell} = E^\circ_{cathode} - E^\circ_{anode}$ Ni^{2+}/Ni is the reduction (cathode) reaction and Fe^{2+}/Fe^{3+} is the oxidation reaction (anode) $\therefore$ $E^\circ_{cell} = -0.23 - 0.77 = -1.00$ V
28. Answer is A.	$NaC\ell(s) \rightarrow Na^+(aq) + C\ell^-(aq)$. When dissolution is endothermic, heat is a reactant. Raising the temperature will push the reaction to the right.
29. Answer is A.	Assume there is one mole of the compound; therefore, the mass of the compound is 6.45×10^4 g. $0.00346 \text{ x } 6.45 \text{ x } 10^4 \text{ g} = 223.17 \text{ g Fe x } \frac{1 \text{ mole Fe}}{55.85 \text{ g Fe}} = 4 \text{ moles Fe}$ 4:1 ratio means 1 molecule contains 4 iron atoms.
30. Answer is D.	The sodium cation has only 10 electrons. $1s^2 2s^2 sp^6$
31. Answer is E.	Elemental copper has an electron configuration of $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1 3d^{10}$. Loss of the valence electron ($4s^1$) to form copper(I) leaves all other sublevels full; therefore, all electrons are paired.
32. Answer is E.	Solve $M_1V_1 = M_2V_2$ for the volume of stock solution needed: $3.5(V_1) = 0.45(250)$ V_1 = 32.14 mL of stock 3.5M solution needed 250 mL – 32.14 mL = 218 mL of water needed
33. Answer is C.	Based on the given information and according to LeChatelier's principle, a shift to the left would decrease red color, while a shift to the right would increase the red color. Only answer C: removing SCN^-, which would shift the equilibrium to the left, matches with the appropriate color change.
34. Answer is B.	Barium fluoride is BaF_2. So, $K_{sp} = [Ba^{2+}][F^-]^2$. Due to the 1:1 ratio of Ba^{2+} to BaF_2, the solubility of 0.018 mol/L is the concentration of barium. The concentration of fluoride would be 2 x 0.018 or 0.036 mol/L. $K_{sp} = [0.018][0.036]^2 = 2.3 \times 10^{-5}$
35. Answer is B.	Ionic bonds form between metals and nonmetals. Metals are characterized by low ionization energies. Nonmetals are characterized by high electron affinities. The most likely metal is R (lowest ionization energy). The most likely nonmetal is Q (highest electron affinity).
36. Answer is C.	Based on the trend on decreasing ionization energy going down a column, C is the correct answer. All other choices are the opposite of the observed periodic property trends.

37. Answer is D.	The equation $\Delta T_f = k_f \times m$ is used to calculate the freezing point depression. $12.8\ \text{g}\ C_{10}H_8 \times \frac{1\ \text{mole}}{128.18\ \text{g}} = 0.09986\ \text{mole}\ C_{10}H_8$ $m = \frac{0.09986\ \text{mole}}{0.500\ \text{kg}} = 0.19972\ m$ $\Delta T_f = 5.12 \times 0.19972 = 1.02\ ^0\text{C}$. $T_f = 5.48\ ^0\text{C} - 1.02\ ^0\text{C} = 4.46\ ^0\text{C}$
38. Answer is B.	The Van't Hoff factor for sucrose is 1, while that for $CaC\ell_2$ is 3. Since the molalities are identical, the compound with the highest Van't Hoff factor would have the highest boiling point.
39. Answer is D.	Shortest wavelength is the highest energy radiation. X-rays are the highest energy radiation of the five choices.
40. Answer is E.	Use the following equation: $\Delta E = -2.18 \times 10^{-18}(1/n_f^2 - 1/n_i^2) = -2.18 \times 10^{-18}(1/2^2 - 1/3^2) = -3.03 \times 10^{-19}$ J The answer is positive because the word released implies the negative sign.