

# Annotated Solution

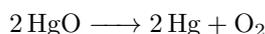
## 2016 USNCO Local Exam

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### 1 Solutions

1. The reaction is



Since the reaction is occurring at STP (273 K and 1 atm) we can use the ratio 22.4 L/mol as the molar volume. This can be shown by solving for  $n/V$  with  $PV = nRT$ . Now we do dimensional analysis.

$$20.0 \text{ g HgO} \times \frac{1 \text{ mol}}{216.6 \text{ g}} \times \frac{1 \text{ mol O}_2}{2 \text{ mol HgO}} \times \frac{22.4 \text{ L}}{\text{mol}} = \boxed{1.03 \text{ L}}$$

This is  $\boxed{A}$ .

2. The reaction is



Now we must find the limiting reactant.

$$30.0 \text{ mL} \times 0.10 \text{ M} = 3.0 \text{ mmol AgNO}_3$$

$$30.0 \text{ mL} \times 0.10 \text{ M} = 3.0 \text{ mmol NaCl}$$

Because both reactants are present in the same amount, we can pick either one.

$$3.0 \text{ mmol} \times \frac{1 \text{ mol}}{1000 \text{ mmol}} \times \frac{1 \text{ mol AgCl}}{\text{mol}} = \boxed{0.0030 \text{ mol}}$$

This is  $\boxed{A}$ .

3. We can simply do dimensional analysis for this question.

$$0.100 \text{ M OH}^- \times 0.2500 \text{ L} \times \frac{1 \text{ mol Sr(OH)}_2 \cdot 8 \text{ H}_2\text{O}}{2 \text{ mol OH}^-} \times \frac{265.76 \text{ g}}{1 \text{ mol}} = \boxed{3.32 \text{ g}}$$

Thus, the answer is  $\boxed{A}$ .

4. The unbalanced combustion reaction is



By conservation of mass, we can find the mass of the  $\text{O}_2$ .

$$10.00 + m = 23.98 + 4.91$$

$$m_{\text{O}_2} = 18.89 \text{ g}$$

Now we can find the number of moles of each chemical species.

$$23.98 \text{ g} \times \frac{1 \text{ mol}}{44.01 \text{ g}} = 0.5449 \text{ mol CO}_2$$

$$4.91 \text{ g} \times \frac{1 \text{ mol}}{18.01 \text{ g}} = 0.273 \text{ mol H}_2\text{O}$$

$$18.89 \text{ g} \times \frac{1 \text{ mol}}{32.00 \text{ g}} = 0.5903 \text{ mol O}_2$$

Now we can find ratios between these.

$$\text{CO}_2 : \text{H}_2\text{O} : \text{O}_2 = 0.545 : 0.273 : 0.590 \approx 2 : 1 : 2.16 \approx 12 : 6 : 13$$

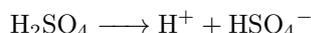


There are 12 carbons, 12 hydrogens, and 30 oxygens on the right side. There are 26 oxygens on the left side. Thus, we must add 12 carbons, 12 hydrogens, and 4 oxygens.

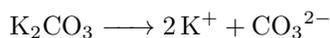
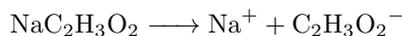


Dividing everything by 4, the empirical formula is then  $\boxed{\text{C}_3\text{H}_3\text{O}}$ , or  $\boxed{B}$ .

5. An electrolyte will dissolve into positive and negative ions which conduct electricity. We can write reactions for some of the answer choices.



Note: the dissociation of  $\text{HSO}_4^-$  is incomplete with a  $K_a$  of  $10^{-2}$ .



We cannot write a reaction for  $\boxed{\text{CH}_2\text{O}}$  as it is a formaldehyde, which is a non-electrolyte that does not dissociate. Thus, the answer is  $\boxed{D}$ .

6. We can use the equation below to calculate the molality.

$$\Delta T = i \times K_f \times m$$

Substituting  $\Delta T = 0 - (-2.24) = 2.24 \text{ }^\circ\text{C}$ ,  $K_f = 1.86 \text{ }^\circ\text{C} \times m^{-1}$ , and  $i = 3$  (this is because upon dissolution there will be 2 particles of potassium and 1 particle of sulfate), we get

$$2.24 = (3)(1.86)(m)$$

$$m = \boxed{0.401 \text{ m}}$$

Thus, the answer is  $\boxed{A}$ .

7. The key fact to understand here is that dissolution of strong acids/bases in water is exothermic. However, dissolution of salts can be exothermic or endothermic, conditional on the difference in 1) lattice energy, and 2) hydration energy. However, the general rule of thumb is that most ammonium salt's dissolution process is endothermic. Thus  $\boxed{D}$  is the correct answer.

8. We can write this example reaction to help provide an answer.

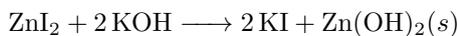
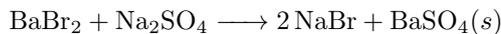
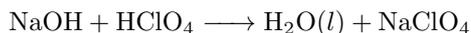
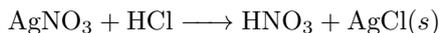


As we know,  $\text{H}_2\text{SO}_3$  is an unstable and weak acid, and will further decompose into



Thus, we will have a gas evolution. The only answer that has this is  $\boxed{D}$ .

9. Let's write a reaction for each answer choice.



We see that all of these produce a precipitate except  $\boxed{\text{NaOH} + \text{HClO}_4}$ , as  $\text{NaClO}_4$  is highly soluble in water. Thus, the answer is  $\boxed{B}$ .

10. This is just memorization of the flame test colors. Na has a yellow color, K has a purple color, Li has a red color, and Cu is green. Thus, the answer is  $\boxed{\text{lithium}}$ , or  $\boxed{A}$ .

11. This is memorization of the transition metal colors. The metal cation  $\boxed{\text{Zn}^{2+}}$  is particularly known for having a colorless aqueous solution. This is because the  $d$ -orbitals are fully filled. Thus, the answer is  $\boxed{D}$ .

12. The beaker, A, does not have enough accuracy. B doesn't have any markings. C is an Erlenmeyer flask that doesn't have enough accuracy.  $\boxed{D}$  is a  $\boxed{\text{graduated cylinder}}$  that has markings to allow accurate measurement, so this is the correct answer.

13. We can write the ideal gas law to solve for the density.

$$PV = nRT$$

Rexpressing  $n = \frac{m}{M}$ , where  $M$  is molar mass, we write it as

$$PV = \frac{m}{M} \times RT$$

We can say the density  $d = \frac{m}{V}$ , and

$$P = \frac{m}{MV} \times RT$$

$$1 = \frac{d}{M} \times \frac{RT}{P}$$

Under constant pressure and temperature, we can say that

$$M_{\text{gas}} \propto d$$

Thus, we can set this following equation.

$$\frac{d_1}{d_2} = \frac{M_1}{M_2}$$

Substituting  $d_1 = 1.30$ ,  $M_1 = 32.0$ , and  $M_2 = 44.0$ , we get

$$\frac{1.30}{d_2} = \frac{32.0}{44.0}$$

Solving we get  $d_2 = \boxed{1.79 \text{ g L}^{-1}}$ , or  $\boxed{B}$ .

14. Looking at a Maxwell-Boltzmann distribution, we see that in any given sample of gas the molecules move at many different speeds even under the same temperature. Not all molecules move at the average speed. Thus I is incorrect. Pressure is determined partially by frequency of collisions with the walls of the container. Looking at  $PV = nRT$ , at 398 K, there would be more collisions (pressure), not less. Thus II is incorrect. The answer is  $\boxed{I + II}$ , or  $\boxed{D}$ .

15. Boiling point is determined by intermolecular forces. Since Ar as well as all the answer choices have only one type of atom, there are no intermolecular forces except London dispersion force (LDF). LDF depends on the number of electrons. From the periodic table, we see Ar has 18 electrons.  $\text{F}_2$  has  $9 + 9 = 18$  electrons. Thus,  $\text{C}$  is the closest answer.

16. There will be two phases in which the volume increases. When the volume increases from 20 mL to 60 mL, the liquid and vapor will exist in dynamic equilibrium. Additionally, the vapor pressure will remain constant as the temperature remains constant. At 60 mL, the liquid-gas equilibrium is met. During the second phase that goes from 60 mL to 120 mL, all of the liquid has vaporized, and pressure decreases according to  $PV = nRT$ . Thus, the correct answer is  $\text{II}$ , or  $\text{B}$ .

17. Si has 4 valence electrons. Each valence electron can combine with a valence electron from another silicon atom to form a covalent bond. Thus allows Si to fulfill the octet rule. Thus, the answer is  $\text{A}$ .

18. We can use  $PV = nRT$  for this question.

$$n = \frac{PV}{RT}$$

We see that all answer choices have the same volume. Let's look at all choices relative to A using temperature and pressure. Remember that STP means 1 atm, 273 K. Also, 1 atm = 760 torr = 760 mmHg.

$$\begin{aligned} n_B &= n_A \\ n_C &= n_A \times \frac{273 \text{ K}}{273 + 25 \text{ K}} < n_A \\ n_D &= n_A \times \frac{790 \text{ torr}}{760 \text{ torr}} > n_A \end{aligned}$$

B and D are both diatomic molecules, so they contain more atoms. So C contains the smallest number of atoms. Thus, the answer is  $\text{C}$ .

19. For the standard enthalpy of formation, we must create one mole of  $\text{HCOOH}(l)$  from elements in their standard states. These are  $\text{H}_2(g)$ ,  $\text{C}(s)$ , and  $\text{O}_2(g)$ . The only reaction that uses the correct standard states is  $\text{B}$ .

20. First we must write the reaction.



The net ionic equation is



Now we can use the information in the table to determine  $\Delta H$ .

$$\Delta H = (-286) + (-677) - (-692) - (-230) = -41 \text{ kJ/mol}_{\text{rxn}}$$

Now we must determine the limiting reactant.

$$40.0 \text{ mL} \times 0.200 \text{ M} = 8.00 \text{ mmol NaOH}$$

$$200.0 \text{ mL} \times 0.100 \text{ M} = 20.0 \text{ mmol NaHCO}_3$$

The limiting reactant is clearly NaOH. Now we can do dimensional analysis to find the heat released,  $q$ . Note that in the reaction, we have written one mole of NaOH. This is why we can say 1 mol NaOH/mol<sub>rxn</sub>.

$$8.00 \text{ mmol NaOH} \times \frac{1 \text{ mol}}{1000 \text{ mmol}} \times \frac{1 \text{ mol}_{\text{rxn}}}{\text{mol NaOH}} \times \frac{-41 \text{ kJ}}{\text{mol}_{\text{rxn}}} \times \frac{1000 \text{ J}}{\text{kJ}} = \boxed{-330 \text{ J}} \longrightarrow \boxed{\text{C}}$$

21. We can set up the following equation, in which the energy entering the system is equal to the energy lost by the surroundings.

$$Q_i = Q_f$$

$$Q_{\text{warm}} + Q_{\text{ice}} = Q_f$$

$$50.0 \times (T_f - 0.0) \times 4.18 + 334 \times 50.0 = 350 \times (32.0 - T_f) \times 4.18$$

The reason for two terms on the left hand side is that some heat is required to melt the ice cube, and additional heat is required to warm the water from the melted ice cube. Solving for  $T_f$ , we get

$$T_f = \boxed{18.0 \text{ }^\circ\text{C}}$$

Thus, the answer is  $\boxed{A}$ .

22. We can eliminate D because from  $\Delta G = \Delta H - T\Delta S$ , we see that entropy and enthalpy are separate. We can eliminate B because  $\text{CaSO}_4$  is an ionic solid. Now, entropy depends on the number of ways something can be arranged. We see  $\Delta S < 0$ , so the number of arranging ways decreased. Thus, we can eliminate A. This leaves only  $\boxed{C}$ . This is the correct answer because some salts decrease entropy upon dissolution through their interactions with water.

23. First, let us write the reaction.



Just from looking at the reaction, we know this is the opposite of a dissolution reaction, and therefore,  $K = \frac{1}{K_{\text{sp}}}$ . Now we use the following equation.

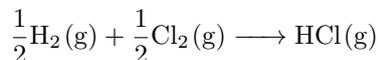
$$\Delta G^\circ = -RT \ln(K) = -RT \ln\left(\frac{1}{K_{\text{sp}}}\right) = RT \ln(K_{\text{sp}})$$

Substituting our values, we get

$$\Delta G^\circ = 8.314 \frac{\text{J}}{\text{mol} \times \text{K}} \times 298 \text{ K} \times \ln(2.0 \times 10^{-31}) = -175132 \text{ J/mol}$$

Converting into kilojoules, we see that our answer will be  $\boxed{-175 \frac{\text{kJ}}{\text{mol}}}$ , or  $\boxed{A}$ . Notice additionally that A is the only option that is negative, which makes it even more correct because the natural log of a small number should produce a negative number when multiplied by a positive number.

24. We start by writing the reaction.



Because  $\text{H}_2$  and  $\text{Cl}_2$  are both in their elemental state, the  $\Delta H_{\text{rxn}} = \Delta H_f^\circ(\text{HCl})$ . We know that there is  $\frac{1}{2}$  H-H bond broken and  $\frac{1}{2}$  H-Cl bond broken. Thus, we set up the equation as follows.

$$\frac{1}{2} \times 435 + \frac{1}{2} \times \text{BDE}(\text{Cl}-\text{Cl}) - 431 = -92$$

Solving, we get

$$\text{BDE}(\text{Cl}-\text{Cl}) = \boxed{243 \frac{\text{kJ}}{\text{mol}}}$$

Thus, the answer is  $\boxed{D}$ .

25. A is incorrect because the rate law depends on which step is rate-determining. B is incorrect because the slowest elementary step is the rate-determining one. D is incorrect because it describes intermediates, not catalysts. Catalysts are consumed and subsequently produced. This leaves  $\boxed{C}$ , which is correct.

26. The average rate of disappearance of  $\text{NO}_2$  is just equal to the change in concentration over time. This is

$$\frac{0.0100 \text{ M} - 0.0050 \text{ M}}{100. \text{ s}} = \boxed{5.0 \times 10^{-5} \text{ M s}^{-1}}$$

Thus, the answer is  $\boxed{C}$ .

27. From the first row to the second row, we see  $[A]_0$  stayed the same, while  $[B]_0$  multiplied by 2. This caused the rate to multiply by 2. Thus the rate is directly proportional to, or first order in, B. From the second row to the third row,  $[B]_0$  multiplied by  $\frac{3}{2}$ , but the rate multiplied not by  $\frac{3}{2}$  but by 3. Looking at  $[A]_0$  we see it multiplied by  $(\frac{3}{2})^1 \times (2)^1 = 3$ , so the reaction is first order in A as well. Thus, the answer is  $\boxed{C}$ .

28. We know

$$\text{Rate} = k[X]^0[Y]^0$$

The units of rate are  $\text{M s}^{-1}$ . The units of  $[X]$  are M. The units of  $[Y]$  are M. Thus we can solve for the units of  $k$ .

$$\text{M s}^{-1} = k(\text{M})^0(\text{M})^0 \rightarrow k = \boxed{\text{M s}^{-1}}$$

Thus, the answer is  $\boxed{A}$ .

29. We know that the  $\text{FeCl}_3$  is not produced by the reaction at any point, so it cannot be an intermediate. A transition state is part of the steps of the reaction as a molecule changes, so this does not apply. This leaves us with C and D. The answer is  $\boxed{D}$ , because a  $\boxed{\text{homogenous catalyst}}$  is something that speeds up a reaction (catalyst) and is the same phase as the reactants (homogenous). Both  $\text{H}_2\text{O}_2(aq)$  and  $\text{FeCl}_3(aq)$  are aqueous.

30. We can use the integrated first order kinetics equation to solve for  $[A]$ , given that  $[A]_0 = 1.50 \text{ M}$ ,  $t = 500. \text{ s}$ , and  $k = 6.70 \times 10^{-4} \text{ s}^{-1}$ .

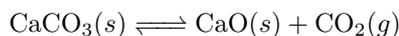
$$\ln[A] = -kt + \ln[A]_0$$

$$[A] = \exp\left(-6.70 \times 10^{-4} \times 500 + \ln(1.50)\right)$$

$$A = \boxed{1.07 \text{ M}}$$

Thus, the answer is  $\boxed{A}$ .

31. Let us first write our reaction and equilibrium expression.



$$K_P = P_{\text{CO}_2} = 30.0 \text{ mm Hg}$$

Say all of the 60.0 g sample of  $\text{CaCO}_3$  decomposes. Then we can use the ideal gas law to say

$$P = \frac{nRT}{V} = \frac{60.0 \text{ g} \times \frac{1 \text{ mol}}{100 \text{ g}} \times (0.0821 \frac{\text{L}\cdot\text{atm}}{\text{K}\cdot\text{mol}}) \times 950 \text{ K}}{1.00 \text{ L}} = 46.8 \text{ atm}$$

Converting this to mm Hg, we have that

$$46.9 \text{ atm} \times \frac{760 \text{ mm Hg}}{1 \text{ atm}} = 3.56 \times 10^4 \text{ mm Hg}$$

Thus, the  $\text{CaCO}_3$  does not fully decompose. Since temperature remains constant,  $K_p$  will not change, and therefore the pressure of the  $\text{CO}_2$  will not change. The correct answer is  $\boxed{B}$ .

**32.** When equilibrium is involved in acid dissociation, we can usually automatically say that very little dissociates and so  $\boxed{A}$  is correct. Let's see what happens when we solve it mathematically.

$$\text{HNO}_2 \rightleftharpoons \text{H}^+ + \text{NO}_2^- \quad K_a = 4.5 \times 10^{-4}$$

$$K_a = \frac{[\text{H}^+][\text{NO}_2^-]}{\text{HNO}_2} \approx \frac{(x)(x)}{0.1}$$

$$x = \sqrt{0.1 \times K_a} = 0.007$$

Clearly,  $\text{HNO}_2$  is present in a much higher amount than  $\text{H}^+$  and  $\text{NO}_2^-$ .

**33.** We know

$$K_{\text{sp}} = [\text{Ag}^+]^2[\text{SO}_4^{2-}]$$

The reaction is



From the reaction, we see there are 2  $\text{Ag}^+$  for each  $\text{SO}_4^{2-}$ . Therefore,

$$K_{\text{sp}} = [\text{Ag}^+]^2[\text{SO}_4^{2-}] = (2[\text{SO}_4^{2-}])^2([\text{SO}_4^{2-}]) = 4[\text{SO}_4^{2-}]^3$$

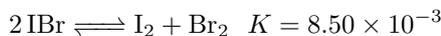
$$[\text{SO}_4^{2-}] = \sqrt[3]{\frac{K_{\text{sp}}}{4}} = 2.5 \times 10^{-2} \text{ mol/L}$$

Now we can do dimensional analysis.

$$2.5 \times 10^{-2} \frac{\text{mol SO}_4^{2-}}{\text{L water}} \times \frac{1 \text{ mol Ag}_2\text{SO}_4}{\text{mol SO}_4^{2-}} \times \frac{311.87 \text{ g}}{\text{mol}} = \frac{7.7 \text{ g}}{\text{L water}}$$

Thus, the answer is  $\boxed{D}$ .

**34.** First, let's write the reaction.



Now let's write our equilibrium expression.

$$K = \frac{P_{\text{I}_2} P_{\text{Br}_2}}{(P_{\text{IBr}})^2}$$

Let's see in which direction the reaction will shift.

$$Q = \frac{(0.750)(0.750)}{(0.350)^2} = 4.59$$

Clearly,  $Q$  is much greater than  $K$ . The reaction must shift left. When this happens, we see from the reaction that if  $\text{I}_2$  and  $\text{Br}_2$  each decrease by an amount  $x$ ,  $\text{IBr}$  will increase by an amount  $2x$ .

$$K = \frac{(0.750 - x)(0.750 - x)}{(0.350 + 2x)^2}$$

$$x = \frac{0.750 - 0.350\sqrt{K}}{2\sqrt{K} + 1} = 0.606 \text{ atm} \longrightarrow (\text{IBr}) = 0.350 + 2x = \boxed{1.56 \text{ atm}}$$

Thus, the answer is  $\boxed{C}$ .

**35.** Since HCl is a strong acid while  $\text{CH}_3\text{CH}_2\text{NH}_2$  is a weak base, we know the pH will be less than 7 at equivalence point so we can immediately eliminate C and D. At the equivalence point, the major compound will be  $\text{CH}_3\text{CH}_2\text{NH}_3^+$ , which has the same mole number with the initial  $\text{CH}_3\text{CH}_2\text{NH}_2$ . We can calculate the number of moles of initial ethylamine, under the assumption of  $1 \frac{\text{g}}{\text{mL}}$  as the density of the solution.

$$n = 20 \text{ mL} \times 1 \frac{\text{g}}{\text{mL}} \times 10\% \times \frac{1 \text{ mol}}{45 \text{ g}} = 4.4 \times 10^{-2} \text{ mol ethylamine}$$

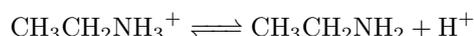
Next, we need to calculate the volume of the HCl added.

$$V = \frac{4.4 \times 10^{-2} \text{ mol}}{0.3000 \text{ mol/L}} \times \frac{1000 \text{ mL}}{\text{L}} = 147 \text{ mL}$$

With the total volume of the solution at end point, we can calculate the concentration of the ethylamine.

$$c = \frac{n}{V_{\text{total}}} = \frac{4.4 \times 10^{-2} \text{ mol}}{(0.020 \text{ L} + 0.147 \text{ L})} = 0.26 \text{ M}$$

With this, we can now set up an equilibrium in terms of the dissociation of the conjugate acid, and solve for  $[\text{H}^+]$  at the end point. We first need to write the dissociation.



Upon reaching the endpoint, both of the products will increase in concentration by  $x$ , while the concentration of  $\text{CH}_3\text{CH}_2\text{NH}_3^+$  decreases by  $x$ . The equilibrium concentration of  $\text{CH}_3\text{CH}_2\text{NH}_3^+$  is pretty much 0.26 M. This is because  $K_a = 10^{-10.75} \ll 1$ , so equilibrium is far to the left. Thus, we can set up an equation in terms of  $K_a$ .

$$K_a = \frac{[\text{H}^+][\text{CH}_3\text{CH}_2\text{NH}_2]}{[\text{CH}_3\text{CH}_2\text{NH}_3^+]}$$

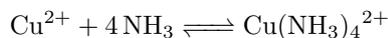
$$K_a = \frac{x^2}{0.26 - x} \approx \frac{x^2}{0.26}$$

Solving for  $x$ , we get  $x = 2.2 \times 10^{-6}$ . With this, we also know that  $[\text{H}^+] = x = 2.2 \times 10^{-6}$  M. To solve for the pH, we can just take the negative log base 10, shown below. This will get us the pH at the endpoint.

$$-\log_{10}[\text{H}^+] = -\log_{10} 2.2 \times 10^{-6} = \boxed{5.66}$$

Thus, the range that the pH is closest to is bromocresol green, or B.

**36.** Let us write the reaction described in the problem.



Let the concentration of  $\text{NH}_3$  be  $x$ . We know that

$$K_f = \frac{[\text{Cu}(\text{NH}_3)_4^{2+}]}{[\text{Cu}^{2+}][\text{NH}_3]^4}$$

$$\frac{[\text{Cu}(\text{NH}_3)_4^{2+}]}{[\text{Cu}^{2+}]} = \frac{99.9\%}{0.1\%}$$

$$K_f = \frac{99.9}{0.1 \times x^4} = 1. \times 10^{13}$$

$$99.9 = (1. \times 10^{13})(0.1 \times x^4)$$

Solving for  $x$ , we get  $3 \times 10^{-3}$ , or D.

37. Looking at the reaction, we have 2 Cl on the products side, and 1 Cl on the reactants side. We also have 1 H on the reactants side, and 2 H on the products side. Thus, we need to multiply  $\text{ClO}_2$  and  $\text{OH}^-$  by 2.



Now the reaction is balanced, and we can determine the ratio. This will be  $\boxed{2 : 1}$ , or  $\boxed{B}$ .

38. We know oxidation occurs at the anode. Since the  $\text{I}^-$  in  $\text{KI}(\text{aq})$  is negative and easier to lose electrons, it must be oxidized. When oxidized, it forms  $\boxed{\text{I}_2}$ . Thus, the answer is  $\boxed{B}$ .

39. First, we must find the oxidation state of Pt. We know K has an oxidation state of +1, Cl has an oxidation state of -1, and the entire compound is neutral. Thus we can say  $2(+1) + (x) + 4(-1) = 0$ . Solving for  $x$ , we see  $x = +2$  so each Platinum is in the form Pt(II). This means each platinum in  $\text{K}_2\text{PtCl}_4$  must get two electrons to become Pt(s). Now we can do dimensional analysis using Faraday's constant  $F = 96500 \text{ C mol}^{-1}$  available in the reference that comes with the olympiad.

$$1.00 \text{ g Pt} \times \frac{1 \text{ mol}}{195.1 \text{ g}} \times \frac{2 e^-}{\text{Pt}} \times \frac{96500 \text{ C}}{\text{mol } e^-} \times \frac{1 \text{ s}}{0.15 \text{ C}} = \boxed{6600 \text{ s}}$$

Thus, the answer is  $\boxed{C}$ .

40. First, we can write the reaction and shift away from the line notation.



With the reaction written, we can just analyze all of the options. For I, decreasing the concentration of  $\text{Al}^{3+}$  will shift the equilibrium to the right, and therefore increase the cell potential. For II, decreasing the concentration of  $\text{Cu}^{2+}$  will see the equilibrium shift to the left, and cause the cell potential to decrease. For III, an increase in surface area will not change  $Q$ , and therefore have no effect on the cell potential. Thus, the only option that increases the cell potential is  $\boxed{I}$ , or  $\boxed{A}$ .

41. We need to set the equations below equal to each other, and then just solve for  $K$ .

$$\Delta G^\circ = -RT \ln(K)$$

$$\Delta G^\circ = -nFE_{\text{cell}}^\circ$$

$$-RT \ln(K) = -nFE_{\text{cell}}^\circ$$

$$\ln K = \frac{nFE_{\text{cell}}^\circ}{RT}$$

Substituting our values of  $n = 2$ ,  $F = 96500$ ,  $E_{\text{cell}}^\circ = 0.80 - 0.34 = 0.46$ ,  $R = 8.314$ , and  $T = 25 + 273 = 298$ , we get

$$\ln K = 36$$

$$K = \boxed{3.6 \times 10^{15}}$$

Thus, the answer is  $\boxed{B}$ .

42. We have to use the Nernst equation to solve for  $Q$ , which we can use to solve for the concentrations.

$$E_{\text{cell}} = E_{\text{cell}}^\circ - \frac{RT}{nF} \ln Q$$

Substituting out values given in the problem, we get

$$\ln Q = \frac{(0.48 - 0.45) \times 2 \times 96500}{8.314 \times 298} = 2.3$$

Solving for  $Q$ , we get  $Q \approx 10$ . Now we have to write the reaction in order to determine the concentration. Let  $x$  denote the change in concentration.



The concentration of  $\text{Cu}^{2+}$  goes from 1.00 to  $1.00 - x$ , while the concentration of  $\text{Sn}^{2+}$  goes from 1.00 to  $1.00 + x$ . Setting up the below equation, we can say

$$Q = \frac{[\text{Sn}^{2+}]}{[\text{Cu}^{2+}]} = \frac{1.00 + x}{1.00 - x} = 10$$

Solving for  $x$ , we get  $x = 0.82$ . Substituting in our original expressions, we get the concentrations of  $[\text{Sn}^{2+}]$  and  $\text{Cu}^{2+}$  as  $\boxed{1.82}$  and  $\boxed{0.18}$ . Thus, the answer is  $\boxed{D}$

**43.** Rutherford shot an alpha particle beam at a piece of gold foil, expecting them all to pass through. To his surprise, some were deflected/reflected. This led to the notion of a  $\boxed{\text{positive nucleus}}$ , or  $\boxed{A}$ .

**44.** We know O has a  $-2$  charge in oxides. Since Fr is in the alkali metal group, we know it is most likely to take a  $+1$  charge. Thus, the answer is  $\text{Fr}_2\text{O}$ , or  $\boxed{A}$ , because  $(2)(+1) + (-2) = 0$  and the compound must be neutral.

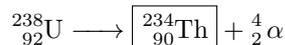
Further more, all alkali metal can form more complicated oxides except Li such as peroxides, superoxides etc. Those oxides are extremely strong oxidant such as  $\text{FrO}_2$ , thus are not very stable.

**45.** This is just the application of periodic trends. As the atomic number increases from 11 to 15, we see we are going left to right of the third period on the periodic table. Therefore, the atomic radii  $\boxed{\text{decrease}}$  due to the increase of the effective nuclear charge,  $Z_{\text{eff}}$  across the period, and the answer is  $\boxed{B}$ .

**46.** We need to compare the number of electrons in each orbital in order to compare the ionization energy. In the  $2p$  subshell of N, there will be one electron in each of the orbitals. However, in the  $2p$  subshell for O, there are 2 electrons in the first orbital and 1 in the other two. Thus, there is  $\boxed{\text{greater electronic repulsion}}$  in the  $2p$  subshell for oxygen, which is  $\boxed{C}$ .

**47.** One of the key facts when writing quantum numbers is that  $n > l$ , with  $l = 0, 1, 2, \dots, n-1$ . Looking at the answer choices, we see that  $\boxed{1, 1, 0, \frac{-1}{2}}$  is a violation of this. Thus, the answer is  $\boxed{A}$ .

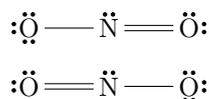
**48.** This is an analysis of nuclear decay pathways. For *alpha* decay,  $\Delta Z = -2$ , and  $\Delta A = -4$ . The reaction is



Thus, the answer is  $\boxed{B}$ .

**49.** Bonds between carbon and oxygen are polar because of the high electronegativity of oxygen. However,  $\boxed{\text{CO}_2}$  is a linear molecule. This means the dipoles from each oxygen are equal but in opposite directions, so they cancel out. Thus, the answer is  $\boxed{A}$ .

**50.** Let's draw the two resonance structures for  $\text{NO}_2^-$ .



In each Lewis structure, nitrogen is in the center with a formal charge of 0, so II is correct. In one, the oxygen on the right has a double bond while the oxygen on the left has a single bond. In

the other, this is reversed. Since these two structures are equivalent, there is no reason why one should contribute more than the other so I is correct. Thus, the answer is  $I + II$ , which is  $C$ .

51. When we draw the Lewis structure for  $\text{NF}_5$ , we see that there are 5 bonds connected to nitrogen. This is not stable because nitrogen can only have up to 4 bonds (i.e. must obey the octet rule), so the answer is  $B$ . Some atoms such as P can have more than 4 bonds (octet rule), as in  $\text{PF}_5$ . However, this is because phosphorus has empty  $3d$  orbitals it can use in addition to its  $3s$  and  $3p$  orbitals.

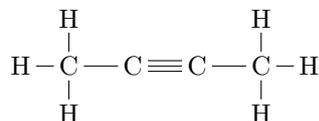
52. This is drawing the Lewis structure and the application of the VSEPR model. When we draw the Lewis structure, we see I has three bonding groups and two lone pairs. From the VSEPR chart, this is  $T$ -shaped with the two lone pairs located in the equatorial positions, or  $C$ .

53. First, let us note that  $\text{N}_2$  is a diatomic molecule made by triple bond, which is composed of 1  $\sigma$  bond and 2  $\pi$  bonds, while  $\text{P}_4$  is a tetrahedral molecule made by P–P single bonds, which are  $\sigma$  bonds only. Through this comparison, we see that the second period elements like N prefer to form multiple bonds with  $\pi$  bonds involved, however, third period elements such as P are very hard to make multiple bonds. This is because the larger size of third period atoms makes the overlap of  $p$  orbitals poorly. Thus, the decrease of overlap in pi bonds will cause the change in stability. The answer is  $C$ .

Furthermore, you may find similar comparisons in  $\text{O}_2$  and  $\text{S}_8$ ,  $\text{CO}_2$  and  $\text{SiO}_2$ .

54. This question is using the hybridization chart and drawing the structures. For example, carbon makes 3 bonding groups in ethene, with no lone pairs. (2 bonds with the hydrogens and 1 with the carbon.) Thus, it is  $sp^2$  hybridized. Only the carbons with four single bonds are  $sp^3$  hybridized, so the answer is ethane, or  $B$ .

55. Drawing the structure makes this easier.



Each single bond will contribute 1  $\sigma$  bond, and each triple bond will contribute 1  $\sigma$  bond. Thus, we count 9  $\sigma$  bonds, which is  $C$ .

56. Alcohols that undergo acid-catalyzed dehydration under the mildest conditions are tertiary alcohols since it can produce the most stable tertiary carbocation after the protonation. We define a tertiary alcohol as a compound with a hydroxyl group attached to a carbon with three other carbons connected. Looking at the answer choices, we get  $(\text{CH}_3)_3\text{COH}$ , or  $D$ .

Furthermore, tertiary carbonocations are stabilized by the three connected electron-donating  $-R$  groups through hyperconjugation, which makes it more stable than the secondary and primary carbocations formed by the dehydration of alcohols in the other options.

57.  $\text{CH}_3\text{COOH}$  has a carboxyl group,  $-\text{COOH}$ . This group is known to act as an acid by donating a proton to become  $-\text{COO}^-$ . Thus, the answer is  $B$ .

58. The key fact here is that ketones cannot be further oxidized, while secondary alcohols can be oxidized into ketones. If there is change in color, then there must have been some process of oxidation that occurred. In the presence of acidified potassium dichromate, there will be a noticeable color change from orange to green due to the reduction of dichromate to Cr(III) by the secondary alcohol. This will not occur with the ketone. Thus, the answer is  $D$ .

59. In DNA, C pairs with G and A pairs with T. Thus, the only answer that works is A. There is no U in DNA. In RNA, the T in DNA is replaced with U.

60. Proteins and peptides are polymer made by amino acids connected by peptide bonds. Peptide bonds are  $-C(=O)-NH-$  formed by the dehydration of the amino group from one amino acid and the carboxyl group from another. In organic chemistry, amides are defined as the dehydration products of amine ( $RNH_2$ ,  $R_2NH$ , or  $R_3N$ ) and carboxylic acids ( $RCOOH$ ). According to this, peptides bonds are a special type of amides bonds. Thus, the answer is amide bonds, or B.