QUIZ CH101

Solutions and Colligative Properties

Lucas Montogue

Notation
In this quiz, the letter "M" is used to denote four different quantities: a capital M, M, denotes molarity; a capital M with an overbar, $\overline{M}$, denotes molality; a lower-case M, m, denotes mass; finally, a fraktur M, $\mathfrak{M}$, denotes molar mass.

PROBLEMS

Problem 1.1

The mass of solute present in 500 mL of a 0.8 M NaCl solution is:

A) m = 10.4 g
B) m = 18.8 g
C) m = 23.4 g
D) m = 31.0 g

Problem 1.2

The mass of solute present in 75 g of a 0.2 m KCl solution is:

A) m = 1.12 g
B) m = 2.24 g
C) m = 3.36 g
D) m = 4.48 g

Problem 1.3

Calculate the molarity of a solution obtained by adding 34.2 g aluminum sulfate, $Al_2(SO_4)_3$, to 250 mL of water.

A) M = 0.2 mol/L
B) M = 0.4 mol/L
C) M = 0.6 mol/L
D) M = 0.8 mol/L

Problem 1.4

Calculate the molarity of a solution obtained by adding 240 g of lithium perchlorate trihydrate, $LiClO_4 \cdot 3\ H_2O$, to 2000 mL of water.

A) M = 0.25 mol/L
B) M = 0.5 mol/L
C) M = 0.75 mol/L
D) M = 1.0 mol/L

Problem 1.5

Calculate the molality of a solution containing 31.2 g of benzene dissolved in 100 g of tetrachloromethane (CCl_4).

A) $\overline{M}$ = 1.0 m
B) $\overline{M}$ = 2.0 m
C) $\overline{M}$ = 3.0 m
D) $\overline{M}$ = 4.0 m

© 2020 Montogue Quiz

→ Problem 1.6

What is the molality of a solution formed by dissolving 15 g KCl in 20 mol of water?

A) $\overline{M}$ = 0.232 m
B) $\overline{M}$ = 0.558 m
C) $\overline{M}$ = 0.831 m
D) $\overline{M}$ = 0.942 m

→ Problem 1.7

How many grams of sulfur (S_8) must be dissolved in 180 g of naphthalene to make a 0.16 m solution?

A) m = 2.44 g
B) m = 7.37 g
C) m = 12.1 g
D) m = 17.2 g

→ Problem 1.8

Calculate the mass percentage of iodine in a solution containing 0.04 mol of I_2 in 80 mL of tetrachloromethane. The density of CCl_4 is 1.49 g/cm³.

A) f_{I_2} = 4.41%
B) f_{I_2} = 7.89%
C) f_{I_2} = 12.3%
D) f_{I_2} = 15.4%

→ Problem 1.9

Seawater contains 0.008 g of strontium ions, Sr^{2+}, and 0.014 mg of zinc ions, Zn^{2+}, per kilogram of water. The concentration of Sr^{2+} in parts per million (ppm) and the concentration of Zn^{2+} in parts per billion (ppb) are, respectively:

A) $c(\mathrm{Sr}^{2+})$ = 8 ppm and $c(\mathrm{Zn}^{2+})$ = 1.4 ppb
B) $c(\mathrm{Sr}^{2+})$ = 8 ppm and $c(\mathrm{Zn}^{2+})$ = 2.8 ppb
C) $c(\mathrm{Sr}^{2+})$ = 16 ppm and $c(\mathrm{Zn}^{2+})$ = 1.4 ppb
D) $c(\mathrm{Sr}^{2+})$ = 16 ppm and $c(\mathrm{Zn}^{2+})$ = 2.8 ppb

→ Problem 1.10

Commercial aqueous nitric acid has a density of 1.12 g/cm³ and is 3.7 M. Calculate the percent HNO_3 by mass in the solution.

A) f_{HNO_3} = 5.33%
B) f_{HNO_3} = 10.8%
C) f_{HNO_3} = 20.8%
D) f_{HNO_3} = 31.8%

→ Problem 1.11

A solution of aqueous sulfuric acid has a density of 1.30 g/cm³ and is 6 M. Calculate the percent H_2SO_4 by mass in the solution.

A) $f_{H_2SO_4}$ = 20.1%
B) $f_{H_2SO_4}$ = 45.2%
C) $f_{H_2SO_4}$ = 60.9%
D) $f_{H_2SO_4}$ = 66.7%

→ Problem 1.12

A solution is made by adding 48 g of methanol to 400 mL of water. True or false?

1.( ) The mass percent of methanol in the solution is greater than 8%.
2.( ) The mole fraction of methanol in the solution is greater than 0.075.
3.( ) The molality of the solution is greater than 3.5 m.

→ Problem 1.13

A solution is made by adding 172 g of hexane to 450 mL of benzene (density = 0.876 g/cm³). True or false?

1.( ) The mass percent of hexane in the solution is greater than 40%.
2.( ) The mole fraction of hexane in the solution is greater than 0.25.
3.( ) The molality of the solution is greater than 5.5 m.

© 2020 Montogue Quiz

→ Problem 2.1

A perchloric acid solution contains 520 g of $HClO_4$ per liter of solution, and the solution has a density of 1.32 g/cm³. True or false?

1.( ) The mass percentage of $HClO_4$ in the solution is greater than 45%.
2.( ) The mole fraction of $HClO_4$ in the solution is greater than 0.08.
3.( ) The molarity of the solution is greater than 4.6 mol/L.
4.( ) The molality of the solution is greater than 7.5 m.

→ Problem 2.2

A nitric acid solution contains 360 g of HNO_3 per liter of solution, and the solution has a density of 1.22 g/cm³. True or false?

1.( ) The mass percentage of HNO_3 in the solution is greater than 25%.
2.( ) The mole fraction of HNO_3 in the solution is greater than 0.15.
3.( ) The molarity of the solution is greater than 5.2 mol/L.
4.( ) The molality of the solution is greater than 7 m.

→ Problem 2.3

The density of acetonitrile, CH_3CN, is 0.786 g/mL, and the density of methanol, CH_3OH, is 0.791 g/mL. A solution is made by dissolving 40 mL of CH_3OH in 120 mL of CH_3CN. True or false?

1.( ) The mass percentage of methanol in the solution is greater than 28%.
2.( ) The mole fraction of methanol in the solution is greater than 0.28.
3.( ) The molarity of the solution is greater than 6.5 mol/L.
4.( ) The molality of the solution is greater than 9 m.

▶ Problem 3

Invar, a nickel-iron alloy, contains 64% iron and 36% nickel by mass, and has a density of 8100 kg/m³. Treating this alloy as a solution, find the **molarity** and the **molality** of nickel in Invar.

A) M = 24.8 mol/L and $\overline{M}$ = 4.80 m
B) M = 24.8 mol/L and $\overline{M}$ = 9.59 m
C) M = 49.7 mol/L and $\overline{M}$ = 4.80 m
D) M = 49.7 mol/L and $\overline{M}$ = 9.59 m

→ Problem 4.1

Two aqueous solutions of the same ionic salt AB are prepared; solution 1 has a concentration of 0.01 M and solution 2 has a concentration of 0.1 M. Assuming the salt ionizes completely, which of the following statements is **false**?

A) The vapor pressure of solution 1 is lower than the vapor pressure of solution 2.
B) The osmotic pressure of solution 1 is lower than the osmotic pressure of solution 2.
C) The boiling point of solution 1 is lower than the boiling point of solution 2.
D) The freezing point of solution 1 is higher (less negative) than the freezing point of solution 2.

→ Problem 4.2

Which of the following aqueous solutions will have the highest boiling point?

A) 0.01 M glucose ($C_6H_{12}O_6$)
B) 0.01 M sodium chloride (NaCl)
C) 0.01 M sodium sulfate (Na_2SO_4)
D) 0.01 M calcium phosphate ($Ca_2(PO_4)_3$)

→ Problem 5.1

Benzene and toluene form an ideal solution. The vapor pressures of benzene (A) and toluene (B) at 20°C are 75 Torr and 20 Torr, respectively. The partial vapor pressure of benzene at 20°C for a solution containing 117 g of benzene and 184 g toluene is:

A) P_A = 22.4 Torr
B) P_A = 32.2 Torr
C) P_A = 48.8 Torr
D) P_A = 61.1 Torr

© 2020 Montogue Quiz

→ Problem 5.2

At 75°C, the vapor pressure of a pure liquid A is 500 mmHg and that of a pure liquid B is 1200 mmHg. If a mixture solution of A and B boils at 75°C and a pressure of 0.85 atm, the mole fraction of A in the mixture is:

A) χ_A = 0.211
B) χ_A = 0.425
C) χ_A = 0.601
D) χ_A = 0.791

→ Problem 5.3

Two liquids A and B form an ideal solution. At 300 K, the vapor pressure of a solution containing 3 mol of A and 1 mol of B is 600 mmHg. At the same temperature, if 1 mol of A is further added to the solution, the vapor pressure of the solution **increases** by 10 mmHg. The vapor pressures of A and B in their pure states are, respectively:

A) P_A^{sat} = 600 mmHg and P_B^{sat} = 450 mmHg
B) P_A^{sat} = 600 mmHg and P_B^{sat} = 500 mmHg
C) P_A^{sat} = 650 mmHg and P_B^{sat} = 450 mmHg
D) P_A^{sat} = 650 mmHg and P_B^{sat} = 500 mmHg

→ Problem 5.4

How many grams of urea, $(NH_2)_2CO$, must be added to 480 g of water to give a solution with a vapor pressure 5 mmHg less than that of pure water at 30°C? The vapor pressure of water at 30°C is 31.8 mmHg.

A) m_{urea} = 105 g
B) m_{urea} = 194 g
C) m_{urea} = 298 g
D) m_{urea} = 415 g

→ Problem 6.1

A 1.0% by mass KCl(aq) solution has a freezing point of −0.4°C. Estimate the van't Hoff i factor from the data. Then, determine the total molality of all solute species. Finally, calculate the percentage dissociation of KCl in the solution. True or false?

1.( ) The van't Hoff factor for this solute is greater than 1.45.
2.( ) The molality of all solute species is greater than 0.25 m.
3.( ) The percentage dissociation of KCl in this solution is greater than 75%.

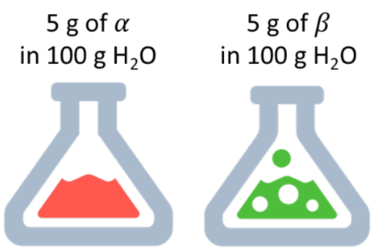
→ Problem 6.2

A 2% by mass $CaCl_2$(aq) solution has a boiling point of 100.26°C. Estimate the van't Hoff factor from the data. Then, determine the molality of all solute species. Finally, calculate the percentage dissociation of $CuCl_2$ in the solution. True or false?

1.( ) The van't Hoff factor for this solute is greater than 2.5.
2.( ) The molality of all solute species is greater than 0.6 m.
3.( ) The percentage dissociation of $CaCl_2$ in this solution is greater than 92%.

→ Problem 7.1

Two unknown molecular compounds were being studied. A solution containing 5.0 g of compound α (alpha) in 100 g of water froze at a lower temperature than a solution containing 5.0 g of compound β (beta) in 100 g of water. Which compound has the greater molar mass?



α) Compound α has the greatest molar mass.
β) Compound β has the greatest molar mass.
γ) There is not enough information.

© 2020 Montogue Quiz

➔ Problem 7.2

Calculate the depression in freezing point of a solution obtained by adding 3 mol of benzene to 30 kg of tetrachloroethane.

A) ΔT_f = 0.588°C

B) ΔT_f = 1.12°C

C) ΔT_f = 1.71°C

D) ΔT_f = 2.98°C

➔ Problem 7.3

Calculate the depression in freezing point of a solution obtained by adding 43 g of hexane to 4.75 L of benzene, which has a density of 0.876 g/cm³.

A) ΔT_f = 0.307°C

B) ΔT_f = 0.614°C

C) ΔT_f = 1.08°C

D) ΔT_f = 2.05°C

➔ Problem 7.4

Find the increase in normal boiling point of an aqueous solution that has a vapor pressure of 740 torr at 100°C.

A) ΔT_b = 0.381°C

B) ΔT_b = 0.763°C

C) ΔT_b = 1.35°C

D) ΔT_b = 2.06°C

➔ Problem 7.5

The freezing point of a carbon tetrachloride solution is −23.8°C. The elevation in boiling point of the same solution is:

A) ΔT_b = 0.133°C

B) ΔT_b = 0.245°C

C) ΔT_b = 0.333°C

D) ΔT_b = 0.492°C

➔ Problem 7.6

A 1.4-g sample of a molecular substance dissolved in 120 g of phenol reduced its freezing point to 41.8°C. What is the molar mass of the substance?

A) $\mathfrak{M}$ = 25.2 g/mol

B) $\mathfrak{M}$ = 40.7 g/mol

C) $\mathfrak{M}$ = 55.2 g/mol

D) $\mathfrak{M}$ = 70.7 g/mol

➔ Problem 7.7

A 8-g sample of a molecular substance dissolved in 150 g of benzene increased its boiling point to 81.6°C. What is the molar mass of the substance?

A) $\mathfrak{M}$ = 60.1 g/mol

B) $\mathfrak{M}$ = 75.1 g/mol

C) $\mathfrak{M}$ = 90.0 g/mol

D) $\mathfrak{M}$ = 105 g/mol

➔ Problem 8.1

Pheromones are compounds secreted by the females of many insect species to attract males. One of these compounds contains 80.78 percent C, 13.56 percent H, and 5.66 percent O. A solution of 1.0 g of this pheromone in 8.5 g of benzene freezes at 3.37°C. What are the molecular formula and molar mass of the compound?

α) The molecular formula is $C_{19}H_{38}O$, and the molar mass is 282 g/mol.

β) The molecular formula is $C_{38}H_{76}O_2$, and the molar mass is 564 g/mol.

γ) There is not enough information.

© 2020 Montogue Quiz

→ Problem 8.2

The elements X and Y constitute two molecules with formulas XY_2 and XY_4. When dissolved in 20 mL of water, 1 g of XY_2 lowers the freezing point by 0.8°C; when dissolved in 10 mL of water, 1 g of XY_4 lowers the freezing point by 1.2°C. In view of these results, determine the atomic masses of X and Y. Assume the van't Hoff factor $i = 1$ for both XY_2 and XY_4.

A) $\mathfrak{M}$(X) = 60.1 g/mol and $\mathfrak{M}$(Y) = 19.4 g/mol

B) $\mathfrak{M}$(X) = 60.1 g/mol and $\mathfrak{M}$(Y) = 38.8 g/mol

C) $\mathfrak{M}$(X) = 77.5 g/mol and $\mathfrak{M}$(Y) = 19.4 g/mol

D) $\mathfrak{M}$(X) = 77.5 g/mol and $\mathfrak{M}$(Y) = 38.8 g/mol

→ Problem 9.1

Consider the following solutions.

P. 0.01 M $C_6H_{12}O_6$(aq) at 20°C

Q. 0.005 M $CuCl_2$(aq) at 10°C

R. 0.004 M $Ca_3(PO_4)_2$(aq) at 5°C

Rank these solutions in order of **decreasing** osmotic pressure. Assume complete dissociation of solute.

A) Π(R) > Π(Q) > Π(P)

B) Π(R) > Π(P) > Π(Q)

C) Π(P) > Π(Q) > Π(R)

D) Π(P) > Π(R) > Π(Q)

→ Problem 9.2

Intravenous medications are often administered in 5.0% glucose, $C_6H_{12}O_6$(aq), by mass. What is the osmotic pressure of such solutions at 37°C (body temperature)? Assume that the density of the solution is 1.1 g/mL.

A) Π = 1.89 atm

B) Π = 4.55 atm

C) Π = 7.79 atm

D) Π = 9.04 atm

→ Problem 9.3

A 0.82-g sample of an organic macromolecule is dissolved in 800 mL of an aqueous medium at 27°C to give a solution with an osmotic pressure of 4 Torr. Determine the molar mass of the molecule.

A) $\mathfrak{M}$ = 3600 g/mol

B) $\mathfrak{M}$ = 4800 g/mol

C) $\mathfrak{M}$ = 6000 g/mol

D) $\mathfrak{M}$ = 7200 g/mol

→ Problem 9.4

A 0.11-g sample of a metal salt is dissolved in 5.2 L of an aqueous medium at 80°C to give a solution with an osmotic pressure of 8.8 Torr. Each salt particle dissociates into 3 ions. Determine the molar mass of the salt.

A) $\mathfrak{M}$ = 85.8 g/mol

B) $\mathfrak{M}$ = 103 g/mol

C) $\mathfrak{M}$ = 159 g/mol

D) $\mathfrak{M}$ = 203 g/mol

→ Problem 9.5

Catalase, a liver enzyme, dissolves in water. A 10.0-mL solution containing 0.166 g of catalase exhibits an osmotic pressure of 1.2 Torr at 20°C. What is the molar mass of catalase?

A) $\mathfrak{M}$ = 1.14×10^4 g/mol

B) $\mathfrak{M}$ = 4.75×10^4 g/mol

C) $\mathfrak{M}$ = 9.49×10^4 g/mol

D) $\mathfrak{M}$ = 2.53×10^5 g/mol

© 2020 Montogue Quiz

ADDITIONAL INFORMATION

Table 1. Freezing-point and boiling-point constants

Solvent	Freezing point (°C)	Freezing-point constant, k_f (K·kg·mol^{-1})	Boiling point (°C)	Boiling-point constant, k_b (K·kg·mol^{-1})
Acetone	−95.35	2.40	56.2	1.71
Benzene	5.5	5.12	80.1	2.53
Cyclohexane	6.5	20.1	80.7	2.79
Phenol	43	7.27	182	3.04
Tetrachloromethane	−23°C	29.8	76.5	4.95
Water	0	1.86	100	0.51

SOLUTIONS

P.1 ➡ *Solution*

Part 1: One liter of this solution contains 0.8 mol of NaCl, so 500 mL should contain 0.5 × 0.8 = 0.4 mol of salt. This corresponds to a mass of 0.4 × 58.5 = 23.4 g.

♦ The correct answer is **C.**

Part 2: A 0.2-m solution 0.2 mol of solute for every kg of solvent. Assume that, for dilute solutions, the mass of solvent is the mass of solution. Thus, the number of moles of solute present in 75 g of solution is

$$\frac{0.2\,\text{mol KCl}}{1\,\text{kg solvent}} = \frac{x}{0.075\,\text{kg solvent}} \rightarrow x = 0.015\,\text{mol KCl}$$

This corresponds to a mass of

$$m = 0.015\,\text{mol KCl} \times \frac{74.6\,\text{g}}{\text{mol KCl}} = \boxed{1.12\,\text{g}}$$

♦ The correct answer is **A.**

Part 3: A mass of 34.2 g of aluminum sulfate corresponds to n = 34.2/342 = 0.1 mol; the molarity of the solution is then

$$M = \frac{n}{V} = \frac{0.1}{0.25} = \boxed{0.4\,\text{mol/L}}$$

♦ The correct answer is **B.**

Part 4: A mass of 280 g of lithium perchlorate trihydrate corresponds to n = 240/160 = 1.5 mol; the molarity of the solution is then

$$M = \frac{n}{V} = \frac{1.5}{2.0} = \boxed{0.75\,\text{mol/L}}$$

♦ The correct answer is **C.**

Part 5: 31.2 g of benzene corresponds to 31.2/78 = 0.4 mol, and the molality of the solution follows as

$$\bar{M} = \frac{0.4\,\text{mol Bz}}{0.1\,\text{kg}\,\text{CCl}_4} = \boxed{4.0\,m}$$

♦ The correct answer is **D.**

Part 6: 15 g of KCl corresponds to 15/74.6 = 0.201 mol, and 20 mol of water has a mass of 20 × 18 = 360 g = 0.36 kg. The molality of the solution in question is then

$$\bar{M} = \frac{0.201\,\text{mol KCl}}{0.36\,\text{kg H}_2\text{O}} = \boxed{0.558\,m}$$

♦ The correct answer is **B.**

Part 7: By definition, molality is the number of moles of solute per kg of solvent. Accordingly, the number of moles of solute required to produce a 0.16 N solution is calculated as

$$\bar{M} = \frac{\text{mol solute}}{\text{kg solute}} \rightarrow \text{No. of mols of solute} = \text{kg solute} \times \bar{M}$$

© 2020 Montogue Quiz

$$\therefore \text{No. of mols of solute} = 0.18 \times 0.16 = 0.0288\,\text{mol S}_8$$

or, in terms of mass,

$$m = 0.0288\,\text{mol S}_8 \times \frac{256\,\text{g S}_8}{\text{mol S}_8} = \boxed{7.37\,\text{g}}$$

♦ The correct answer is **B.**

Part 8: 0.04 mol of iodine corresponds to a mass of 0.04 × 254 = 10.2 g, while 80 mL of tetrachloromethane corresponds to a mass of 80 × 1.49 = 119 g. It follows that the mass percentage of I_2 is

$$f_{I_2} = \frac{10.2}{10.2 + 119} \times 100 = \boxed{7.89\%}$$

♦ The correct answer is **B.**

Part 9: The concentration of Sr^{2+} in ppm is calculated as

$$c\left(\text{Sr}^{2+}\right) = \frac{0.008}{1000} \times 10^6 = \boxed{8\,\text{ppm}}$$

The concentration of Zn^{2+} in ppb, in turn, is

$$c\left(\text{Zn}^{2+}\right) = \frac{0.014 \times 10^{-3}}{1000} \times 10^9 = \boxed{1.4\,\text{ppb}}$$

♦ The correct answer is **A.**

Part 10: Assume we have 1 liter of solution. The mass of the solution is then 1.12 × 1000 = 1120 g. The number of moles of HNO_3 contained in the solution is 3.7 mol/L × 1 L = 3.7 mol, and the corresponding mass of acid is 3.7 × 63 = 233 g. The percent acid by mass is then

$$f_{\text{HNO}_3} = \frac{233}{1120} = 0.208 = \boxed{20.8\%}$$

♦ The correct answer is **C.**

Part 11: As we did in the previous problem, assume we have 1 liter of solution. The mass of the sample is then 1.30 × 1000 = 1300 g. The number of moles of H_2SO_4 contained in the solution is then 6 × 1 = 6 mol, which amounts to a mass of 6 × 98 = 588 g. The percent acid by mass is then

$$f_{\text{H}_2\text{SO}_4} = \frac{588}{1300} = 0.452 = \boxed{45.2\%}$$

♦ The correct answer is **B.**

Part 12: Noting that 400 mL of water of course corresponds to 400 g, the mass percent of methanol is determined as

$$f_{\text{CH}_3\text{OH}} = \frac{48}{48 + 400} = 0.107 = \boxed{10.7\%}$$

48 g of methanol corresponds to 48/32 = 1.5 mol, while 400 g of water amounts to 400/18 = 22.2 mol. The mole fraction of CH_3OH is then

$$\chi_{\text{CH}_3\text{OH}} = \frac{1.5}{22.2 + 1.5} = \boxed{0.0633}$$

Molality is the ratio of number of moles of solute to the mass of solvent in kilograms. For the solution at hand,

$$\bar{M} = \frac{1.5\,\text{mol CH}_3\text{OH}}{0.4\,\text{kg H}_2\text{O}} = \boxed{3.75\ m}$$

♦ Statements **1** and **3** are true, while statement **2** is false.

Part 13: Observing that 450 mL of benzene corresponds to 450 × 0.876 = 394 g, the mass percent of hexane is calculated as

$$f_{\text{C}_6\text{H}_{14}} = \frac{172}{172 + 394} = 0.304 = \boxed{30.4\%}$$

172 g of hexane corresponds to 172/86 = 2 mol, while 394 g of benzene amounts to 394/78 = 5.05 mol. The mole fraction of C_6H_{14} is then

© 2020 Montogue Quiz

$$\chi_{C_6H_{14}} = \frac{2}{2+5.05} = \boxed{0.284}$$

The molality of the solution is given by

$$\bar{M} = \frac{2\,\text{mol } C_6H_{14}}{0.394\,\text{kg Bz}} = \boxed{5.08\ m}$$

♦ Statement **2** is true, while statements **1** and **3** are false.

P.2 ➡ Solution

Part 1: 1. False. Assume 1 liter of solution. The mass of perchloric acid in 1 L of solution is 520 g, and the total mass is 1.32 × 1000 = 1320 g. The mass percentage of acid is then

$$f_{HClO_4} = \frac{520}{1320} = 0.394 = \boxed{39.4\%}$$

2. True. 1 L of solution contains 520/100 = 5.2 mol of perchloric acid, and the remaining 1320 − 520 = 800 g, or 800/18 = 44.4 mol, is water. The mole fraction of acid is then

$$\chi_{HClO_4} = \frac{5.2}{5.2+44.4} = \boxed{0.105}$$

3. True. 1L of solution contains 5.2 mol of acid, and the molarity straightforwardly follows as

$$M = \frac{5.2}{1.0} = \boxed{5.2\,\text{mol/L}}$$

4. False. 1 L of solution contains 5.2 mol of acid and 1320 − 520 = 800 g = 0.8 kg of water. Thus, the molality is calculated as

$$\bar{M} = \frac{5.2\,\text{mol } HClO_4}{0.8\,\text{kg } H_2O} = \boxed{6.5\ m}$$

Part 2: 1. True. Assume 1 liter of solution. The mass of nitric acid in 1 L of solution is 360 g, and the total mass is 1.22 × 1000 = 1220 g. The mass percentage of acid is then

$$f_{HNO_3} = \frac{360}{1220} = 0.295 = \boxed{29.5\%}$$

2. False. 1 L of solution contains 360/63 = 5.71 mol of nitric acid, and the remaining 1220 − 360 = 860 g, or 860/18 = 47.8 mol, is water. Accordingly, the mole fraction of acid is given by

$$\chi_{HNO_3} = \frac{5.71}{5.71+47.8} = \boxed{0.107}$$

3. True. 1L of solution contains 5.71 mol of acid, and the molarity straightforwardly follows as

$$M = \frac{5.71}{1.0} = \boxed{5.71\,\text{mol/L}}$$

4. False. 1 L of solution contains 5.71 mol of acid and 1220 − 360 = 860 g = 0.86 kg of water. Thus, the molality is calculated as

$$\bar{M} = \frac{5.71\,\text{mol } HNO_3}{0.86\,\text{kg } H_2O} = \boxed{6.64\ m}$$

Part 3: 1. False. 40 mL of CH_3OH corresponds to a mass of 40 × 0.791 = 31.6 g, or 31.6/32 = 0.988 mol, while 120 mL of CH_3CN corresponds to a mass of 120 × 0.786 = 94.3 g, or 94.3/41 = 2.3 mol. The mass percentage of methanol is then

$$f_{CH_3OH} = \frac{31.6}{31.6+94.3} = 0.251 = \boxed{25.1\%}$$

2. True. The mole fraction of methanol is

© 2020 Montogue Quiz

$$\chi_{CH_3OH} = \frac{0.988}{0.988+2.3} = \boxed{0.300}$$

3. False. The solution contains 0.988 mol of methanol and a total volume of 0.04 + 0.12 = 0.16 L. The molarity is then

$$M = \frac{0.988}{0.16} = \boxed{6.18\,\text{mol/L}}$$

4. True. The solution contains 0.988 mol of methanol and a mass of solvent of 94.3 g = 0.0943 kg. The molality is then

$$\overline{M} = \frac{0.988\text{ mol CH}_3\text{OH}}{0.0943\text{ kg CH}_3\text{CN}} = \boxed{10.5\ m}$$

P.3 ➡ *Solution*

Assume we have 1 liter of invar, which corresponds to 0.001 × 8100 = 8.1 kg. Since the alloy is 36% Ni, this amount of invar contains 0.36 × 8.1 = 2.92 kg of nickel, or 2920/58.7 = 49.7 mol of this metal. The molarity is then

$$M = \frac{49.7\,\text{mol Ni}}{1\,\text{L}} = \boxed{49.7\,\text{mol/L}}$$

Now, 1 liter of invar contains 8.1 − 2.92 = 5.18 kg of iron, which is the solvent, and the molality follows as

$$\overline{M} = \frac{\text{moles of solute}}{\text{mass of solvent}} = \frac{49.7\,\text{mol Ni}}{5.18\,\text{kg Fe}} = \boxed{9.59\,m}$$

♦ The correct answer is **D.**

P.4 ➡ *Solution*

Part 1: The osmotic pressure of solution 2, which is more concentrated than solution 1, is surely greater than that of solution 1. Furthermore, the more concentrated solution is bound to have a higher boiling point and a lower freezing point. Statement A errs when it says that solution 1 should have the lower vapor pressure; solution 2 is more concentrated and, accordingly, should have the lower P^{sat}.

♦ The false statement is **A.**

Part 2: Like every other colligative property, boiling point elevation is directly dependent on the number of particles contained in the solution. Among the solutions offered as alternatives, calcium phosphate dissociates into the greatest number of ions, and as such should increase the boiling temperature of water more substantially than the other three solutions.

♦ The correct answer is **D.**

P.5 ➡ *Solution*

Part 1: The mole fraction of benzene is

$$\chi_{C_6H_6} = \frac{117/78}{117/78+184/92} = 0.429$$

Given P^{sat} = 75 Torr, the partial vapor pressure of benzene follows from Raoult's law,

$$P_A = \chi_{C_6H_6} P^{sat} = 0.429 \times 75 = \boxed{32.2\text{ Torr}}$$

♦ The correct answer is **B.**

Part 2: From Raoult's law, we have

$$P_T = P_A^{sat}\chi_A + P_B^{sat}\chi_B \rightarrow 0.85\times 760 = P_A^{sat}\chi_A + P_B^{sat}(1-\chi_A)$$

$$\therefore 646 = 500\times\chi_A + 1200\times(1-\chi_A)$$

$$\therefore \boxed{\chi_A = 0.791}$$

♦ The correct answer is **D.**

© 2020 Montogue Quiz

Part 3: Let P_A^{sat} and P_B^{sat} denote the vapor pressures of A and B. From Raoult's law, we initially have

$$P_T = P_A^{\text{sat}}\chi_A + P_B^{\text{sat}}\chi_B \rightarrow 600 = P_A^{\text{sat}} \times \left(\frac{3}{3+1}\right) + P_B^{\text{sat}}\left(\frac{1}{3+1}\right)$$

$$\therefore 600 = 0.75P_{\text{A}}^{\text{sat}} + 0.25P_B^{\text{sat}} \;\; \text{(I)}$$

Once 1 additional mol of A is added to the mixture, the vapor pressure of the solution increases by 10 mmHg, so that

$$600 + 10 = P_A^{\text{sat}} \times \left(\frac{3+1}{5}\right) + P_B^{\text{sat}}\left(\frac{1}{5}\right)$$

$$\therefore 610 = 0.8P_{\text{A}}^{\text{sat}} + 0.2P_B^{\text{sat}} \;\; \text{(II)}$$

Equations (I) and (II) constitute a system of linear equations with two unknowns. Solving it yields P_A^{sat} = 650 mmHg and P_B^{sat} = 450 mmHg.

♦ The correct answer is **C.**

Part 4: The molar fraction of urea required to produce ΔP = 5 mmHg is

$$\Delta P = \chi_{\text{urea}} P_{\text{water}}^{o} \rightarrow 5 = \chi_{\text{urea}} \times 31.8$$

$$\therefore \chi_{\text{urea}} = 0.157$$

The number of moles of water contained in 480 g is n_{water} = 480/18 = 26.7 mol. The number of moles of urea, in turn, is

$$\chi_{\text{urea}} = \frac{n_{\text{urea}}}{n_{\text{water}} + n_{\text{urea}}} \rightarrow 0.157 = \frac{n_{\text{urea}}}{26.7 + n_{\text{urea}}}$$

$$\therefore n_{\text{urea}} = 4.97 \text{ mol}$$

so that, in terms of mass,

$$m_{\text{urea}} = n_{\text{urea}} \times \mathfrak{M}_{\text{urea}} = 4.97 \times 60 = \boxed{298 \text{ g}}$$

♦ The correct answer is **C.**

P.6 ➡ *Solution*

Part 1: A 1% aqueous solution of KCl will contain 1.0 g KCl for 99.0 g of water. To use the freezing point depression equation, we need the molality of the solution, namely,

$$\bar{M} = \frac{1.0/74.6}{0.099} = 0.135 \; m$$

Given the freezing point constant k_f = 1.86 K·kg·mol^{-1} (Table 1), the van't Hoff factor is determined next,

$$\Delta T_f = ik_f\bar{M} \rightarrow i = \frac{\Delta T_f}{k_f\bar{M}}$$

$$\therefore i = \frac{0.4}{1.86 \times 0.135} = \boxed{1.59}$$

The molality of all solute species is obtained by multiplying the van't Hoff factor by the overall molarity of the solution; mathematically,

$$\bar{M}_{\text{solution}} = 1.59 \times 0.135 = \boxed{0.215 \; m}$$

If all KCl had dissociated, the value of i would be 2 and the molality in solution would be 2 × 0.135 = 0.270 m. If no dissociation had taken place, the molality in solution would be 0.135 m. In order to determine the dissociation fraction x, consider the following concentration diagram.

	KCl(aq)	Na^+(aq)	Cl^-(aq)
Initial	0.135	0	0
Final	0.135 − x	x	x

Knowing that $\bar{M}_{\text{solution}}$ = 0.215 mol/kg, the value of x is determined to be

© 2020 Montogue Quiz

$$(0.135 - x) + x + x = 0.215 \rightarrow x = 0.08 \text{ mol/kg}$$

Lastly, the percent dissociation is calculated to be

$$\%\text{dissociation} = \frac{0.08}{0.135} = \boxed{59.3\%}$$

♦ Statement **1** is true, while statements **2** and **3** are false.

Part 2: A 2% calcium chloride ion will contain 2.0 g $CaCl_2$ for 98 g of water. To use the boiling point increase equation, we need the molality of the solution, namely,

$$\bar{M} = \frac{2.0/111}{0.098} = 0.184\,m$$

Given the boiling point constant k_b = 0.51 K·kg·mol^{-1} (Table 1), the van't Hoff factor is determined next,

$$\Delta T_b = ik_b\bar{M} \rightarrow i = \frac{\Delta T_b}{k_b\bar{M}}$$

$$\therefore i = \frac{0.26}{0.51 \times 0.184} = \boxed{2.77}$$

The molality of all solute species is obtained by multiplying the van't Hoff factor by the overall molarity of the solution; in mathematical terms,

$$\bar{M}_{\text{solution}} = 2.77 \times 0.184 = \boxed{0.510\ m}$$

If all KCl had dissociated, the value of i would be 3 and the molality in solution would be 3 × 0.184 = 0.552 m. If no dissociation had taken place, the molality in solution would be 0.184 m. In order to determine the dissociation fraction x, refer to the following concentration diagram.

	$CaCl_2$(aq)	Ca^{2+}(aq)	Cl^-(aq)
Initial	0.184	0	0
Final	0.184 − x	x	$2x$

Knowing that $\bar{M}_{\text{solution}}$ = 0.510 mol/kg, the value of x follows as

$$(0.184 - x) + x + 2x = 0.510 \rightarrow x = 0.163 \text{ mol/kg}$$

Finally, the percent dissociation is such that

$$\%\text{dissociation} = \frac{0.163}{0.184} = \boxed{88.6\%}$$

♦ Statement **1** is true, while statements **2** and **3** are false.

P.7 ➡ *Solution*

Part 1: The compound that freezes at the lower temperature has the greater ΔT_f. Since the same mass of each compound is present in the same amount of solvent for each solution, the compound with the lower molar mass will have the larger number of moles and therefore the greater ΔT_f (because the compound with the lower molar mass will have the larger amount of solute particles present). Knowing that compound α produced a greater freezing temperature depression than compound β, we surmise that compound α has a lower molar mass than compound β.

♦ The correct answer is **β**.

Part 2: The molality of the solution is

$$\bar{M} = \frac{\text{No. of moles } C_6H_6}{\text{Mass (kg) of } CCl_4} = \frac{3}{30} = 0.10\,m$$

and, given the freezing-point constant of tetrachloromethane k_f = 29.8 K·kg·mol^{-1} (Table 1), it follows that

$$\Delta T_f = k_f \times \bar{M} = 29.8 \times 0.1 = \boxed{2.98^\circ\text{C}}$$

♦ The correct answer is **D**.

© 2020 Montogue Quiz

Part 3: 43 g of hexane corresponds to 43/86 = 0.5 mol, and a volume of 4.75 L of benzene corresponds to a mass of 0.876 × 4750 = 4160 g = 4.16 kg. The molality of the solution is then

$$\bar{M} = \frac{0.5}{4.16} = 0.120\ m$$

and, given the freezing-point constant k_f = 5.12 K·kg·mol (Table 1), it follows that

$$\Delta T_f = k_f \times \bar{M} = 5.12 \times 0.120 = \boxed{0.614^{\circ}\text{C}}$$

♦ The correct answer is **B.**

Part 4: We first determine the mole fraction,

$$P = \chi_{\text{solvent}} P_{\text{pure solvent}} \rightarrow \chi_{\text{solvent}} = \frac{P}{P_{\text{pure solvent}}}$$

$$\therefore \chi_{\text{solvent}} = \frac{740}{760} = 0.974$$

The mole fraction must be converted to molality. Let the total number of moles equal 1.0. It follows that

$$\chi_{\text{solvent}} = \frac{n_{H_2O}}{n_{H_2O} + n_{\text{solute}}} = 0.974 \rightarrow n_{H_2O} = 0.974\,\text{mol}$$

and n_{solute} = 1 − 0.974 = 0.026 mol. The mass of water is m = 0.974 × 18/1000 = 0.0175 kg, and the molality follows as

$$\bar{M} = \frac{0.026}{0.0175} = 1.49\,m$$

Knowing the molality and the boiling-point constant k_b = 0.512 K·kg·mol^{-1} (Table 1), we can determine the increase in boiling point,

$$\Delta T_b = k_b \bar{M} = 0.512 \times 1.49 = \boxed{0.763^{\circ}\text{C}}$$

♦ The correct answer is **B.**

Part 5: The depression of freeze point is given by

$$\Delta T_f = k_f \times \bar{M}$$

Similarly, the elevation of boiling point is given by

$$\Delta T_b = k_b \times \bar{M}$$

Dividing one equation by the other brings to

$$\frac{\Delta T_b}{\Delta T_f} = \frac{k_b \times \cancel{\bar{M}}}{k_f \times \cancel{\bar{M}}} \rightarrow \frac{\Delta T_b}{\Delta T_f} = \frac{k_b}{k_f}$$

From Table 1, we read the freezing point of tetrachloromethane = −23°C and the constants k_b = 4.95 K·kg·mol^{-1} and k_f = 29.8 K·kg·mol^{-1}, so that

$$\Delta T_b = \Delta T_f \times \frac{k_b}{k_f} = 0.8 \times \frac{4.95}{29.8} = \boxed{0.133^{\circ}\text{C}}$$

♦ The correct answer is **A.**

Part 6: Given the change in freezing point ΔT_f = 43 − 41.8 = 1.2°C and phenol's cryoscopic constant k_f = 7.27 K·kg·mol^{-1} (Table 1), the molar mass of the solute in question is determined as

$$\Delta T_f = k_f \bar{M} \rightarrow 1.2 = 7.27 \times \frac{1.4/\mathfrak{M}}{0.12}$$

$$\therefore \boxed{\mathfrak{M} = 70.7\text{ g/mol}}$$

♦ The correct answer is **D.**

Part 7: Given the change in boiling point ΔT_b = 81.6 − 80.1 = 1.5°C and benzene's ebulioscopic constant k_b = 2.53 K·kg·mol^{-1} (Table 1), the molar mass of the solute in question is determined as

© 2020 Montogue Quiz

$$\Delta T_b = k_b \bar{M} \rightarrow 1.5 = 2.53 \times \frac{8/\mathfrak{M}}{0.15}$$

$$\therefore \boxed{\mathfrak{M} = 90.0\ \text{g/mol}}$$

♦ The correct answer is **C**.

P.8 ➡ *Solution*

Part 1: The empirical formula can be deduced by considering a 100-g sample of the compound in question.

$$\text{No. of moles C} = \frac{80.78}{12} = 6.73\ \text{mol}$$

$$\text{No. of moles H} = \frac{13.56}{1.0} = 13.56\ \text{mol}$$

$$\text{No. of moles O} = \frac{5.66}{16} = 0.354\ \text{mol}$$

Dividing through by the smallest subscript gives No. of moles C = 6.73/0.354 = 19, No. of moles H = 13.56/0.354 = 38, and No. of moles O = 0.354/0.354 = 1, hence the empirical formula is $C_{19}H_{38}O$. Now, the freezing point depression is ΔT_f = 5.5 − 3.37 = 2.13°C, and the molality of the solution, given k_f = 5.12 K·kg·mol^{-1} (Table 1), is found as

$$\Delta T_f = k_f \times \bar{M} \rightarrow \bar{M} = \frac{\Delta T_f}{k_f}$$

$$\therefore \bar{M} = \frac{2.13}{5.12} = 0.416\ m$$

The amount of solute contained in the solution is

$$\frac{0.416\ \text{mol solute}}{1\ \text{kg benzene}} \times 0.0085\ \text{kg benzene} = 0.00354\ \text{mol solute}$$

This amount of solute corresponds to 1 g; for one full mole, we must have

$$\frac{1\ \text{g solute}}{0.00354\ \text{mol solute}} = \frac{\mathfrak{M}}{1\ \text{mol solute}} \rightarrow \boxed{\mathfrak{M} = 282\ \text{g/mol}}$$

The mass of the empirical formula is 282 g/mol, so the molecular formula is the same as the empirical formula, $C_{19}H_{38}O$.

♦ The correct answer is **α**.

Part 2: Let $\mathcal{M}_X$ and $\mathcal{M}_Y$ denote the molar masses of pure elements X and Y, respectively. The number of moles of XY_2 contained in 1 g of the compound is $1/(\mathcal{M}_X + 2\mathcal{M}_Y)$, and the molality must be

$$\bar{M} = \frac{\dfrac{1}{(\mathfrak{M}_X + 2\mathfrak{M}_Y)}}{\dfrac{20}{1000}} = \frac{50}{\mathfrak{M}_X + 2\mathfrak{M}_Y}$$

Substituting in the freeze-point depression equation brings to

$$\Delta T_f = k_f \times \bar{M} \rightarrow 0.8 = 1.86 \times \frac{50}{\mathfrak{M}_X + 2\mathfrak{M}_Y}\ \text{(I)}$$

In a similar manner, the number of moles of XY_4 contained in 1 g of the compound is $1/(\mathcal{M}_X + 4\mathcal{M}_Y)$, and the molality follows as

$$\bar{M} = \frac{\dfrac{1}{(\mathfrak{M}_X + 4\mathfrak{M}_Y)}}{\dfrac{10}{1000}} = \frac{100}{\mathfrak{M}_X + 4\mathfrak{M}_Y}$$

As before, we substitute in the freeze-point depression equation to obtain

© 2020 Montogue Quiz

$$\Delta T_f = k_f \times \overline{M} \rightarrow 1.2 = 1.86 \times \frac{100}{\mathfrak{M}_X + 4\mathfrak{M}_Y} \text{(II)}$$

Equations (I) and (II) constitute a system of linear equations with two unknowns, and can be solved with the Mathematica code

```
Solve[0.8 == 1.86 * 50/(x + 2 * y) && 1.2 == 1.86 * 100/(x + 4 * y), {x, y}]
```

This returns $\mathcal{M}_X$ = 77.5 g/mol and $\mathcal{M}_Y$ = 19.4 g/mol. The molar masses of the two elements have been determined.

♦ The correct answer is **C.**

P.9 ➡ *Solution*

Part 1: For a glucose solution, i = 1, and the osmotic pressure follows as

$$\Pi_P = iRTM = 1 \times 0.0821 \times 293 \times 0.01 = 0.241 \text{ atm}$$

Since copper(II) chloride dissociates into 3 ions, we have i = 3 and therefore

$$\Pi_Q = iRTM = 3 \times 0.0821 \times 283 \times 0.005 = 0.349 \text{ atm}$$

Since calcium phosphate dissociates into 5 ions, we have i = 5 and, accordingly,

$$\Pi_R = iRTM = 5 \times 0.0821 \times 278 \times 0.004 = 0.456 \text{ atm}$$

Note that, even though the calcium phosphate solution is the most dilute of the three systems, the fact that each unit dissociates into such a large number of ions causes it to have the highest osmotic pressure. After all, osmotic pressure, much like other colligative properties, is primarily dependent on the number of particles dissolved in the solution.

♦ The correct answer is **A.**

Part 2: In order to compute the osmotic pressure of the solution, we first require the molarity. Assume we have 1 L of solution; this corresponds to a mass of 1000 × 1.1 = 1100 g, of which 0.05 × 1100 = 55 g is glucose. The molarity of the solution is then

$$M = \frac{55 \text{ g } C_6H_{12}O_6}{1 \text{ L sltn}} \times \frac{1 \text{ mol } C_6H_{12}O_6}{180 \text{ g } C_6H_{12}O_6} = 0.306 \text{ mol/L}$$

Therefore, the osmotic pressure is

$$\Pi = iRTM = 1 \times 0.0821 \times 310 \times 0.306 = \boxed{7.79 \text{ atm}}$$

♦ The correct answer is **C.**

Part 3: The osmotic pressure is Π = 4/760 = 0.00526 atm, and the molarity of the solution is M = (0.82/$\mathcal{M}$)/0.8, where $\mathcal{M}$ is molar mass. Substituting in the osmotic pressure equation brings to

$$\Pi = iRTM \rightarrow 0.00526 = 1 \times 0.0821 \times 300 \times \left(\frac{0.82/\mathfrak{M}}{0.8}\right)$$

$$\therefore \boxed{\mathfrak{M} = 4800 \text{ g/mol}}$$

♦ The correct answer is **B.**

Part 4: The osmotic pressure is Π = 8.8/760 = 0.0116 atm, and the molarity of the solution is M = (0.11/$\mathcal{M}$)/5.2. Substituting in the osmotic pressure equation brings to

$$\Pi = iRTM \rightarrow 0.0116 = 3 \times 0.0821 \times 353 \times \left(\frac{0.11/\mathfrak{M}}{5.2}\right)$$

$$\therefore \boxed{\mathfrak{M} = 159 \text{ g/mol}}$$

♦ The correct answer is **C.**

© 2020 Montogue Quiz

Part 5: As we have done in previous parts, the molar mass can be extracted from the osmotic pressure equation, namely,

$$\Pi = iRTM = iRT \times \frac{n}{V} = iRT \times \frac{m}{\mathfrak{M}V}$$

$$\therefore \Pi = \frac{iRTm}{\mathfrak{M}V}$$

$$\therefore \mathfrak{M} = \frac{iRTm}{\Pi V} = \frac{1.0 \times 0.0821 \times 293 \times 0.166}{1.2/760 \times 0.01} = \boxed{2.53 \times 10^5 \text{ g/mol}}$$

♦ The correct answer is **D**.

ANSWER SUMMARY

Problem 1	1.1	C
	1.2	A
	1.3	B
	1.4	C
	1.5	D
	1.6	B
	1.7	B
	1.8	B
	1.9	A
	1.10	C
	1.11	B
	1.12	T/F
	1.13	T/F
Problem 2	2.1	T/F
	2.2	T/F
	2.3	T/F
Problem 3		D
Problem 4	4.1	A
	4.2	D
Problem 5	5.1	B
	5.2	D
	5.3	C
	5.4	C
Problem 6	6.1	T/F
	6.2	T/F
Problem 7	7.1	β
	7.2	D
	7.3	B
	7.4	B
	7.5	A
	7.6	D
	7.7	C
Problem 8	8.1	α
	8.2	C
Problem 9	9.1	A
	9.2	C
	9.3	B
	9.4	C
	9.5	D

REFERENCES

- ATKINS, P. and JONES, L. (2010). *Chemical Principles.* 5th edition. New York: W.H. Freeman and Company.
- BROWN et al. (2018). *Chemistry: The Central Science*. 14th edition. Upper Saddle River: Pearson.
- CHANG, R. (2010). *Chemistry*. 10th edition. New York: McGraw-Hill.
- SINGHAL, A. (2010). *The Pearson Guide to Physical Chemistry for the IIT-JEE*. Upper Saddle River: Pearson.

© 2020 Montogue Quiz

Got any questions related to this quiz? We can help!
Send a message to contact@montogue.com and we'll
answer your question as soon as possible.

© 2020 Montogue Quiz