

Chapter 8

Problems

Background information about lead:

From WebMd: “Lead is dangerous because it can spread in your body and cause health problems. It can affect almost every organ and system in your body. The CDC estimates that about a half-million kids between ages 1 and 5 have high levels of lead in their blood.

https://www.aacap.org/aacap/families_and_youth/facts_for_families/FFF-Guide/Lead-Exposure-In-Children-Affects-Brain-And-Behavior-045.aspx

Exposure to lead can have a wide range of effects on a child's development and behavior. Even when exposed to small amounts of lead levels, children may appear inattentive, hyperactive, and irritable. Children with greater lead levels may also have problems with learning and reading, delayed growth, and hearing loss.

Problem 8.1

An aqueous solution contains lead (Pb^{2+}), calcium (Ca^{2+}), and sodium (Na^+) ions. There are sophisticated tests for Pb^{2+} ions; however, a simple precipitation reaction can be used to test for the presence of Pb^{2+} ions selectively.

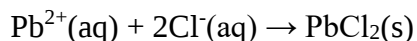
(a). True or False

The addition of concentrated hydrochloric acid will result in the precipitation of both calcium chloride and lead chloride in the solution that contains lead (Pb^{2+}), calcium (Ca^{2+}), and sodium (Na^+) ions.

Answer

False. We refer to the solubility rules in Chapter 8. The chlorides of metals are soluble in water, EXCEPT those of silver, mercury or lead. In other words, AgCl , Hg_2Cl_2 and PbCl_2 are insoluble in water and would precipitate out. Since Pb^{2+} is present, PbCl_2 will precipitate out. CaCl_2 is soluble, and will not precipitate out.

The net ionic equation is given below.



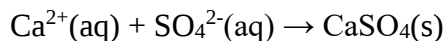
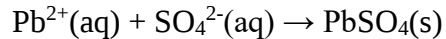
(b). True or False

The addition of concentrated sulfuric acid will result in the precipitation of both calcium sulfate and lead sulfate in the solution that contains lead (Pb^{2+}), calcium (Ca^{2+}), and sodium (Na^+) ions.

Answer

True. We refer to the solubility rules in Chapter 8. The sulfates of metals are soluble in water, EXCEPT those of silver, mercury, lead, calcium, strontium and barium. In other words, Ag_2SO_4 , Hg_2SO_4 , PbSO_4 , CaSO_4 , SrSO_4 , and BaSO_4 are insoluble in water. Since Pb^{2+} and Ca^{2+} are present in the solution, PbSO_4 and CaSO_4 would precipitate out.

The net ionic equations are given below.



Problem 8.2

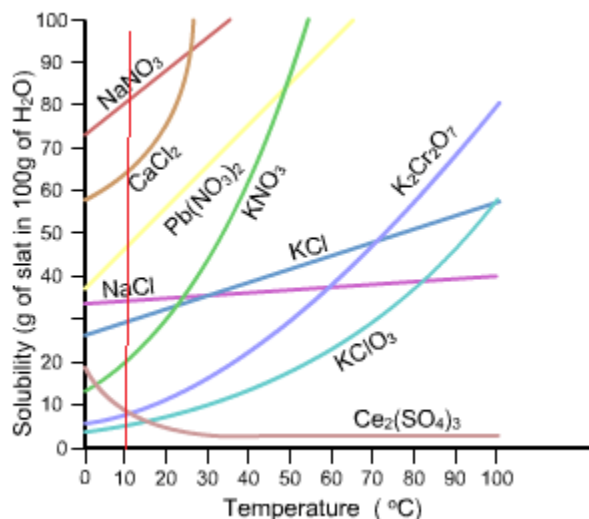


Figure for Problem 8.2

(a). Which of the following has the highest solubility (expressed as *g* of salt in 100 *g* of water) 10°C?

- *(a) Sodium nitrate
- (b) Calcium chloride
- (c) Potassium nitrate
- (d) Cerium sulfate

Answer

Draw a vertical line at 10°C, sodium nitrate has the highest solubility.

(b). For which of the following does solubility decrease with temperature over the range 0°C to 20°C?

- (a) Sodium nitrate
- (b) Calcium chloride
- (c) Potassium nitrate
- *(d) Cerium sulfate

Answer

For cerium sulfate, Ce₂(SO₄)₃, the values decrease with temperature over the range 0°C to 20°C.

Problem 8.3

Saline, a solution of salt (sodium chloride) in water is used to clean wounds and remove contact lenses.

(a). A student is given the task of preparing a 1.00 L stock solution of sodium chloride in water with a molarity of 1.50 M.

Answer

We apply the definition of molarity, given below.

$$M = \frac{\text{mol solute}}{\text{L of solution}}$$

Consider 1.00 L of solution. The amount of the solute, NaCl, is given by:

$$\text{Mass of sodium chloride} = 1.00 \text{ L} \times \frac{1.50 \text{ mol NaCl}}{1 \text{ L}} \times \frac{58.44 \text{ g NaCl}}{1 \text{ mol NaCl}} = 87.66 \text{ g NaCl}$$

We round this to 87.7 g, with 3 sf.

(b). In saline, the concentration of NaCl is 0.15 M. A student is given a stock solution of NaCl, 1.50 M, prepared in part (a). What volume of the stock solution is needed to prepare 100.0 mL of saline, that is, a 0.15 M solution?

Answer

We recognize this as a dilution problem. The applicable equation is:

$$C_1 V_1 = C_2 V_2$$

We can rewrite this as:

$$C_{\text{concentrated}} V_{\text{concentrated}} = C_{\text{dilute}} V_{\text{dilute}}$$

Solving for $V_{\text{concentrated}}$,

$$V_{\text{concentrated}} = \frac{C_{\text{dilute}} V_{\text{dilute}}}{C_{\text{concentrated}}} = \frac{(0.15 \text{ M})(100.0 \text{ mL})}{1.50 \text{ M}} = 10. \text{ mL} \quad (2 \text{ sf})$$

Problem 8.4

Glucose binds to the hemoglobin in red blood cells. The A1c test (recommended to manage diabetes) measures how much glucose is bound. Red blood cells live for about three months, so the test shows the average level of glucose in blood for the past three months. (*WebMd*)

An individual measures a A1c level of 7.0. This is the recommended upper limit for individuals with diabetes. This corresponds to an average glucose level of 154 *mg/dL*, (https://professional.diabetes.org/diapro/glucose_calc). Convert this to units of molarity (*mol/L*) and *mmol/L*. For this problem, assume 3 sf.

Answer

We apply the definition of molarity, given below. We also note that glucose has the molecular formula, $C_6H_{12}O_6$.

$$M = \frac{\text{mol solute}}{L \text{ of solution}}$$

$$M = \frac{154 \text{ mg } C_6H_{12}O_6}{100.0 \text{ mL}} \times \frac{1 \text{ g } C_6H_{12}O_6}{1000 \text{ mg } C_6H_{12}O_6} \times \frac{1 \text{ mol } C_6H_{12}O_6}{180.156 \text{ g } C_6H_{12}O_6} \times \frac{1000 \text{ mL}}{1 \text{ L}} = 8.55 \times 10^{-3} M$$

We can replace $10^{-3} M$ with *mM*. Thus, the concentration is 8.55 *mM*.

Assessment 8.5

Diagnosis of lead poisoning is typically by measurement of the blood lead level. The Centers for Disease Control and Prevention, (CDC, headquartered in Atlanta) has set the upper limit for blood lead for adults at 10 $\mu\text{g/dL}$ and for children at 5 $\mu\text{g/dL}$. Elevated lead may also be detected by changes in red blood cells or dense lines in the bones of children as seen on X-rays.

In a sample containing Pb^{2+} ions at a concentration of 5.0 $\mu\text{g/dL}$, the concentration is _ ppb. Assume that the density of the sample is 1.00 g/mL .

- (a) 5 ppb
- *(b) 50 ppb**
- (c) 500 ppb
- (d) 5,000 ppb

Answer

We apply the definition, given below. Since the solution is very dilute, its density is 1.00 g/mL , or the mass of 1.0 dL (0.10 L or 100 mL) of sample is 100 g .

$$\text{ppb} = \frac{\text{mass of solute}}{\text{mass of solution}} \times 10^9$$

$$\text{ppb} = \frac{\text{mass of } \text{Pb}^{2+}}{\text{mass of solution}} \times 10^9 = \frac{5 \mu\text{g } \text{Pb}^{2+}}{100 \text{g sample}} \times \frac{10^{-6} \text{g } \text{Pb}^{2+}}{1 \mu\text{g } \text{Pb}^{2+}} \times 10^9 = 50. \text{ ppb} \quad (2 \text{ sf})$$

Problem 8.6

Sulfuric acid (H_2SO_4) is a commonly used acid in laboratory experiments and in manufacturing processes. A concentrated aqueous solution of sulfuric acid has a density of 1.509 g/mL and contains 61.0% sulfuric acid by mass. Calculate the **molarity** of sulfuric acid.

- (a) 0.620 M
- * (b) 9.39 M
- (c) 16.0 M
- (d) 66.0 M

Answer

Given the definition of molarity,

$$M = \frac{\text{mol solute}}{\text{L of solution}}$$

We can start with 1.000 L of the solution, and then calculate the mass of sulfuric acid, and hence moles of sulfuric acid.

$$\text{mass of solution} = 1.000 \text{ L} \times \frac{1000 \text{ mL}}{1 \text{ L}} \times \frac{1.509 \text{ g}}{1 \text{ mL}} = 1509 \text{ g}$$

(We will round to 3 sf later)

$$\frac{\text{mass of } \text{H}_2\text{SO}_4}{\text{mass of solution}} \times 100 = 61.0$$

$$\text{mass of } \text{H}_2\text{SO}_4 = \frac{61.0 \times \text{mass of solution}}{100} = \frac{61.0 \times 1509 \text{ g}}{100} = 920.49 \text{ g}$$

(We will round to 3 sf later)

$$\text{moles of } \text{H}_2\text{SO}_4 = 920.49 \text{ g} \frac{1 \text{ mol } \text{H}_2\text{SO}_4}{98.076 \text{ g } \text{H}_2\text{SO}_4} = 9.39 \text{ mol} \quad (3 \text{ sf})$$

Since we have a volume of 1.000 L (that we chose), and the number of moles of H_2SO_4 is 9.39 mol, the molarity of H_2SO_4 is 9.39 M.

Problem 8.7

Which of the following aqueous solutions contains the **largest** total concentration of ions, assuming complete dissociation?

- (a) 0.010 *m* sodium sulfate
- (b) 0.010 *m* magnesium sulfate
- (c) 0.010 *m* ammonium sulfate
- *(d) 0.010 *m* aluminum sulfate

Answer

Each of the solutions contains 0.010 mole of solute per kg of solvent, based on the definition of molality. We will assume that in a dilute solution, the compounds will fully dissociate in water.

The ions in each of the compounds are listed below. The total number of ions per formula unit is also listed.

Compound	Formula	Ions in 1 formula unit	Total number of ions per formula unit
Sodium sulfate	Na ₂ SO ₄	2 Na ⁺ ; 1 SO ₄ ²⁻	3
Magnesium sulfate	MgSO ₄	1 Mg ²⁺ ; 1 SO ₄ ²⁻	2
Ammonium sulfate	(NH ₄) ₂ SO ₄	2 NH ₄ ⁺ ; 1 SO ₄ ²⁻	3
Aluminum sulfate	Al ₂ (SO ₄) ₃	2 Al ³⁺ ; 3 SO ₄ ²⁻	5

We note that aluminum sulfate produces the most number of ions per formula unit. Thus, the highest concentration of ions will result from aluminum sulfate, and the effective molality due to all ions will be 0.050 *m*.

Problem 8.8

Which of the following aqueous solutions has the highest osmotic pressure at 298K? Assume that for dilute aqueous solutions, molality (*m*) and molarity (*M*) are equal.

- (a) 0.010 *m* sodium sulfate
- (b) 0.010 *m* magnesium sulfate
- (c) 0.010 *m* ammonium sulfate
- *(d) 0.010 *m* aluminum sulfate

Answer

Each of the compounds has the same concentration. Thus, the larger the number of ions per formula unit (Problem 8.7), the larger is the effective concentration of ions, and the higher is the osmotic pressure.

Problem 8.9

We have been introduced to mass spectrometry earlier, which is the technique of choice to determine molar masses, very useful in forensic analyses. However, we can estimate molar masses very rapidly and inexpensively using a very precise thermometer (or a thermocouple), a balance and simple glassware.

The normal freezing point of benzene (C_6H_6) is 5.48°C . The normal freezing point of a solution prepared by dissolving 2.00 g of a covalent compound in 100.0 g of benzene is 5.08°C . What is the molar mass of the compound? For benzene, $K_f = 5.12^\circ\text{C/m}$.

Hint: The covalent compound does not dissociate in benzene.

Answer

We first calculate the molality of the solute, and then the number of moles.

$$\Delta T_f = K_f m_{\text{solute}}$$

$$\text{Molality of compound} = \frac{\Delta T_f}{K_f} = \frac{(5.48 - 5.08)^\circ\text{C}}{(5.12^\circ\text{C/m})} = 0.0781 \frac{\text{mol}}{\text{kg}}$$

Noting that the mass of the solution is 100.0 g or 0.1000 kg,

$$\text{Mol compound} = 0.0781 \frac{\text{mol}}{\text{kg}} (0.1000 \text{ kg}) = 0.00781 \text{ mol}$$

$$\text{Molar mass of compound} = \frac{2.00 \text{ g}}{0.00781 \text{ mol}} = 260 \frac{\text{g}}{\text{mol}} \quad (2 \text{ sf})$$

Note: There are 2 sf in the temperature difference, $(5.48 - 5.08) = 0.40$

Problem 8.10

Anti-freeze is a solution of ethylene glycol ($C_2H_6O_2$) in water. How much ethylene glycol must be added to a quart (quarter gallon) of water such that the mole fraction of ethylene glycol is 0.500?

1 gallon = 3.78L

Answer

For the mole fraction of ethylene glycol ($C_2H_6O_2$) to be 0.500; the moles of ethylene glycol and water are the same.

We convert one quart, 0.250 gallon (with 3 sf) water to mass, and then moles, then calculate moles and mass of ethylene glycol.

$$\begin{aligned} \text{Mass of } C_2H_6O_2 &= (0.250 \text{ gallon } H_2O) \left(\frac{3.78 \text{ L } H_2O}{1 \text{ gallon } H_2O} \right) \left(\frac{1000 \text{ mL } H_2O}{1 \text{ L } H_2O} \right) \left(\frac{1.00 \text{ g } H_2O}{1 \text{ mL } H_2O} \right) \left(\frac{1 \text{ mol } H_2O}{18.016 \text{ g } H_2O} \right) \\ &\left(\frac{1 \text{ mol } C_2H_6O_2}{1 \text{ mol } H_2O} \right) \left(\frac{62.068 \text{ g } C_2H_6O_2}{1 \text{ mol } C_2H_6O_2} \right) = 3.26 \times 10^3 \text{ g } C_2H_6O_2 \end{aligned}$$

Problem 8.11

What is the osmotic pressure of saline, 0.15 M NaCl at 25°C?

Answer

We use the equation,

$$\Pi = MRT$$

However, the molarity (M) must be based on all solutes. Since 1 unit of NaCl in an aqueous solution gives 2 species (Na^+ and Cl^-), the effective molarity of this solution is 0.30 M . We also need to convert the temperature to K .

$$\Pi = MRT = (0.30M) \left(0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \right) (298.15 \text{ K}) = 7.3 \text{ atm} \quad (2\text{sf})$$

Problem 8.12

A story: while waiting for the food to arrive at a very busy restaurant, my restless 13-year old sometimes plays with the salt and sugar.

Now, here is the problem. In a 100.0g sample of water, 0.010 mole of sodium chloride and 0.010 mole of glucose ($C_6H_{12}O_6$) are completely dissolved. What is the osmotic pressure of the resulting solution at 25°C?

Answer

We use the equation

$$\Pi = MRT$$

However, let's figure out moles due to **all solutes**

0.010 mol NaCl gives	0.010 mol Na^+ ions
	0.010 mol Cl^- ions

0.010 mol glucose remains intact, thus gives	0.010 mol glucose
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All solutes	0.030 mol
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We note 100.0 g of water is 0.1000 kg. Thus, the effective molality is

$$\left(\frac{0.030 \text{ mol}}{0.1000 \text{ kg}}\right) = 0.30m$$

Noting that in a dilute aqueous solution *Molarity* = *molality*,

$$\Pi = MRT = (0.30M)(0.08206 \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}})(298.15 \text{ K}) = 7.3 \text{ atm} \quad (2\text{sf})$$