REMEmber: Bubble in ALL Bubblesheet information!
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Please refer to the back of the bubble sheet for more info.

\[ R = 8.314 \text{ J/mol-K} \]
\[ R = 0.08206 \text{ L atm/mol-K} \]
\[ R = 62.36 \text{ L torr/mol-K} \]
\[ 1 \text{ atm} = 1.01325 \times 10^5 \text{ Pa} \]
\[ 1 \text{ atm} = 760 \text{ torr} \]
\[ 1 \text{ atm} = 14.7 \text{ psi} \]

**water data**
\[ K_f = 1.86 \text{ °C/m} \]
\[ K_b = 0.512 \text{ °C/m} \]
\[ C_{s,ice} = 2.09 \text{ J/g K} \]
\[ C_{s,water} = 4.184 \text{ J/g K} \]
\[ C_{s,steam} = 2.03 \text{ J/g K} \]
\[ \Delta H_{fus} = 334 \text{ J/g} \]
\[ \Delta H_{vap} = 2260 \text{ J/g} \]

**NOTE:** Please keep your Exam copy intact (all pages still stapled). You must turn in your exam copy, plus your bubble sheet, and any scratch paper.
This print-out should have 25 questions. Multiple-choice questions may continue on the next column or page – find all choices before answering.

001 4.0 points
On a hiking expedition with Bear Grylls, you ‘accidentally’ end up in a huge chasm 2 km below sea level. Bear, being the resourceful TV star that he is, builds a fire and promptly starts to heat some water to cook the local snake for dinner. At what temperature do you expect Bear’s water to boil?

1. At 100°C exactly
2. Higher than 100°C correct
3. None of these; Bear Grylls eats his food raw!
4. Lower than 100°C

Explanation:
At sea level, the pressure is 1 atm (760 torr). As you decrease elevation, pressure increases, raising the boiling point of water.

002 4.0 points
Nitrogen gas, N\(_2\)(g), has a certain solubility when dissolved in water. In which of the following cases would the solubility of N\(_2\)(g) increase?

I) changing to a less polar solvent
II) increasing the amount of solvent
III) increasing the pressure of N\(_2\)(g)

1. I only
2. I, II and III
3. I and II
4. I and III correct
5. II only
6. III only
7. II and III

Explanation:
The solubility of a gas is directly proportional to the gas’ pressure and inversely proportional to the temperature of the solvent. Considering the principle of like dissolve like, a non-polar species such as N\(_2\)(g) will be more soluble in non-polar solvents. The volume of the solvent does not impact the solubility, which is an intensive property; this is evident when one considers the units of solubility such as grams per liter, etc.

003 4.0 points
A solution containing all of the solute that a solvent can dissolve at a certain temperature and pressure is called

1. an unsaturated solution.
2. a supersaturated solution.
3. a concentrated solution.
4. a saturated solution. correct

Explanation:

004 4.0 points
What is \(K_{sp}\) for Ag\(_3\)PO\(_4\), if its molar solubility is \(2.7 \times 10^{-6}\) mol/L?

1. \(1.4 \times 10^{-21}\) correct
2. \(7.3 \times 10^{-12}\)
3. \(5.3 \times 10^{-16}\)
4. \(2.0 \times 10^{-17}\)
5. \(5.3 \times 10^{-23}\)
6. \(4.8 \times 10^{-22}\)
7. \(1.7 \times 10^{-14}\)

Explanation:

\(S = 2.7 \times 10^{-6}\) mol/L
The solubility equilibrium is

\[\text{Ag}_3\text{PO}_4(s) \rightleftharpoons 3\text{Ag}^+(aq) + \text{PO}_4^{3-}(aq)\]
\[ [\text{Ag}^+] = 3\,S = 8.1 \times 10^{-6} \text{ mol/L} \]
\[ [\text{PO}_4^{3-}] = S = 2.7 \times 10^{-6} \text{ mol/L} \]

\[ K_{sp} = [\text{Ag}^+]^3[\text{PO}_4^{3-}] = (8.1 \times 10^{-6})^3 (2.7 \times 10^{-6}) = 1.43489 \times 10^{-21} \]

005 4.0 points
The phase diagram for a pure compound is given below.

All of the following could have a similar phase diagram except

1. methanol.
2. carbon dioxide.
3. benzene.
4. water. correct
5. carbon tetrachloride.

Explanation:
Al\(_2\)S\(_3\) has a higher charge density (Al\(^{3+}\), S\(^{2-}\)) than NaCl (Na\(^{+}\), Cl\(^{-}\)). High charge density corresponds to high lattice energy and thus much more endothermic (i.e. less spontaneous) dissolution.

007 4.0 points
What mass of ethylene glycol ((CH\(_2\)OH\(_2\)) with molecular weight 62 g/mol) must be added to 1.00 L of H\(_2\)O (of mass 1 kg) to lower the freezing point to \(-5^\circ\)C? \(K_f\)\(H_2O = 1.86^\circ\)C/m.

1. 330 g
2. 66 g
3. 25 g
4. 167 g correct
5. 123 g

Explanation:
MW\(\text{CH}_2\text{OH} = 62 \text{ g/mol} \quad V_{\text{H}_2\text{O}} = 1 \text{ L} \quad m_{\text{H}_2\text{O}} = 1 \text{ kg} \quad T_f = -5^\circ\)C

\[ T_f = T_f^0 - \Delta T_f \]
\[ \Delta T_f = T_f^0 - T_f \]
\[ = 0.00^\circ\)C - (-5^\circ\)C) \]
\[ = 5^\circ\)C \]

\[ \Delta T_f = K_f \cdot m \]
\[ m = \frac{\Delta T_f}{K_f} \]
\[ = \frac{5^\circ\)C}{1.86^\circ\)C/m} = 2.688 \text{ m} \]

\[ m = \frac{n_{(\text{CH}_2\text{OH})_2}}{\text{kg water}} = \frac{g_{(\text{CH}_2\text{OH})_2}}{\text{kg water}} \frac{\text{MW}_{(\text{CH}_2\text{OH})_2}}{\text{kg water}} \]
\[ g \text{ (CH}_2\text{OH})_2 = m \text{ (MW (CH}_2\text{OH})_2)(kg \text{ water)} = \frac{2.688 \text{ mol (CH}_2\text{OH})_2}{\text{kg water}} \times \frac{62.0 \text{ g (CH}_2\text{OH})_2}{\text{mol (CH}_2\text{OH})_2} \times (1 \text{ kg water)} = 167 \text{ g (CH}_2\text{OH})_2 \]

008 4.0 points

The phase diagram for a pure substance is given below.

The substance is stored in a container at 150 atm at 25°C. Describe what happens if the container is opened at 25°C.

1. The liquid in the container vaporizes. correct
2. The solid in the container melts.
3. The vapor in the container escapes.
4. The liquid in the container freezes.
5. The solid in the container sublimes.

Explanation:

\[ \Delta \text{H}^0_{\text{vap}} = \frac{R \ln \left( \frac{P_2}{P_1} \right)}{\frac{1}{T_1} + \frac{1}{T_2}} \]

\[ \Delta \text{H}^0_{\text{vap}} = \frac{8.314 \text{ J} \cdot \text{mol}^{-1} \cdot \text{K}}{298.15 \text{ K} - 331.15 \text{ K}} \times \ln \left( \frac{405 \text{ torr}}{107 \text{ torr}} \right) = 33109.5 \text{ J} \cdot \text{mol}^{-1} \]

011 4.0 points
What is the molar solubility of Ag₂S? The \( K_{sp} \) is \( 6.3 \times 10^{-51} \).

1. \( 6.37 \times 10^{-15} \)
2. \( 7.94 \times 10^{-26} \)
3. \( 5.8 \times 10^{-18} \)
4. \( 2.82 \times 10^{-13} \)
5. \( 1.16 \times 10^{-17} \) correct

Explanation:

012 4.0 points
Consider a 200 g block of ice at standard pressure. If it is initially at \(-23^\circ C\) and is heated until it is steam at \(148^\circ C\), how much total heat was added to the sample of water? Use the following thermodynamic values for your calculation:

\[
c_{\text{ice}} = 2.09 \text{ J} \cdot \text{g}^{-1} \cdot \text{K}^{-1}
\]

\[
c_{\text{water}} = 4.184 \text{ J} \cdot \text{g}^{-1} \cdot \text{K}^{-1}
\]

\[
c_{\text{steam}} = 2.03 \text{ J} \cdot \text{g}^{-1} \cdot \text{K}^{-1}
\]

\[
\Delta H_{\text{vap}} = 2260 \text{ J} \cdot \text{g}^{-1}
\]

\[
\Delta H_{\text{fus}} = 334 \text{ J} \cdot \text{g}^{-1}
\]

1. 565 kJ
2. 548 kJ
3. 822 kJ
4. 29.1 kJ
5. 632 kJ correct

Explanation:

\[\Delta T_1 = 0^\circ C - (-23^\circ C) = 23^\circ C\]

\[\Delta T_2 = 100^\circ C\]

\[\Delta T_3 = 148^\circ C - 100^\circ C = 48^\circ C\]

\[m = 200 \text{ g}\]

\[q = 632 \text{ kJ}\]

013 4.0 points
Suppose that you wanted to be sure that a metal ion, any metal ion, would dissolve in water.

What salt of the metal ion compound would you choose?

1. the nitrate (NO\(^{3-}\)) salt of the metal ion correct
2. the hydroxide (OH\(^{-}\)) salt of the metal ion
3. the carbonate (CO\(^{2-}\)) salt of the metal ion
4. the chloride (Cl\(^{-}\)) salt of the metal ion

Explanation:

Nitrate (NO\(^{3-}\)) salts of any metal are always soluble.

014 4.0 points
Which of the following salts would have the greatest molar solubility?

1. Al(OH)\(_3\) \( K_{sp} = 1.90 \times 10^{-33} \)
2. PbCrO\(_4\) \( K_{sp} = 1.77 \times 10^{-14} \) correct
3. CdS \( K_{sp} = 3.60 \times 10^{-29} \)
4. Cu\(_2\)S \( K_{sp} = 2.00 \times 10^{-47} \)

Explanation:

Lead chromate is a salt composed of only two ions and thus its molar solubility is equal to the square root of its \( K_{sp} \). The best approximation is therefore \((10^{-14})^{1/2} = 10^{-7}\).

015 4.0 points
Which of the following highly soluble salts would be the most useful for lowering the freezing point of a solution?

1. Ce\(_2\)(SeO\(_4\))\(_3\) correct
2. (NH\(_4\))\(_3\)PO\(_4\)
3. KBr
4. Cs\(_2\)SO\(_4\)
5. Cs\(_2\)Cr\(_2\)O\(_7\)
Explanation:
Cerium Selenate, Ce$_2$(SeO$_4$)$_3$, has the largest van’t Hoff factor ($i = 5$), and would require the smallest molar quantity to lower a solution’s freezing point by a given amount.

**016 4.0 points**
Water from a local stream is added to one side of the U-tube shown below. Pure water is placed in the tube on the other side of the semipermeable membrane. With the left side open to barometric pressure of 1.0 atm and 1.15 atm applied to the right side, the two liquids do not move.

![U-tube diagram]

In which half of the U-tube is the pure water located?

1. A correct
2. B
3. Not enough information is given.

**Explanation:**

**017 4.0 points**
In general, decreasing the temperature makes which phase transitions more likely to occur?

1. evaporation, fusion, sublimation
2. evaporation, deposition, freezing
3. sublimation, condensation, freezing
4. condensation, freezing, deposition correct
5. condensation, fusion, deposition

**Explanation:**

**018 4.0 points**
Pure water is saturated with PbCl$_2$. In this saturated solution

1. $[\text{Pb}^{2+}] = 0.5 [\text{Cl}^-]$. correct
2. $K_{sp} = [\text{Pb}^{2+}]$.
3. $[\text{Pb}^{2+}] [\text{Cl}^-] = K_{sp}$.
4. $[\text{Pb}^{2+}] = [\text{Cl}^-]$.
5. $2 [\text{Cl}^-] = [\text{Pb}^{2+}]$.

**Explanation:**

**019 4.0 points**
Assume the molar solubility of silver chromate (Ag$_2$CrO$_4$) is represented as $x$. Which of the following expressions correctly expresses the relationship between the molar solubility of silver chromate and the solubility product constant ($K_{sp}$) for this compound?

1. $K_{sp} = 2 x^2$
2. $K_{sp} = x^2$
3. $K_{sp} = 4 x^2$
4. $K_{sp} = 2 x^3$
5. $K_{sp} = 4 x^3$ correct

**Explanation:**
The equation for the dissociation of Ag$_2$CrO$_4$ is written as

$\text{Ag}_2\text{CrO}_4 \rightleftharpoons 2 \text{Ag}^+ + \text{CrO}_4^{2-}$.

The expression for $K_{sp} = [\text{Ag}^+]^2 [\text{CrO}_4^-]$. Since the molar solubility is $x$, $K_{sp}$ can be rewritten (in terms of $x$) as

$$K_{sp} = [2x]^2 [x] = 4 x^3.$$
\[ [\text{Ag}^+] = 2x \] because for every salt molecule that dissociates, 2 Ag\(^+\) ions are produced.

020 4.0 points
The vapor pressure of pure CH\(_2\)Cl\(_2\) (with molecular weight 85 g/mol) is 133 torr at 0°C and the vapor pressure of pure CH\(_2\)Br\(_2\) (with molecular weight 174 g/mol) is 11 torr at the same temperature. What is the total vapor pressure at 0°C of a solution prepared from equal masses of these two substances?

1. 124 torr
2. 89 torr
3. 72 torr
4. 7.4 torr
5. 3.6 torr
6. 105 torr
7. 93 torr correct
8. 144 torr
9. 44 torr

Explanation:
For CH\(_2\)Cl\(_2\),
\[ P^0 = 133 \text{ torr} \]
For CH\(_2\)Br\(_2\),
\[ P^0 = 11 \text{ torr} \]
The mole fractions are
\[
X_{\text{CH}_2\text{Cl}_2} = \frac{n_{\text{CH}_2\text{Cl}_2}}{n_{\text{CH}_2\text{Cl}_2} + n_{\text{CH}_2\text{Br}_2}} = \frac{g/85}{g/85 + g/174} = 0.672
\]
\[
X_{\text{CH}_2\text{Br}_2} = \frac{n_{\text{CH}_2\text{Br}_2}}{n_{\text{CH}_2\text{Br}_2} + n_{\text{CH}_2\text{Cl}_2}} = \frac{g/174}{g/174 + g/85} = 0.328
\]
Thus
\[
P_\text{solution} = P_{\text{CH}_2\text{Cl}_2} + P_{\text{CH}_2\text{Br}_2} = X_{\text{CH}_2\text{Cl}_2} P^0_{\text{CH}_2\text{Cl}_2} + X_{\text{CH}_2\text{Br}_2} P^0_{\text{CH}_2\text{Br}_2}
\]
\[
= (0.672)(133 \text{ torr}) + (0.328)(11 \text{ torr})
\]
\[= 93.0 \text{ torr} \]

021 4.0 points
Rank the liquids NH\(_3\), CH\(_3\)OH, CH\(_3\)CH\(_2\)F, CCl\(_4\) by their miscibility in heptane (C\(_7\)H\(_{16}\)), from most miscible to least.

1. NH\(_3\) > CH\(_3\)OH > CH\(_3\)CH\(_2\)F > CCl\(_4\)
2. CCl\(_4\) > CH\(_3\)CH\(_2\)F > NH\(_3\) > CH\(_3\)OH
3. CH\(_3\)CH\(_2\)F > CCl\(_4\) > CH\(_3\)OH > NH\(_3\)
4. CH\(_3\)CH\(_2\)F > CH\(_3\)OH > CCl\(_4\) > NH\(_3\)
5. CCl\(_4\) > CH\(_3\)CH\(_2\)F > CH\(_3\)OH > NH\(_3\) correct

Explanation:
“Like dissolves like.” Heptane is hydrocarbon, and thus completely non-polar. Carbon tetrachloride is most soluble since even though the C−Cl bond is polar, there is no net dipole in the molecule, followed by fluoroethane, which is polar. Methanol is small and very polar (exhibiting hydrogen bonding), and ammonia is the most polar of the liquids, and thus least soluble.

022 4.0 points
\( K_{sp} \) for CaF\(_2\) is \( 3.9 \times 10^{-11} \). Would a precipitate of CaF\(_2\) form if Ca(NO\(_3\))\(_2\) and NaF solutions were mixed such that \([\text{Ca}^{2+}] = 2.0 \times 10^{-4} \text{ M}\) and \([\text{F}^-] = 3.0 \times 10^{-4} \text{ M}\)?

1. yes, because Q is larger than \( K_{sp} \)
2. yes, because Q is smaller than \( K_{sp} \)
3. no correct

Explanation:
\[
K_{sp} \text{ for CaF}_2 = \frac{[\text{Ca}^{2+}][\text{F}^-]^2}{\text{CaF}_2} = \text{CaF}_2
\]
\[
Q = \frac{2.0 \times 10^{-4} \times (3.0 \times 10^{-4})^2}{1} = 1.8 \times 10^{-11}
\]
\[
Q = \frac{2.0 \times 10^{-4} \times (3.0 \times 10^{-4})^2}{1} = 1.8 \times 10^{-11}
\]
\[Q < K_{sp} \]

023 4.0 points
Identify the spectator ion(s) in the equation
\[ \text{CaCl}_2(\text{aq}) + \text{Na}_2\text{CO}_3(\text{aq}) \rightarrow \text{CaCO}_3(\text{s}) + 2\text{NaCl(}\text{aq}) \].

1. \( \text{Na}^+ \), \( \text{Cl}^- \) **correct**
2. \( \text{Ca}^{2+} \), \( \text{CO}_3^{2-} \)
3. \( \text{Ca}^{2+} \), \( \text{Cl}^- \)
4. \( \text{Na}^+ \), \( \text{CO}_3^{2-} \)

**Explanation:**
Spectator ions are those that do not participate in the reaction nor appear in the net ionic equation. Sodium ions (\( \text{Na}^+ \)), potassium ions (\( \text{K}^+ \)), nitrate (\( \text{NO}_3^- \)) and chloride (\( \text{Cl}^- \)) are common spectator ions.

**024** 4.0 points
The solubility product constant of \( \text{Ag}_2\text{CrO}_4 \) is \( 9.0 \times 10^{-12} \). What is the molar solubility of \( \text{Ag}_2\text{CrO}_4 \) in a solution in which the silver ion concentration is maintained at \( 2.0 \times 10^{-3} \text{ M} \) by addition of \( \text{AgNO}_3 \)?

1. \( 5.6 \times 10^{-7} \)
2. \( 4.0 \times 10^{-3} \)
3. \( 2.3 \times 10^{-6} \) **correct**
4. \( 1.3 \times 10^{-4} \)
5. \( 4.5 \times 10^{-9} \)

**Explanation:**

Which of the following would raise the vapor pressure of a sample of isopropanol in a closed container?

I) increasing the size of the container
II) increasing the temperature of the sample
III) increasing the applied pressure

1. III only
2. I, II and III

**Explanation:**
Because evaporation is always an endothermic process, a substance’s vapor pressure is always directly proportional to its temperature. Adding a non-volatile solute to any substance will decrease its vapor pressure. Factors such as sample size and container size do not influence the vapor pressure.