Chapter 17: Phenomena

Phenomena: Different masses of solute were added to 1 kg of either H_2O or C_6H_6. The boiling and freezing points of the solutions were then measured. Examine the data to determine patterns in how these variables affect the boiling and freezing points of the solutions.

Solvent	Exp.	Solute	Mass of Solute	Moles of Solute	Boiling Point	Freezing Point
H_2O	1	None	0.0 g	0.00 mol	100.0°C	0.0°C
	2	NaCl	50.0 g	0.85 mol	100.9°C	-3.2°C
	3	NaCl	100.0 g	1.71 mol	101.7°C	-6.4°C
	4	K_2O	50.0 g	0.53 mol	100.8°C	-3.0°C
	5	K_2O	107.0 g	1.14 mol	101.7°C	-6.3°C
	6	$C_{12}H_{22}O_{11}$	1169.0 g	3.42 mol	101.7°C	-6.4°C
	7	$NaHCO_3$	71.7 g	0.85 mol	100.9°C	-3.2°C
	8	$C_6H_{12}O_6$	616.1 g	3.42 mol	101.7°C	-6.4°C
C_6H_6	**Exp.**	**Solute**	**Mass of Solute**	**Moles of Solute**	**Boiling Point**	**Freezing Point**
	1	None	0.0 g	0.00 mol	80.1°C	5.5°C
	2	NaCl	50.0 g	0.85 mol	84.4°C	-3.2°C
	3	NaCl	100.0 g	1.71 mol	88.7°C	-12.0°C
	4	K_2O	50.0 g	0.53 mol	84.1°C	-2.7°C
	5	K_2O	107.0 g	1.14 mol	88.7°C	-11.9°C
	6	$C_{12}H_{22}O_{11}$	1169.0 g	3.42 mol	88.7°C	-12.0°C
	7	$NaHCO_3$	71.7 g	0.85 mol	84.4°C	-3.2°C
	8	$C_6H_{12}O_6$	616.1 g	3.42 mol	88.8°C	-12.0°C

Chapter 17 Properties of Solutions

- Types of Solutions
- Solubility
- Colligative Properties
- Vapor Pressure
- Boiling and Freezing Point
- Osmotic Pressure

Big Idea: Liquids will mix together if both liquids are polar or both are nonpolar. The presence of a solute changes the physical properties of the system. For non-volatile solutes the vapor pressure, boiling point, freezing point, and osmotic pressure are only dependent on the number of ions/particles.

Types of Solutions

Matter can be broken in to two subcategories: pure substances and mixtures.

Pure Substances

- **Elements:** A substance that cannot be separated into simpler components by chemical techniques.
- **Compounds:** A specific combination of elements that can be separated into its elements by chemical techniques but not by physical techniques.

Examples: Water (H_2O), salt (NaCl), and sucrose ($C_{12}H_{22}O_{11}$)

Types of Solutions

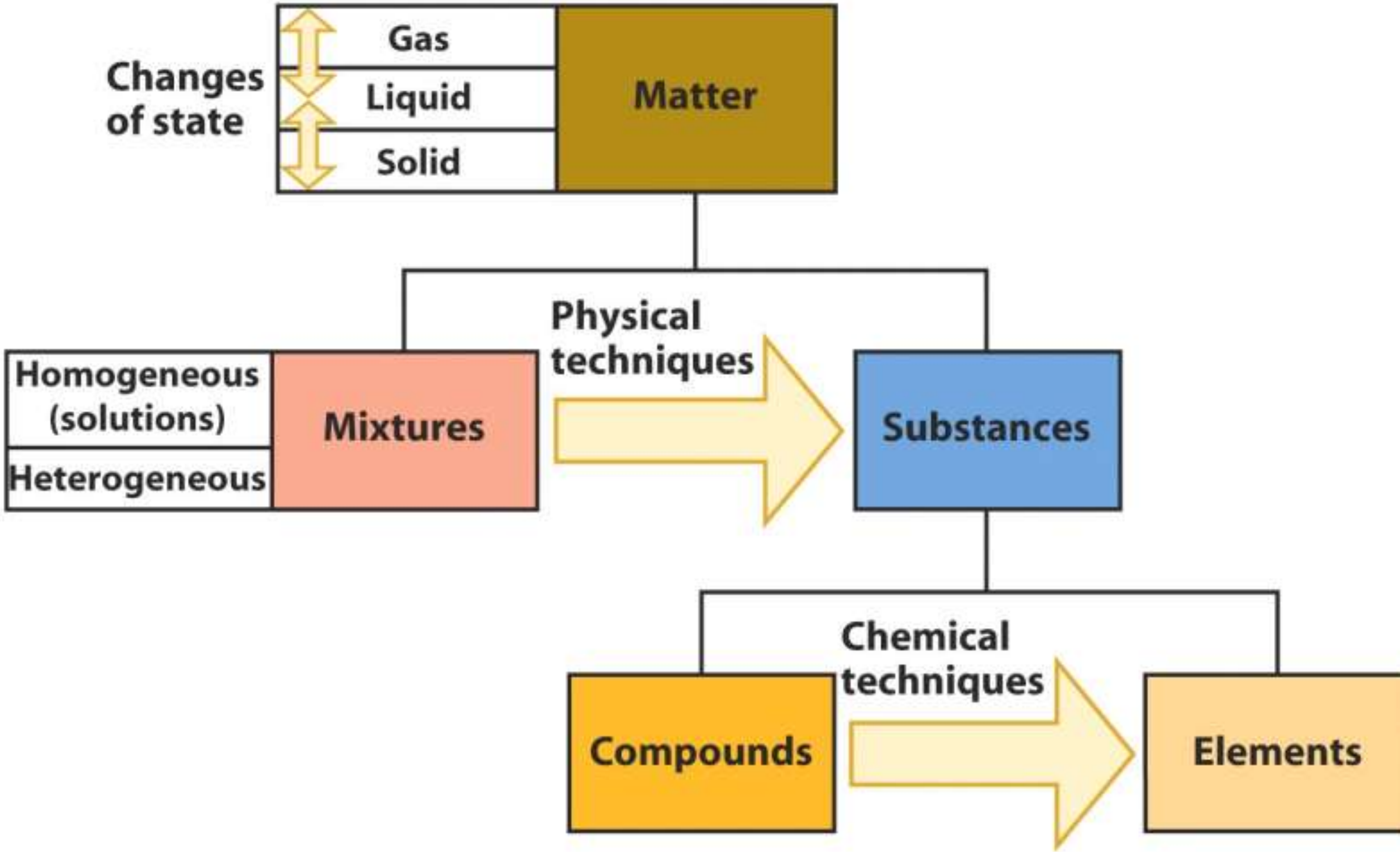
Mixtures

- **Heterogeneous Mixtures:** A mixture in which the individual components, although mixed together, lie in distinct regions that can be distinguished with an optical microscope.

- **Homogeneous Mixture:** A mixture in which the individual components are uniformly mixed, even on the molecular scale.

Example: Air (nitrogen, oxygen, argon, …)

Types of Solutions



Types of Solutions

Student Question

How many of the following are homogeneous mixtures?

Oil and vinegar
Salt water
Chalk and table salt
Kool-Aid
Charcoal and sugar

a) 1 is homogeneous
b) 2 are homogeneous
c) 3 are homogeneous
d) 4 are homogeneous
e) All are homogeneous

Types of Solutions

- **Solution:** A homogeneous mixture.

Solutions are made up of at least two parts

- **Solvent:** The most abundant component of a solution.
- **Solute:** A dissolved substance.

State of Solution	State of Solvent	State of Solute	Example
Gas	Gas	Gas	Air Natural gas
Liquid	Liquid	Liquid	Tequila Antifreeze
Liquid	Liquid	Gas	Soda water
Liquid	Liquid	Solid	Sea water Sugar water
Solid	Solid	Solid	Alloys (Steel or brass)
Solid	Solid	Gas	Hydrogen in platinum

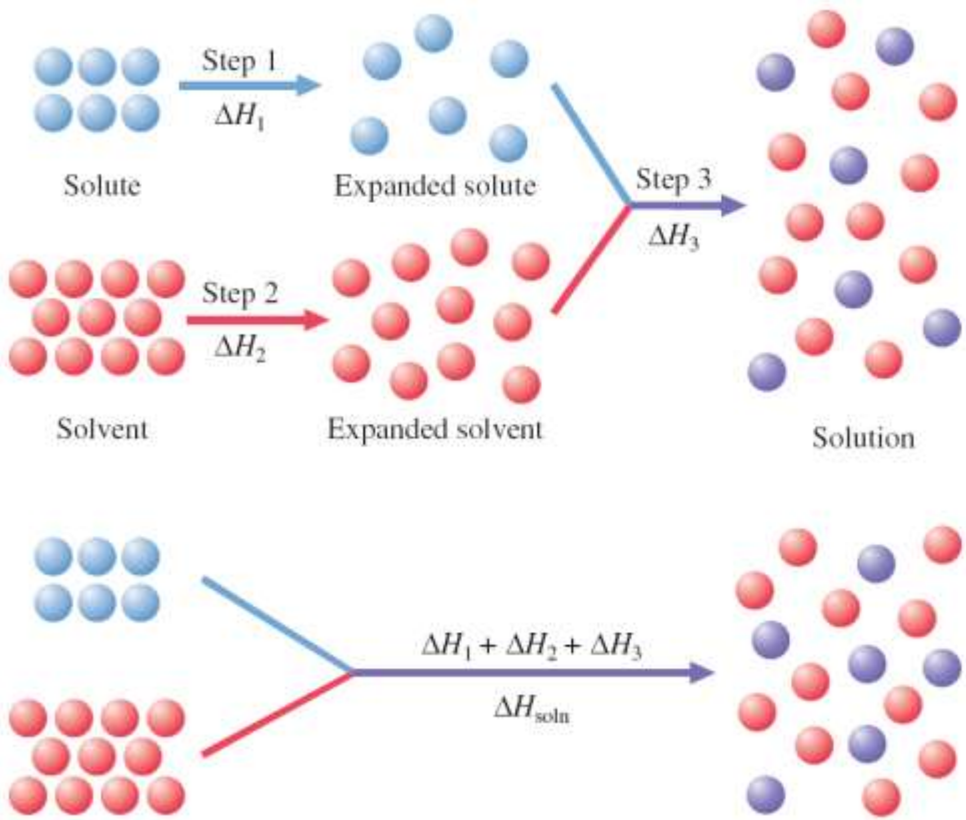
Student Question

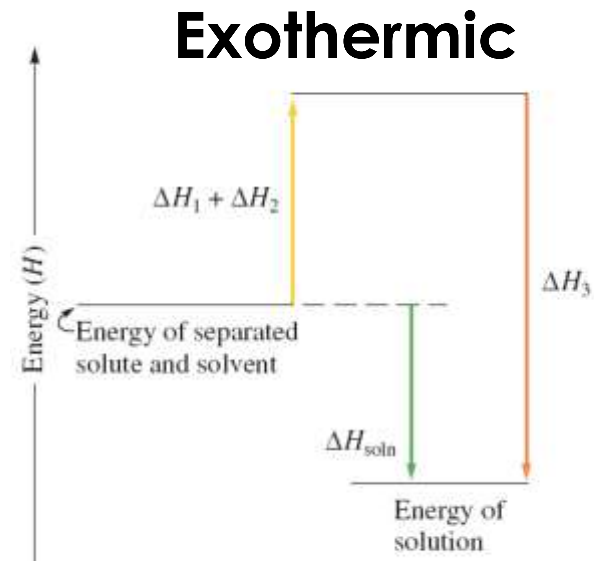
The density of a 40.0% by weight aqueous solution of NaOH is 1.432 $\frac{g}{cm^3}$. What is the molality of NaOH?

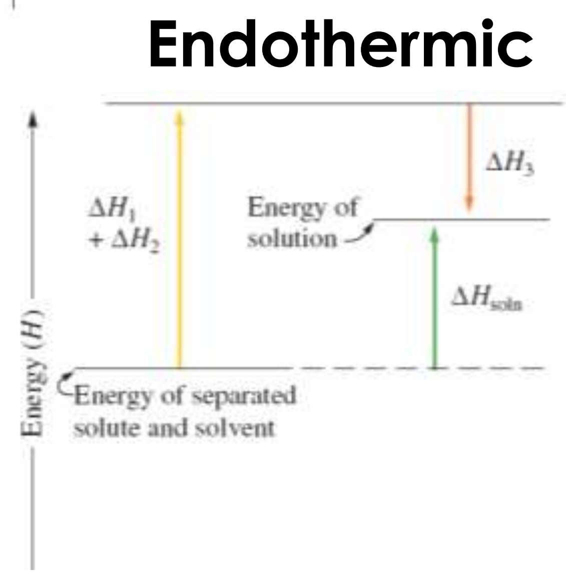
Helpful Information: $M_{NaOH} = 40.00\frac{g}{mol}$

a) 12.9 m
b) 14.3 m
c) 16.7 m
d) 13.8 m
e) None of the above

Solubility


Step 1
ΔH_1
Solute
Expanded solute
Step 2
ΔH_2
Solvent
Expanded solvent
Step 3
ΔH_3
Solution
$\Delta H_1 + \Delta H_2 + \Delta H_3$
ΔH_{soln}


Exothermic
Energy (H)
$\Delta H_1 + \Delta H_2$
ΔH_3
Energy of separated solute and solvent
ΔH_{soln}
Energy of solution


Endothermic
Energy (H)
$\Delta H_1 + \Delta H_2$
Energy of solution
ΔH_3
ΔH_{soln}
Energy of separated solute and solvent

Solubility

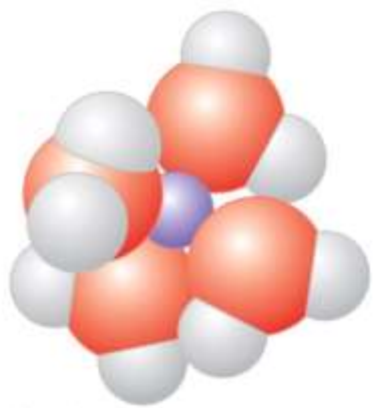
Student Question

Which one of the following substances would be the most soluble in CCl_4?

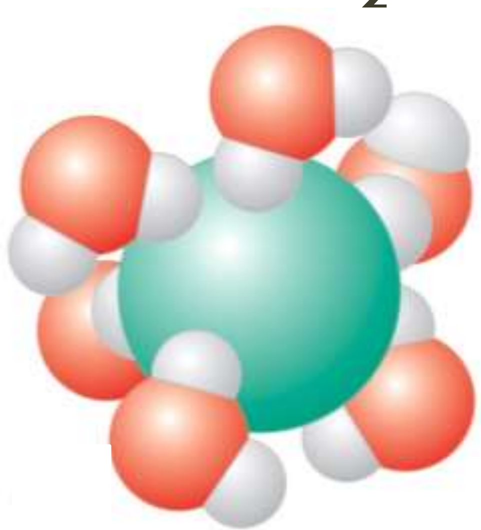
a) CH_3CH_2OH
b) $C_{10}H_{22}$
c) H_2O
d) NaCl
e) NH_3

Solubility

Cation and H_2O



Anion and H_2O



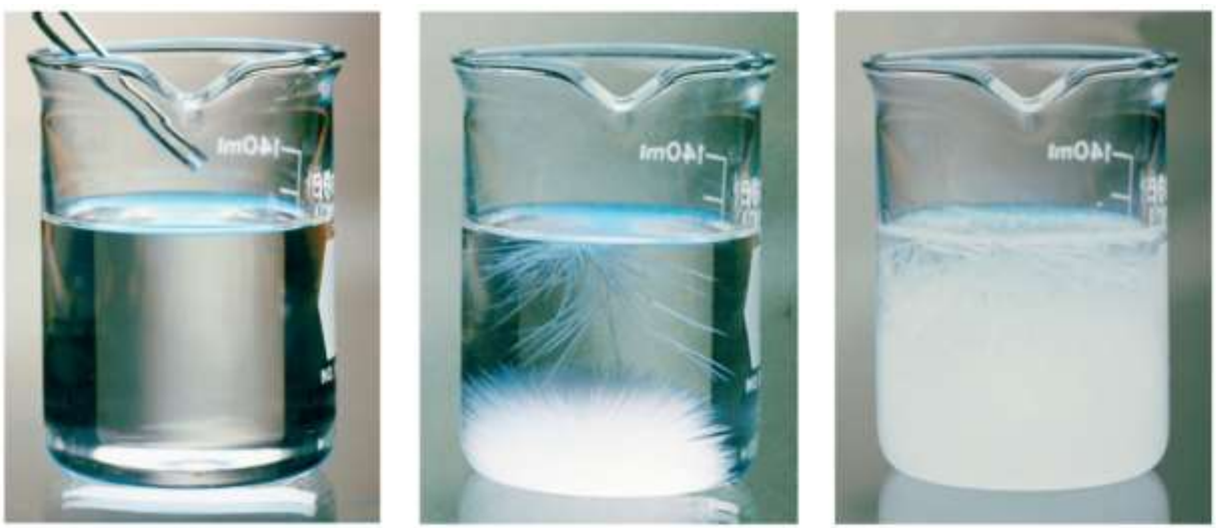
- **Hydration:** The reaction of a substance with water.

Note: For molecules, the extent of hydration increases as polarity increases.

Note: For ions, the extent of hydration increases as charge density (charge per volume) increases. In general, the smaller the size, the larger the charge density and the larger the charge, the larger the charge density.

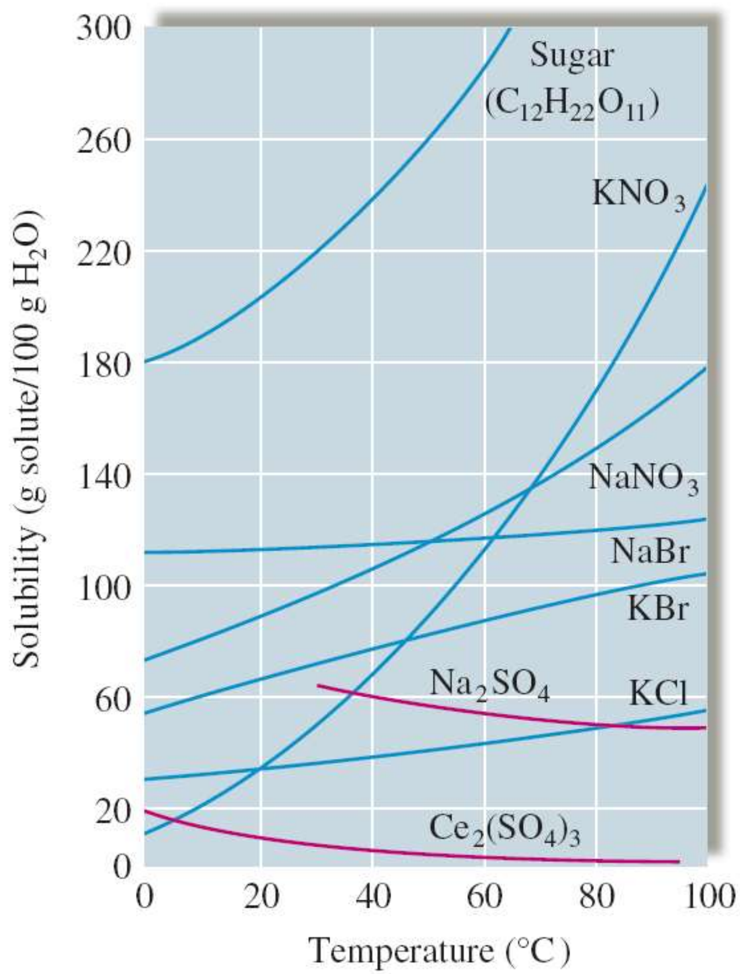
Solubility

- **Saturated Solution:** A solution that holds the maximum amount of solute.
- **Unsaturated Solution:** A solution that holds less than the maximum amount of solute.
- **Supersaturated Solution:** A solution that holds more than the maximum amount of solute.



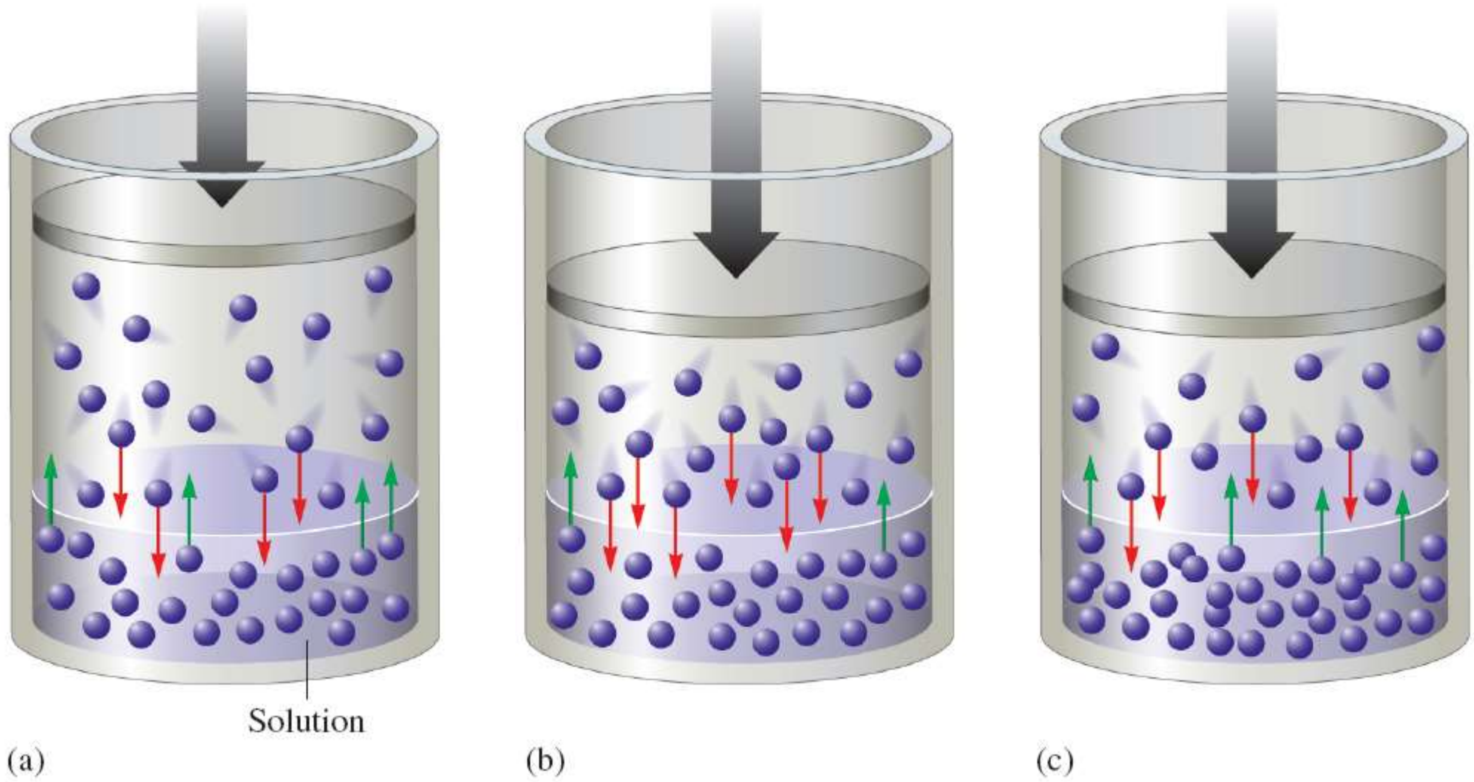
- If a solutions is supersaturated any small disturbance can cause the solute to recrystallize

Solubility



- The graph shows the saturation level of different solutions at a given temperature. If a solution has a solubility that results in a point above the line, then the solution is considered to be supersaturated. However, if a solution has a solubility that results in a point under the line, then the solution is considered unsaturated.

Solubility



$$P = k_H \chi_{gas}$$

Note: Where χ is the mole fraction of the gas dissolved in solution.

Note: An alternate form of henry's Law is: $P = k_H c$ where c is the molarity.

Colligative Properties

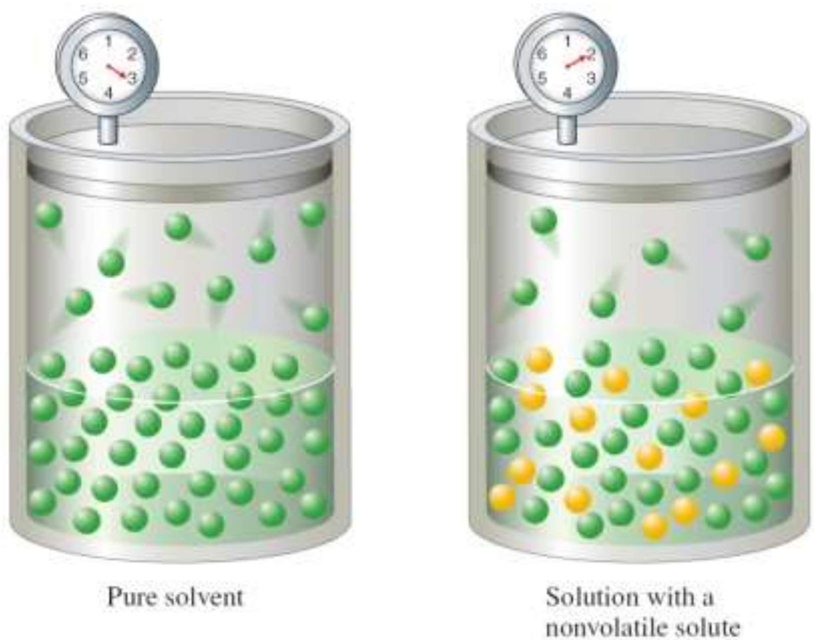
- **Colligative Properties:** Physical properties of solutions that depend on the number of solute particles present but not the type of solute particles.

- Examples of Colligative Properties:
  - Vapor Pressure (non volatile solutes)
  - Freezing Point
  - Boiling Point
  - Osmotic Pressure

Vapor Pressure

- **Vapor Pressure:** The pressure exerted by the vapor of a liquid or solid.
- **Volatile:** Having a high vapor pressure at ordinary temperatures (evaporates easily).
- **Nonvolatile:** Having a low vapor pressure at ordinary temperatures (does not evaporate easily).

Nonvolatile Solute



- Raoult's Law
  - $P_{solution} = \chi_{solvent} P^{\circ}_{solvent}$

Note: Where χ is the mole fraction of the solvent $\left(\frac{n_{solvent}}{n_{tot}}\right)$.

Vapor Pressure

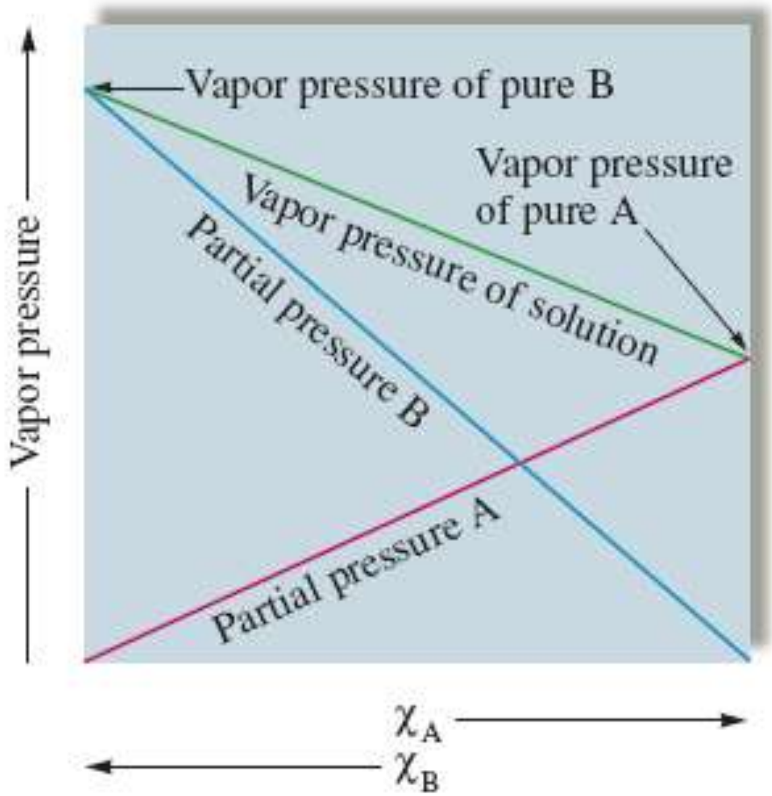
Student Question

Which of the following aqueous solutions containing nonvolatile solutes should have the highest boiling point?

a) 0.02 m $C_6H_{12}O_6$
b) 0.02 m $(NH_4)_2SO_4$
c) 0.02 m NaCl
d) 0.02 m $Ce(NO_3)_4$
e) All have the same boiling point

Vapor Pressure

Ideal Solution (Obeys Raoult's Law)



- Which substance (A or B) has the higher boiling point?

Vapor Pressure

Student Question

What is the vapor pressure of a solution of 50.0 g of CCl_4 and 50.0 g of $CHCl_3$ at 25°C. The vapor pressures at 25°C for pure CCl_4 and $CHCl_3$ are 98.3 torr and 172.0 torr respectively.

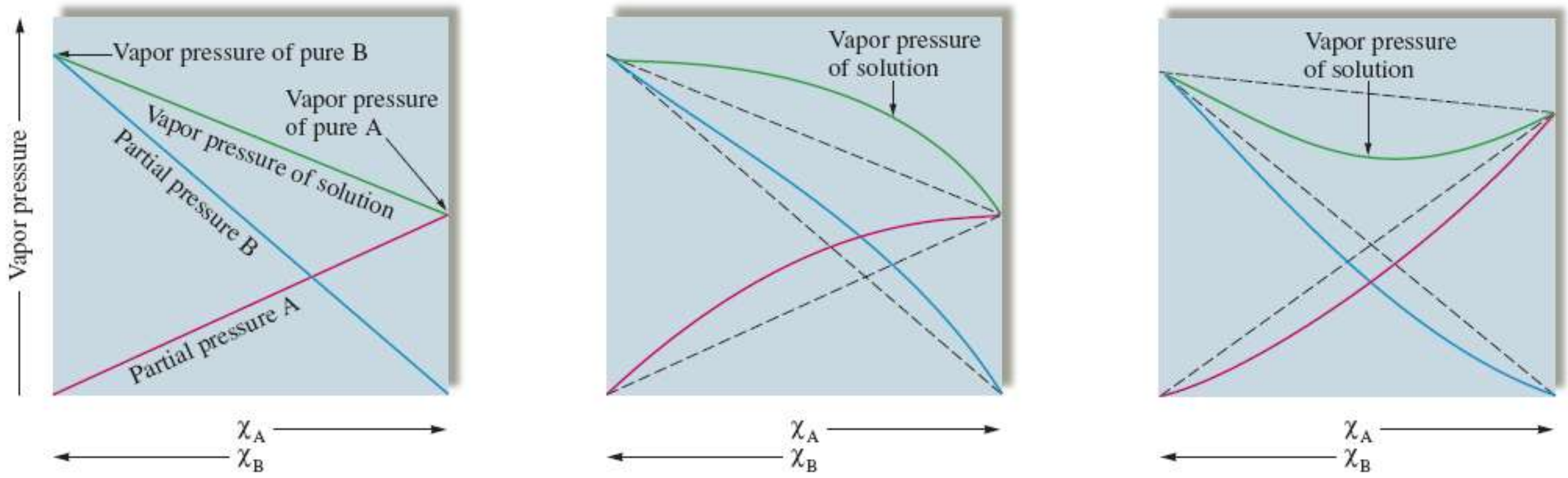
Helpful Information: $M_{CHCl_3} = 119.37\frac{g}{mol}$ *and* $M_{CCl_4} = 153.81\frac{g}{mol}$

a) 131 torr
b) 140. torr
c) 149 torr
d) 126 torr
e) None of the Above

Vapor Pressure

Deviations from Raoult's Law

Ideal



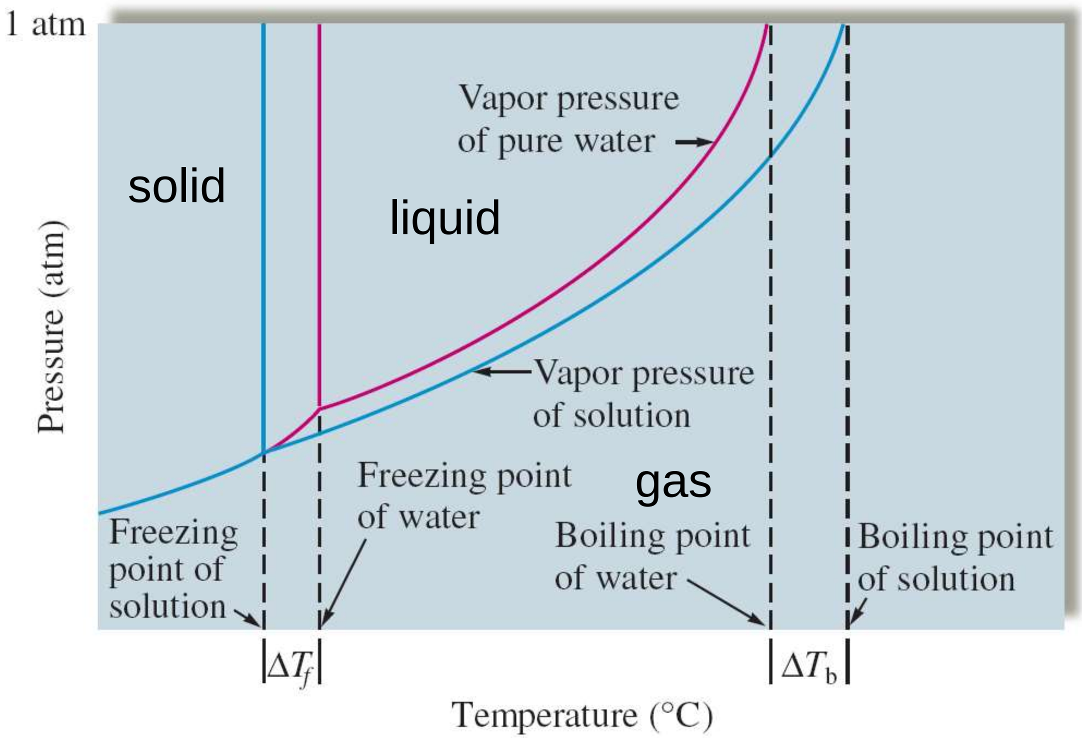
ΔH=0

Boiling and Freezing Points

- **Freezing Point Depression:** The decrease in the freezing point of a solvent caused by the presence of a solute.
- **Boiling Point Elevation:** The increase in the boiling point of a solution caused by the presence of a solute.

Boiling and Freezing Points

Boiling Point Elevation

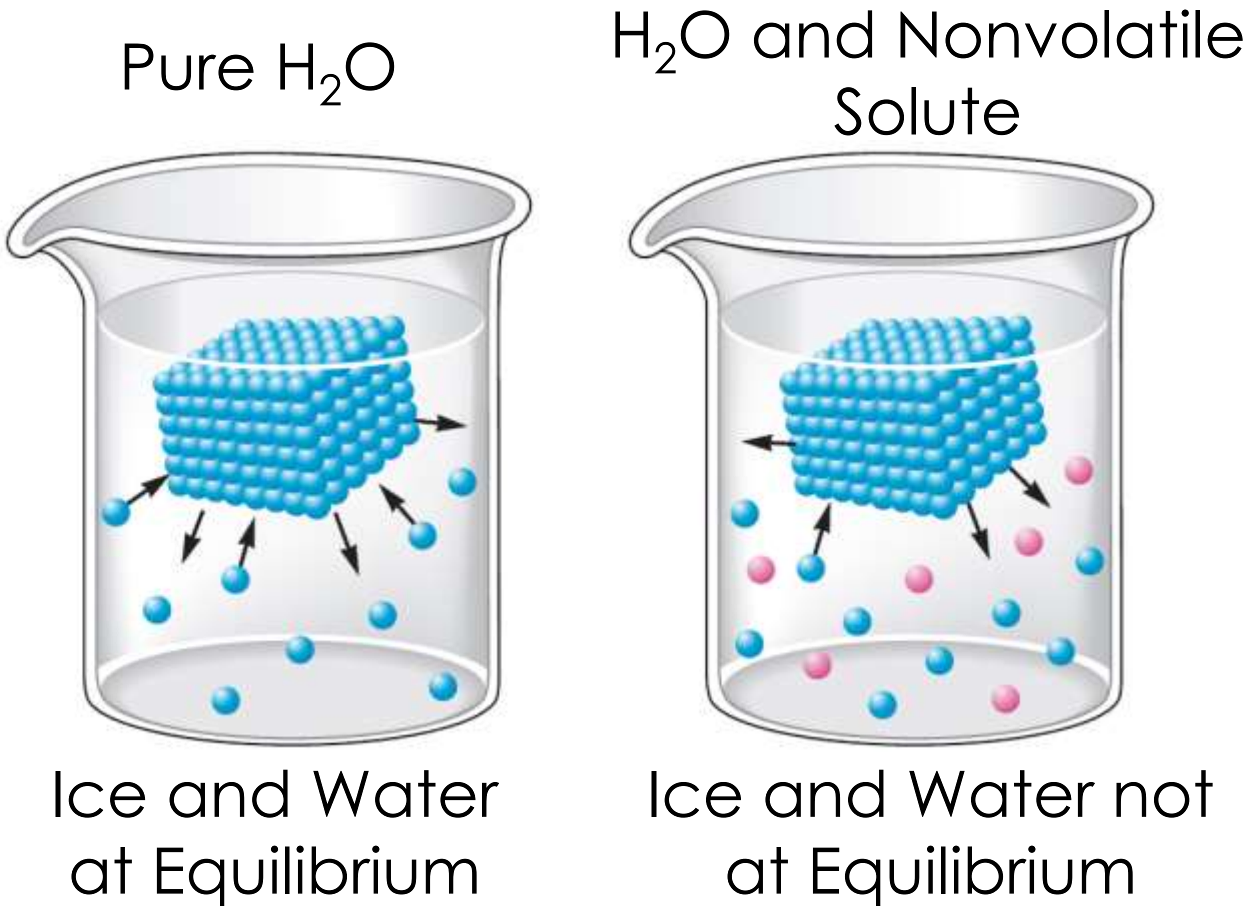


- The presence of a nonvolatile solute lowers the vapor pressure of the solution, therefore, a higher temperature must be present in order for the vapor pressure of the solution to reach 1 atm (normal boiling point).

Boiling and Freezing Points

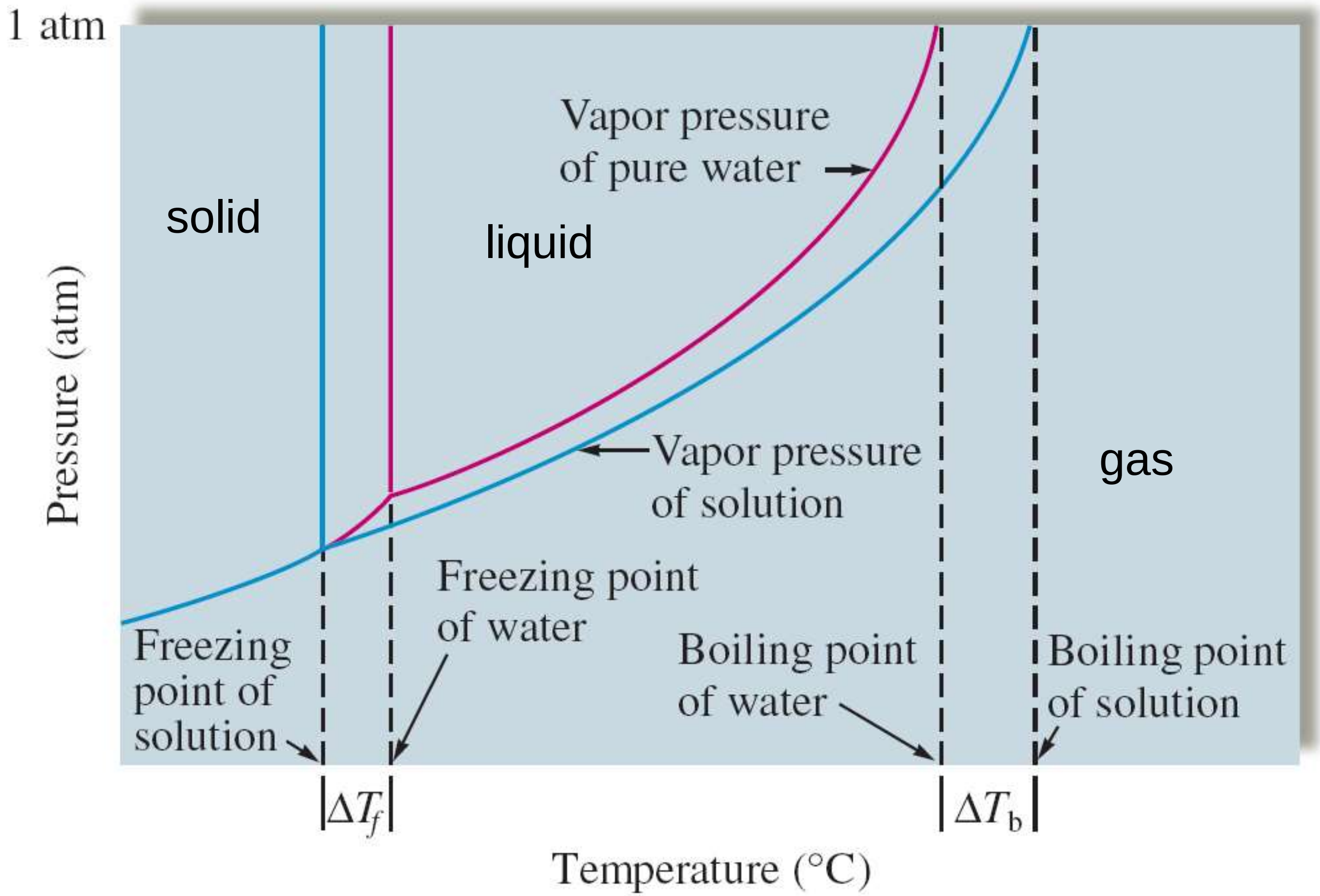
- At the freezing point, the solid and the liquid are in equilibrium.

Both Beakers are at 0°C



Boiling and Freezing Points

Freezing Point Depression



Boiling and Freezing Points

Boiling and Freezing Point Data				
Solvent	Boiling Point $(°C)$	K_b $\left(\frac{°C \cdot kg}{mol}\right)$	Freezing Point $(°C)$	K_f $\left(\frac{°C \cdot kg}{mol}\right)$
H_2O	100.0	0.51	0.0	1.86
CCl_4	76.5	5.03	-22.99	30.
$CHCl_3$	61.2	3.63	-63.5	4.70
C_6H_5	80.1	2.53	5.5	5.12
CS_2	46.2	2.34	-111.5	3.83
$C_4H_{10}O$	34.5	2.02	-116.2	1.79
$C_{10}H_{16}O$	208.0	2.95	179.8	40.

Boiling and Freezing Points

Student Question

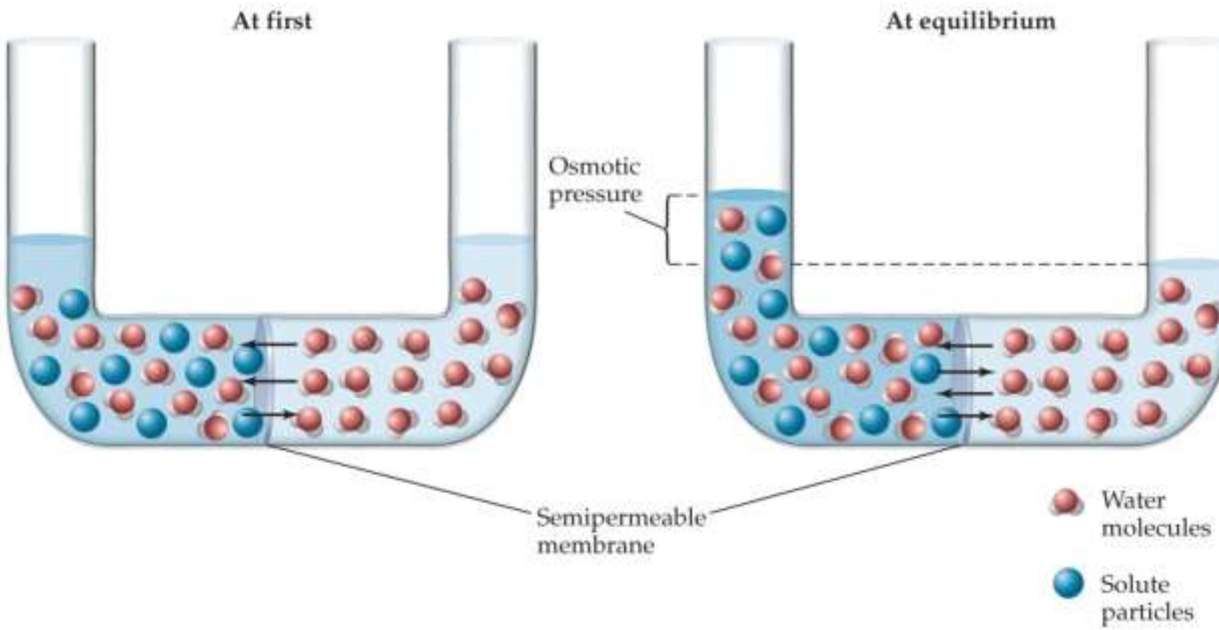
A solution of 0.640 g of azulene in 100.0 g of benzene boils at 80.230˚C. The boiling point of benzene is 80.100˚C; the K_b is 2.53 $\frac{°C \cdot kg}{mol}$. What is the molecular weight of azulene?

Helpful Information: The van't Hoff factor is 1 for azulene.

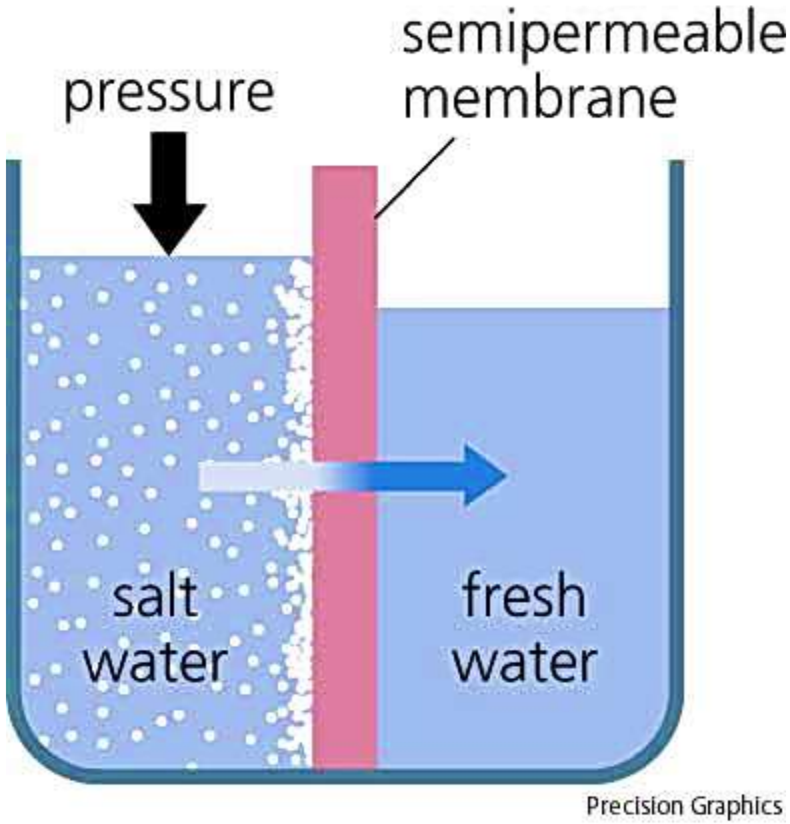
a) 108 $\frac{g}{mol}$
b) 117 $\frac{g}{mol}$
c) 134 $\frac{g}{mol}$
d) 99 $\frac{g}{mol}$
e) None of the Above

Osmotic Pressure

- **Osmosis:** The flow of solvent from a lower concentration solution through a semipermeable membrane to a higher concentration solution
- **Osmotic Pressure:** The pressure needed to stop the flow of solvent through a semipermeable membrane.



Osmotic Pressure



Take Away From Chapter 17

- **Big Idea:** Liquid will mix together if both liquids are polar or both are nonpolar. The presence of a solute changes the physical properties of the system. For non-volatile solutes the vapor pressure, boiling point, freezing points, and osmotic pressure are only dependent on the number of ions/particles.

- **Types of Solutions**
  - Know the difference between homogeneous and heterogeneous mixtures
    - Homogeneous Mixtures: Uniformly mixed (air)
    - Heterogeneous Mixtures: Not uniformly mixed (chocolate chip cookie)

Numbers correspond to end of chapter questions.

Take Away From Chapter 17

- **Types of Solutions (Continue)**
  - Know the definition of a solution
    - Solution: Homogeneous mixture
  - Be able to determine solution composition (15,16,17)
    - Molarity
      - $M = \frac{n_{solute}}{V_{solution}}$
    - Mole Fraction
      - $\chi_A = \frac{n_A}{n_{total}}$
    - Mass Percent
      - $mass\ \%\ A = \left(\frac{m_A}{m_{total}}\right) 100\%$
    - Molality
      - $m = \frac{n_{solute}}{m_{solvent}}$

Numbers correspond to end of chapter questions.

Take Away From Chapter 17

- **Solubility**
  - Be able to predict whether two substance are soluble (33,34)
    - Like dissolves like
      - *Two polar substances are soluble with each other*
      - *Two nonpolar substances are soluble with each other*
      - *A nonpolar and a polar substance are not soluble with each other*
  - Be able to predict the extent of hydration (32)
    - The more polar the ion/molecule the greater the hydration
    - The greater the charge density the greater the hydration (In general the smaller the ion/molecule the greater the hydration and the larger the charge the greater the hydration)
  - Know the effects of temperature on solubility
    - In general the greater the temperature the higher the solubility of a solid in a liquid
    - The greater the temperature the lower the solubility of a gas in a liquid
  - Know the effects of pressure on the solubility of a gas (39)
    - $P = k_H \chi$

Numbers correspond to end of chapter questions.

Take Away From Chapter 17

- **Colligative Properties**
- **Vapor Pressure**
  - Be able to calculate the vapor pressure of a solvent and a nonvolatile solute (42,44,47,79)
    - $P_{solution} = \chi_{solvent} P^{\circ}_{solvent}$
  - Be able to calculate the vapor pressure of solvent and volatile solute (49,51)
    - $P_{solution} = \chi_{solvent} P^{\circ}_{solvent} + \chi_{solute\ A} P^{\circ}_{solute\ A} + \cdots$
  - Be able to construct mole fraction vs. vapor pressure plots (52,53,54,55,57)
    - Know what a positive deviation to Raoult's Law implies
      - $\Delta H>0$: *solute/solvent interaction are weaker than solute/solute interactions or solvent/solvent interactions*
    - Know what a negative deviation of Raoult's Law implies
      - $\Delta H<0$: solute/solvent interaction are stronger than solute/solute interactions or solvent/solvent interactions

Numbers correspond to end of chapter questions.

Take Away From Chapter 17

- **Boiling and Freezing Points**
  - Be able to determine the van't Hoff factor (i) and know how this factor effects colligative properties (13,81,82)
  - Be able to calculate freezing point and boiling point of a solution (62,63,70,74,124)
    - $T_f = T_f^{\circ} - \Delta T_f$ or $T_b = T_b^{\circ} + \Delta T_b$
    - $\Delta T_f = iK_f m$ or $\Delta T_b = iK_b m$
- **Osmotic Pressure**
  - Be able to calculate osmotic pressure (71,117)
    - $\Pi = iMRT$

Numbers correspond to end of chapter questions.