Raoult's Law: Vapor Pressure (Revisited)

DR. MIOY T. HUYNH
YALE UNIVERSITY
CHEMISTRY 161
FALL 2019

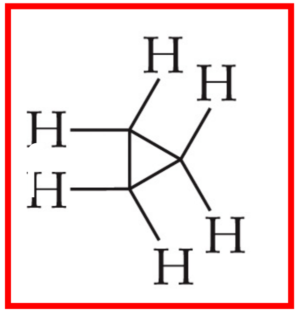
www.mioy.org/chem161

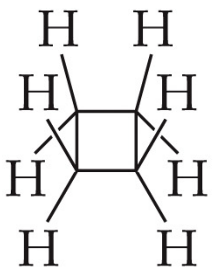
Which has the higher vapor pressure?

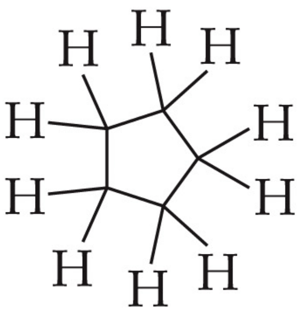
A. $C_2H_5OC_2H_5$ or H_2O

H_2O has stronger IMFs: hydrogen bonding, dipole-dipole, and dispersion. $C_2H_5OC_2H_5$ only has dipole-dipole and dispersion.

B.







All three only have dispersion forces, and the heaviest compound has the strongest.

VAPOR PRESSURE

Pressure exerted by the vapor (gaseous state) of a liquid when the two states are in equilibrium.

Intermolecular forces: as the intermolecular forces between liquid molecules strengthen, vapor pressure decreases because it requires more energy to escape the liquid phase.

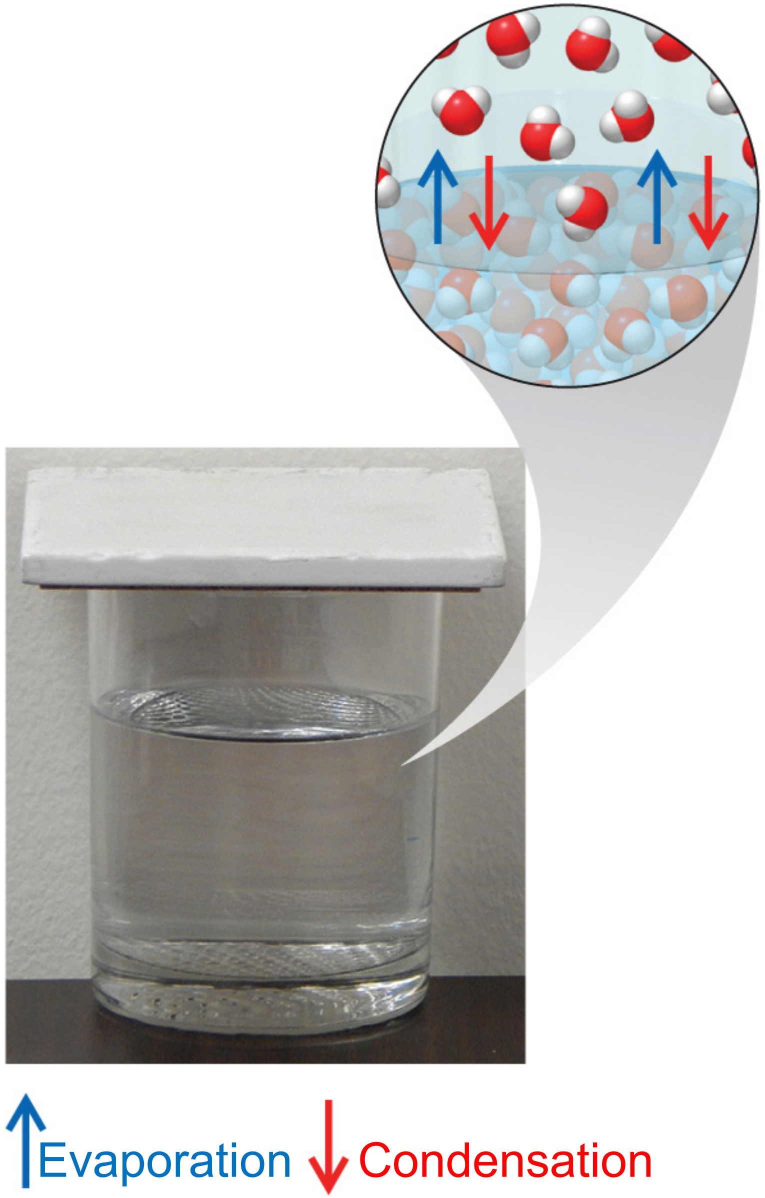
IMF ⇧, P_{vap} ⇩

VAPOR PRESSURE

Pressure exerted by the vapor (gaseous state) of a liquid when the two states are in equilibrium.

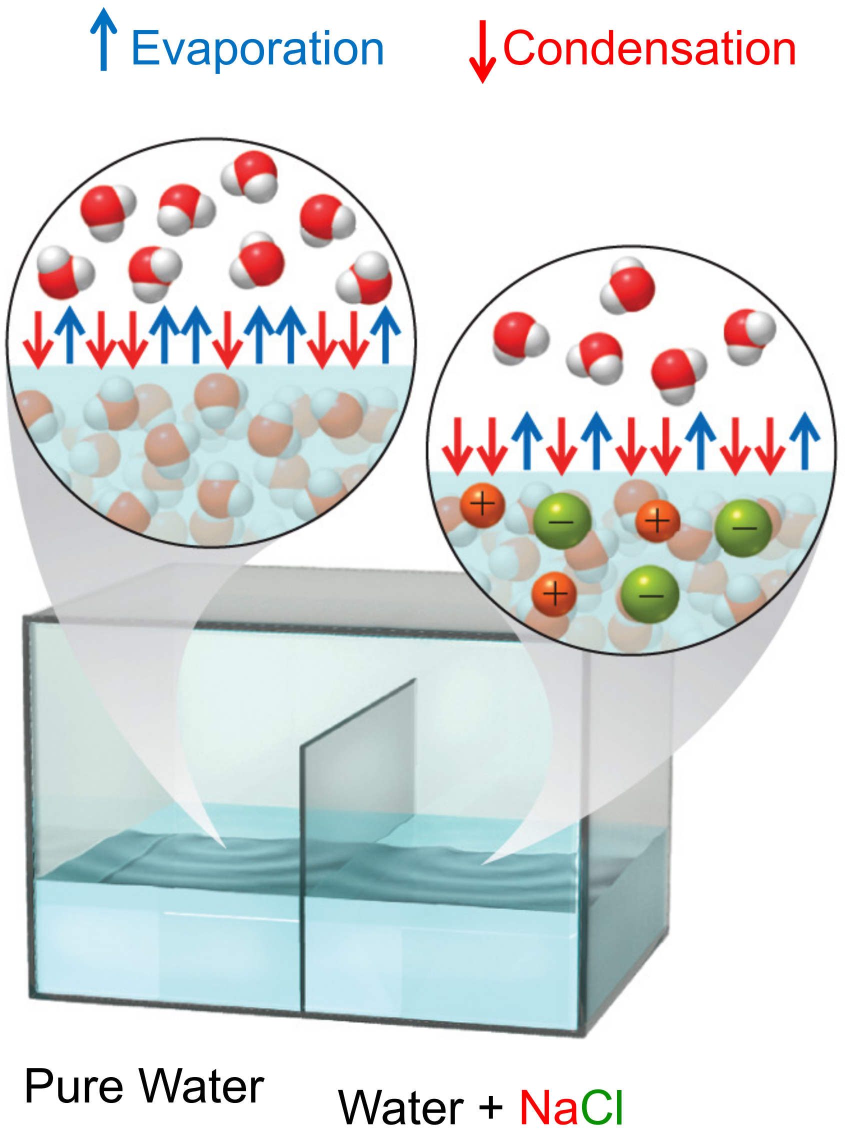
Vapor pressure is affected by three things:

1. Temperature: as temperature increases, more liquid molecules have sufficient kinetic energy to escape into the gas phase. T ⇧, P_{vap} ⇧
2. Surface area: as surface area increases, more liquid molecules are exposed to the surface. Surface Area ⇧, P_{vap} ⇧
3. Intermolecular forces: as the intermolecular forces between liquid molecules strengthens, vapor pressure decreases because it requires more energy to escape the liquid phase. IMF ⇧, P_{vap} ⇩



RAOULT'S LAW

If we have less solvent molecules at the surface, vapor pressure should decrease!



RAOULT'S LAW

If we have less solvent molecules at the surface, vapor pressure should decrease!

Raoult's Law allows us to calculate the vapor pressure of the solution (solvent + solute).

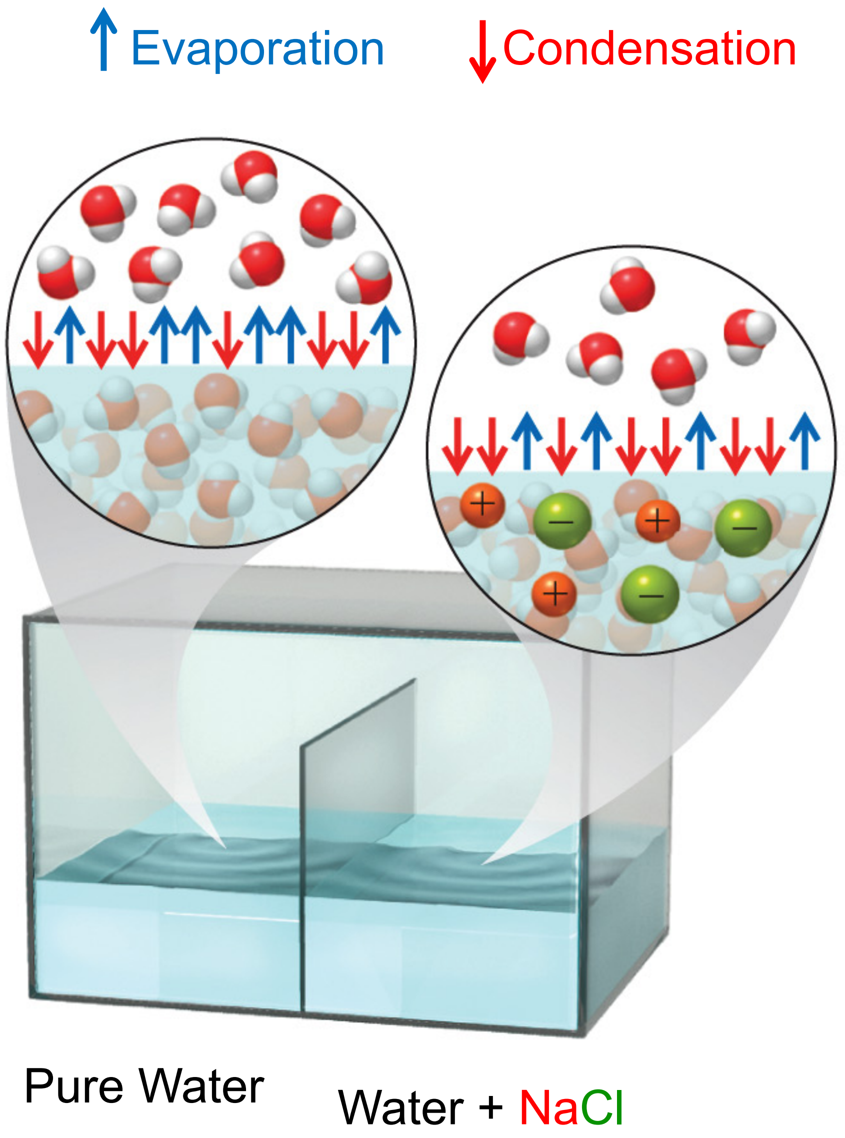
$$P_{solution} = X_{solvent}P_{solvent}$$

$P_{solution}$ = vapor pressure of solution (solvent + solute)

$P_{solvent}$ = vapor pressure of the pure solvent

$X_{solvent}$ = mole fraction of solvent

$$X_{solvent} = \frac{n_{solvent}}{n_{solvent} + n_{solute}}$$



RAOULT'S LAW

If we have less solvent molecules at the surface, vapor pressure should decrease!

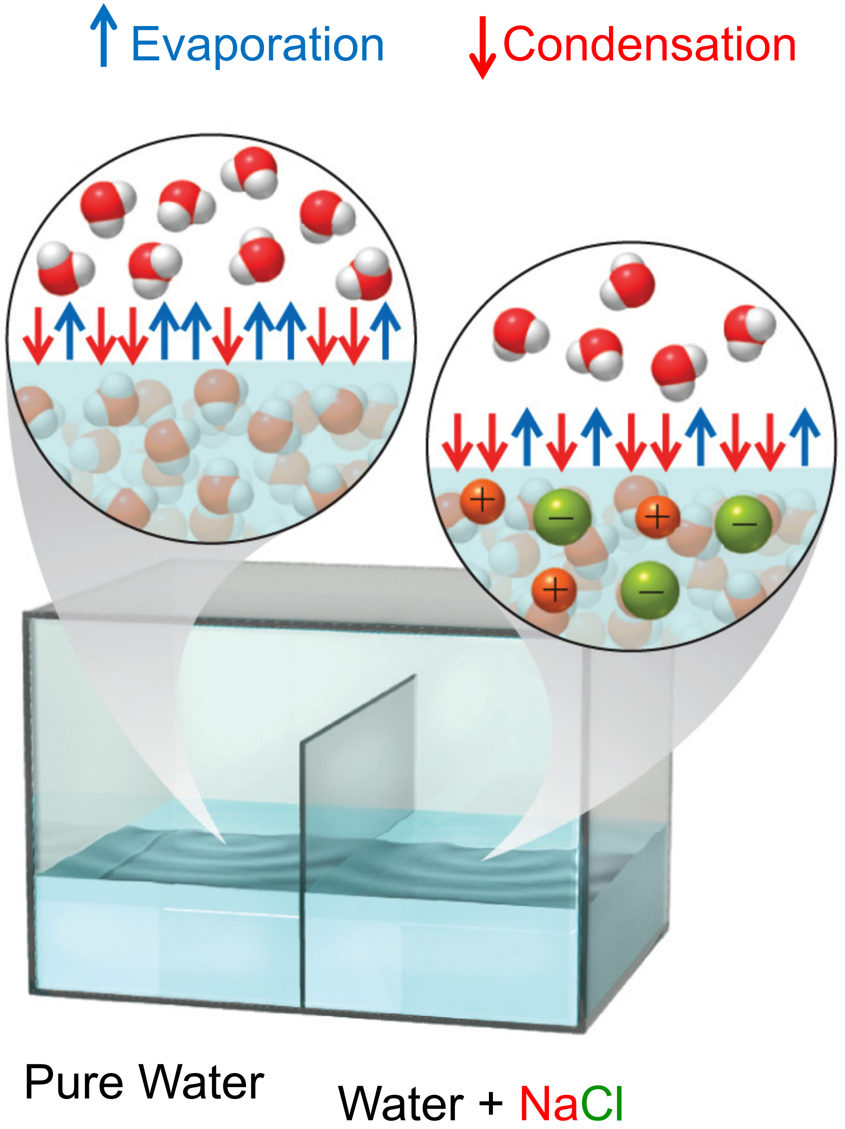
Raoult's Law allows us to calculate the vapor pressure of the solution (solvent + solute).

$$P_{solution} = X_{solvent} P_{solvent}$$

$P_{solution}$ = vapor pressure of solution (solvent + solute)
$P_{solvent}$ = vapor pressure of the pure solvent
$X_{solvent}$ = mole fraction of solvent

$$X_{solvent} = \frac{n_{solvent}}{n_{solvent} + n_{solute}}$$

Adding solute to solvent will always decrease vapor pressure because $X_{solvent}$ is a fraction less than 1 and gets smaller as we add solute.



RAOULT'S LAW: MULTIPLE SOLVENTS

Raoult's Law also works for multiple solvents.

$$P_{solution} = X_{solvent,1}P_{solvent,1} + X_{solvent,2}P_{solvent,2} + \cdots$$

$P_{solution}$ = vapor pressure of solution (solvent1 + solvent2 +…)
$P_{solvent,1}$ = vapor pressure of the pure solvent1
$X_{solvent,1}$ = mole fraction of solvent1
$P_{solvent,2}$ = vapor pressure of the pure solvent2
$X_{solvent,2}$ = mole fraction of solvent2

$$X_{solvent,1} = \frac{n_{solvent,1}}{n_{solvent,1} + n_{solute,2}}$$

$$X_{solvent,2} = \frac{n_{solvent,2}}{n_{solvent,1} + n_{solute,2}}$$

A solution contains 4.5 moles of water, 0.3 moles of sucrose, and 0.2 moles of glucose. What is the vapor pressure of the solution at 35 °C if the vapor pressure of water is 42.2 Torr at 35 °C?

A solution contains 4.5 moles of water, 0.3 moles of sucrose, and 0.2 moles of glucose. What is the vapor pressure of the solution at 35 °C if the vapor pressure of water is 42.2 Torr at 35 °C?

Recall that (vapor) pressure will only depend on the quantity of gas particles not the identity of the gas itself. Therefore, we need not worry about whether our solute is sucrose or glucose, but rather just how much total solute we have in solution.

A solution contains 4.5 moles of water, 0.3 moles of sucrose, and 0.2 moles of glucose. What is the vapor pressure of the solution at 35 °C if the vapor pressure of water is 42.2 Torr at 35 °C?

Recall that (vapor) pressure will only depend on the quantity of gas particles not the identity of the gas itself. Therefore, we need not worry about whether our solute is sucrose or glucose, but rather just how much total solute we have in solution.

Now, determine the mole fraction of the solvent (water):

$$X_{solvent} = \frac{n_{water}}{n_{water} + n_{sucrose} + n_{glucose}} = \frac{4.5\text{ mol}}{4.5\text{ mol} + 0.3\text{ mol} + 0.2\text{ mol}} = 0.90$$

A solution contains 4.5 moles of water, 0.3 moles of sucrose, and 0.2 moles of glucose. What is the vapor pressure of the solution at 35 °C if the vapor pressure of water is 42.2 Torr at 35 °C?

Recall that (vapor) pressure will only depend on the quantity of gas particles not the identity of the gas itself. Therefore, we need not worry about whether our solute is sucrose or glucose, but rather just how much total solute we have in solution.

Now, determine the mole fraction of the solvent (water):

$$X_{\text{solvent}} = \frac{n_{\text{water}}}{n_{\text{water}} + n_{\text{sucrose}} + n_{\text{glucose}}} = \frac{4.5\text{ mol}}{4.5\text{ mol} + 0.3\text{ mol} + 0.2\text{ mol}} = 0.90$$

Finally, apply Raoult's Law to find the vapor pressure of the solution:

$$P_{\text{solution}} = X_{\text{solvent}} P_{\text{solvent}}$$

$$= (0.90)(42.2\text{ Torr})$$

$$P_{\text{solution}} = 38\text{ Torr}$$

A solution contains 4.5 moles of water, 0.3 moles of sucrose, and 0.2 moles of glucose. What is the vapor pressure of the solution at 35 °C if the vapor pressure of water is 42.2 Torr at 35 °C?

Recall that (vapor) pressure will only depend on the quantity of gas particles not the identity of the gas itself. Therefore, we need not worry about whether our solute is sucrose or glucose, but rather just how much total solute we have in solution.

Now, determine the mole fraction of the solvent (water):

$$X_{solvent} = \frac{n_{water}}{n_{water} + n_{sucrose} + n_{glucose}} = \frac{4.5\text{ mol}}{4.5\text{ mol} + 0.3\text{ mol} + 0.2\text{ mol}} = 0.90$$

Finally, apply Raoult's Law to find the vapor pressure of the solution:

$$P_{solution} = X_{solvent}P_{solvent}$$

$$= (0.90)(42.2\text{ Torr})$$

$$P_{solution} = 38\text{ Torr}$$

Remember that adding solute(s) to a solvent will always decrease the vapor pressure, so we know that our vapor pressure of the solution should be less than 42.2 Torr.

At 90 °C, the vapor pressure of C_8H_8 is 134 Torr and C_8H_{10} is 183 Torr. We make a solution by mixing together 38 g of C_8H_8 and 62 g of C_8H_{10}. What is the vapor pressure of the solution?

At 90 °C, the vapor pressure of C_8H_8 is 134 Torr and C_8H_{10} is 183 Torr. We make a solution by mixing together 38 g of C_8H_8 and 62 g of C_8H_{10}. What is the vapor pressure of the solution?

First, determine the mole fraction of each solvent by converting their masses into mole amounts:

At 90 °C, the vapor pressure of C_8H_8 is 134 Torr and C_8H_{10} is 183 Torr. We make a solution by mixing together 38 g of C_8H_8 and 62 g of C_8H_{10}. What is the vapor pressure of the solution?

First, determine the mole fraction of each solvent by converting their masses into mole amounts:

$$n_{C_8H_8} = 38\ \text{g}\ C_8H_8 \times \frac{1\ \text{mol}\ C_8H_8}{104.15\ \text{g}} = 0.36_5\ \text{mol}\ C_8H_8 \qquad n_{C_8H_{10}} = 62\ \text{g}\ C_8H_{10} \times \frac{1\ \text{mol}\ C_8H_{10}}{106.16\ \text{g}} = 0.58_4\ \text{mol}\ C_8H_{10}$$

At 90 °C, the vapor pressure of C_8H_8 is 134 Torr and C_8H_{10} is 183 Torr. We make a solution by mixing together 38 g of C_8H_8 and 62 g of C_8H_{10}. What is the vapor pressure of the solution?

First, determine the mole fraction of each solvent by converting their masses into mole amounts:

$$n_{C_8H_8} = 38\text{ g } C_8H_8 \times \frac{1\text{ mol } C_8H_8}{104.15\text{ g}} = 0.36_5\text{ mol } C_8H_8$$

$$n_{C_8H_{10}} = 62\text{ g } C_8H_{10} \times \frac{1\text{ mol } C_8H_{10}}{106.16\text{ g}} = 0.58_4\text{ mol } C_8H_{10}$$

$$X_{C_8H_8} = \frac{0.36_5\text{ mol}}{0.36_5\text{ mol} + 0.58_4\text{ mol}} = 0.38_5$$

$$X_{C_8H_{10}} = \frac{0.58_4\text{ mol}}{0.36_5\text{ mol} + 0.58_4\text{ mol}} = 0.61_5$$

At 90 °C, the vapor pressure of C_8H_8 is 134 Torr and C_8H_{10} is 183 Torr. We make a solution by mixing together 38 g of C_8H_8 and 62 g of C_8H_{10}. What is the vapor pressure of the solution?

First, determine the mole fraction of each solvent by converting their masses into mole amounts:

$$n_{C_8H_8} = 38\text{ g }C_8H_8 \times \frac{1\text{ mol }C_8H_8}{104.15\text{ g}} = 0.36_5\text{ mol }C_8H_8 \qquad n_{C_8H_{10}} = 62\text{ g }C_8H_{10} \times \frac{1\text{ mol }C_8H_{10}}{106.16\text{ g}} = 0.58_4\text{ mol }C_8H_{10}$$

$$X_{C_8H_8} = \frac{0.36_5\text{ mol}}{0.36_5\text{ mol} + 0.58_4\text{ mol}} = 0.38_5 \qquad X_{C_8H_{10}} = \frac{0.58_4\text{ mol}}{0.36_5\text{ mol} + 0.58_4\text{ mol}} = 0.61_5$$

Finally, apply Raoult's Law to find the vapor pressure of the solution:

$$\begin{aligned} P_{\text{solution}} &= X_{C_8H_8}P_{C_8H_8} + X_{C_8H_{10}}P_{C_8H_{10}} \\ &= (0.38_5)(134\text{ Torr}) + (0.61_5)(183\text{ Torr}) \end{aligned}$$

$$P_{\text{solution}} = 164\text{ Torr}$$

At 90 °C, the vapor pressure of C_8H_8 is 134 Torr and C_8H_{10} is 183 Torr. We make a solution by mixing together 38 g of C_8H_8 and 62 g of C_8H_{10}. What is the vapor pressure of the solution?

First, determine the mole fraction of each solvent by converting their masses into mole amounts:

$$n_{C_8H_8} = 38\text{ g } C_8H_8 \times \frac{1\text{ mol } C_8H_8}{104.15\text{ g}} = 0.36_5\text{ mol } C_8H_8 \qquad n_{C_8H_{10}} = 62\text{ g } C_8H_{10} \times \frac{1\text{ mol } C_8H_{10}}{106.16\text{ g}} = 0.58_4\text{ mol } C_8H_{10}$$

$$X_{C_8H_8} = \frac{0.36_5\text{ mol}}{0.36_5\text{ mol} + 0.58_4\text{ mol}} = 0.38_5 \qquad X_{C_8H_{10}} = \frac{0.58_4\text{ mol}}{0.36_5\text{ mol} + 0.58_4\text{ mol}} = 0.61_5$$

Finally, apply Raoult's Law to find the vapor pressure of the solution:

$$P_{solution} = X_{C_8H_8}P_{C_8H_8} + X_{C_8H_{10}}P_{C_8H_{10}}$$

$$= (0.38_5)(134\text{ Torr}) + (0.61_5)(183\text{ Torr})$$

$$P_{solution} = 164\text{ Torr}$$

We should expect that the solution's vapor pressure in a value in between the vapor pressures of the two pure solvents!

RAOULT'S LAW WORKS FOR IDEAL SOLUTIONS

What is an ideal solution?

RAOULT'S LAW WORKS FOR IDEAL SOLUTIONS

What is an ideal solution?

Just as we assumed that ideal gases do not interact with one another, the characteristics of ideal solutions are quite similar.

RAOULT'S LAW WORKS FOR IDEAL SOLUTIONS

What is an ideal solution?

Just as we assumed that ideal gases do not interact with one another, the characteristics of ideal solutions are quite similar.

For an ideal solution, the types and strengths of the solute-solute, solvent-solvent, and solute-solvent (all intermolecular) interactions are similar.

RAOULT'S LAW WORKS FOR IDEAL SOLUTIONS

What is an ideal solution?

Just as we assumed that ideal gases do not interact with one another, the characteristics of ideal solutions are quite similar.

For an ideal solution, the types and strengths of the solute-solute, solvent-solvent, and solute-solvent (all intermolecular) interactions are similar.

When the intermolecular interactions of two solvents (or a solute and solvent) are similar in type and strength, we can approximate the total vapor pressure of the solution as the sum of the vapor pressures of the two solvents weighted by their mole fractions.

RAOULT'S LAW WORKS FOR IDEAL SOLUTIONS

What is an ideal solution?

Just as we assumed that ideal gases do not interact with one another, the characteristics of ideal solutions are quite similar.

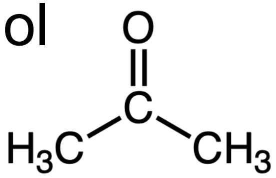
For an ideal solution, the types and strengths of the solute-solute, solvent-solvent, and solute-solvent (all intermolecular) interactions are similar.

When the intermolecular interactions of two solvents (or a solute and solvent) are similar in type and strength, we can approximate the total vapor pressure of the solution as the sum of the vapor pressures of the two solvents weighted by their mole fractions.

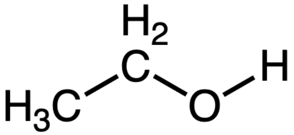
Does this remind you of partial pressures? Good, it should.

For each pair of molecules, determine if a solution of two would be ideal or non-ideal.

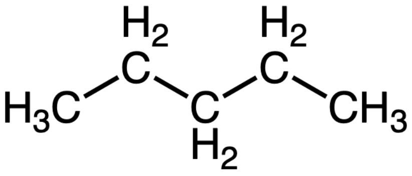
Acetone + Ethanol



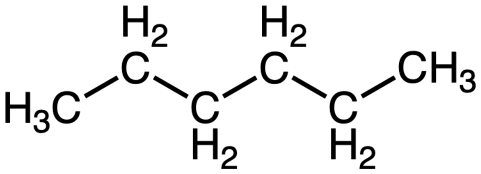
+



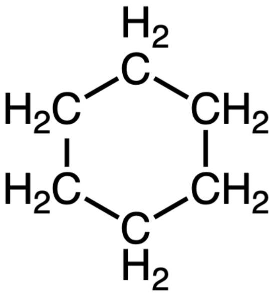
Pentane + Hexane



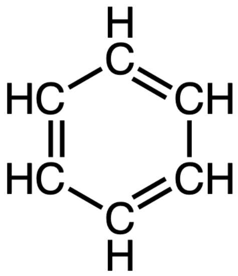
+



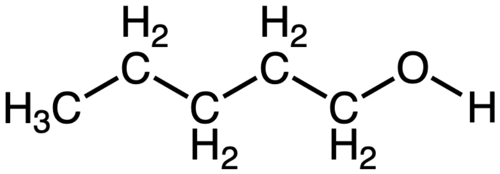
Cyclohexane + Benzene



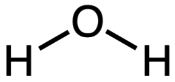
+



Pentanol + Water

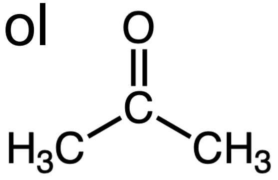


+

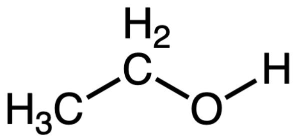


For each pair of molecules, determine if a solution of two would be ideal or non-ideal.

Acetone + Ethanol

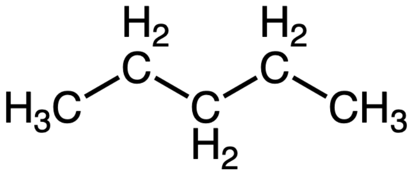


+

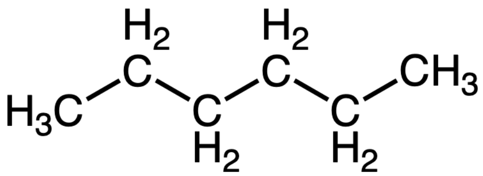


Pure acetone: dipole-dipole, dispersion
Pure ethanol: hydrogen bonding, dipole-dipole, dispersion
Acetone + Ethanol: hydrogen bonding, dipole-dipole, dispersion
➞ non-ideal because of <u>new</u> hydrogen bonding

Pentane + Hexane

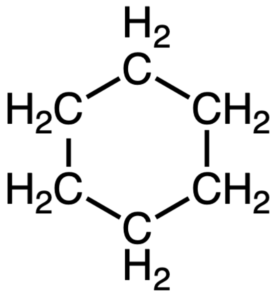


+

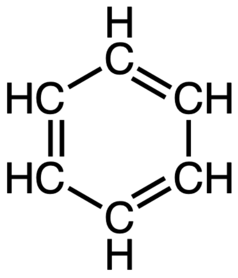


Pure pentane: dispersion
Pure hexane: dispersion
Pentane + Hexane: dispersion
➞ ideal because of similar IMFs

Cyclohexane + Benzene

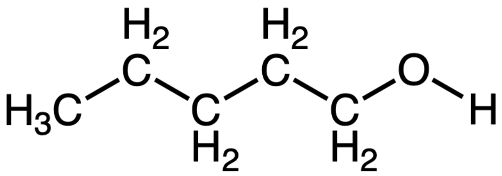


+

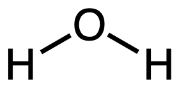


Pure cyclohexane: dispersion
Pure benzene: dispersion
Cyclohexane + Benzene: dispersion
➞ ideal because of similar IMFs

Pentanol + Water



+



Pure pentanol: hydrogen bonding, dipole-dipole, dispersion
Pure water: hydrogen bonding, dipole-dipole, dispersion
Pentanol + Water: hydrogen bonding, dipole, dipole, dispersion
➞ non-ideal because of new hydrogen bonding