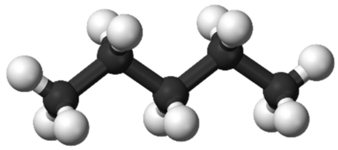
CHEM 1032

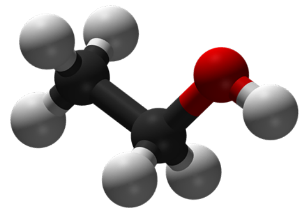
KEY

Quantifying IMF – BP + ΔH_{vap} + P_{vap}

Now that we have a good handle on intermolecular forces let's work to connect them to quantifiable measurements. Whether a compound has weak or strong IMF will have major implications on the boiling point (BP), the enthalpy of vaporization (ΔH_{vap}), and the vapor pressure (P_{vap}). Using the material we learn in lecture this week and your textbook, work with your group to determine the interrelations between the variables:



pentane



ethanol

Determine the chemical formula and molecular weight of the two compounds.

	pentane	ethanol
Formula	C_5H_{12}	C_2H_6O
Molar Mass (g/mol)	72.05	46.02

Using the molecules determine the strongest IMF for each. Explain how you came to this conclusion.

	pentane	ethanol
Strongest IMF	dispersion	hydrogen bonding

pentane only has C-C and C-H bonds therefore there is no dipole on the molecule.

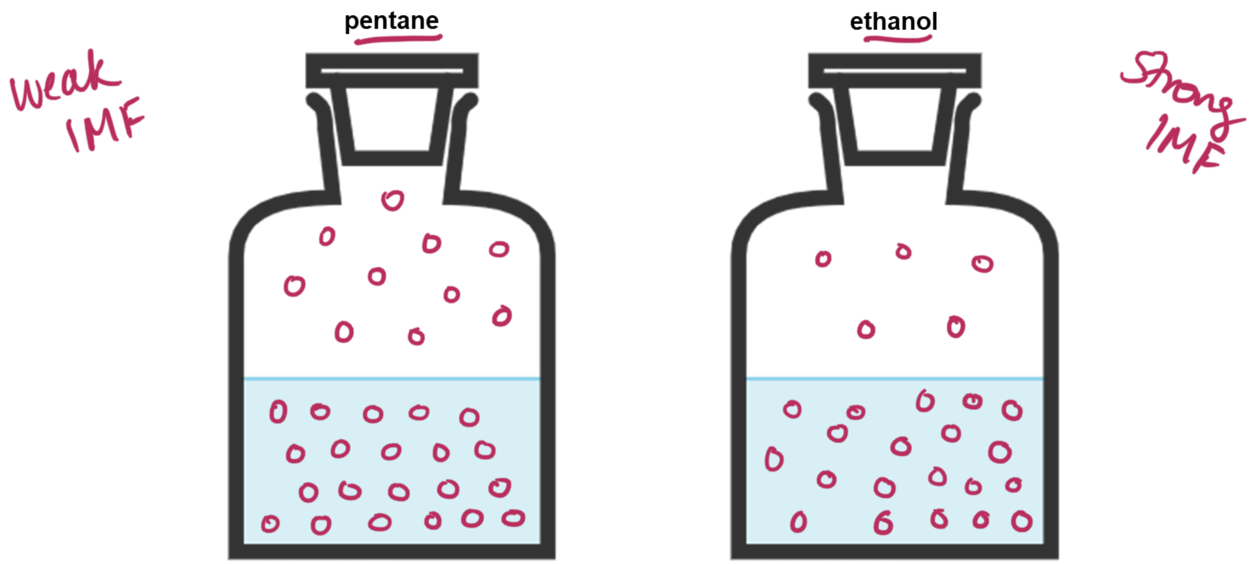
Ethanol contains an O-H bond therefore it can participate in H-bonding

Using what you have learned so far this semester, hypothesize which molecule will have the highest boiling point. How did you come to this conclusion?

Even though pentane has a larger molar mass, the presence of O-H in the ethanol molecule will cause it to have a higher BP due to stronger IMF. More heat is needed to increase the KE of the H-bonded molecule versus the molecule which only has dispersion

To understand how boiling point (BP), the enthalpy of vaporization (ΔH_{vap}), and the vapor pressure (P_{vap}) are all related, let's take a closer look. Below are two closed bottles of the compounds at room temperature (21 ºC).

First, draw 20 circles in each liquid to represent molecules in this phase.

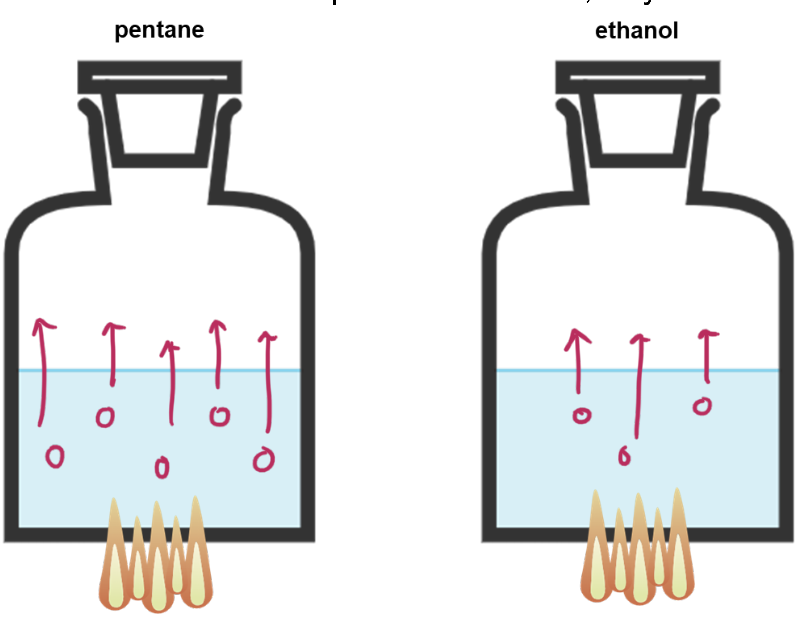


Because temperature is the average kinetic energy of the molecules, we know that even at 21 ºC there will be some molecules that can escape to the gas phase. Based on your analysis of IMF, draw 5 vapor molecules in the container with strong IMF and 10 vapor molecules in the container with weak IMF.

Look at your containers, which has a higher vapor pressure? What is the relationship between vapor pressure and IMF?

pentane! more molecules are in gas phase so P_{vap} is higher. Therefore $\uparrow P_{vap}$ $\downarrow$ IMF.

If a small amount of heat were added to both containers, how would the systems react? Would one molecule have more vapor than the other, why? Draw and explain.



Both containers would see vaporization increase because molecules gain KE as temp goes up. The pentane molecules will gain more vaporized molecules however because of weaker IMF.

$P_{vap\ pentane} > P_{vap\ ethanol}$

Since the systems reacted differently to heat, this indicates there is a difference in the energy required to vaporize the molecules. **This is the enthalpy of vaporization!** Which molecule has a lower ΔH_{vap}? Explain.

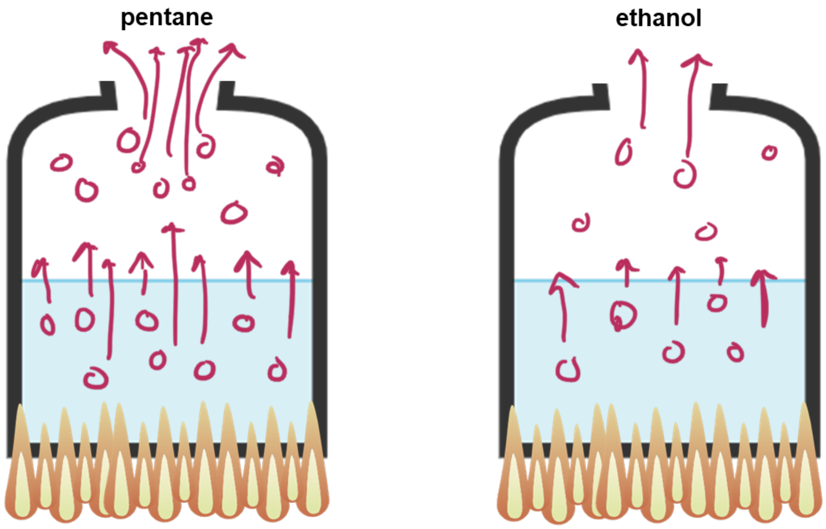
ΔH_{vap} is the energy required to vaporize, so the molecule with weaker IMF would be expected have smaller ΔH_{vap}. ΔH_{vap} pentane < ΔH_{vap} ethanol

Is ΔH_{vap} endothermic or exothermic? Why?

To vaporize, energy needs to be added since the molecules need to speed up.

Heat enters ΔH_{vap} (+) endothermic

So far we have been looking at closed containers to visualize the vapor pressure, now we'll switch to open containers.



If I added the same amount of heat to both open containers, which would empty first? Why?

The pentane will empty first because of the smaller ΔH_{vap}. Less E is needed per mole of material.

So, which compound has a lower boiling point?

Because less E is needed and P_{vap} will reach P_{ext} sooner, pentane has lower BP.

Now, link them all together! Check the box for the molecule with the <u>higher</u> value for each variable:

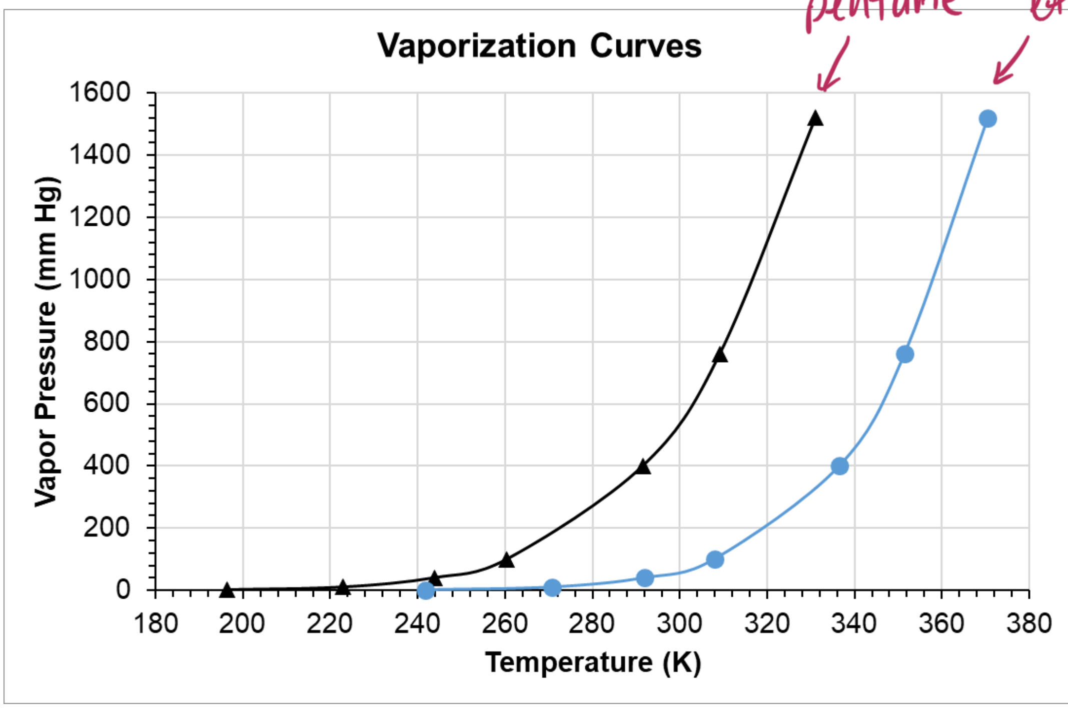
	pentane	ethanol
IMF		X
P_{vap}	X	
ΔH_{vap}		X
BP		X

Because we can qualitatively see the relationships between the variables, we can now quantitatively link them together with the Clausius Clapeyron equation.

$$\ln(P) = \left(\frac{-\Delta H_{vap}}{R}\right)\left(\frac{1}{T}\right) + \ln(\beta) \qquad \ln\left(\frac{P_2}{P_1}\right) = \left(\frac{-\Delta H_{vap}}{R}\right)\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

Using the graph below, **calculate** the ΔH_{vap} for each curve. Then label each curve for the molecule it represents.

pentane ethanol



Black Triangles

P_1 400 mmHg T_1 292 K

P_2 100 mmHg T_2 260 K

$$\ln\left(\frac{400\text{ mmHg}}{100\text{ mmHg}}\right) = \frac{\Delta H_{vap}}{8.314\text{ J/mol}\cdot\text{K}}\left(\frac{1}{260\text{K}} - \frac{1}{292\text{K}}\right)$$

$\Delta H_{vap} = 36257$ J/mol

↳ 36.2 kJ/mol

Blue Circles

P_1 400 mmHg T_1 336 K

P_2 100 mmHg T_2 308 K

$$\ln\left(\frac{400\text{ mmHg}}{100\text{ mmHg}}\right) = \frac{\Delta H_{vap}}{8.314\text{ J/mol}\cdot\text{K}}\left(\frac{1}{308\text{K}} - \frac{1}{336\text{K}}\right)$$

$\Delta H_{vap} = 42.6$ K

Blue ΔH_{vap} > Black ΔH_{vap} so Blue = Ethanol