7.9: Miscibility

So far, we've been thinking about how one molecule could interact with another molecule of the same compound to form a liquid or a solid. What about two different compounds? It turns out that whether two different compounds interact with each other depends on the same kinds of interactions we have looked at so far.

Two liquids that do not really mix well together, such as oil and water, are described as immiscible. Two liquids that appear to mix completely together are said to be miscible. Water and ethanol are one example of a pair of miscible liquids, because you can take any amount of ethanol and mix it with any amount of water and you will always end up with a clear, colorless liquid just like the ones you started with.

Exercise 7.9.1

What kind of intermolecular attraction allows water and ethanol to mix together?

Answer

Hydrogen bonding.

Exercise 7.9.2

The following pairs of liquids are miscible. Identify the predominant type of intermolecular attraction between each pair.

a. 2-propanone and ethyl ethanoate (ethyl acetate)
b. pentane and octane
c. dichloromethane and 2-butanone
d. methanol and ethanoic acid

Answer a:

dipole interactions

Answer b:

London interactions

Answer c:

dipole interactions

Answer d:

hydrogen bonding

Exercise 7.9.3

Explain, in terms of intermolecular forces, why water and octane are not miscible.

Answer

Water molecules interact with each other mainly through hydrogen bonding, whereas octane molecules interact with each other via London interactions. The main problem here is the strong hydrogen bonding between the water molecules. All molecules, in principle, could interact with each other via London interactions. However, if octane molecules were introduced among the water molecules, they would take up space. Some of the water molecules would not be able to get close enough to each other to hydrogen bond anymore. The loss of that very stabilizing interaction would be too costly.

Exercise 7.9.4

Explain, in terms of intermolecular forces, why ethanenitrile and hexane are not miscible.

Answer

This problem is similar to the previous one, but in this case the attraction between the strong dipoles of the nitrile groups would be too much to overcome.

Sometimes, the attractions between molecules are a little more complicated. Two molecules may have different interactions on their own, but when placed together still manage to interact with each other. For example, dichloromethane and hexane mix together pretty well.

How can that be? Dichloromethane has dipole interactions. Hexane has nothing more than London interactions. Ethanenitrile and hexane didn't mix for that very reason. But the problem was not whether those two molecules could interact with each other; they could. The problem was that ethanenitrile would not give up its dipole-dipole interactions for the small amount it could gain by mixing with hexane.

In this case, the dipoles between dichloromethane are much smaller; they aren't held back from the hexane molecules as strongly. On the other hand, the interaction between the the hexane and dichloromethane is actually amplified a little bit. Whereas hexane molecules rely solely on weak, transient London interactions to cling to each other, dichloromethane has a permanent dipole. That permanent dipole is able to enhance the transient dipole in hexane.

This is called a dipole / induced dipole interaction. The slight tug dichloromethane exerts on hexane's electrons actually helps the two different molecules interact more strongly.

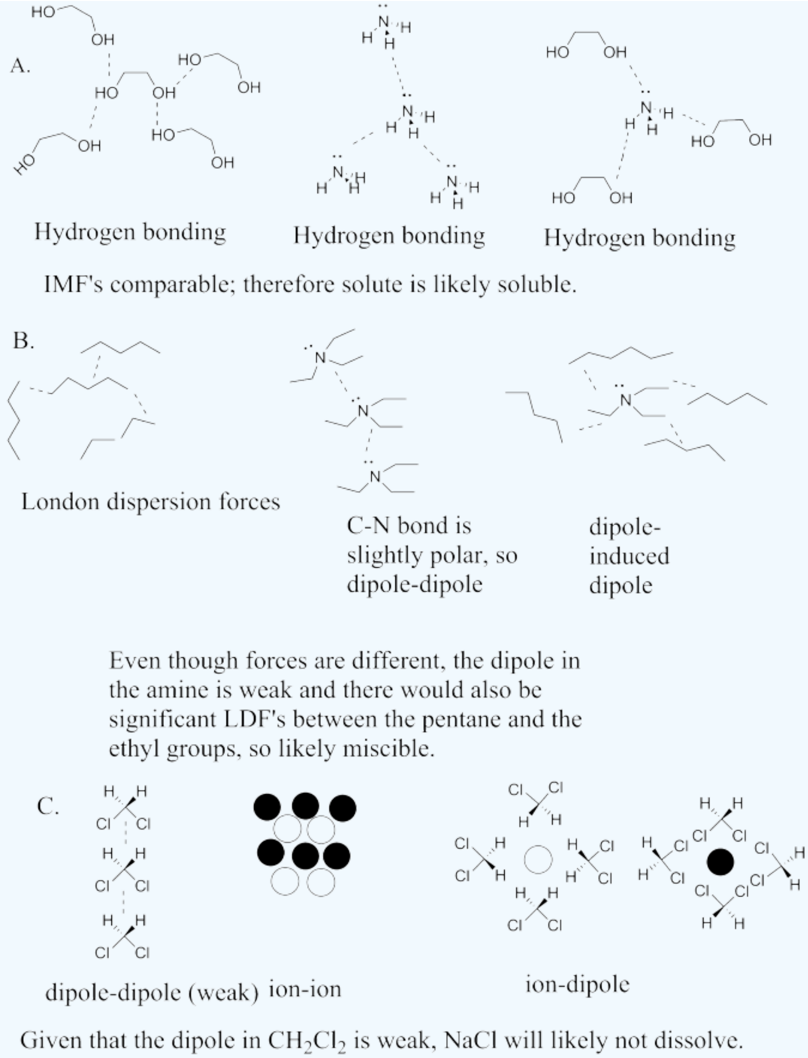
Exercise 7.9.5

Below are several solvents and some possible solutes. For each pair,

i. Draw a solvent molecule interacting with several other (identical) solvent molecules. Label the strongest intermolecular force holding them together.
ii. Draw a solute molecule interacting with several other (identical) solute molecules. Label the strongest intermolecular force holding them together.
iii. Draw one solute molecule interacting with several solvent molecules. Label the strongest intermolecular force holding them together. Predict whether the solvent will dissolve significant amounts of the solute.

A. Solvent = Ethylene glycol ($HOCH_2CH_2OH$); Solute = NH_3
B. Solvent = Pentane ($CH_3(CH_2)_2CH_3$); Solute = triethylamine, $[(CH_3CH_2)_3N]$
C. Solvent = CH_2Cl_2; Solute = NaCl

Answer



Exercise 7.9.6

Describe the intermolecular interaction between each of the following pairs.

a) 2-propanone; benzene

b) 2-propanol; dichloromethane

c) ethanol; ethanoic acid

d) octanol; methylbenzene

Answer a:

dipole / induced dipole

Answer b:

dipole / dipole

Answer c:

hydrogen bonding

Answer d:

dipole / induce dipole

Solubility is conceptually similar to miscibility. If you can mix a solid with a liquid and the solid particle gets smaller and smaller until it disappears, it must have dissolved in the liquid. At that point it may look like you are left only with the original liquid, but really the individual molecules of the solid are just distributed throughout the liquid instead of all sitting together on the bottom. You can see this when blue kool-aid powder dissolves in water to give blue kool-aid. The blue substance has not disappeared; it has become intimately mixed with the water. Just as you cannot see an individual "chunk" of water, you cannot see an individual "chunk" of the original solid anymore -- it has separated into individual units (molecules) that are too small to be seen.