Inorganic Chemistry with Doc M.

Fall Semester, 2011

Day 4. Intermolecular forces.

Name(s):	Element:

A. Covalent forces

C-C	ΔH = 347 kJ/mol
H-H	ΔH = 431 kJ/mol
F-F	ΔH = 155 kJ/mol

B. Ionic forces ($E = Z^+Z^-/r$)

$LiF \longrightarrow Li^+(g) + F^-(g)$ ΔH = 755 kJ/mol (reverse of lattice energy)

$LiF \longrightarrow Li(g) + F(g)$ ΔH = 567 kJ/mol

C. Metallic forces (metal cations in a "sea of electrons": M(s) → M(g))

Fe	ΔH = 416 kJ/mol
W	ΔH = 849 kJ/mol
Pb	ΔH = 195 kJ/mol
Hg	ΔH = 61 kJ/mol (Hg(l) → Hg(g))

D. Network covalent forces (endless lattice of covalent bonds)

C	ΔH = 717 kJ/mol (C(s) → C(g))
Si	ΔH = 450 kJ/mol (Si(s) → Si(g))

E. Intermolecular forces

1. Dipole-dipole forces (3 – 4 kJ/mol)

For the polar molecule: the dipole forces is given by m = qr where q = the equal and opposite charges in the molecule (δ^+, δ^-) and r is the distance between δ^+ and δ^-.

For dipole-dipole forces, $E \propto \frac{-\mu_A \mu_B}{r^3}$

Molecule	Dipole?	MM (g/mol)	bp (K)
F_2		38	85
Cl_2		71	
ClF		55	

2. Hydrogen bonding forces (10 - 40 kJ/mol)
   a. Extra-effective dipole-dipole force that occurs when N-H, O-H and F-H bonds exist.
   b. For neutral molecules, oxygen has the optimal balance between bonding groups (potentially hydrogen atoms and electron pair groups; both are required for hydrogen bonding:

Atom	B groups	E-groups	Example
N			NH_3
O			H_2O
F			HF

   c. Boiling points of Groups IV, V, VI, and VII hydrides:

Molecule	MM (g/mol)	bp (^oC)	state at 25 ^oC
CH_4	16	-164	gas
SiH_4	32		
GeH_4	77		

Molecule	MM (g/mol)	bp (^oC)	state at 25 ^oC
NH_3	17	-33	gas
PH_3	34		
AsH_3	78		
SbH_3	125		
BiH_3	212		

Molecule	MM (g/mol)	bp (^oC)	state at 25 ^oC
OH_2	18		
SH_2	34		gas
SeH_2	81		gas
TeH_2	130	-2	gas

Molecule	MM (g/mol)	bp (^oC)	state at 25 ^oC
FH	20	+20	gas
ClH	36		
BrH	81		

d. Hydrogen bonding occurs in solutions even when only one of the members can actually hydrogen bond. For example, aqueous methanal (formaldehyde, HCHO): the aldehyde has no hydrogen-bonding H, but it has two lone pairs on oxygen that can participate in H-bonding with water's O-H hydrogens.

3. Instantaneous dipole (London-dispersion) forces (1 – 10 kJ/mol)

A. Strength of the forces: $E \propto \frac{-IE\alpha^2}{r^6}$ where a is the polarizability and IE is the ionization energy

1. The polarizability increases with MM and shape of the molecule

MM factors: All molecules have MM so all molecules have LDF to some extent.

Molecule	MM (g/mol)	bp (K)	state at 25 °C
F_2	38		
Cl_2	71		
Br_2	160		
I_2	254		

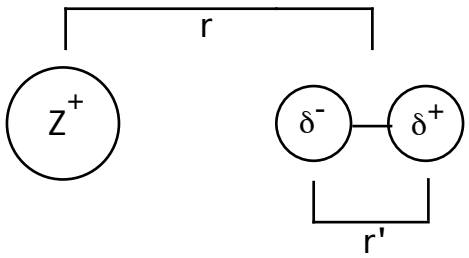
Molecule	MM (g/mol)	bp (°C)	state at 25 °C
n-C_5H_{12}	72		
iso-C_5H_{12}	72		
neo-C_5H_{12}	72		

4. Ion-dipole forces (10 – 50 kJ/mol)

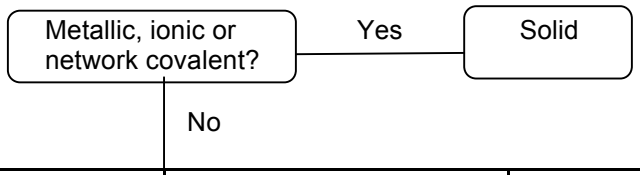
Only applies to solutions, usually aqueous solutions

For polar molecule: the dipole force is given by m = qr where q = the equal and opposite charges in the molecule (δ^+, δ^-) and r is the distance between δ^+ and δ^- and ***e*** is the charge on the ion.

For ion-dipole forces, $E \propto \frac{\mu e}{r^2}$



C. Pulling it all together. This chart is overly simplistic, but it shows how LDF can be a very important factor (high MM). In the chart, the MM cut-offs of 100 and 200 g/mol, are rather arbitrary and you can expect to find numerous exceptions.



MM	Non-polar	Polar A little … A lot	H-bonding A little … A lot
< 100	Gas	Gas … liquid	Liquid … Gas
100 – 200	Gas or liquid	Gas … Liquid	Liquid
200 – 300	Liquid or solid	Liquid … Solid	Solid
> 300	Solid	Solid	Solid

1. Use the chart to predict the physical state at room temperature for each of the following. Also, identify which forces led you to your conclusion. In our next class, I will "reveal" the actual melting and boiling points! (Or, if you just can't wait, look them up in a chemistry handbook!)

Compound:	Actual mp, bp, phase at room temperature
$AsBr_3$ MM = 315 g/mol	
BF_3 MM = 68 g/mol	
CSe_2 MM = 170 g/mol	
CH_3Cl MM = 50.5 g/mol	
NH_4Br MM = 98 g/mol	
CCl_4 MM = 154 g/mol	
ClO_2 MM = 67.5 g/mol	
ClF_3 MM = 92.5 g/mol	
Cl_2O_7 MM = 183 g/mol	
$(C_2F_4)_n$ MM = 100 g/mol	
$PSCl_3$ MM = 169.5 g/mol	
$PSBr_3$ MM = 303 g/mol	

SCl_2O_2 MM = 135 g/mol	

$BaCl_2$ MM = 208 g/mol	
$GeBr_4$ MM = 392 g/mol	
PBr_3 MM = 271 g/mol	
C_2H_6O, ethanol, C_2H_5OH MM = 46 g/mol	
C_2H_6O, dimethylether, CH_3OCH_3 MM = 46 g/mol	
SiC MM = 43 g/mol	
PF_3 MM = 88 g/mol	
PF_5 MM = 126 g/mol	
PCl_3 MM = 137.5 g/mol	
MgO MM = 40.3 g/mol	
Fe MM = 55.9 g/mol	
$(C_2H_5)_2NH$ MM = 73 g/mol	
$(CH_3)_2NH$ MM = 45 g/mol	
$(CH_3)_3N$ MM = 59 g/mol	

Review for ACS Final Exam in Inorganic Chemistry

Intermolecular forces

1. Which of these compounds most likely a gas at room temperature?
   (a) BF_3
   (b) PBr_3
   (c) $K_2S_2O_3$
   (d) SnF_2
   (e) SiO_2

2. Which of these compounds exhibits hydrogen bonding?
   (a) B_2H_6
   (b) CH_4
   (c) $CH_3CH_2NCl_2$
   (d) CH_3OCl
   (e) HOBr

3. Lattice energy is greatest for:
   (a) NaCl
   (b) MgO
   (c) $BaCl_2$
   (d) Na_2O
   (e) CsF

4. Identify the species with the highest melting point.
   (a) $AsCl_3$
   (b) $NH_4C_2H_3O_2$
   (c) SiC
   (d) Mn
   (e) S_8

Answers: A, E, B, C