Problem 1. The standard enthalpy of formation of $KBr_{(s)}$ from solid potassium and liquid bromine is -392kJ/mol. The enthalpy of sublimation for $K_{(s)}$ is 89.8kJ/mol, the enthalpy of vaporization of $Br_{(l)}$ is 111.9kJ/mol, the ionization energy of $K_{(g)}$ is 418.9kJ/mol and the electron affinity of $Br_{(g)}$ is -328.0kJ/mol. Draw the Born-Haber cycle for the formation of $KBr_{(s)}$ and calculate its lattice energy.

Problem 2. Using a Born-Haber process and the information provided below, calculate the ionization energy of lithium. For full credit, either provide a Born-Haber Cycle diagram or a complete set of chemical equations to explain the process of forming the ionic Li$-$F bond.

Heat of sublimation for $Li_{(s)}$:	+161 kJ/mol
$F_{2(g)}$ bond dissociation enthalpy:	+78 kJ/mol
Electron affinity for $F_{(g)}$:	-338 kJ/mol
Crystal latice enthalpy for $LiF_{(s)}$:	-1047 kJ/mol
Heat of formation for $LiF_{(s)}$:	-617 kJ/mol

Problem 3. Calculane a value for the heat of formation (ΔH_f°) for the hypothetical Ca^+ salt CaCl by devising the appropriate Born-Haber cycle. Show all work, including your Born-Haber cycle. Some or all of the following information may be of use to you.

$Cl_{2(g)}$ bond dissociation enthalpy:	+200 kJ/mol
Heat of sublimation for $Ca_{(s)}$:	+176 kJ/mol
First ionization potential for $Ca_{(g)}$:	+590 kJ/mol
Second ionization potential for $Ca_{(g)}$:	+1145 kJ/mol
Electron affinity for $Cl_{(g)}$:	-349 kJ/mol
Crystal latice enthalpy for $CaCl_{(s)}$:	-700 kJ/mol

Problem 4. Determine the heat of formation (ΔH_f°) of beryllium oxide (BeO), using a Born-Haber thermodynamic cycle and the appropriate data given at the end of this exam. Show all you work.

Heat of sublimation for $Be_{(s)}$:	+324 kJ/mol
$O_{2(g)}$ bond dissociation enthalpy:	+494 kJ/mol
First ionization potential for $Be_{(g)}$:	+900 kJ/mol
Second ionization potential for $Be_{(g)}$:	+1757 kJ/mol
Electron affinity for $O_{(g)}$:	-141 kJ/mol
Electron affinity for $O^-_{(g)}$:	+744 kJ/mol
Crystal latice enthalpy for $BeO_{(s)}$:	-4443 kJ/mol

Problem 5. Dilithium, a substance which is crucial to the propulsion system of the Federation starship 'Enterprise', is actually a known species (though it does

not exhibit all of the properties which Roddenberry et. al. have ascribed to it!). Dilithium is formed by the adhesion of two lithium atoms in the gas phase:

$$Li_{(g)} + Li_{(g)} \rightleftharpoons Li_{2(g)}$$

The enthalpy of formation of dilithium is not easily measurable by direct means. However, the following thermochemical parameters are known:

$D^0(Li_2^+) = 129.8$ kJ/mol
$IE(Li_2) = 5.113$ eV
$\Delta H_f^\circ(Li_{(g)}) = 159.4$ kJ/mol
$IE(Li) = 5.392$ eV

$D^0(Li_2^+)$ is the bond strength of $Li_{2(g)}^+$
1 ev = 96.486 kJ/mol

Problem 6. A number of processes with salts and crystals can be understood by estimating the energies involved with a simple ionic model in which the ions have a specific radius and a charge equal to an integer number times the elementary charge. This model is used to describe the dissociation of ionic molecules in the gas phase. Such dissociations usually lead directly to neutral atoms, but the dissociation energy can be calculated by assuming a hypothetical reaction path which involves dissociation to free ions, followed by neutralization of the ions. This is the Born-Haber cycle.

The bonding energies, electron affinity and ionization energies of the following diatomic species have been measured:

Bonding energy NaCl	−464 kJ/mol	2st Ionisation energy Ca	+1148 kJ/mol
Bonding energy KCl	−423 kJ/mol	1st Ionisation energy Ca	+592 kJ/mol
Bonding energy MgCl	−406 kJ/mol	Electron affinity Cl	−360 kJ/mol
Bonding energy CaCl	−429 kJ/mol	Ionisation energy Na	+496 kJ/mol

Design a Born-Haber cycle for the dissociation of NaCl into neutral atoms and calculate the dissociation energy of NaCl. Assume that the bonding is completely (100 %) ionic in nature.

Design a Born-Haber cycle for the dissociation of $CaCl_2$ into three neutral atoms and calculate the dissociation energy of $CaCl_2$, assuming that the bond length in the triatomic species is 9 % shorter that in the diatomic species.

Problem 7. Draw a clear Born-Haber cycle for the ionic solid $CrCl_2I$. Using your Born-Haber cycle, calculate the lattice energy of $CrCl_2I$.

$\Delta H_f^\circ(CrCl_2I) = -420$ kJ/mol
$D_{Cl-Cl} = 242$ kJ/mol
$D_{I-I} = 151$ kJ/mol
$\Delta H_{sub}(I_2) = 62$ kJ/mol
$\Delta H_{sub}(Cr) = 398$ kJ/mol

$IE_1(Cr) = 652$ kJ/mol
$IE_2(Cr) = 1588$ kJ/mol
$IE_3(Cr) = 2882$ kJ/mol
$EA(Cl) = -349$ kJ/mol
$EA(I) = -295$ kJ/mol