Chapter 12

# THE GROUP 2 ELEMENTS: THE ALKALINE EARTH METALS

Exercises

12.1   (a) $2 \, Ca(s) + O_2(g) \rightarrow 2 \, CaO(s)$

      (b) $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$

      (c) $Ca(HCO_3)_2(aq) \rightarrow CaCO_3(s) + H_2O(l) + CO_2(g)$

      (d) $CaO(s) + 3 \, C(s) \rightarrow CaC_2(s) + CO(g)$

12.3   (a) Barium; (b) barium.

12.5   Even though there will be a greater increase in entropy when the magnesium chloride lattice vaporizes compared to that of the sodium chloride lattice (three moles of ions instead of two), the higher charge density magnesium ion will cause the water molecules surrounding it during the hydration step to become much more ordered than with the lower charge density sodium ion. It is this significant difference in hydration entropy that causes the considerable difference in solution entropy change.

12.7   They form 2+ ions exclusively and their salts tend to be highly hydrated.

12.9   The commonly accepted explanation is that the beryllium 2+ cation is so small that six water molecules cannot fit around it.

12.11 Rainwater, an aqueous solution of carbon dioxide, percolates into limestone deposits, reacting with the calcium carbonate to give a solution of calcium hydrogen carbonate. The solution flows away, leaving a space that, with continued rain, enlarges to cave size.

$$CaCO_3(s) + CO_2(aq) + H_2O(l) \rightarrow Ca(HCO_3)_2(aq)$$

12.13 Calcium hydroxide is added to seawater, causing precipitation of the less soluble magnesium hydroxide:

$$Ca(OH)_2(aq) + Mg^{2+}(aq) \rightarrow Mg(OH)_2(s) + Ca^{2+}(aq)$$

The magnesium hydroxide is filtered off and neutralized with hydrochloric acid:

$$Mg(OH)_2(s) + 2 \, HCl(aq) \rightarrow MgCl_2(aq) + 2 \, H_2O(l)$$

The solution is evaporated to dryness and electrolysed:

$$Mg^{2+}(MgCl_2) + 2\ e^- \rightarrow Mg(l)$$

$$2\ Cl^-(MgCl_2) \rightarrow Cl_2(g) + 2\ e^-$$
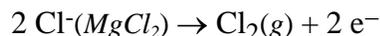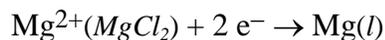
(It can be added that the chlorine is recycled to produce the hydrochloric acid reagent, while the calcium hydroxide comes from limestone by heating to calcium oxide and adding water.)

12.15 (a) $Ca(OH)_2$ (hydrated lime) or CaO (quicklime); (b) $Mg(OH)_2$; (c) $MgSO_4 \cdot 7\ H_2O$.

12.17 The absorption of X-rays depends on the square of the atomic number of the element. Thus lead is used because it has the highest atomic number of the common, non-radioactive elements (and it is a soft, malleable metal, so it is feasible to make lead aprons and other shields).

12.19 Both metals form tough oxide coatings over their surface that protect the bulk of the metal from oxidation; the two metals are amphoteric, forming beryllate and aluminate anions; they both form carbides containing the C^{4-} ion.

12.21 Magnesium ion is a key component of chlorophyll, the one molecule that has been crucial to converting our planet's atmosphere from carbon dioxide to dioxygen.

12.23 (a) $Mg(s) + HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$
               then evaporate to dryness to crystallize $MgCl_2 \cdot 6\ H_2O(s)$.
       (b) $Mg(s) + Cl_2(g) \rightarrow MgCl_2(s)$

Beyond the Basics

12.25 $CaSO_4 \cdot 2\ H_2O(s) \rightarrow CaSO_4 \cdot \frac{1}{2}\ H_2O(s) + 1\frac{1}{2}\ H_2O(g)$

$\Delta H^\circ \quad = [1(-1577) + 1\frac{1}{2}(-242) - 1(-2023)]\ kJ \cdot mol^{-1}$

$\qquad = +83\ kJ \cdot mol^{-1}$

$\Delta S^\circ \quad = [1(131) + 1\frac{1}{2}(189) - 1(194)]\ J \cdot mol^{-1} \cdot K^{-1}$

$\qquad = +220\ J \cdot mol^{-1} \cdot K^{-1} = 0.220\ kJ \cdot mol^{-1} \cdot K^{-1}$

$\Delta G^\circ \quad = (+83\ kJ \cdot mol^{-1}) - T(+0.220\ kJ \cdot mol^{-1} \cdot K^{-1}) = 0$

$T \qquad = 377\ K = 104°C$ (close to the actual value of about 100°C)

(If liquid water is used as product, a temperature of 132°C is calculated, which indicates that the value for $H_2O(g)$ has to be used.)

12.27 Except for the second period, most metal ions are hydrated by six water molecules. Thus the formula is actually $[Mg(OH_2)_6]^{2+}[SO_4 \cdot H_2O]^{2-}$. It is also possible to use the analogy with the zinc sulfate heptahydrate formula (Chapter 5).

12.29 BeH^+, as the molecular orbital diagrams show. This ion would possess a single bond, while the neutral molecule would have a half bond and BeH^- would not exist.

12.31 $Ca_3N_2(s) + 4\ NH_3(l) \rightarrow 3\ Ca(NH_2)_2(NH_3)$

12.33 $BeF_2(s) + Mg(s) \rightarrow MgF_2(s) + Be(s)$
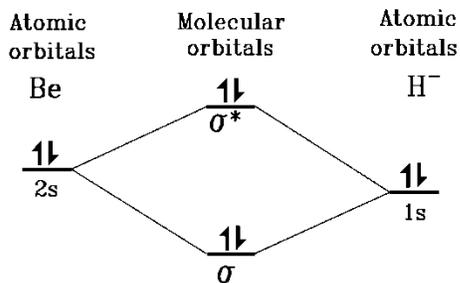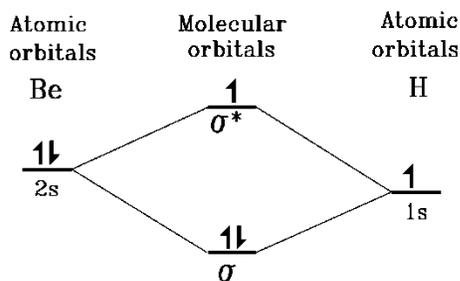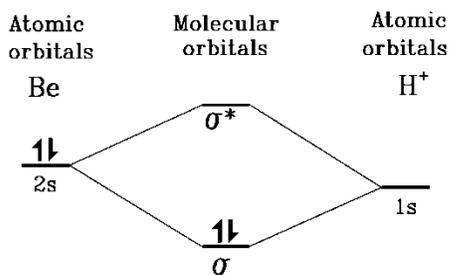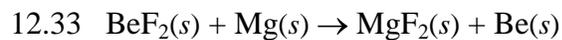
$\Delta G^{\circ} = [(-1071) - (-979)] \text{ kJ·mol}^{-1} = -92 \text{ kJ·mol}^{-1}$

Less favorable, for at a higher temperature, the low-melting magnesium will be a liquid:

$BeF_2(s) + Mg(l) \rightarrow MgF_2(s) + Be(s)$

Because liquids have higher entropies than solids, there will be a decrease in entropy for the process, and hence as $\Delta G = \Delta H - T\Delta S$, a less-negative free energy change.

The reason for synthesizing at a higher temperature is the greatly increased rate of reaction resulting from the liquid magnesium acting as a "solvent." At room temperature, reaction between two solids will be very slow.

12.35   The species is probably Na_2BeCl_4, containing sodium ions and the tetrahedral tetrachloroberyllate ion, $[BeCl_4]^{2-}$.