Calcium Reactions

Reaction #1 Calcium metal reacts with the weak acid water.

\[ \text{Ca (s)} + 2 \text{H}_2\text{O (l)} \rightarrow \text{Ca(OH)}_2 (s) + \text{H}_2(g) \]

1. Assign oxidation numbers. Write the number above the element in the equation. Identify the element oxidized. Write a half-reaction.

2. Draw the electron configuration of the calcium atom.

   Assign quantum numbers to an electron in the valence shell.

   What do the four numbers tell you about the electron?

   How would the electron configuration of the ion differ from the atom?

   Name and describe the bond between the calcium atoms in the metal.

3. Draw the Lewis structure for the water molecule. Use the Lewis structure to draw and name the VSEPR shape, then describe the location of the 4 electron pairs around the oxygen atom. Use VSEPR to explain why it takes on this shape.

   Identify and describe the orbital hybridization of the oxygen. How does orbital hybridization relate to the covalent bonding. Describe the sigma bond in your answer.

4. The hydrogen ions in the water actually react with the calcium atoms. \[ \text{H}_2\text{O} \rightleftharpoons \text{H}^+(aq) + \text{OH}^-(aq) \]

   As hydrogen ions leave the water as a gas, Use Le Chatelier’s Principle to predict the shift in this equilibrium.

5. Water is a weak acid, while hydrochloric acid is a strong acid. How does the weak acid differ from the strong acid. What does this suggest about the strength of the O-H bond compared to the H-Cl?

   The electronegativity of H is 2.1, O is 35, and Cl is 3.0. Identify and describe the bond between H-Cl. Is this bond more or less polar than the O-H bond. Explain why.
Reaction #2  Calcium chloride solution reacts with the sodium carbonate solution.

\[
\text{CaCl}_2 (aq) + \text{Na}_2\text{CO}_3(aq) \rightarrow \text{CaCO}_3(s) + \text{NaCl (aq)}
\]

1. Write the total and net ionic equations.

2. Use the net ionic equation to describe the reaction including collisions and the attractions broken and formed.

3. Compare the solubility of calcium carbonate and calcium chloride. Which do you expect to have a higher Ksp.

Reaction #3  The calcium carbonate is isolated and then reacted with acid.

\[
\text{CaCO}_3(s) \rightleftharpoons \text{Ca}^{2+} (aq) + \text{CO}_3^{2-}(aq)
\]

1. Describe the equilibrium in the saturated solution.

2. Write the equation for the Ksp. The Ksp is 3.0 x 10^{-9}

3. Calculate the maximum concentration of calcium carbonate in solution.

4. If an acid is added to the cloudy saturated solution, the cloudiness disappears. The hydrogen ions from the acid react with the carbonate ions producing water and carbon dioxide. The concentration of carbonate ions in solution decreases. Use collision model to predict and explain the mechanism of the shift by addressing the impact on the rate.
Reaction #1  Calcium metal reacts with the weak acid water.

\[ \begin{array}{cccccc}
0 & +1 & -2 & +2 & -2 & +1 & 0 \\
\text{Ca (s)} & + & 2 \text{H}_2\text{O (l)} & \rightarrow & \text{Ca(OH)}_2 (s) & + & \text{H}_2(g) \\
\end{array} \]

1. Assign oxidation numbers. Write the number above the element in the equation.
   Identify the element oxidized. Write a half-reaction.

   \[ \text{Ca(s)} \rightarrow \text{Ca}^{2+}(aq) + 2\text{e}^- \]

2. Draw the electron configuration of the calcium atom.

   \[ 1s^22s^23s^23p^64s^2 \]
   \[ \text{Draw means show the boxes. Not done here due to time consuming nature on computer.} \]

   Assign quantum numbers to an electron in the valence shell. \( 4 \quad 0 \quad 0 \quad \frac{1}{2} \)

   What do the four numbers tell you about the electron?

   4 the principal quantum number tells the energy level which to distance from the nucleus (increasing distance increasing PE)

   0 the angular momentum quantum number indicates the shape of the orbital or is it a s, p, d, or f. Each of these different orbitals has different shapes of the electron probability density in space

   0 is the magnetic quantum number which indicates the orientation of the orbital in space. The sphere-shaped s orbital has only one orientation. That is why there is only one s orbital.

   ½ is the magnetic spin quantum number. Electrons may have either an up (+½) or down spin (-½).

   How would the electron configuration of the ion differ from the atom?

   The calcium ion has lost two electrons from the 4s orbital. \( 1s^22s^23s^23p^6 \)

   Name and describe the bond between the calcium atoms in the metal.

   Metallic bond – atoms within the metal are attracted to a sea of free moving electron that is shared between all the atoms.

3. Draw the Lewis structure for the water molecule. Use the Lewis structure to describe the location of the 4 electron pairs around the oxygen atom. Use VSEPR to explain why it takes on this shape.

   \[ \text{H} \quad \text{O} \quad \text{H} \]
   Count the # of valence electrons \( 2(1) + 6 = 8 \)
   Give each atom a stable octet (4 pairs) except for H which only gets a pair.
   Check to see if you have used only the exact number of electrons available.
   Based upon this Lewis structure. The central atom oxygen has 4 electron pairs around the atom. These electron pairs repel each other and thus push each other as far apart as possible. The shape of the electron pair geometry is tetrahedral with 109.5° angles between the hybrid orbitals. Two of the orbitals contain only lone pairs of electrons. The molecule is described as bent since the two atoms will be found along at two of the vertices of the tetrahedron. The lone pairs of electrons occupy more space or generate more repulsions thus the bond angle between the H atoms and O atoms is reduced from the expected 109.5° to about 105°.

   Identify and describe the orbital hybridization of the oxygen. How does orbital hybridization relate to the covalent bonding. Describe the sigma bond in your answer.

   Covalent bonds form between atoms when the electron pair is shared between the two atoms. The ideal location for that electron pair is directly between the two atoms since this is the shortest distance between
the two atoms (maximizing electrical attraction) and also puts negative e- between two positive nuclei (minimizing the repulsion). This sharing of e- directly between nuclei is a sigma bond. Sigma bonds are formed by overlapping orbitals (think of the orbital as simply the region of space where the e- is most likely found). Hybrid orbitals predict a better shape of the orbital – optimizing the electron density between the nuclei and also predict the angles of VSEPR – Valence Shell Electron Pair Repulsion. Since the oxygen atom will have four electron pair around it – each requiring a hybrid orbital in which to be “located”, four atomic orbitals will be hybridized the s and all three p orbitals. Four sp3 hybrid orbitals are formed with bond angles of 109.5 °.

4. The hydrogen ions in the water actually react with the calcium atoms. \( \text{H}_2\text{O} \rightleftharpoons \text{H}^+(\text{aq}) + \text{OH}^-(\text{aq}) \)

As hydrogen ions leave the water as a gas, Use Le Chatelier’s Principle to predict the shift in this equilibrium. 2nd system responds to replace product 1st product removed

\[ \text{H}_2\text{O} \rightleftharpoons \text{H}^+(\text{aq}) + \text{OH}^-(\text{aq}) \]

Hydrogen ions leave the solution. Hydrogen ions are a product in this equilibrium. Since product is removed, the system responds to offset this change – replace product. The product is on the right so this is a shift to the right.

5. Water is a weak acid, while hydrochloric acid is a strong acid. How does the weak acid differ from the strong acid? What does this suggest about the strength of the O-H bond compared to the H-Cl?

Water is a weak acid so it only partially ionizes to form hydrogen ions in solution. The reaction is shown as reversible and there will be mostly water molecules in the solution (approximately 56 M H$_2$O and only 1 x $10^{-7}$ M H$^+$)

HCl is a strong acid and completely ionizes in solution. The reaction shown going to completion. If the solution is 1M HCl than the concentration of H$^+$ ions is 1M. This suggest that the HCl bond is weaker than the H-O bond.

The electronegativity of H is 2.1, O is 35, and Cl is 3.0. Identify and describe the bond between H-Cl. Is this bond more or less polar than the O-H bond. Explain why.

Electronegativity is a measure of an atom’s pull on electrons within a bond. The difference in electronegativity predicts the relative sharing of electrons between the two atoms. The greater the difference the more likely the electron pair will be found with the more electronegative atom. Thus the more polar the bond.

The more electronegative atoms pulls harder on the shared pair of electrons so the shared pair of electrons will spend more time around that atom (or the e- probability cloud will be denser around that atom). This results in partially charged ends within the bond. The more electronegative atom has a greater electron density and is thus partially negative while the other end is partially positive.

The O-H bond is more polar than the H-Cl bond, due to the greater difference in electronegativity. However do NOT confuse this for any prediction of bond strength. The strength of the bond can be predicted by considering the electrical force acting between the two positive nuclei and the negative electrons (consider distance and charge).
Reaction #2  Calcium chloride solution reacts with the sodium carbonate solution.

\[
\text{CaCl}_2(\text{aq}) + \text{Na}_2\text{CO}_3(\text{aq}) \rightarrow \text{CaCO}_3(\text{s}) + \text{NaCl (aq)}
\]

4. Write the total and net ionic equations.

\[
\begin{align*}
\text{CaCl}_2(\text{aq}) + \text{Na}_2\text{CO}_3(\text{aq}) & \rightarrow \text{CaCO}_3(\text{s}) + 2 \text{NaCl (aq)} \\
\text{Ca}^{2+}(\text{aq}) + \text{Cl}^- (\text{aq}) + \text{Na}^+(\text{aq}) + \text{CO}_3^{2-}(\text{aq}) & \rightarrow \text{CaCO}_3(\text{s}) + \text{Na}^+(\text{aq}) + \text{Cl}^- (\text{aq}) \\
\text{Ca}^{2+}(\text{aq}) + \text{CO}_3^{2-}(\text{aq}) & \rightarrow \text{CaCO}_3(\text{s})
\end{align*}
\]

5. Use the net ionic equation to describe the reaction including collisions and the attractions broken and formed.

Calcium ions that are in solution surrounded by water molecules (ion-dipole attractions) collide with carbonate ions also in solution surrounded by water molecules (ion-dipole attractions). Strong ionic bonds form between these ions and clumps of ions rapidly accumulate and the solution begins to appear cloudy. This solid crystal lattice of ions eventually settles to the bottom.

6. Compare the solubility of calcium carbonate and calcium chloride. Which do you expect to have a higher Ksp.

Ksp is equilibrium constant for the reversible reaction in the saturated solution of an ionic compound. Example

\[
\text{CaCO}_3(\text{s}) \rightleftharpoons \text{Ca}^{2+}(\text{aq}) + \text{CO}_3^{2-}(\text{aq}) \quad \text{Ksp} = [\text{Ca}^{2+}][\text{CO}_3^{2-}].
\]

Since calcium chloride is more soluble, we can expect more ions in the solution before it reaches the saturated solution. Thus the Ksp will be larger when these higher concentrations of ions in solution are plugged into the Ksp.

Reaction #3  The calcium carbonate is isolated and then reacted with acid.

\[
\text{CaCO}_3(\text{s}) \rightleftharpoons \text{Ca}^{2+}(\text{aq}) + \text{CO}_3^{2-}(\text{aq})
\]

5. Describe the equilibrium in the saturated solution.

At equilibrium the rate of the forward reaction (ions dissociating into solution) is equal to rate of the reverse reaction (ions crystallizing into the solid). Since the rates are equal the concentrations of the ions in the solution will remain constant until some disturbance is introduced.

6. Write the equation for the Ksp. The Ksp is 3.0 x 10^{-9} \text{ Ksp} = [\text{Ca}^{2+}][\text{CO}_3^{2-}].

7. Calculate the maximum concentration of calcium carbonate in solution.

\[
x = [\text{CaCO}_3] \quad \text{so} \quad x = [\text{Ca}^{2+}] \quad \text{and} \quad x = [\text{CO}_3^{2-}]
\]

so \text{ Ksp} = [\text{Ca}^{2+}][\text{CO}_3^{2-}] = (x)(x) = 3.0 \times 10^{-9}

8. If an acid is added to the cloudy saturated solution, the cloudiness disappears. The hydrogen ions from the acid react with the carbonate ions producing water and carbon dioxide. The concentration of carbonate ions in solution decreases. Use collision model to predict and explain the mechanism of the shift by addressing the impact on the rate.

\[
\text{CaCO}_3(\text{s}) \rightleftharpoons \text{Ca}^{2+}(\text{aq}) + \text{CO}_3^{2-}(\text{aq})
\]

The carbonate ions (CO_3^{2-}) leave solution as carbon dioxide gas.
This decreases the concentration of carbonate.
The reverse reaction is the collisions between calcium ions and carbonate ions.
So the decreased concentration of carbonate ions will affect the reverse reaction – decreasing the likelihood of collisions between these ions and thus decreasing the rate of the reverse reaction. So the forward reaction will be temporarily faster than the rate of the reverse. The equilibrium will shift to the right (in the direction of the faster reaction) until equilibrium is restored (or the solid calcium carbonate is used up).