This module will introduce the basic chemistry of hydrogen and the general reactions between hydrogen and the main group elements. Hydrogen cannot simply be grouped with any other element due to its uniqueness, which is exhibited through its ability of obtaining multiple forms and producing unique compounds in its reactions with other elements.

**Introduction**

Hydrogen is an element that frequently participates in chemical reactions. Free dihydrogen (H₂, hydrogen gas) is found in nature having a bond dissociation energy of +436 kJ mol⁻¹ and being unreactive at room temperature. However, H₂(g) is very reactive with elevated temperatures and/or with the use of a catalyst.

Main group elements (Figure 1) are the elements found in the s-block (Groups 1 and 2) and p-block (Groups 13-18) on the periodic table. Some of these elements are metals, metalloids, or nonmetals. The metalloids are represented below as the yellow staircase. Everything above the staircase are nonmetals and everything below the staircase are metals. The elements of group 18 are stable nonmetals referred to as the noble gases.

![Figure 1. Main group elements of the periodic table.](image)

**Characteristics of Hydrogen**

Hydrogen's unique electron configuration allows it to possess various distinct characteristics. The 1s¹ electron configuration of hydrogen represents the one electron in its s orbital (also known as its valence shell). The s orbital only needs two electrons in order to be considered filled. Hydrogen's nucleus is not shielded because it has no inner shell to act as a shield. Hydrogen's electron configuration affects how it is able to react with other elements (Figure 2). Due to its electron configuration, hydrogen cannot be grouped with any of the other main group elements in the periodic table.

Similar to the alkali metals of Group 1, hydrogen has a tendency of losing its electron and obtaining a +1 charge. What differentiates hydrogen from the other Group 1 elements is that when hydrogen loses its electron it becomes a proton, H⁺. Hydrogen is also like the halogens of Group 17 because it needs only one more electron to fill its valence shell. This results in hydrogen's tendency of forming a particular kind of covalent bond known as a hydrogen bond. Unlike halogens, hydrogen rarely forms H⁻ ions (also called hydrides). Halides are stable in water while hydrides are not. Hydrides are hydrolyzed:
\[H^-{(aq)} + H_2O_{(l)} \rightarrow H_{2 (g)} + OH^-{(aq)}\]

Hydrogen also has a half filled valence shell comparable to the elements of Group 14. Group 14 and hydrogen also have similar electronegativity values. Both hydrogen and elements in Group 14 have a tendency of sharing their electrons and forming covalent bonds. Due to these characteristics presented above, hydrogen is proven to be a unique element because of its ability to be found in three forms in which it can perform chemical reactions:

- \(H^+\): a proton
- \(H^-\): a hydride with a filled valence shell (electron configuration of 1s\(^2\))
- \(H^\cdot\): a covalent-sharing its electrons

**S-Block P-Block**

![Figure 2](image)

*Figure 2: Possible compounds hydrogen is capable of creating with the main group elements.*

**Hydrogen Reactions**

Hydrides are binary compounds of hydrogen. There are three possible hydrides that can be formed: ionic hydrides, covalent hydrides, and metallic hydrides. Metallic hydrides form when hydrogen reacts with transition metals, therefore they will not be introduced in this module.

**Hydrogen and the S-Block**

Ionic hydrides form when hydrogen reacts with s-block metals, not including Be and Mg. These s-block elements are found in Group 1 and Group 2 of the periodic table and are the most active metals. Group 1 metals are referred to as alkali metals and have a charge of +1 Group 2 metals are referred to as alkaline earth metals and have a charge of +2. Both Group 1 and Group 2 metals have low electronegativity values (less than 1.2).

**Example 1**

Reaction between Hydrogen and **Group 1 Alkali Metal** (M can represent any Group 1 alkali metal)
\[2M_{(s)} + H_{(g)} \rightarrow 2MH_{(s)}\]

Example 2

Reaction between Hydrogen and Group 2 Alkaline Earth Metal (M can represent Ca, Sr, or Ba)

\[M_{(s)} + H_{(g)} \rightarrow MH_{(s)}\]

In ionic hydrides, hydrogen acts like a "halogen" in its hydride form needing 1 electron to fill its valence shell.

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**Hydrogen and the p-Block Elements**

Covalent hydrides are formed when hydrogen reacts with the p-block nonmetals by sharing its electrons. Elements with high electronegativity values (Table A2), from as low as 1.5, can form covalent hydrides. Relative to hydrogen's reaction with other elements, hydrogen can readily react with nitrogen, oxygen, and halogens because they are very electronegative, therefore reactive.

Example 3: Group 13 Elements

The hydride of boron \(B_2H_6\) is an example of an electron-deficient hydride (compounds with at least one atom sharing less than eight electrons).

Example 4: Group 14 Elements

Reaction between Hydrogen and Group 14 Elements (C is interchangeable with Si, Ge, and Sn)

\[C_{(s)} + 2H_{(g)} \rightarrow CH_{4 (g)}\]

A hydrocarbon is a compound that consists only of the two elements: carbon and hydrogen. There is no apparent limit to how many chains of C-H can form. Hydrocarbons can be arranged in straight chains, in branched chains, or ring structures.

Example 5: Group 15 Elements

Reaction between Hydrogen and Group 15 Elements (N is interchangeable with P, As, and Sb)

\[N_{(g)} + 3H_{(g)} \rightarrow 2NH_{3 (g)}\]

Example 6: Group 16 elements

Reaction between Hydrogen and Group 16 Elements (O is interchangeable with S, Se, and Te)

\[2H_{(g)} + O_{(g)} \rightarrow 2H_2O_{(l)}\]

Example 7: group 17 elements

Reaction between Hydrogen and Group 17 Elements (X can represent F, Cl, Br, or I)
Acidic halides are composed of a hydrogen and a halide (a binary compound made up of a halogen and an element less electronegative than the halide). Hydrogen's reaction with fluorine occurs very fast because fluorine is the most electronegative. Hydrogen's reaction with chlorine is rapid in the presence of light because it is photochemically initiated. The reaction between bromine and hydrogen occurs more slowly.

There are no compounds formed between the noble gases (Group 18) and hydrogen due to the electron configuration of the noble gases. The noble gases have full valence shells, therefore they are stable and very unreactive. When elements react together, they try to achieve a stable state (a full valence shell). Since the noble gases already possess a full valence shell and stable state, they have no need to react with any elements, thus they will not react with hydrogen.

Hydrogen Bonding

A hydrogen bond forms between a partially positively charged hydrogen of one molecule (X-H-) and a partially negatively charged atom that can either be the same as the atom in the molecule (-X) or it can be another atom (-Y). This bonding can be depicted as: X-H-X or X-H-Y. Hydrogen bonds occur when covalent hydrides bond with another highly electronegative element. The only elements that are electronegative enough to do so are fluorine, oxygen, nitrogen, and sometimes chlorine (the previous depiction of X and Y can only be representations of these particular elements).

The most abundant hydrogen compound is water, H$_2$O, and it is a great example of how hydrogen bonding works.

\[
\delta^- \delta^+ \\
\text{-O-----H-}
\]

the partially positive hydrogen end can still attract another highly electronegative atom

\[
\delta^- \delta^+ \delta^- \\
\text{-O-----H-----O-}
\]

this is an example of a hydrogen bond

Hydrogen bonds are relatively strong. These bonds have higher boiling points and remain in liquid state for a wide range of temperatures. This is good for biology such as maintaining the chemistry in the human body; even the DNA structure maintains its double helix structure due to hydrogen bonding.

The Ability of Group 1 and Group 2 to Reduce Hydrogen

Group 1 and Group 2 metals of hydride compounds have the ability to reduce the oxidation state of hydrogen when reacting with or in water.

Example 8: Reducing Hydrogen
The hydrolysis of ionic hydrides results in dihydrogen gas.

\[ \text{NaH}_{(s)} + \text{H}_2\text{O}_{(l)} \rightarrow \text{NaOH}_{(s)} + \text{H}_2\text{(g)} \]

solid precipitates out when it is not in H$_2$O solvent

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

in H$_2$O solvent

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References


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Problems

1. Write the equation of the reaction between hydrogen and strontium.
2. Write the equation of the reaction between hydrogen and phosphorus.
3. Write the equation of the reaction between hydrogen and potassium.
4. Write the equation of the reaction between hydrogen and bromine.
5. Write 3 possible hydrocarbons that contains 3 carbons atoms.

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Answers

1. \( \text{Sr(s)} + \text{H}_2\text{(s)} \rightarrow \text{SrH}_2\text{(s)} \)
2. \( \text{P}_2\text{(g)} + 3\text{H}_2\text{(g)} \rightarrow 2\text{PH}_3\text{(g)} \)
3. \( 2\text{K(s)} + \text{H}_2\text{(g)} \rightarrow 2\text{KH(s)} \)
4. \( \text{H}_2\text{(g)} + \text{Br}_2\text{(g)} \rightarrow 2\text{HBr(g)} \)
5. \( \text{C}_3\text{H}_8, \text{C}_3\text{H}_6, \text{C}_3\text{H}_4 \ldots \text{answers may vary} \)