Hydrogen

Hydrogen, the simplest atom, combines with itself to make the simplest molecule, H₂. Most other elements in the periodic table combine with hydrogen to make compounds. The chemical bonds between hydrogen and other elements result from sharing electrons. The electrons are shared equally in non-polar covalent bonds and unequally in polar covalent bonds. The chemical energy stored in covalent bonds can be transformed into heat or electrical energy.

Outline
- Atomic and Molecular Hydrogen
- Hydrogen Compounds
- Energy from Hydrogen
- Homework

Atomic and Molecular Hydrogen

Electronic Structure of Atomic Hydrogen

We can represent a hydrogen atom with the symbol H and a dot that stands for the single electron in the neutral atom. In its lowest energy form, the electron occupies the 1s orbital, spherically symmetrical around the hydrogen nucleus.

As you saw in the section on electronic configuration, all atoms have many possible energy levels for their electrons. The lowest energy state (ground state) of an atom has its electrons filling orbitals beginning from lowest energy, with 2 electrons per orbital.

When energy is added to the ground state atom, an electron can be promoted to one of the higher energy orbitals. The energy added must be exactly the same as the energy between the orbital occupied by the electron and one of the higher energy, unoccupied orbitals.

Below you can see an orbital energy diagram showing the ground state hydrogen atom on the left. When hydrogen absorbs a quantity of energy exactly equal to ΔE₁, the electron goes from the orbital in the first shell (n = 1) to an orbital in the second shell (n = 2). This hydrogen molecule is in an excited state. Similarly, the electron can be excited to the n = 3 level with energy ΔE₂, to the n = 4 level with ΔE₃, to the n = 5 level with energy ΔE₄, etc.
The excited state electron can move back down to one of the lower energy levels if it releases the energy difference as electromagnetic radiation. Remember that the energy of electromagnetic radiation is inversely proportional to its wavelength:

\[ E = \frac{hc}{\lambda} \]

where \( h = 6.626 \times 10^{-34} \text{ J s} \), and \( c = 2.997 \times 10^8 \text{ m/s} \)

For an assortment of all possible excited state hydrogen molecules, an electron in each one of the higher orbital energy levels can drop to the ground state level, \( n = 1 \). This would release electromagnetic radiation corresponding to \( \Delta E_1, \Delta E_2, \Delta E_3, \Delta E_4 \), and energies from a few higher levels. These energies all correspond to electromagnetic radiation in the UV region of the spectrum.

If an excited state electron in \( n = 3 \) drops to the \( n = 2 \) level, it releases electromagnetic radiation of wavelength 656.3 nm. This is red light in the visible region of the spectrum. The transitions from \( n = 4 \) to \( n = 2 \), from \( n = 5 \) to \( n = 2 \), and from \( n = 6 \) to \( n = 2 \) also release visible light.
Astronomers use these four bands of visible light to identify atomic hydrogen in the universe. Below is a picture of the visible emission spectrum of hydrogen.

**Adding and Losing an Electron**
Helium is more stable (less reactive) than hydrogen because it has a completely filled $n = 1$ shell of electron density. Hydrogen can attain the same filled-shell configuration as helium by adding another electron. The resulting hydrogen anion is called a hydride. Because hydrogen has only the one electron, it can also lose that electron to form a completely empty $n = 1$ shell.
From the reaction coordinate diagrams above, we see that the hydride is more stable (lower energy) than the separated hydrogen atom and electron. The proton and free electron are much less stable than the hydrogen atom though.

A reaction that adds an electron to an atom or molecule is a reduction. An oxidation reaction is one in which an electron is removed from a chemical species.

**Hydrogen-Hydrogen Reaction**

Another way for a hydrogen atom to attain a filled shell electron configuration is to share its electron with another hydrogen atom. When the electron cloud of one hydrogen atom combines with another, the resulting orbital is filled with 2 electrons.
Here is a simulation of the two hydrogen atoms, each with an electron in a 1s orbital, as they go from 4.0 Å to the bond distance of 0.74 Å. The total energy of the H H system decreases by 436 kJ per mole of H₂ as the orbitals overlap.

There is repulsion between the nuclei that increases the energy greatly if the two atoms get closer than 0.74 Å.

## Hydrogen Compounds

Two hydrogen atoms form a bond with each other to share electrons so that each has the more stable electronic configuration of helium with 2 electrons. A bond where two atoms share electrons is called a **covalent bond**. The elements in the second row, lithium through fluorine, also form bonds so that they can attain the stable, filled-shell electron configuration of neon with 8 electrons.

### Representing the Electronic Configuration

The electronic configuration of the second row (n = 2) elements is in the table. We can represent the valence electrons, those in the outermost shell, with dots. The filled shell orbital (1s² for these elements) can't be shared and it is not involved in any chemical bonds. Each of the second row elements has 4 valence orbitals: 2s, 2pₓ, 2pᵧ, and 2pᵦ.

<table>
<thead>
<tr>
<th>lithium</th>
<th>beryllium</th>
<th>boron</th>
<th>carbon</th>
<th>nitrogen</th>
<th>oxygen</th>
<th>fluorine</th>
<th>neon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li⁺</td>
<td>Be⁺</td>
<td>B⁺</td>
<td>C⁺</td>
<td>N⁺</td>
<td>O⁺</td>
<td>F⁺</td>
<td>N⁺</td>
</tr>
<tr>
<td>[He]2s¹</td>
<td>[He]2s²</td>
<td>[He]2s²²p¹</td>
<td>[He]2s²²p²</td>
<td>[He]2s²²p²</td>
<td>[He]2s²²p³</td>
<td>[He]2s²²p⁴</td>
<td>[He]2s²²p⁵</td>
</tr>
<tr>
<td>Li·</td>
<td>Be∶</td>
<td>B∶</td>
<td>C∶</td>
<td>N∶</td>
<td>O∶</td>
<td>F∶</td>
<td>N∶</td>
</tr>
</tbody>
</table>

Lithium has a single electron in its 2s orbital (represented by the dot). Beryllium has 2 electrons in its 2s orbital, represented by 2 dots close together. Carbon has a pair of electrons in its 2s orbital (2 dots together) and 1 electron each in 2 of its 2p orbitals (2pₓ and 2pᵧ, for example) represented by single dots.

Because there are 4 valence orbitals, some of the elements have another electron configuration that is only slightly higher in energy.
**Bonds to Hydrogen**

Hydrogen can combine with all of the second role elements except neon to make molecules. The half-filled hydrogen 1s orbital can combine with any other half-filled orbitals of these elements. Neon doesn't have any half-filled orbitals. When electrons are shared between two atoms, they are included in the count of valence electrons for each.

<table>
<thead>
<tr>
<th>Left Atom</th>
<th>Right Atom</th>
<th>Bond Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li·</td>
<td>H</td>
<td>Li—H</td>
</tr>
<tr>
<td>H·:</td>
<td>Be·:</td>
<td>H—Be·H</td>
</tr>
<tr>
<td>H·:</td>
<td>B·:</td>
<td>H—B·H</td>
</tr>
<tr>
<td>H·:</td>
<td>C·:</td>
<td>H—C·H</td>
</tr>
<tr>
<td>H·:</td>
<td>N·:</td>
<td>H—N·H</td>
</tr>
<tr>
<td>H·:</td>
<td>O·:</td>
<td>H—O·H</td>
</tr>
<tr>
<td>F·:</td>
<td>H</td>
<td>F—H</td>
</tr>
</tbody>
</table>

- **Lithium** has 2 valence electrons in the product because it can make only 1 bond with hydrogen.
- **Beryllium** has 4 valence electrons in the product because it can only make 2 bonds. It has fewer electrons than neon and can react with electron donors. Each hydrogen has 2 valence electrons, the same as helium.
- **Boron** has 6 valence electrons in the product because it can only make 3 bonds. It has fewer electrons than neon and can react with electron donors. Each hydrogen has 2 valence electrons, the same as helium.
- **Carbon** has 8 valence electrons in the product, the same as neon. Each hydrogen has 2 valence electrons, the same as helium.
- **Nitrogen** has 8 valence electrons in the product, the same as neon. Each hydrogen has 2 valence electrons, the same as helium.
- **Oxygen** has 8 valence electrons in the product, the same as neon. Each hydrogen has 2 valence electrons, the same as helium.
- **Fluorine** has 8 valence electrons in the product, the same as neon. Hydrogen has 2 valence electrons, the same as helium.

**Polar and Non-Polar Bonds**

The electrons in the bond between two atoms are shared but, in bonds between different atoms, they are not necessarily shared equally. In going from left to right across the second row of the periodic table, the elements have an increasingly greater tendency to pull the bonding electrons in to themselves. This tendency is called **electronegativity**.
Numbers are assigned to elements that indicate their relative electronegativity. Electronegativity is a periodic property that increases from left to right across a row and increases from bottom to top of a column.

When two bonded atoms differ in electronegativity by more than 0.4 units, we say that the bond is polar. The element with the lower electronegativity number will be more electron poor than the element with the higher number.

Energy from Hydrogen

Hydrogen is the ultimate energy source. It powers the sun and the sun provides, directly or indirectly, most of the energy on Earth. Although it is the most abundant material in the universe, there is virtually no free hydrogen or molecular hydrogen on Earth. It can be produced from hydrogen compounds, such as those in the previous page.

Nuclear Fusion Reactors
It is possible to reproduce the nuclear fusion reaction that occurs in the sun to provide energy. However, the very high temperature and high pressure conditions of the solar core must be duplicated for fusion to occur.
In a fusion reactor, the deuterium and tritium gas mixture is heated to 150,000,000 degrees Celsius. The energy available at this temperature breaks the H-H bonds and causes the atoms to ionize, forming a plasma of free electrons and positively charged nuclei. The plasma is contained by very powerful magnets. The magnets are made of materials that must be kept at 4 Kelvin.

The heating and cooling of the system requires so much energy that the fusion process is not commercially feasible.

**Combustion**
Molecular hydrogen burns in air to produce water and heat energy.
The same reaction can be carried out in a hydrogen fuel cell to produce electrical energy instead of heat.

The energy from hydrogen combustion can be used to power cars. Instead of toxic exhaust, there is only water released from the tailpipe.