Chemistry 8.2
The Nature of Covalent Bonding
– The colors in this map indicate the concentrations of ozone in various parts of Earth’s atmosphere. Oxygen atoms can join in pairs to form the oxygen you breathe and can also join in groups of three oxygen atoms to form ozone, \( \text{O}_3 \).
• The Octet Rule in Covalent Bonding
  – What is the result of electron sharing in covalent bonds?
– In covalent bonds, electron sharing usually occurs so that atoms attain the electron configurations of noble gases.
• Single Covalent Bonds
  – How do electron dot structures represent shared electrons?
– single covalent bond

• two atoms held together by sharing one pair of electrons
– electron dot structure
  • H:H
  • represents the shared pair of electrons of the covalent bond
    – by two dots.

– structural formula
  • represents the covalent bonds by dashes
  • shows the arrangement of covalently bonded atoms.
• The halogens form single covalent bonds in their diatomic molecules. Fluorine is one example.
• **unshared pair**
  
  – A pair of valence electrons that is not shared between atoms
  – also known as a lone pair or a nonbonding pair

\[
\begin{align*}
\text{SO}_4^{2-} & \quad \begin{array}{c}
\text{O}\quad \text{S}\quad \text{O}\quad \text{O}
\end{array} \\
\text{H}_2\text{O} & \quad \begin{array}{c}
\text{H}\quad \text{O}\quad \text{H}
\end{array} \\
\text{MnO}_4^- & \quad \begin{array}{c}
\text{O}\quad \text{Mn}\quad \text{O}\quad \text{O}
\end{array} \\
\text{NH}_3 & \quad \begin{array}{c}
\text{H}\quad \text{N}\quad \text{H}
\end{array} \\
\text{CH}_3\text{OH} & \quad \begin{array}{c}
\text{H}\quad \text{C}\quad \text{O}\quad \text{H}
\end{array}
\end{align*}
\]
– The hydrogen and oxygen atoms attain noble-gas configurations by sharing electrons.
• The ammonia molecule has one unshared pair of electrons.

\[ 3\text{H}^+ + :\text{N}^- \rightarrow :\text{N}::\text{H} \quad or \quad :\text{N}—\text{H} \]

Hydrogen atoms  Nitrogen atom

Ammonia molecule
• Methane has no unshared pairs of electrons.

\[ 4\text{H} \cdot + \cdot\text{C} \cdot \rightarrow \text{H} : \text{C} : \text{H} \text{ or } \text{H} \equiv \text{C} \equiv \text{H} \]

Hydrogen atoms \hspace{1cm} Carbon atom \hspace{1cm} Methane molecule

\[
\begin{align*}
\text{C} & \uparrow \downarrow \\
1s & 2s, 2p \\
\text{H} & \text{H} \text{H} \text{H}
\end{align*}
\]

Methane molecule
Drawing an Electron Dot Structure

Hydrochloric acid (HCl \((aq)\)) is prepared by dissolving gaseous hydrogen chloride (HCl \((g)\)) in water. Hydrogen chloride is a diatomic molecule with a single covalent bond. Draw the electron dot structure for HCl.
• Double and Triple Covalent Bonds
  – How do atoms form double or triple covalent bonds?
Atoms form double or triple covalent bonds if they can attain a noble gas structure by sharing two pairs or three pairs of electrons.
• **double covalent bond**
  – A bond that involves two shared pairs of electrons

• **triple covalent bond**
  – A bond formed by sharing three pairs of electrons

\[
\begin{align*}
\text{H}^\cdot + \text{O}^\cdot \cdot + \text{H}^\cdot & \quad \rightarrow \quad \text{H} : \text{O} : \text{H} \quad \text{or} \quad \text{H} = \text{O} = \text{H} \\
\text{O}^\cdot + \text{C}^\cdot + \text{O}^\cdot & \quad \rightarrow \quad \text{O} : \text{C} : \text{O} \quad \text{or} \quad \text{O} = \text{C} = \text{O} \\
\text{N}^\cdot + \text{N}^\cdot & \quad \rightarrow \quad \text{N} : \text{N} : \text{N} \quad \text{or} \quad \text{N} = \text{N} = \text{N}
\end{align*}
\]

All these diagrams show the formation of covalent bonds as electrons from elements are shared to form single, double, and triple bonds.
• Each oxygen atom has one unshared pair of electrons.

\[
\begin{align*}
\cdot\text{O} & \quad + \quad \cdot\text{O} \\
\text{Oxygen atom} & \quad \text{Oxygen atom} \quad \rightarrow \quad \cdot\text{O} \cdot\text{O} \quad \text{or} \quad \cdot\text{O} = \cdot\text{O}
\end{align*}
\]

Oxygen molecule

\[
\begin{array}{c|c|c}
1s & 2s & 2p \\
\uparrow\downarrow & \uparrow\downarrow & \uparrow \\
O & O & \\
1s & 2s & 2p \\
\uparrow\downarrow & \uparrow\downarrow & \downarrow \uparrow
\end{array}
\]

Oxygen molecule
<table>
<thead>
<tr>
<th>Name</th>
<th>Chemical formula</th>
<th>Electron dot structure</th>
<th>Properties and uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluorine</td>
<td>$F_2$</td>
<td>$\cdot\cdot$</td>
<td>Greenish-yellow reactive toxic gas. Compounds of fluorine, a halogen, are added to drinking water and toothpaste to promote healthy teeth.</td>
</tr>
<tr>
<td>Chlorine</td>
<td>$Cl_2$</td>
<td>$\cdot Cl-Cl\cdot$</td>
<td>Greenish-yellow reactive toxic gas. Chlorine is a halogen used in household bleaching agents.</td>
</tr>
<tr>
<td>Bromine</td>
<td>$Br_2$</td>
<td>$\cdot Br-Br\cdot$</td>
<td>Dense red-brown liquid with pungent odor. Compounds of bromine, a halogen, are used in the preparation of photographic emulsions.</td>
</tr>
<tr>
<td>Iodine</td>
<td>$I_2$</td>
<td>$\cdot I-I\cdot$</td>
<td>Dense gray-black solid that produces purple vapors; a halogen. A solution of iodine in alcohol (tincture of iodine) is used as an antiseptic.</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>$H_2$</td>
<td>$H-H$</td>
<td>Colorless, odorless, tasteless gas. Hydrogen is the lightest known element.</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>$N_2$</td>
<td>$:N=\equiv N:$</td>
<td>Colorless, odorless, tasteless gas. Air is almost 80% nitrogen by volume.</td>
</tr>
<tr>
<td>Oxygen</td>
<td>$O_2$</td>
<td>Inadequate</td>
<td>Colorless, odorless, tasteless gas that is vital for life. Air is about 20% oxygen by volume.</td>
</tr>
</tbody>
</table>
• Carbon dioxide gas is soluble in water and is used to carbonate many beverages. A carbon dioxide molecule has two carbon-oxygen double bonds.

• Carbon dioxide is an example of a triatomic molecule.
Coordinate Covalent Bonds

• Coordinate Covalent Bonds
  – How are coordinate covalent bonds different from other covalent bonds?
Coordinate Covalent Bonds

- In carbon monoxide, oxygen has a stable configuration but the carbon does not.

\[ \cdot\text{C}^\cdot + \cdot\text{O}^\cdot \rightarrow \cdot\text{C}::\text{O}^\cdot \]

Carbon atom  Oxygen atom  Carbon monoxide

```
C          O
1s  ↑↓  ↑↓  ↑↓  ↑↓  1s  2s  2p
```

Carbon monoxide molecule
Coordinate Covalent Bonds

• As shown below, the dilemma is solved if the oxygen donates one of its unshared pairs of electrons for bonding.

:CO: → :C=O:
Carbon monoxide molecule
• **coordinate covalent bond**
  – a covalent bond in which one atom contributes both bonding electrons.
  – In a structural formula
    • you can show coordinate covalent bonds as arrows that point from the atom donating the pair of electrons to the atom receiving them.
– In a coordinate covalent bond
  • the shared electron pair comes from one of the bonding atoms.
• polyatomic ion
  – a tightly bound group of atoms that has a positive or negative charge and behaves as a unit.
  – Example:
    • $\text{NH}_4^+$
<table>
<thead>
<tr>
<th>Name</th>
<th>Chemical formula</th>
<th>Structure</th>
<th>Properties and uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen peroxide</td>
<td>$\text{H}_2\text{O}_2$</td>
<td><img src="image" alt="H2O2_structure" /></td>
<td>Colorless, unstable liquid when pure. It is used as rocket fuel. A 3% solution is used as a bleach and antiseptic.</td>
</tr>
<tr>
<td>Sulfur dioxide</td>
<td>$\text{SO}_2$</td>
<td><img src="image" alt="SO2_structure" /></td>
<td>Oxides of sulfur are produced in combustion of petroleum products and coal. They are major air pollutants in industrial areas. Oxides of sulfur can lead to respiratory problems.</td>
</tr>
<tr>
<td>Sulfur trioxide</td>
<td>$\text{SO}_3$</td>
<td><img src="image" alt="SO3_structure" /></td>
<td></td>
</tr>
<tr>
<td>Nitric oxide</td>
<td>$\text{NO}$</td>
<td><img src="image" alt="NO_structure" /></td>
<td>Oxides of nitrogen are major air pollutants produced by the combustion of fossil fuels in automobile engines. They irritate the eyes, throat, and lungs.</td>
</tr>
<tr>
<td>Nitrogen dioxide</td>
<td>$\text{NO}_2$</td>
<td><img src="image" alt="NO2_structure" /></td>
<td></td>
</tr>
<tr>
<td>Nitrous oxide</td>
<td>$\text{N}_2\text{O}$</td>
<td><img src="image" alt="N2O_structure" /></td>
<td>Colorless, sweet-smelling gas. It is used as an anesthetic commonly called laughing gas.</td>
</tr>
<tr>
<td>Hydrogen cyanide</td>
<td>$\text{HCN}$</td>
<td><img src="image" alt="HCN_structure" /></td>
<td>Colorless, toxic gas with the smell of almonds.</td>
</tr>
<tr>
<td>Hydrogen fluoride</td>
<td>$\text{HF}$</td>
<td><img src="image" alt="HF_structure" /></td>
<td>Two hydrogen halides, all extremely soluble in water. Hydrogen chloride, a colorless gas with pungent odor, readily dissolves in water to give a solution called hydrochloric acid.</td>
</tr>
<tr>
<td>Hydrogen chloride</td>
<td>$\text{HCl}$</td>
<td><img src="image" alt="HCl_structure" /></td>
<td></td>
</tr>
</tbody>
</table>
Drawing the Electron Dot Structure of a Polyatomic Ion

The polyatomic hydronium ion (H$_3$O$^+$), which is found in acidic mixtures such as lemon juice, contains a coordinate covalent bond. The H$_3$O$^+$ ion forms when a hydrogen ion is attracted to an unshared electron pair in a water molecule. Draw the electron dot structure of the hydronium ion.
Apply the concepts to this situation.

\[ \text{H}^+ + \text{H}^+\text{:O}^+\text{H} \rightarrow [\text{H}^+\text{O}^+\text{H}]^+ \text{ or } [\text{H}^+\text{O}^+\text{H}]^+ \]

Hydrogen ion (proton)  Water molecule (H₂O)  Hydronium ion (H₃O⁺)

The oxygen in the hydronium ion has eight valence electrons, and each hydrogen shares two valence electrons. This satisfies the needs of both hydrogen and oxygen for valence electrons. The water molecule is electrically neutral, and the hydrogen ion has a positive charge. The combination of these two species must have a charge of 1+, as is found in the hydronium ion.
• Bond Dissociation Energies
  – How is the strength of a covalent bond related to its bond dissociation energy?
Bond Dissociation Energies

• bond dissociation energy
  – The energy required to break the bond between two covalently bonded atoms.
  – A large bond dissociation energy corresponds to a strong covalent bond.
• Resonance
  – How are oxygen atoms bonded in ozone?
• Ozone in the upper atmosphere blocks harmful ultraviolet radiation from the sun.
• At lower elevations, it contributes to smog.
The actual bonding of oxygen atoms in ozone is a hybrid, or mixture, of the extremes represented by the resonance forms.
• **resonance structure**
  
  – a structure that occurs when it is possible to draw two or more valid electron dot structures that have the same number of electron pairs for a molecule or ion.
• Exceptions to the Octet Rule
  – What are some exceptions to the rule?
– The octet rule cannot be satisfied in molecules whose total number of valence electrons is an odd number.
– There are also molecules in which an atom has fewer, or more, than a complete octet of valence electrons.
Two electron dot structures can be drawn for the NO$_2$ molecule.

\[
\begin{align*}
\text{O} & \quad \text{N} \quad \text{O} \\
\uparrow \downarrow & \quad \uparrow \downarrow \quad \uparrow \downarrow \\
\text{O} & \quad \text{N} \quad \text{O} \\
\uparrow \downarrow & \quad \uparrow \downarrow \quad \uparrow \downarrow
\end{align*}
\]

Nitrogen dioxide molecule
• NO$_2$ is produced naturally by lightning strikes.
The electron dot structure for PCl₅ can be written so that phosphorus has ten valence electrons.
Quiz.
1. In covalent bonding, atoms attain the configuration of noble gases by
   A. losing electrons.
   B. gaining electrons.
   C. transferring electrons.
   D. sharing electrons.
2. Electron dot diagrams are superior to molecular formulas in that they
   A. show which electrons are shared.
   B. indicate the number of each kind of atom in the molecule.
   C. show the arrangement of atoms in the molecule.
   D. are easier to write or draw.
3. Which of the following molecules would contain a bond formed when atoms share three pairs of electrons?

A. Se₂
B. As₂
C. Br₂
D. Te₂
END