What is the difference between the oxygen you breathe and the oxygen in ozone in the atmosphere?

Our atmosphere contains two different molecules that are both made of oxygen atoms.
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.
In covalent bonds, electron sharing usually occurs so that atoms attain the electron configurations of noble gases.

- For example, a single hydrogen atom has one electron. But a pair of hydrogen atoms shares electrons to form a covalent bond in a diatomic hydrogen molecule.
- Each hydrogen atom thus attains the electron configuration of helium, a noble gas with two electrons.

Combinations of atoms of the nonmetals and metalloids in Groups 4A, 5A, 6A, and 7A of the periodic table are likely to form covalent bonds.

- The combined atoms usually acquire a total of eight electrons, or an octet, by sharing electrons, so that the octet rule applies.
Single Covalent Bonds

- Two atoms held together by sharing one pair of electrons are joined by a **single covalent bond**.

Hydrogen gas consists of diatomic molecules whose atoms share only one pair of electrons, forming a single covalent bond.
8.2 The Nature of Covalent Bonding

Single Covalent Bonds

- An electron dot structure such as H:H represents the shared pair of electrons of the covalent bond by two dots.

- The pair of shared electrons forming the covalent bond is also often represented as a dash, as in H—H for hydrogen.

- A **structural formula** represents the covalent bonds as dashes and shows the arrangement of covalently bonded atoms.

The halogens also form single covalent bonds in their diatomic molecules. Fluorine is one example.
8.2 The Nature of Covalent Bonding

Single Covalent Bonds

- In the $F_2$ molecule, each fluorine atom contributes one electron to complete the octet.

- Notice that the two fluorine atoms share only one pair of valence electrons.

\[ \cdot \overset{\cdot}{F} \cdot + \cdot \overset{\cdot}{F} \cdot \rightarrow \cdot \overset{\cdot}{F} \cdot \overset{\cdot}{F} \cdot \text{ or } \cdot \overset{\cdot}{F} \cdot \overset{\cdot}{F} \cdot \]

Fluorine atom \hspace{2cm} Fluorine atom \hspace{2cm} Fluorine molecule

Shared pair of electrons

The Octet Rule in Covalent Bonding

8.2 The Nature of Covalent Bonding

Single Covalent Bonds

- A pair of valence electrons that is not shared between atoms is called an unshared pair.
  - In $F_2$, each fluorine atom has three unshared pairs of electrons.

\[ \cdot \overset{\cdot}{F} \cdot + \cdot \overset{\cdot}{F} \cdot \rightarrow \cdot \overset{\cdot}{F} \cdot \overset{\cdot}{F} \cdot \text{ or } \cdot \overset{\cdot}{F} \cdot \overset{\cdot}{F} \cdot \]

Fluorine atom \hspace{2cm} Fluorine atom \hspace{2cm} Fluorine molecule

Shared pair of electrons
Single Covalent Bonds

As you can see in the electron dot structures below, the oxygen atom in water has two unshared pairs of valence electrons.

\[ 2\text{H}^+ + \text{O}^+ \rightarrow \text{O}^+\text{H}^+ \text{ or } \text{O}^-\text{H}^- \]

Hydrogen atoms  Oxygen atom  Water molecule

- Methane contains four single covalent bonds.

- The carbon atom has four valence electrons and needs four more valence electrons to attain a noble-gas configuration.
8.2 The Nature of Covalent Bonding

Sample Problem 8.1

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.

2 Solve  Apply concepts to the problem.

Draw the electron dot structures for the hydrogen and chlorine atoms.

$$
\begin{align*}
\text{H}^+ & \quad + \\
\text{Cl}^- & \\
\text{Hydrogen atom} & \quad \text{Chlorine atom}
\end{align*}
$$
2 Solve Apply concepts to the problem.

Draw the electron dot structure for the hydrogen chloride molecule.

Through electron sharing, the hydrogen and chlorine atoms attain the electron configurations of the noble gases helium and argon, respectively.

H· + Cl·

H:Cl:

Dotted line: Hydrogen chloride molecule

Atoms form double or triple covalent bonds if they can attain a noble gas structure by sharing two or three pairs of electrons.
Double and Triple Covalent Bonds

- A **double covalent bond** is a bond that involves two shared pairs of electrons.

- Similarly, a bond formed by sharing three pairs of electrons is a **triple covalent bond**.

The carbon dioxide (CO$_2$) molecule contains two oxygens, each of which shares two electrons with carbon to form a total of two carbon–oxygen double bonds.

\[
\overset{\cdot}\text{O} + \overset{\cdot}\text{C} + \overset{\cdot}\text{O} \rightarrow \overset{\cdot}\text{O} \overset{\cdot\cdot\cdot}{\text{C}} \overset{\cdot\cdot\cdot}{\text{O}} \quad \text{or} \quad \overset{\cdot}{\text{O}} \equiv \overset{\cdot\cdot}{\text{C}} \equiv \overset{\cdot}{\text{O}}
\]

Oxygen atom  Carbon atom  Oxygen atom  Carbon dioxide molecule
Double and Triple Covalent Bonds

- Nitrogen ($N_2$), a major component of Earth’s atmosphere, contains triple bonds.
- A single nitrogen atom has five valence electrons; each nitrogen atom in the molecule must share three electrons to have the electron configuration of neon.

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

Nitrogen atom \hspace{1cm} Nitrogen atom \hspace{1cm} Nitrogen molecule

Double and Triple Covalent Bonds

- You might think that an oxygen atom, with six valence electrons, would form a double bond by sharing two of its electrons with another oxygen atom.

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

- In such an arrangement, all the electrons within the molecule would be paired.
Double and Triple Covalent Bonds

- Experimental evidence, however, indicates that two of the electrons in $O_2$ are still unpaired.
  - Thus, the bonding in the oxygen molecule ($O_2$) does not obey the octet rule.

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

Nitrogen and oxygen are both diatomic molecules; the table below lists some other diatomic molecules.

<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>:F=\cdot\cdot\cdot=F</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>Bromine</td>
<td>Br$_2$</td>
<td>:Br=\cdot\cdot\cdot=Br</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>Hydrogen</td>
<td>H$_2$</td>
<td>H=H</td>
<td>Colorless, odorless, tasteless gas. Hydrogen is the lightest known element.</td>
</tr>
</tbody>
</table>
The “octet” in the octet rule refers to eight of what?

Each of the atoms joined by a covalent bond usually acquires eight electrons in its valence shell. Most noble gases have eight valence electrons.
Coordinate Covalent Bonds

How are coordinate covalent bonds different from other covalent bonds?

- Carbon monoxide (CO) is an example of a type of covalent bonding different from that seen in water, ammonia, methane, and carbon dioxide.

- It is possible for both carbon (which needs to gain four electrons) and oxygen (which needs to gain two electrons) to achieve noble-gas electron configurations by a type of bonding called coordinate covalent bonding.
Look at the double covalent bond between carbon and oxygen.

\[
\text{\begin{align*}
\text{\carbon atom} & \quad + \quad \text{\oxygen atom} \\
\rightarrow \quad \text{\carbon \ monoxide \ molecule}
\end{align*}}
\]

With the double bond in place, the oxygen had a stable electron configuration, but the carbon does not.

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

\[
\text{\begin{align*}
\text{\carbon \ monoxide \ molecule}
\end{align*}}
\]

A covalent bond in which one atom contributes both bonding electrons is a coordinate covalent bond.
In a coordinate covalent bond, the shared electron pair comes from one of the bonding atoms.

- The ammonium ion (NH$_4^+$) consists of atoms joined by covalent bonds, including a coordinate covalent bond.

- A polyatomic ion, such as NH$_4^+$, is a tightly bound group of atoms that has a positive or negative charge and behaves as a unit.
The ammonium ion forms when a positively charged hydrogen ion (H\(^+\)) attaches to the unshared electron pair of an ammonia molecule (NH\(_3\)).

\[
\begin{align*}
\text{Hydrogen ion (proton)} & \quad \text{Ammonia molecule (NH}_3\text{)} \\
\text{Ammonium ion (NH}_4^+\text{)} & \quad \text{coordinate covalent bond}
\end{align*}
\]

- Most polyatomic ions contain covalent and coordinate covalent bonds.
- Therefore, compounds containing polyatomic ions include both ionic and covalent bonding.
Drawing the Electron Dot Structure of a Polyatomic Ion

The H₃O⁺ 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.

1 Analyze Identify the relevant concepts. Each atom must share electrons to satisfy the octet rule.
2 Solve  

Apply the concepts to the problem.

Draw the electron dot structure of the water molecule and the hydrogen ion. Then draw the electron dot structure of the hydronium ion.

\[
\begin{align*}
\text{H}^+ & \quad + \quad \cdot\cdot\cdot\text{H} \\
\text{Hydrogen ion (proton)} & \quad \text{Water molecule (H}_2\text{O)}
\end{align*}
\]

The oxygen must share a pair of electrons with the added hydrogen ion to form a coordinate covalent bond.

\[
\begin{align*}
\text{H}^+ & \quad + \quad \cdot\cdot\cdot\text{H} \\
\text{Hydrogen ion (proton)} & \quad \text{Water molecule (H}_2\text{O)}
\end{align*} \rightarrow \quad \left[ \text{H}^+ \quad \cdot\cdot\cdot\text{H} \right]^+ \quad \text{or} \quad \left[ \text{H}^+ \quad \cdot\cdot\cdot\text{H} \right]^+
\]

\[
\begin{align*}
\text{H}^+ & \quad + \quad \cdot\cdot\cdot\text{H} \\
\text{Hydrogen ion (proton)} & \quad \text{Water molecule (H}_2\text{O)}
\end{align*} \rightarrow \quad \left[ \text{H}^+ \quad \cdot\cdot\cdot\text{H} \right]^+ \quad \text{or} \quad \left[ \text{H}^+ \quad \cdot\cdot\cdot\text{H} \right]^+
\]
Do all atoms joined in covalent bonds donate electrons to the bond?

No. In coordinate covalent bonds, the shared electron pair comes from one of the bonding atoms.
Exceptions to the Octet Rule

What are some exceptions to the octet 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 less, or more, than a complete octet of valence electrons.
Two plausible electron dot structures can be drawn for the NO₂ molecule, which has a total of seventeen valence electrons.

It is impossible to draw an electron dot structure for NO₂ that satisfies the octet rule for all atoms, yet NO₂ does exist as a stable molecule.

Nitrogen dioxide molecule

Are molecules that do not obey the octet rule necessarily unstable?
Are molecules that do not obey the octet rule necessarily unstable?

No. There are molecules like NO₂ that do not obey the octet rule, but that are stable, naturally occurring molecules.

Bond Dissociation Energies

How is the strength of a covalent bond related to its bond dissociation energy?
The energy required to break the bond between two covalently bonded atoms is known as the **bond dissociation energy**.

- The units for this energy are often given in kJ/mol, which is the energy needed to break one mole of bonds.

A large bond dissociation energy corresponds to a strong covalent bond.

- A typical carbon–carbon single bond has a bond dissociation energy of 347 kJ/mol.
- Strong carbon–carbon bonds help explain the stability of carbon compounds.
  - They are unreactive partly because the dissociation energy is high.
True or False: A strong covalent bond has a low bond dissociation energy.

*False. A large bond dissociation energy corresponds to a strong covalent bond.*
In covalent bonds, electron sharing occurs so that atoms attain the configurations of noble gases.

In a coordinate covalent bond, the shared electron pair comes from a single atom.

The octet rule is not satisfied in molecules with an odd number of electrons and in molecules in which an atom has less, or more, than a complete octet of valence electrons.

A large bond dissociation energy corresponds to a strong covalent bond.

In ozone, the bonding of oxygen atoms is a hybrid of the extremes represented by the resonance forms.
• **single covalent bond**: a bond formed when two atoms share a pair of electrons

• **structural formula**: a chemical formula that shows the arrangement of atoms in a molecule or a polyatomic ion; each dash between a pair of atoms indicates a pair of shared electrons

• **unshared pair**: a pair of valence electrons that is not shared between atoms

• **double covalent bond**: a bond in which two atoms share two pairs of electrons

• **triple covalent bond**: a covalent bond in which three pairs of electrons are shared by two atoms

• **coordinate covalent bond**: a covalent bond in which one atom contributes both bonding electrons
• **polyatomic ion**: a tightly bound group of atoms that behaves as a unit and has a positive or negative charge

• **bond dissociation energy**: the energy required to break the bond between two covalently bonded atoms; this value is usually expressed in kJ per mol of substance