A carbon atom has 4 valence (outer shell) electrons. There are three ways we can represent its Lewis structure:

- Single bond: \( C-H \)
- Double bond: \( C=H \)
- Triple bond: \( C\equiv H \)

We can apply this theory to draw Lewis diagrams for covalent molecules:

**Example:** CO

\[
\begin{align*}
\text{O} & \quad \text{C} \\
\end{align*}
\]

If there are charges on the species you need to draw then when counting valence electrons:

- Add 1 for a negative charge
- Remove 1 for a positive charge

Draw a Lewis diagram for an \( \text{OH}^- \) ion and the \( \text{SO}_4^{2-} \) ion:

\[
\begin{align*}
\text{O} & \quad \text{H} \\
+1e^- & \quad +2e^- \\
\end{align*}
\]

In coordinate bonds both shared electrons come from one atom:

**Example:** \( \text{H}_2\text{O} \)

\[
\begin{align*}
\text{O} & \quad \text{H} \\
\end{align*}
\]

We will see the relevance of these coordinate bonds in Topic 8 and 18.

The octet rule is not always followed.

For example, the molecule \( \text{BeF}_2 \) does not obey the octet rule because each atom has only six electrons around it. This is an example where the octet rule is not strictly followed.

Overtones:

14. Draw the Lewis structure of:
- (a) \( \text{H}_2\text{O} \)
- (b) \( \text{Cl}_2 \)
- (c) \( \text{HCl} \)
- (d) \( \text{PCl}_3 \)

15. How many electron pairs are in the following resonance?
- (a) \( \text{BCl}_3 \)
- (b) \( \text{CS}_2 \)
- (c) \( \text{CO}_2 \)
- (d) \( \text{NH}_3 \)
- (e) \( \text{NH}_4^+ \)

16. Use Lewis structures to show the formation of a coordinate bond between \( \text{H}_2\text{O} \) and \( \text{Li}^+ \):

\[
\begin{align*}
\text{O} & \quad \text{H} \\
\text{H} & \quad \text{H} \\
\end{align*}
\]

17. Use Lewis structures to show the formation of a coordinate bond between \( \text{N}_2 \) and \( \text{H}^+ \):

\[
\begin{align*}
\text{N} & \quad \text{N} \\
\text{H} & \quad \text{H} \\
\end{align*}
\]
As the electron pairs behave as a single unit, we often describe them as electron domains. Every lone pair, single bond, double bond and triple bond count as 1 electron domain. How many are there in each example below?

As these domains repel each other, they are directly responsible for the position of bonds and hence the shape of a covalent molecule.

Note: Lone pairs of electrons repel other domains more than bonding pairs of electrons.

WARNING - Although lone pairs affect the shape of a molecule, when describing the geometry we only take into account where the bonded atoms are positioned.

Draw the Lewis diagram for ozone, O₃.

Why do we call its geometry v-shaped or bent and NOT trigonal planar?

Why are the bond angles progressively smaller?
Electrons in multiple bonds can sometimes spread themselves between more than one bonding position.

Delocalization is a characteristic of electrons in multiple bonds when there is more than one possible position for a double bond within a molecule. For example, let us look at the Lewis structure of ozone, Oz, from page 139.

We can see that different Lewis structure would equally valid:

$$\text{O}_3$$

To represent it correctly we must show the individual resonance structures. The actual structure is a mixture of these structures and we call it a resonance hybrid.

What does this data suggest?

<table>
<thead>
<tr>
<th>Bond length (Å)</th>
<th>Bond order</th>
<th>Bond energy (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O=O</td>
<td>1.21</td>
<td>107</td>
</tr>
<tr>
<td>O=O=O</td>
<td>1.19</td>
<td>105</td>
</tr>
</tbody>
</table>

Ozone and ozone is a valid Lewis structure.

Benzene is another interesting example:

What is the bond order of each carbon-oxygen bond?

Because it is another interesting example:

Examples

23 Put the following species in order of increasing carbon-oxygen bond length:

CO, CO$_2$, CO$_3$, CO$_4$H$_4$}

24 By reference to their resonance structures, compare the nitrogen-oxygen bond lengths in nitrate$^-$ (NO$_3^-$) and nitro(II) acid (HNO$_3$)
Some covalent substances exist as structures in which all atoms are bonded covalently to others forming a giant covalent structure instead of individual covalent molecules. This has a large affect on their properties.

**Allotropes** are different forms of an element in the same physical state, such as oxygen (O₂) and ozone (O₃) which both exist as gases. Different bonding within these structures gives rise to distinct forms with different properties.

For carbon these are 4 allotropes:

<table>
<thead>
<tr>
<th>Structure</th>
<th>Graphite</th>
<th>Diamond</th>
<th>Fullerene C₆₀</th>
<th>Graphene</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hexagonal layers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delocalised electrons can move freely in between the layers.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very strong!</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The development of tiny (<100 nm) structures involving graphite, graphene and nanotubes is called nanotechnology.

Silicon (also in Group 14) exists as a similar structure to diamond.

Silicon dioxide also exists as a giant covalent structure.
Selectividad questions

For the molecules: water, methane and iodine (biological molecules):
1. Arrange the structures of Lewis.
2. Draw the structure of water.

3. A) Lewis structures of water, methane and iodine.
   B) The molecule with a greater angular H – H – H
      is the trifluorine.

4. A) Lewis structures of water, methane and iodine.
   B) The molecule with a greater angular H – H – H
      is water.

5. A) Lewis structures of water, methane and iodine.
   B) The molecule with a greater angular H – H – H
      is water.

6. A) Lewis structures of water, methane and iodine.
   B) The molecule with a greater angular H – H – H
      is water.

7. A) Lewis structures of water, methane and iodine.
   B) The molecule with a greater angular H – H – H
      is water.

8. A) Lewis structures of water, methane and iodine.
   B) The molecule with a greater angular H – H – H
      is water.

   B) The molecule with a greater angular H – H – H
      is water.

10. A) Lewis structures of water, methane and iodine.
    B) The molecule with a greater angular H – H – H
        is water.

11. A) Lewis structures of water, methane and iodine.
    B) The molecule with a greater angular H – H – H
        is water.

12. A) Lewis structures of water, methane and iodine.
    B) The molecule with a greater angular H – H – H
        is water.

    B) The molecule with a greater angular H – H – H
        is water.

    B) The molecule with a greater angular H – H – H
        is water.

15. A) Lewis structures of water, methane and iodine.
    B) The molecule with a greater angular H – H – H
        is water.
1. Lewis electron geometry, bond angles

2. \( \text{CO}_2 \rightarrow 6e^- + 2e^- \rightarrow [\text{C}=\text{O}]^2^- \)

3. \( [\text{CO}_3]^{2-} \)

4. \( \text{NO}_2 \)

5. \( O_3 \)

1. Draw \( \text{PCl}_3 \) bond angles + geometry

2. Draw resonance structures for \( \text{CO}_3^{2-} \), draw a resonance hybrid; what is bond order?

\[
\left[ \frac{\text{O}=-\text{N}=\text{O}}{1} \right] \leftrightarrow \left[ \frac{\text{O}=\text{N}=-\text{O}}{2} \right] \quad \frac{1+2}{2} = 1.5
\]

\[
\left[ \text{O}=-\text{N}=\text{O} \right]^{-}
\]

\[
\text{C} \quad \text{O}^{2-} \quad \left[ \begin{array}{c} \text{O}^{2-} \\ \text{O}^{2-} \\ \text{O}^{2-} \end{array} \right] \quad \left[ \begin{array}{c} \text{O}^{2-} \\ \text{O}^{2-} \\ \end{array} \right] \quad \left[ \begin{array}{c} \text{O}^{2-} \\ \text{O}^{2-} \end{array} \right]
\]

\[
\frac{1+1+2}{3} = \frac{4}{3}
\]

\( \text{PCl}_3 \)

Trigonal pyramidal