3. Conjugation
Conjugation refers to the sideways-on (π-type) overlap of two or more adjacent orbitals in a molecule, such that delocalisation of electrons is possible over two or more atoms.

The π-type overlap between two p orbitals in alkenes is the simplest example of conjugation, but the general concept extends to multiple orbitals, provided that they are all adjacent to one another (i.e., able to overlap with one another).

The simplest example of three p orbitals in conjugation is the allyl system, which can accommodate either 2, 3, or 4 π-electrons:

- allyl anion (4 π⁻)
- allyl radical (3 π⁻)
- allyl cation (2 π⁻)

Let’s build up the molecular orbital (MO) diagram for the allyl system:

- antibonding orbital (2 nodes)
- non-bonding orbital (1 node)
- bonding orbital (0 nodes)

Though it is not important at our current level of analysis, the coefficients (lobe size) of each p orbital component in the allyl system is not uniform.

Both the coefficients and phasing actually follow a sine wave, which passes through each node.

Take-home message: Conjugation is defined as sideways-on (π-type) overlap of two or more adjacent orbitals in a molecule.

The term "conjugated" was coined in 1899 by the German chemist Johannes Thiele.
Conjugation Leads to Delocalisation of Electrons and Charge: The allyl cation as an example

- Let's look at the **allyl cation** to begin with. We have only 2 electrons to accommodate in the π-system (i.e., those in the C=C bond).
- This shows us that the **lowest unoccupied molecular orbital** (LUMO) is focused on the termini of the allyl system. This is the empty orbital that nucleophiles best interact with, so we can predict that nucleophiles will only attack at C(1) or C(3).

We also learn that the 2 electrons in the HOMO are spread out (**delocalised**) over the entire allyl system, and not constrained to a single π-bond. We already met delocalisation in our earlier treatment of the MOs of methane.

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**Take-home message**: Conjugation inevitably leads to delocalisation of both electrons and charge, though the distribution is not even.
**Resonance:** A way of illustrating delocalised bonding using only localised Lewis structures

- The allyl cation is just one example of a molecule (or ion/radical) that cannot be adequately described by a single Lewis structure:

![Diagram of allyl cation with delocalised bonding]

**localised bonding picture**  
**delocalised bonding picture**

- The right-hand representation, in which the electrons and charge are **delocalised** over both carbons equally, is the true structure.

- But how are we to interpret these dotted bonds in Lewis structures? A total bond order of 1.5? This may be true above, but it’s easy to think of other molecules where there would be ambiguity.

![Diagram of formaldehyde with ambiguous bond order]

- To deal with this predicament, chemist Linus Pauling introduced the concept of **resonance** in the 1930s. By this concept, a true structure (**resonance hybrid**) is an average of two (or more) hypothetical localised structures (**canonicals**) weighted according to their contribution.

![Diagram of resonance canonicals and hybrid]

**Take-home message:** Resonance describes delocalised bonding utilising localised Lewis structures to depict hypothetical structures.

*In physics, resonance is the tendency of a physical system to oscillate at great amplitude at certain frequencies. The adoption of this word by Pauling came from Werner Heisenburg’s earlier use of harmonic oscillators as an analogy when discussing the quantum states of the helium atom.*

*The word canonical - originally a religious term - is used to describe something that follows a principle or rule. In this case, a resonance canonical follows the conventions of valence bond theory (i.e., localised bonding), as represented by Lewis structures.*
To help visualise how one resonance canonical relates to another, chemists use **curly arrows** to illustrate bonding changes.

Though curly arrows are normally used to show electron 'flow' in chemical reactions, in this context they only represent *hypothetical*, as opposed to real, bonding changes (because canonical structures themselves are hypothetical!).

The above right example illustrates that chemists are forced to use a single canonical representation* to represent delocalised molecules when drawing out reaction mechanisms, because dotted lines for partial bonds are incompatible with 'arrowing pushing'.

It is critical to understand that resonance canonical structures are **not** interconverting. The true (hybrid) structure is static and is somewhere inbetween these extremes. It is **not** a dynamic equilibrium process that shuffles back and forth like a windscreen wiper (hence the different type of arrow).

*It is conventional to draw the canonical that contributes most to the resonance hybrid, though this is not mandatory.
**Rules for Drawing Resonance Structures: Things to avoid....**

- When drawing resonance canonicals, there are several rules that we must adhere to:

1. **Nuclear positions must remain the same (only electrons are in different positions)**

   ![Resonance canonicals example 1](image1)

2. **The maximum number of valence electrons for 1st row (2nd Period) elements is 8 (octet rule). This cannot be exceeded**

   ![Resonance canonicals example 2](image2)
   
   *The nitro group is an example of a functional group that can only be drawn with separated formal charges. Don't forget that hydrogens are attached to carbon atoms just because we don't tend to draw them in!*  
   
   This is a very common error among students.

3. **All resonance forms must have the same number of unpaired electrons**

   ![Resonance canonicals example 3](image3)

   *0 unpaired electrons*  
   *2 unpaired electrons*
** Canonical Contributions to Resonance Hybrid: What makes one canonical better/worse than another? **

- The extent of contribution of a given canonical structure to the resonance hybrid is determined by its **thermodynamic stability**. To ascertain the relative stability (contribution) of canonical structures, you must use the following general guidelines:

1. Minimise number of electron-deficient atoms [i.e., $1^{st}$ row ($2^{nd}$ Period) elements with valence electrons less than 8]

   ![Diagram](image1)
   
   Put another way, breaking $\pi$-bonds to leave behind a 6 ve$^-$ carbocation is energy-raising

2. Minimise number of formally charged atoms. If unavoidable, ensure separation for unlike and like charges is minimised and maximised, respectively. [This rule arises from electrostatic attraction/repulsion forces, but also embraces rule 1 (see below right)]

   ![Diagram](image2)

   *unavoidable charge separation*

   *avoidable charge separation, but doesn't break the octet rule for any atom*

   *avoidable charge separation and fails to satisfy octet rule for carbon*

3. Place negative charge, if any, on the most electronegative atoms, and positive charge, if any, on the most electropositive atoms

4. Do not deviate from idealised bond lengths and angles

   ![Diagram](image3)

   *The molecule on the right is called Dewar benzene. It does actually exist but it is strained and unstable*
Hybridisation for Heteroatoms Revisited: Conjugation of heteroatom lone pairs

- We learnt previously that heteroatoms with only $\sigma$-bonds to their neighbours, and no unoccupied (empty) orbitals, are $sp^3$-hybridised.
- However, conjugation of a lone pair with an adjacent $p$ or $\pi$ orbital is most effective when the lone pair is situated in a pure $p$ orbital.
- Thus, conjugated heteroatoms are always $sp^2$-hybridised, even though we don't typically draw the partial double-bonding in structures.

**Amines** are $sp^3$-hybridised at N... **...but amides** are $sp^2$-hybridised at N

Exceptions to this generalisation can be found, when the strain inherent in a structure prevents the required orbital alignment.

**Take-home message:** Heteroatoms that are conjugated with an empty (or half-filled) $p$ orbital or a $\pi$ bond are always $sp^2$-hybridised, with the conjugated lone pair in a pure $p$ orbital. However, exceptions can occur when strain prevents effective orbital overlap.
**Conjugation also Leads to Stabilisation: Back to the allyl system as an example**

- We can consider the \( \pi \)-network of the allyl cation as a \( \pi \) bond conjugated with a carbocation (empty \( p \) orbital), and build the MO scheme by starting with the \( \pi \) and \( \pi^* \) orbitals of ethylene. Naturally, we arrive at the same MOs as earlier (see below left).

- Similarly, we can construct the MO scheme for the allyl anion in the same sort of way, but we must now feed in 2 more electrons.

**the allyl cation MOs built from \( \pi \) orbitals and an empty \( p \) orbital**

**the allyl anion MOs built from \( \pi \) orbitals and a filled \( p \) orbital**

- In both cases (and this is true for the 3e\(^-\) allyl radical also), we can see that conjugating a \( \pi \) bond with a \( p \) orbital, regardless of the number of electrons in the \( p \) orbital, leads to electronic stabilisation (by an amount \( E_{\text{stab}} \)).

- Compare and contrast the above situations with the \( \text{H}_2 \) molecule and the (notional) \( \text{He}_2 \) molecule, the latter of which is not stable. The critical difference here is the presence of a \( \pi^* \) orbital on one component, which mixes in to prevent \( \psi_2 \) being raised in energy above that of the \( p \) orbital.

**Take-home message:** A cation, anion, or radical that is conjugated with an alkene is often said to benefit from allylic stabilisation, even though inspection of the MO diagrams shows that it is strictly the \( \pi \) electrons of the alkene that are being lowered in energy!
Conjugation of $\pi$-Bonds with One Another: Butadiene as an example

- So far we've seen $p$ orbitals conjugated with $\pi$ bonds (e.g., allyl system) and $p$ orbitals conjugated with one another (e.g., oxocarbenium ion), all leading to stabilisation and electron/charge delocalisation.

- Another possibility is to conjugate $\pi$ bonds with one another, and the simplest example of this is butadiene:

As for the allyl anion, mixing in $\pi^*$ orbitals lowers the energy of $\frac{1}{2}$, such that net stabilisation can still occur for a 4e$^-$ system (c.f. He$_2$)

- Just as for the other cases of conjugation that we have discussed, conjugating $\pi$ bonds in this way again leads to electronic stabilisation (by an amount $E_{\text{stab}} - E_{\text{destab}}$).

**Take-home message:** Conjugation of $\pi$ bonds with one another leads to electronic stabilisation, so conjugated dienes (or related systems) are generally always more thermodynamically-stable than their non-conjugated isomers.
Effect of Conjugation on Colour: Longer conjugated systems enable absorption in the visible range

- Increasing conjugation lowers the HOMO-LUMO gap ($\pi \rightarrow \pi^*$), and means that photons of increasingly longer wavelength are absorbed.

- Many dyes make use of conjugated electron systems to absorb visible light, giving rise to strong colors.

- For example, the long conjugated hydrocarbon chain in $\beta$-carotene leads to its strong orange color. Conjugated systems of <8 conjugated double bonds absorb only in the UV region and are colorless to the human eye.

- This absorption of light in the UV to visible spectrum can be quantified using ultraviolet–visible spectroscopy, and forms the basis for the entire field of photochemistry.

**Take-home message:** Increased conjugation lowers the HOMO-LUMO gap ($\pi \rightarrow \pi^*$), and compounds with sufficiently extended conjugation can absorb visible photons, leading to coloured compounds (e.g., dyes). This concept also underpins UV-vis spectroscopy and photochemistry.
**Effect of Conjugation on Reactivity: Butadiene as an example**

- We already know that butadiene is more **stable** than two separate ethylenes (in terms of net electronic stabilisation) but it may surprise you that it is also more **reactive**.

- If this seems counterintuitive, you should remember that **stability** is a *thermodynamic* property, whereas **reactivity** is a *kinetic* property, so we are talking about different things.

- Our MO schemes show that butadiene has both a **higher HOMO** and a **lower LUMO** than ethylene (see below left), so it is both more nucleophilic and more electrophilic.

- Because both the HOMO and the LUMO **coefficients** are largest at the terminal atoms C(1) and C(4), this is where both nucleophiles and electrophiles would attack:

- Drawing **resonance canonicals** predicts the same sites of reactivity as the orbital coefficients:

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**Take-home message 1**: Conjugation of an alkene with another (simple) alkene increases *both* nucleophilicity and electrophilicity.

**Take-home message 2**: Regioselectivity of attack of nucleophiles/electrophiles on a conjugated system can be predicted by sizes of orbital coefficients in the LUMO/HOMO (or in most cases by inspection of charge distribution in resonance canonicals).
Effect of Conjugation on Reactivity: Conjugation of alkenes with oxygen lone pairs

- What happens to alkene reactivity if we conjugate the C=C bond with a methoxy group (-OMe) to give an enol ether?
- The oxygen lone pair is now conjugated with the C=C bond, so the lone pair occupies a \( p \) orbital in order to maximise overlap.
- The MOs for the enol ether are analogous to those for the allyl anion, but the symmetry is broken and all of the MOs are lowered in energy due to the electronegative oxygen.

\[ \text{allyl anion} \quad \text{enol ether} \]

Relative to ethylene, we can see that the effect of conjugating the C=C bond with a methoxy group is to significantly raise the HOMO and make the C=C bond much more reactive towards electrophiles. This polarisation of the C=C bond is also apparent from resonance canonicals:

Take-home message: Conjugation of alkenes to a lone pair makes the C=C bond more nucleophilic (raises the HOMO).
Effect of Conjugation on Reactivity: Conjugation of alkenes with carbonyl (C=O) groups

- With butadiene, we have shown that the reactivity of an alkene towards both electrophiles and nucleophiles is increased by conjugating it with another C=C bond.
- What happens then to alkene reactivity if we conjugate the C=C bond with a carbonyl group (C=O) instead of another alkene (C=C)?
- Introduction of an electronegative oxygen into the system lowers the energies of all the MOs, including the HOMO and the LUMO.

Relative to ethylene, we can see that the effect of conjugating the C=C bond with a carbonyl group is to significantly lower the LUMO and make the C=C bond much more reactive towards nucleophiles. This polarisation of the C=C bond is also apparent from resonance canonicals:

Take-home message: Conjugation of alkenes to carbonyl (C=O) groups makes the C=C bond more electrophilic (lowers the LUMO).
**Mesomeric Effects:** Electron donation or withdrawal effects through a \( \pi \)-bonding network

- For molecules containing \( \pi \)-bonds, we can crudely assume that the \( \pi \)-bonding network is independent from the \( \sigma \)-bonding network.
- The **inductive effect** – based on electronegativity – refers to electron-donation (\( +I \)) or withdrawal (\( -I \)) effects operating in the \( \sigma \)-network.
- We’ve now learnt that electron-donation or withdrawal effects can also operate in the \( \pi \)-network, and that these can be qualitatively described using **resonance** structures.
- These effects are generally termed **mesomeric effects**, and given the symbols \( +M \) (for \( \pi \)-electron donors) or \( -M \) (for \( \pi \)-electron acceptors).

**Take-home message:** Mesomeric (\( +M,-M \)) effects describe the donation or withdrawal of electron density through the \( \pi \)-network of a molecule (contrast with inductive effects in \( \sigma \)-network). A \( -M \) **group** makes a conjugated C=C bond more **electrophilic** by lowering the LUMO, whereas a \( +M \) **group** makes a conjugated C=C bond more **nucleophilic** by raising the HOMO.
Hyperconjugation (\(\sigma\)-Conjugation): Conjugation involving \(\sigma\)-bonds in organic molecules

- So far we have only considered the conjugation of \(p\) orbitals (filled or empty) and \(\pi\)-orbitals (\(\pi\) or \(\pi^*\)). This type of conjugation - involving side-on interaction of \(p-p\), \(p-\pi\) or \(\pi-\pi\) orbital combinations - is more specifically termed \(\pi\)-conjugation.

- It is perfectly possible for \(\sigma\)-orbitals to engage in conjugation also, either by side-on overlap with \(p\) or \(\pi\) orbitals, or with other \(\sigma\)-orbitals. This type of conjugation - which is inherently weaker, as we'll see - is called hyperconjugation\(^*\) (or \(\sigma\)-conjugation).

- A classic example of this interaction is found in the tert-butyl carbocation, where the system is stabilised by donation of electron density from the C–H bonds on the attached methyl groups to the empty \(p\) orbital.** Note the geometrical requirement here.

This interaction is much less stabilising than \(\pi\)-conjugation (i.e., interaction with an adjacent alkene, electron-rich aromatic ring, or a heteroatom lone pair), because the donor orbital (a \(\sigma_{C-H}\) bonding orbital) is far lower in energy than a \(\pi\) bonding orbital or a non-bonded pair, and so the orbital-orbital interaction is less strong (see above MO scheme). Orbital overlap being less efficient may also play a role.

- It is not only C–H bonds that are effective 'donor' orbitals in hyperconjugation - C–C bonds are also competent and suitably electron-rich. Even more electron-rich \(\sigma\)-bonds, like C–SiMe\(_3\) are better still (a fact that underpins much of organosilicon chemistry...).

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\*The term was introduced by Mulliken in the 1930s to describe the "conjugation" of CH\(_3\) with double or triple bonds. "Hyper" is derived from the Greek word for "over", versus "hypo" for "under". As \(\sigma\)-conjugation is much weaker than \(\pi\)-conjugation, it arguably should have been called 'hypoconjugation'!

**It is important to recognise that the molecule/ion is not 'frozen' in this geometry. Rapid C–C bond rotation still occurs, so the hyperconjugative stabilisation is switched on and off very rapidly. However, the geometries with the lowest energy are those in which this interaction can take place.
**Classification of σ-Bonds as Mesomeric Donors (+M) or Acceptors (−M): Positive versus negative hyperconjugation**

- Now we know that σ-bonds can interact with $p$ or $\pi$-orbitals via conjugation, we need to learn how to classify σ-bonds as mesomeric donors (high-energy $\sigma$) or acceptors (low-energy $\sigma^*$) to/from the $p/\pi$ system.

A $+M$ mesomeric effect (AKA "positive hyperconjugation") occurs when a filled $\sigma$-orbital serves as a donor (electron source) in the stabilising interaction, the effect being more powerful when the $\sigma_{C-M}$ orbital is higher in energy (typically "M" more electropositive).

A $-M$ mesomeric effect (AKA "negative hyperconjugation") occurs when an empty $\sigma^*$-orbital serves as an acceptor (electron sink) in the stabilising interaction, the effect being more powerful when the $\sigma^*_{C-X}$ orbital is lower in energy (typically "X" more electronegative).

![Diagram](https://via.placeholder.com/150)

- Because these interactions are hyperconjugative in nature, they are inherently much weaker than mesomeric effects involving $\pi$-conjugation. This is, for example, why a methoxy group (-OMe) is a much stronger $-M$ group than a methyl (-CH$_3$) group, or a carbonyl group (-C=O) is a much stronger $-M$ group than a trifluoromethyl (-CF$_3$) group.

**Take-home message:** σ-Bonds can act as mesomeric donors ($+M$) or acceptors ($-M$) in the same way as functional groups having $p$ or $\pi/\pi^*$ orbitals, though the electron donation/withdrawal effects are generally much weaker. The terms 'positive' or 'negative' hyperconjugation are sometimes used for these phenomena.

**Effect of Hyperconjugation on Stability:** Carbocations and alkenes

- Although hyperconjugation is a relatively weak effect, when compared to π-conjugation, its effect is magnified when several such interactions can occur within the same molecule.

- For example, hyperconjugation accounts for the stability ordering of carbocations: $\text{CH}_3 < 1^c < 2^c < 3^c$.

- It is also the reason that more heavily-alkylated alkenes are more thermodynamically-stable than less-alkylated alkenes.

- Chemists usually refer to alkyl groups "stabilising" carbocations or alkenes, but we should remember that what is actually being stabilised in electronic terms is the C–H electrons (look at the MO interaction diagrams). This is a subtle point, but worth remembering!

**Take-home message:** Increasing alkyl substitution on carbocations or alkenes leads to increasing thermodynamic stability of the molecule, by increasing the number of stabilising hyperconjugative interactions that are possible.
Effect of Hyperconjugation on Conformation: Lowest energy geometries of organic molecules can be controlled by hyperconjugation

- Weak hyperconjugative interactions ($6 \times \sigma_{\text{C-H}} \rightarrow \sigma^*_{\text{C-H}}$) are responsible for the lowest energy conformation of ethane being staggered (see F. Weinhold, *Nature* 2001, 539). The eclipsed conformation is also destabilised by repulsive overlap of the filled $\sigma_{\text{C-H}}$ orbitals.

\[
\begin{align*}
\text{staggered} & \quad \sigma_{\text{C-H}} \\
(0.0 \text{ kcal mol}^{-1}) & \quad \sigma^*_{\text{C-H}}
\end{align*}
\]

\[
\begin{align*}
\text{eclipsed} & \quad \sigma_{\text{C-H}} \\
(3.0 \text{ kcal mol}^{-1}) & \quad \sigma^*_{\text{C-H}}
\end{align*}
\]

- As another example, the lowest energy conformation of acetaldehyde is one in which a C–H bond eclipses the C=O group, because this gives the best orbital alignment for stabilising $\sigma_{\text{C-H}} \rightarrow \pi^*_{\text{C=O}}$ interactions.

\[
\begin{align*}
\text{eclipsed } C=H
\end{align*}
\]

- This $\sigma_{\text{C-H}} \rightarrow \pi^*_{\text{C=O}}$ hyperconjugative interaction is also part of the reason that ketones are less reactive than aldehydes, as it raises the energy of the $\pi^*_{\text{C=O}}$ LUMO and makes the C=O bond less electrophilic.

**Take-home message**: Hyperconjugation can stabilise certain conformations of organic molecules, and is part of the reason that hydrocarbons prefer staggered conformations about their C–C bonds (but beyond the simple case of ethane, steric effects also play a role).
**C, Z, and X-Type Substituents:** A general classification of substituents attached to alkenes, aromatic rings, or carbocations

**C-Substituents** (where "C" denotes "conjugated") are simple conjugated systems of carbon atoms, like vinyl or phenyl. They are either moderate π-donors (M) or π-acceptors (–M), depending upon what they are conjugated with, responding to and stabilising electron demand or electron excess, as appropriate. They are quite strongly σ-withdrawing (–I effect) by virtue of the carbon atom hybridisation.

![C-Substituents diagram]

**Z-Substituents** are strong π-acceptors (–M) and, since most of them have electronegative atoms, they are moderate (but occasionally strong) σ-acceptors (–I).

![Z-Substituents diagram]

**X-Substituents** are by definition π-donors, but they fall into three distinct sub-classes, depending on their mode of π-donation (lone pair or σ-bond hyperconjugation) and their electronegativity. Amino and hydroxyl/ether groups exert a strong +M effect using their lone pairs [though this is greatly diminished when the heteroatom is further conjugated with a Z-group] and a strong –I effect. Thiol/thioether groups fall into the same class, but both +M and –I effects are toned down. Simple alkyl groups (e.g., Me, Et) exert a weak +M effect by overlap of their C–H (or C–C) bonds with the π system (hyperconjugation), and exert a –I effect. Finally, halogens are weak +M groups (because their lone pairs are tightly bound) but are strongly inductively-withdrawing (–I).

![X-Substituents diagram]

For the original classification of these substituent types by Houk, see: *J. Am. Chem. Soc.* 1973, 95, 4092
**Revision Checklist**

- Conjugation is the sideways-on (π-type) overlap of one or more orbitals, and this leads to the delocalisation of electrons and charge.
- Pauling's theory of resonance* is used to depict delocalised bonding in organic molecules, when they are drawn as Lewis structures.
- Resonance canonicals are hypothetical structures - the true structure (resonance hybrid) lies somewhere between the extremes.
- There are rules when drawing resonance canonicals, and general guidelines to determine the lowest energy contributor.
- Conjugated heteroatoms are always $sp^2$-hybridised, with the conjugated lone pair in a $p$ orbital for maximum overlap.
- Conjugation between a filled orbital and an empty orbital is always stabilising, as is conjugation between one or more $\pi$-bonds.
- Conjugation of C=C bonds decreases the HOMO/LUMO gap, and highly conjugated compounds can be coloured (e.g., dyes).
- Conjugation can affect reactivity (electrophilicity/nucleophilicity) by altering the HOMO/LUMO energy of, for example, a C=C bond.
- Conjugating two simple C=C bonds together, as in butadiene, increases both the nucleophilicity and electrophilicity of the $\pi$-system (a hallmark of so-called "C-type" substituents, which includes a simple phenyl group, *vide infra*).
- A mesomeric effect ($+M, -M$) is the electron donating or withdrawing nature of a substituent that is conjugated with an unsaturated group (e.g., alkene, aromatic ring). Contrast with the inductive effect ($+I, -I$), which operates in the $\sigma$-network only and is short range.
- Hyperconjugation ($\sigma$-conjugation) is conjugation where at least one of the orbitals is a $\sigma$-orbital ($\sigma$ or $\sigma^*$). It is a weaker stabilising effect than $\pi$-conjugation because $\sigma/\sigma^*$ orbitals are very low/high in energy and therefore interact quite poorly with other orbitals.
- Hyperconjugation can affect molecular stability (e.g., carbocations, alkenes) and also conformation (e.g., ethane, acetaldehyde).
- A substituent that is conjugated with an unsaturated group (e.g., alkene, aromatic ring) can be classified as C-, Z-, or X-type, based on its $\pi$-donor/acceptor properties. This is important to understand the effect of substituents on stabilisation of charged intermediates (e.g., carbocations, carbanions), as well as the chemical reactivity of substituted alkenes or aromatic rings.

*Confusingly, many organic chemists use the terms "resonance", "conjugation", and "delocalisation" almost interchangeably, but whilst they are interrelated, they have different meanings. The somewhat misleading or redundant terms "resonance effect" and "resonance-stabilised" are also in widespread use.