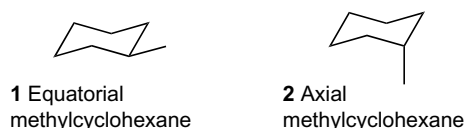


IMPACT 7 ON UNDERSTANDING CHEMICAL PROPERTIES

Applications of molecular orbital theory

One goal of computational chemistry—at least when applied to large molecules—is to gain insight into trends in molecular properties without necessarily striving for ultimate accuracy. For example, consider the prediction of standard enthalpies of formation of the equatorial (1) and axial (2) conformations of methylcyclohexane in the gas phase. If mean bond energies are used, the same enthalpy of formation for both conformers is obtained. However, it has been observed experimentally that molecules in these two conformations have different standard enthalpies of formation as a result of the greater steric repulsion when the methyl group is in an axial position than when it is equatorial.



Computational chemistry is now widely used to estimate standard enthalpies of formation of molecules with complex three-dimensional structures, and can distinguish between different conformations of the same molecule. However, good agreement between calculated and experimental values is relatively rare. Computational methods almost always predict correctly which conformation of a molecule is most stable but do not always predict the correct numerical values of the difference in enthalpies of formation.





Each software package has its own procedures; the general approach, though, is the same in most cases: the structure of the molecule is specified and the nature of the calculation selected. When the procedure is applied to the two isomers of methylcyclohexane in the gas phase, a typical *ab initio* value for the standard enthalpy of formation of equatorial isomer in the gas phase is -153 kJ mol^{-1} whereas that for the axial isomer is -139 kJ mol^{-1} , a difference of 14 kJ mol^{-1} . The experimental difference is 7.5 kJ mol^{-1} .

Computational methods are also available that model the effect of the solvent on the enthalpy of formation of the solute. Again, the numerical results are only estimates and the primary purpose of the calculation is to predict whether interactions with the solvent increase or decrease the enthalpy of formation. As an example, consider the amino acid glycine, which can exist in a neutral or zwitterionic form, $\text{H}_2\text{NCH}_2\text{COOH}$ and $^+\text{H}_3\text{NCH}_2\text{CO}_2^-$, respectively, in which in the latter the amino group is protonated and the carboxyl group is deprotonated. Molecular modelling shows that in the gas phase the neutral form has a lower enthalpy of formation than the zwitterionic form. However, in water the opposite is true on account of the strong interactions between the polar solvent and the charges on the zwitterion.

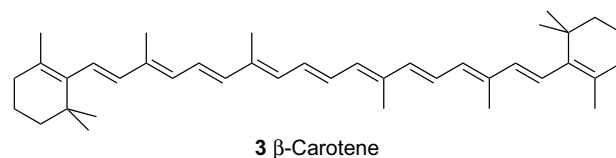
Molecular orbital calculations may also be used to predict trends in electrochemical properties, such as standard potentials. Several experimental and computational studies of aromatic hydrocarbons indicate that decreasing the energy of the LUMO enhances the ability of a molecule to accept an electron into the LUMO, with an attendant increase in the value of the molecule's standard potential.

A molecule can absorb or emit a photon of energy hc/λ , resulting in a transition between two quantized molecular energy levels. The transition of lowest energy (and longest wavelength) occurs between the HOMO and LUMO. A reliable approach for estimating transition wavelengths makes use of computational chemistry to correlate the HOMO–LUMO energy gap with the wavelength of absorption. For example, consider the linear polyenes shown in Table 1, all of which absorb in the ultraviolet region of the spectrum. The table also shows that, as expected, the wavelength of the lowest-energy electronic transition decreases as the energy separation between the HOMO and LUMO increases. The smallest HOMO–LUMO gap and longest wavelength of absorption correspond to octatetraene, the longest polyene in the group. It follows that the wavelength of the transition increases with increasing number of conjugated double bonds in linear polyenes. Extrapolation of the trend suggests that a sufficiently long linear polyene should absorb light in the visible region of the electromagnetic spectrum. This is indeed the case for β -carotene (3), which absorbs light with $\lambda \approx 450 \text{ nm}$. The ability of β -carotene to absorb visible light is part of the strategy employed by plants to harvest solar energy for use in photosynthesis.

Table 1
Correlation of *ab initio* calculations and spectroscopic data for four linear polyenes

	$\Delta E_{\text{HOMO-LUMO}}/\text{eV}^*$	$\lambda_{\text{transition}}/\text{nm}$
	18.1	163
	14.5	217
	12.7	252
	11.6	304

1 eV = $1.602 \times 10^{-19} \text{ J}$



There are several ways in which molecular orbital calculations lend insight into reactivity. For example, electrostatic potential surfaces may be used to reveal an electron-poor region of a molecule, a region that is susceptible to association with or chemical attack by an electron-rich region of another molecule. Such considerations are important for assessing the pharmacological activity of potential drugs. Computational chemistry may also be used to model species that may be too unstable or short-lived to be studied experimentally. For this reason, it is often used to study the transition state, with an eye toward describing factors that increase the reaction rate.