

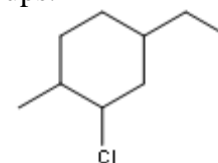
Ch 4 Cycloalkanes and their Stereochemistry

Cycloalkanes (or alicyclic compounds) are alkanes with rings.

- If you remove an H from each of two C's, you can bond the two C's together, so the general formula for a cycloalkane is C_nH_{2n} .
- Includes natural compounds such as [chrysanthemic acid](#) (has a 3-membered ring), [prostaglandins](#) (have 5-membered rings), and [steroids](#) (has a system with four fused rings).

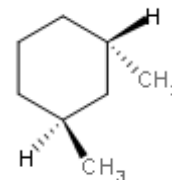
Nomenclature Rules

- Find the parent. If (# of C's in ring) \geq (# of C's in longest chain), then ring is parent, and the chains are substituents. If not, longest chain is parent and ring is a substituent, which is a cycloalkyl group. Name ring as an alkane preceded by cyclo, so a 3-membered parent ring is cyclopropane. A 3-membered substituent ring is cyclopropyl.
- Number substituents and write the name. Choose C #1 so that lowest combination of substituent #'s is created. Then, write name so that substituents are written in alphabetical order.
 - a) If two different combinations have identical #'s, then match #'s with alphabetical order.
 - b) Treat halogen substituents (bromo, chloro, and iodo) just like alkyl groups.
- See 2-chloro-4-ethyl-1-methylcyclohexane (at right). Note how substituents are listed in alphabetical order. Also, note how lowest set of #'s is used (1, 2, & 4, not 1, 2, & 5, or 1, 3, & 4, or 1, 3, & 6)



Cis-Trans Isomerism

- For open-chain alkanes, we saw that the (cylindrically-symmetrical) σ bonds can rotate, so that different conformations are possible. In this case, two substituents attached to neighboring C's can rotate from the same side (eclipsing) to the opposite side (anti).
- For cycloalkanes, the ring's bonding structure prevents this rotation from happening.
- Cis-Trans is a type of Stereoisomerism, which is where different molecules have all of the same atoms, and the atoms each have the same attachments to other atoms, but their 3D arrangements in space (their geometries) are different.
- Cis-Trans refers to different spatial arrangements of atoms about a ring or double bond.
- For cycloalkanes possessing two substituents that are each attached to different C's in a ring, cis means that both substituents are on the same side of the ring. That is, both are on top or both are on bottom.
- Trans means both substituents are opposite sides of the ring. One is on top and one is on bottom, such as with *trans* 1,3-dimethylcyclohexane (at right).



Stability of Cycloalkanes and Angle Strain

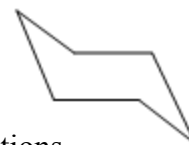
- Adolph von Baeyer's theory (1885) proposed that angle strain is introduced when a tetrahedral atom has bond angles that deviate from 109.5° .
- Cyclopropane's ring is triangular with 60° bond angles, which make the ring relatively unstable. As a result, cyclopropane has a large heat of combustion with O_2 (-115 kJ/mol, very exothermic).
- Cyclobutane's ring is square with 90° bond angles, which is also unstable and has a large heat of combustion (-110 kJ/mol).
- Cyclopentane's ring has 108° bond angles and only a small amount of angle strain.
- Baeyer's theory breaks down for larger rings, which Baeyer thought were flat and could not exist due to large angle strains.
- However, larger rings have 3D bonding that "puckers" out of plane when their σ bonds rotate.
- Cyclohexane adopts a 3D shape that allows all bond angles to be at 109.5° , so that there it has no angle strain.

Conformations of Small Cycloalkanes

- Cyclopropane is flat with 60° bond angles. This causes the σ bonds to be "bent", so that the bonding orbitals do not meet head-on, and have less overlap. As a result, the bonds are weaker and more reactive than normal alkane bonds. Cyclopropane also has a lot of torsional strain because its H's must eclipse each other.
- Cyclobutane has less angle strain than cyclopropane with its 90° bond angles, but more torsional strain because it has more eclipsing H's. This causes the molecule to bend somewhat, so that one C is out-of-plane, and the molecule is not completely flat. The result is that torsional strain is reduced by removing some of the eclipses, but at the expense of a small increase in angle strain.
- Cyclopentane would have very little angle strain if flat, but would have a great deal of torsional strain from eclipsing H's. So, like cyclobutane, the molecule bends somewhat with one C out-of-plane, so that again torsional strain is reduced at the expense of a small increase in angle strain.

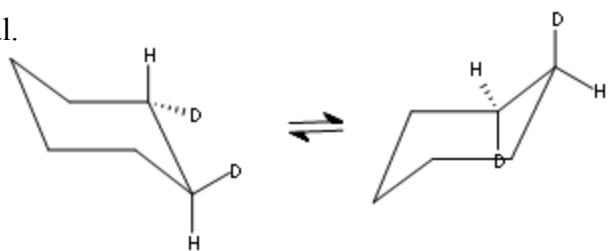
Conformations of Cyclohexane

- Cyclohexane eliminates all angle and torsional strain by adopting the "chair" conformation (at right), which has only 109.5° bond angles. Essentially, C's on opposite ends point bend away from the plane in opposite directions. One is up, forming the chair's back, while the other is down, forming the chair's footrest. The other four C's are in the same plane, forming the seat of the chair.
- Cyclohexane can also adopt a higher-energy (less-stable) conformation called the "twist-boat", where the end C's both point up, and the other four twist slightly out of plane. It still has practically no angle strain, but 23 kJ/mol combined steric and torsional strain.



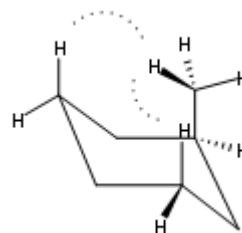
Axial and Equatorial Bonds in Cyclohexane

- Each C in cyclohexane has two bonds to H's. The two bonds point in different directions.
- Axial (Ax) is perpendicular to the ring's plane and parallel to its axis. Three of the six axial bonds on the molecule point up, and the other three point down. The up and down bonds are on alternating C's.
- Equatorial (Eq) is in the ring's plane and perpendicular to its axis.
- The molecule can undergo a ring flip by bending the chair's foot up and, at the same time, bending the chair's back down. As a result, cyclohexane rings have two conformations.
- The ring flip causes axial H's to become equatorial, and equatorial H's to become axial. When an up Ax H becomes Eq, the other H on the C goes from Eq to down Ax. When a down Ax H becomes Eq, the other H on the C goes from Eq to up Ax.
- Substituents, such as methyls, on the ring are also either Eq or Ax, and change positions during a ring flip.



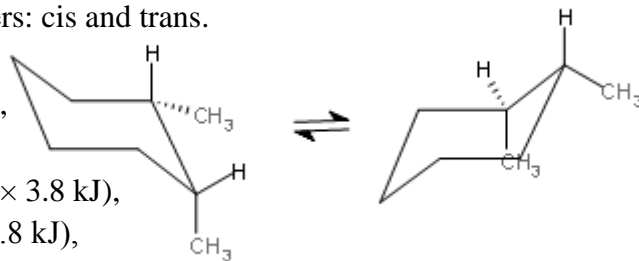
Monosubstituted Cyclohexanes

- Methylcyclohexane's two conformations are different. One has an Ax CH₃ (see right), while the other has an Eq CH₃.
- The Ax CH₃ is less stable and requires 7.6 kJ more energy.
- The energy difference occurs because the Ax CH₃ is too close to the two Ax H's on C's 3 and 5. This type of strain on a cyclohexane ring is called a 1,3-diaxial interaction.
- Each H/CH₃ strain is identical to a gauche, which requires 3.8 kJ, as seen in chapter 3.
- The concentration ratio for the two conformations can be found by:
 $\Delta E = - (RT)\ln(K)$ where $K = [\text{Ax}] / [\text{Eq}]$ and $R = 8.314 \text{ J/K}\cdot\text{mol}$
- Energies for diaxials between H and other substituents are given in McMurry, Table 4.1.



Disubstituted Cyclohexanes

- 1,2-dimethylcyclohexane has two stereoisomers: cis and trans.
- The cis has one Ax CH₃ and the other Eq. Ring flips change the Ax to Eq and vice-versa, so that both conformations are identical.
- In both cases, the Ax CH₃ has two diaxials ($2 \times 3.8 \text{ kJ}$), and the two CH₃'s are gauche to each other (3.8 kJ), giving each conformation a total strain energy of 11.4 kJ.



- Trans has two different conformations. One has two Ax CH₃'s (left image) and the other has two Eq CH₃'s (right image).

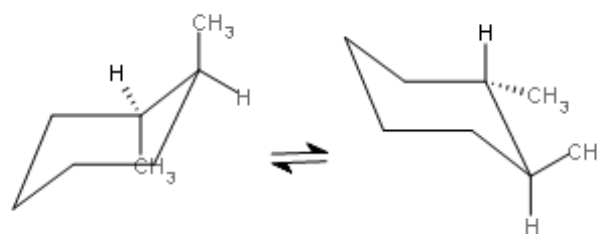
- The both Ax conformation has two diaxials on each CH₃, which is four total diaxials.

The two CH₃'s are not gauche to each other, so the diaxials give $E = 4 \times 3.8 \text{ kJ} = 15.2 \text{ kJ}$.

- The both Eq conformation has no diaxials, but the CH₃'s are gauche to each other.

So, the gauche gives $E = 3.8 \text{ kJ}$.

Energy is much lower than if both are Ax, so both Eq is much more stable.



Polycyclic Compounds (having more than one ring)

- If two or more rings share at least one C, then we say the rings are fused.
- If two rings share two C's, we call the two shared C's bridgeheads.
- Decalin has ten C's and two cyclohexane rings.

The two rings share a pair of adjacent bridgehead C's.

Decalin is called bicyclic because two rings must be broken to create an acyclic structure.

[Decalin](#) has two different stereoisomers: cis and trans (Fig 4.17).

- Steroids, such as testosterone and cholesterol, have four fused rings, which are connected by three pairs of bridgehead C's.

Three rings have six members and the other has five members.

- Compounds with one pair of bridgeheads are named with the total number of ring C's as the parent alkane. The name begins with bicyclo, and there are numbers in brackets between bicyclo and the alkane name. The numbers describe how many intervening C's are between the bridgeheads for each path from one bridgehead C to another. The numbers are separated by period dots, and are arranged highest to lowest.

- For instance, [norbornane](#) (McMurry, Section 4.9) is bicyclo[2.2.1]heptane.

There are three paths between the bridgeheads, where two paths pass through two more C's, and the other path passes through one more C.

- Norbornane's cyclohexane ring is locked in a boat conformation, where the two bridgeheads C's are both at the top of the cyclohexane ring.

Practice drawing norbornane until this makes sense.

Note that the three front C-C bonds are drawn with thicker lines than the other bonds.

- [Camphor](#) (McMurry, Section 4.9) is a naturally-occurring norbornane derivative that is substituted with three methyls and a carbonyl.