Cyclohexanes

- Cyclohexane is a six membered carbocycle of formula \( \text{C}_6\text{H}_{12} \).
- There are two extreme conformations of cyclohexane (the planar and chair conformations) that can be envisaged.

  Planar conformer → puckering → Chair conformer

- In the planar conformation postulated in the Baeyer theory, the bond angle in the ring is 120°, all 12 C-H bonds are eclipsed and as a result very unstable.
- Recall that the combustion data of cyclohexane suggests that it is free from ring strain and torsional strain.
In the chair conformation of cyclohexane, all 12 C-H bonds are staggered and the bond angle is 109.5° (tetrahedral bond angle).

With no angle strain and no torsional strain, the chair conformer of cyclohexane is very stable and is the preferred conformation in which cyclohexane systems exist in.
Cyclohexanes
Chair Conformers

• Looking at the chair conformation, one can identify a back-rest, a seat and a leg-rest like that of a chair.
Cyclohexanes

Boat Conformations

• Boat conformations are also possible with cyclohexane systems, but they are of higher energy than the chair conformations.
• Of all conformations of cyclohexane, the chair conformations are of least energy and thus most stable.
• Chair conformations are therefore the most realistic representations of cyclohexanes.
Cyclohexanes
Chair Conformation: Axial and Equitorial Bonds

- There are two types of bonds in cyclohexanes: Equitorial bonds are oriented towards the rings equator, while axial bonds are on the rings axis.
Substituted Cyclohexanes

Ring flipping

- To ring flip, identify where the substituents are.
- In one conformer, push up at C-4 and down at C-1 to obtain the $^4C_1$ conformer.
- The other conformer is obtained by pushing up at C-1 and down at C-4 to provide the $^1C_4$ conformer.
Substituted Cyclohexanes
Drawing Chair Conformations of Cyclohexanes

• Draw two parallel lines, slanted downward and slightly offset from each other.

• Locate the topmost carbon atom above and to the right of the plane and connect the bonds.

• Locate the bottom-most carbon atom below and to the left of the plane of the middle four carbons and connect the bonds.

• Note that the bonds to the bottom-most carbon are parallel to the bonds to the top-most carbon.
Substituted Cyclohexanes
Drawing Chair Conformations of Cyclohexanes

• Draw the six axial bonds on each carbon parallel to the ring axis and alternating up-down.

• Now add the six equatorial bonds on each carbon in three sets of two parallel lines. Each set is also parallel to two ring bonds.
Substituted Cyclohexanes

Chair Conformation: Axial and Equitorial Bonds

- In methylcyclohexane, the methyl group can be in an equatorial or axial position.
- We might, therefore, expect to find two conformers of methylcyclohexane.
Substituted Cyclohexanes
Stability of Cyclohexane Conformers

• Although cyclohexane rings rapidly flip between conformations at room temperature, the two conformers of a monosubstituted cyclohexane are not of equal stability.

![Diagram of cyclohexane conformers]

\[ ^1C_4 \text{ conformer} = 5\% \quad ^4C_1 \text{ conformer} = 95\% \]

• In the \(^1C_4\) conformer, there is van der Waals strain between hydrogens of the axial CH\(_3\) and hydrogens at C-3 and C-5, while in the \(^4C_1\) conformer, there is a smaller van der Waals strain between hydrogens at C-1 and hydrogens at C-3 and C-5.
A look at molecular conformations and their relative energies (conformational analysis) depicts the relative stabilities of the two conformers.

As a generalization, for other monosubstituted cycloalkanes: "a substituent is almost always stable in an equatorial position than in an axial position".
Substituted Cyclohexanes
Stability of Conformers

• The exact amount of 1,3-diaxial steric strain for axial groups depends on the nature and size of the axial group.

• The steric strain increases through the series CH$_3$- $<$ CH$_3$CH$_2$- $<$ (CH$_3$)$_2$CH- $<$ (CH$_3$)$_3$C- in parallel with increasing bulk of the successively larger alkyl groups.

![Diagram showing ring flip and percentages](image)

• There is severe 1,3-diaxial interaction involving the $t$-butyl group in $^1$C$_4$, while decreased van der Waals strain in $^4$C$_1$. 
Conformational Analysis of 1,2-Dimethylcyclohexane

• Whereas monosubstituted cycloalkanes prefer its substituent in an equatorial position, in disubstituted cyclohexanes, the situation is more complicated because the steric effects of both substituents must be taken into account.

• All steric interactions in both possible chair conformers must be analyzed before deciding which conformer is favored (more stable).

• Between cis- and trans-1,2-dimethylcyclohexane, which is most stable?
Disubstituted Cyclohexanes

*Cis* and *Trans* Substituted Systems

- The terms *cis/trans* describe the relative orientations of substituents on systems that are conformationally restricted.

- In rings, two substituents are considered *cis when they are oriented* on the same side of the planar ring and *trans* when they are on opposite sides of the planar ring.

- Note that the terms *cis/trans* and *axial/equatorial* describe unrelated properties of substituents on a cyclohexane skeleton.
Disubstituted Cyclohexanes
Conformational Analysis of 1,2-Dimethylcyclohexane

Cis-1,2-Dimethylcyclohexane

- In both chair-conformations of cis-1,2-dimethylcyclohexane, there is one methyl group in an axial position and one in an equatorial position. Therefore, the energies of these conformations are the same.
Disubstituted Cyclohexanes
Conformational Analysis of 1,2-Dimethylcyclohexane

Trans-1,2-Dimethylcyclohexane

- One *trans* conformation has both methyl groups equatorial and no 1,3-diaxial interactions. The ring-flipped conformation has both methyl groups axial with four 1,3-diaxial interactions.

- The $^1C_4$ conformer is the most stable (>99%), while the $^4C_1$ conformation is <1%. 
Practice Questions
Conformations of Cycloalkanes and Related Molecules

(1) Draw the two chair conformations ($^5\text{C}_2$ and $^2\text{C}_5$) of menthol (2-isopropyl-5-methylcyclohexanol) that occurs naturally in mint oils and determine the most stable conformer.

(2) Draw the two chair conformations ($^4\text{C}_1$ and $^1\text{C}_4$) of D-glucose, the most prevalent sugar in nature, and determine the most stable conformer.
Reactions of Cycloalkanes

• Cycloalkanes undergo the common reactions of alkanes:
  (a) Combustion
  (b) Halogenation
• Further, cyclopropane and cyclobutane are unstable due to their ring strain compared with the larger cycloalkanes (cyclopentane and cyclohexane) and do undergo ring opening reactions that relieve the angle strain.
• Cyclopropanes and cyclobutanes react with hydrogen, even though they are not alkenes. In the presence of a nickel catalyst, the rings open to form corresponding acyclic (open chain) alkanes.
Reactions of Cycloalkanes

- Hydrogenolysis (cleavage by hydrogen) of cyclopropanes and cyclobutanes provide straight chain alkanes free from angle strain and torsional strain.
- Cyclobutanes require higher temperature than cyclopropane for ring opening.

\[ \text{Cyclopropane} + \text{H}_2 \xrightarrow{\text{Ni} \ 120^\circ \text{C}} \text{Propane} \]

\[ \text{Cyclobutane} + \text{H}_2 \xrightarrow{\text{Ni} \ 200^\circ \text{C}} \text{Butane} \]

\[ \text{Cyclohexane} + \text{H}_2 \xrightarrow{\text{Ni} \ 200^\circ \text{C}} \text{No Reaction} \]
Practice Questions
Preparation and Reactions of Cycloalkanes

Complete the following reactions by giving the principal organic product.

(i) \[ \text{Cyclic Ketone} + \text{N}_2\text{H}_4 \text{ (Excess)} \xrightarrow{\text{KOH/Heat}} \]

(ii) \[ \text{Cyclic Ester} + \text{H}_2 \xrightarrow{\text{Ni/120°C}} \]

(iii) \[ \text{Limonene} + \text{H}_2 \text{ (Excess)} \xrightarrow{\text{Pd}} \text{Cis-1-methyl-4-(1'-methylene)cylohexane} \]