4. Stereochemistry of Alkanes and Cycloalkanes

The Shapes of Molecules

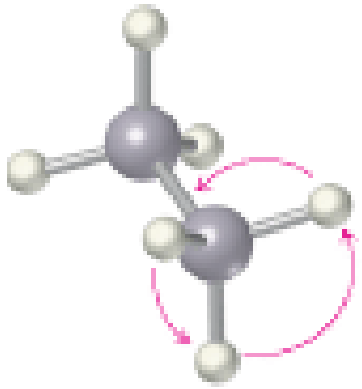
- The three-dimensional shapes of molecules result from many forces (internal and external) acting upon these molecules

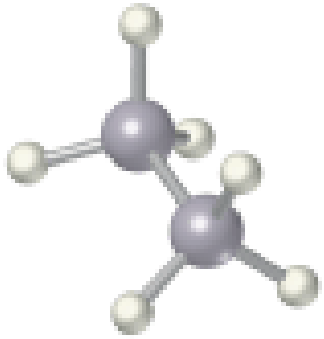
- Different arrangements of atoms within a molecule in space resulting from rotation about single bonds are called **conformations**. These are in equilibrium at room temperature (the conformational isomers are called **conformers**, emphasis on the first syllable)

- The systematic study of molecular shapes (3 D) and properties from these shapes is called **stereochemistry**

4.1 Conformations of Ethane

- Conformers interconvert rapidly and a structure is an average of conformers
- Representing three dimensional conformers in two dimensions is done with standard types of drawings

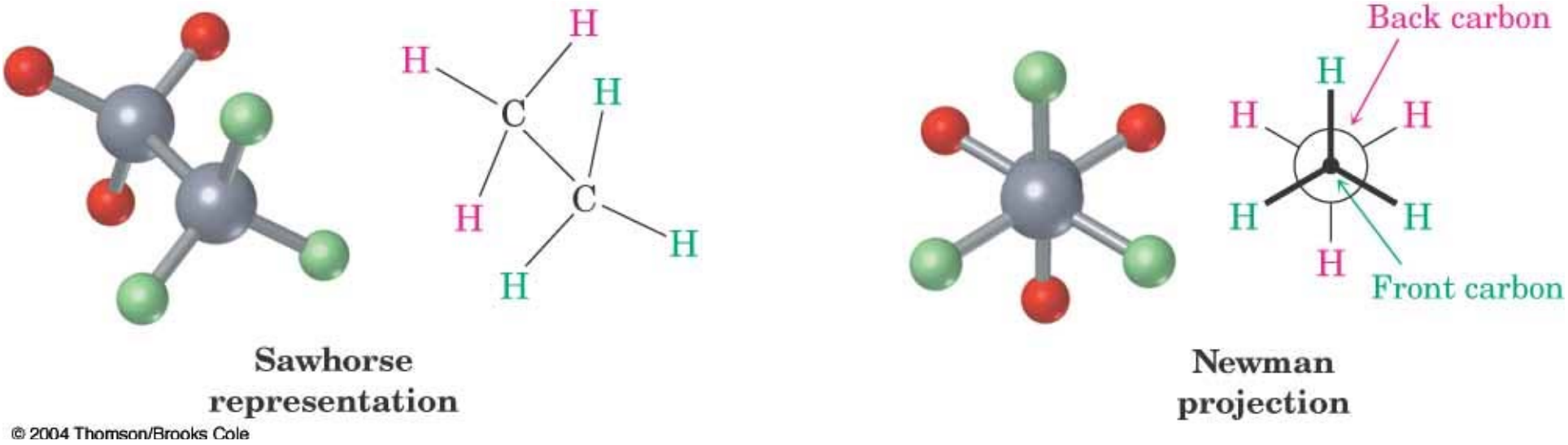




Representing Conformations

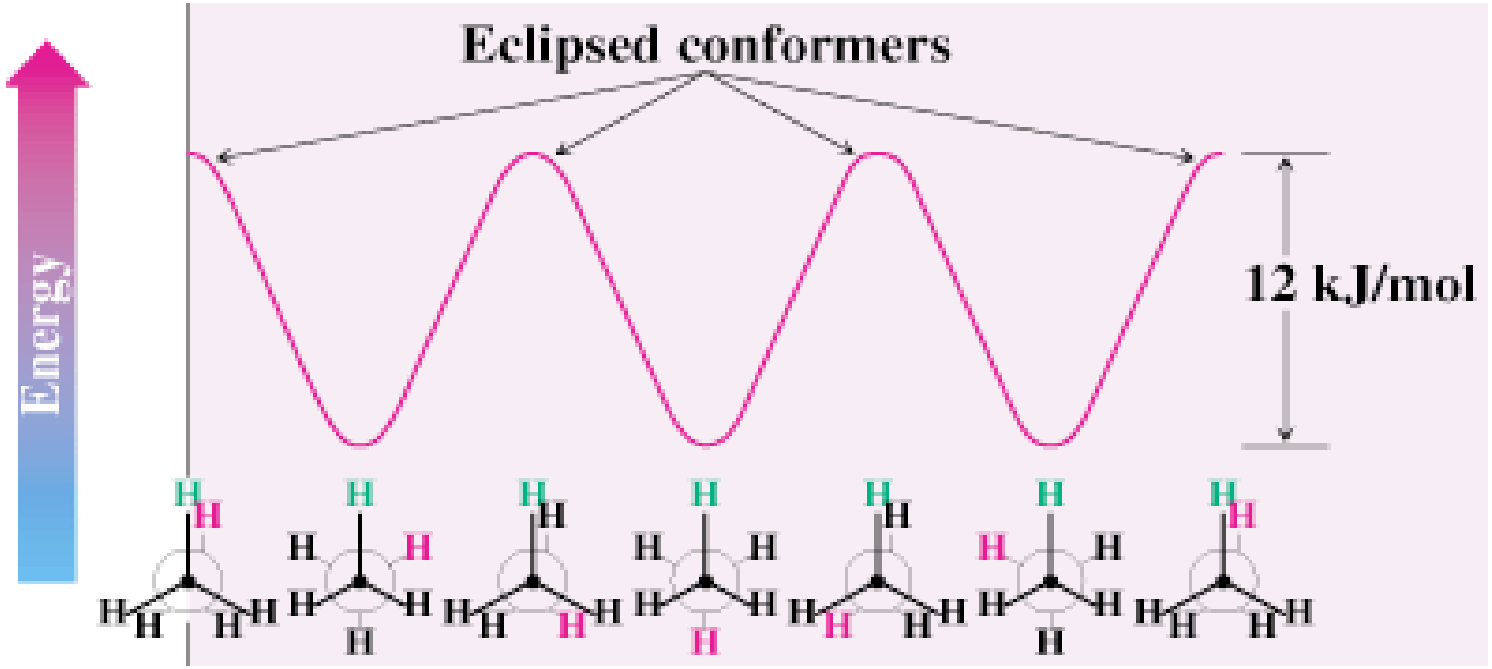
- **Sawhorse representations** show molecules at an angle, showing a molecular model
  - C-C bonds are at an angle to the edge of the page and all C-H bonds are shown

- **Newman projections** show how the C-C bond would project end-on onto the paper
  - Bonds to front carbon are lines going to the center
  - Bonds to rear carbon are lines going to the edge of the circle



- The barrier to rotation between ethane conformations is small (12 kJ/mol; 2.9 kcal/mol) The most stable conformation of ethane has all six C–H bonds away from each other (**staggered**)

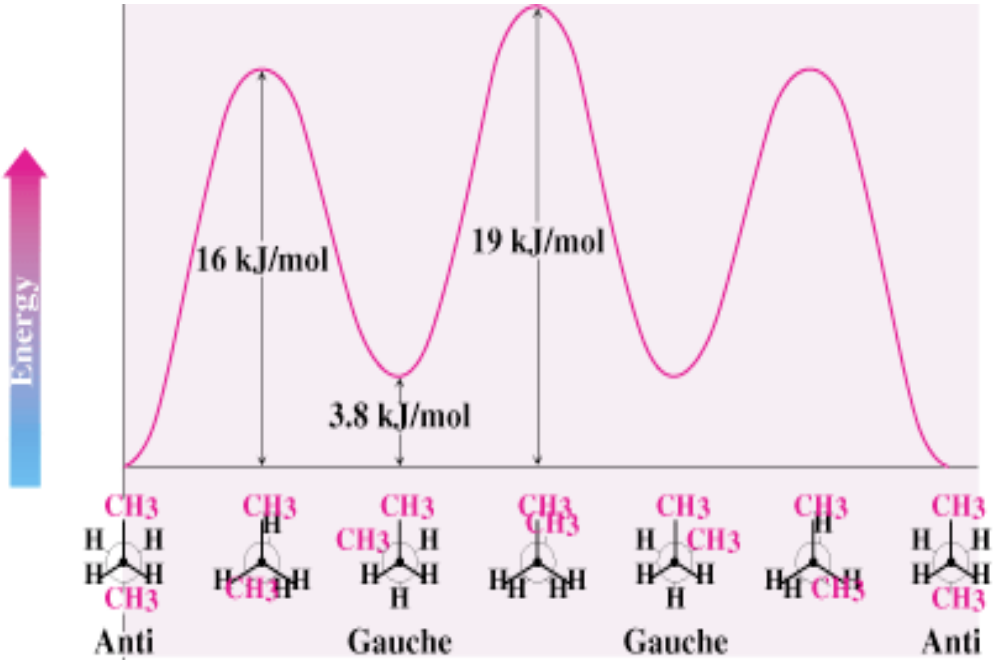
- The least stable conformation has all six C–H bonds as close as possible (**eclipsed**) in a Newman projection – energy due to torsional strain

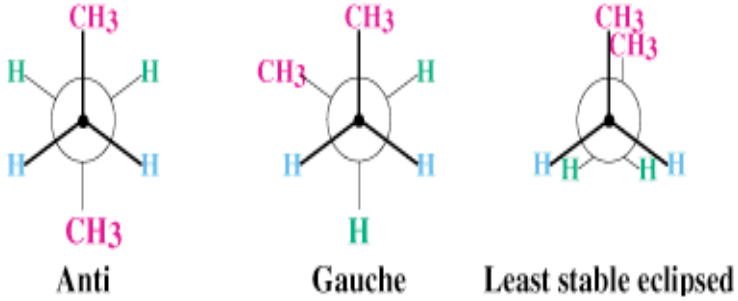


4.3 Conformations of Butane

- **anti conformation** (fully staggered) has two methyl groups 180° away from each other

- Rotation around the C2–C3 gives eclipsed conformation
- Staggered conformation with methyl groups 60° apart is **gauche conformation**

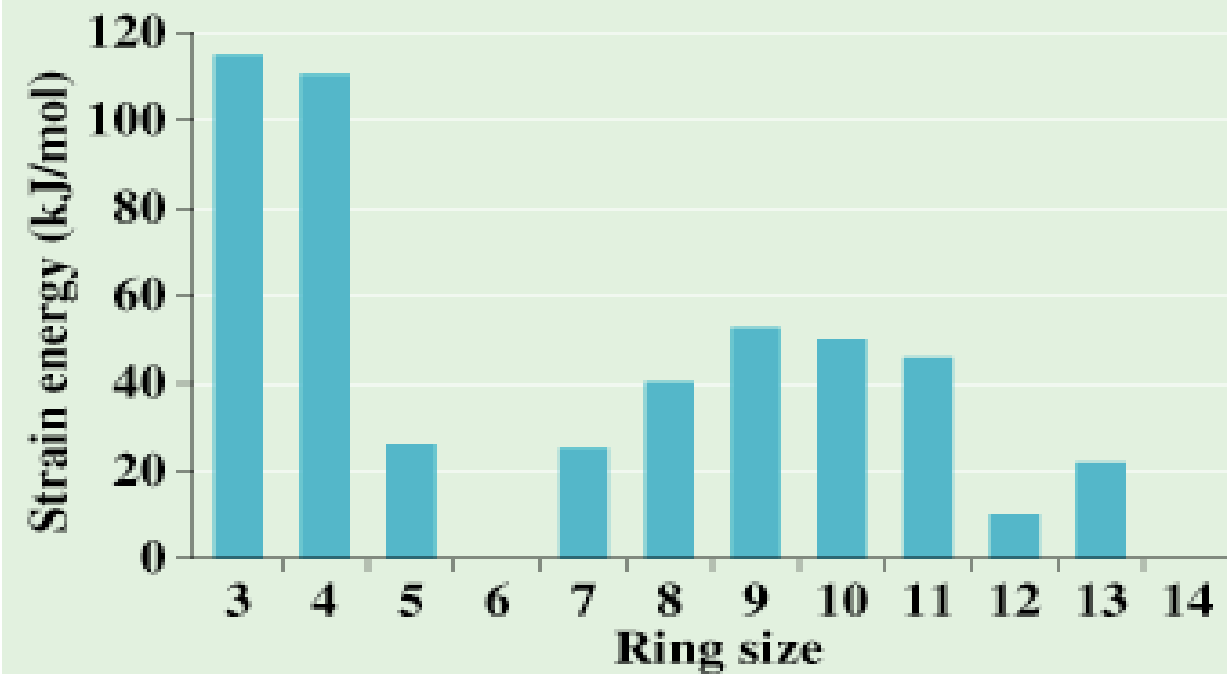


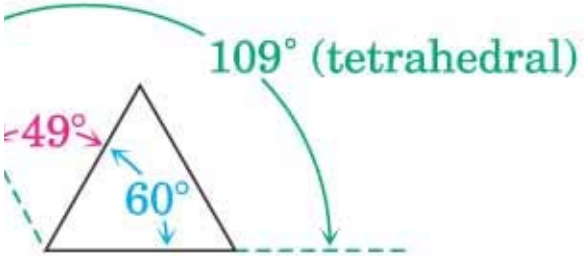


4.4 Conformation & Stability of Cycloalkanes: The Baeyer Strain Theory

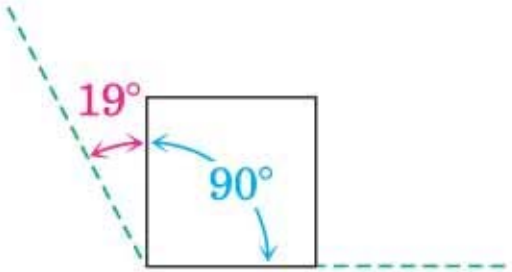
Baeyer (1885): since carbon prefers to have bond angles of approximately 109°, ring sizes other than five and six may be too *strained* to exist

- Rings from 3 to 30 C's do exist but are strained due to bond bending distortions and steric interactions

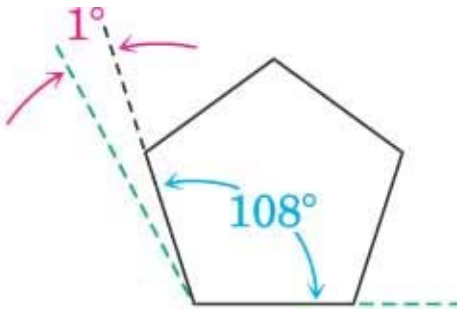




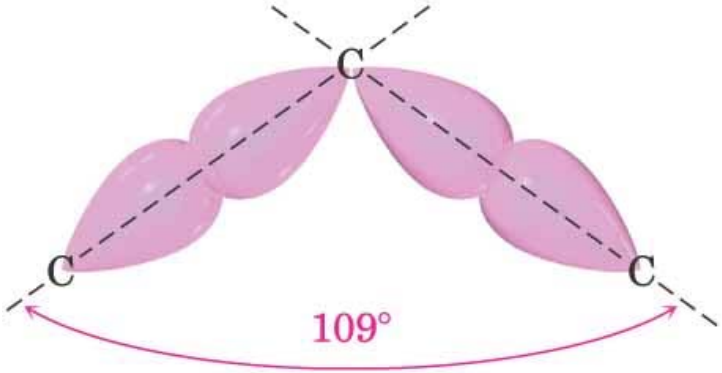
Cyclopropane



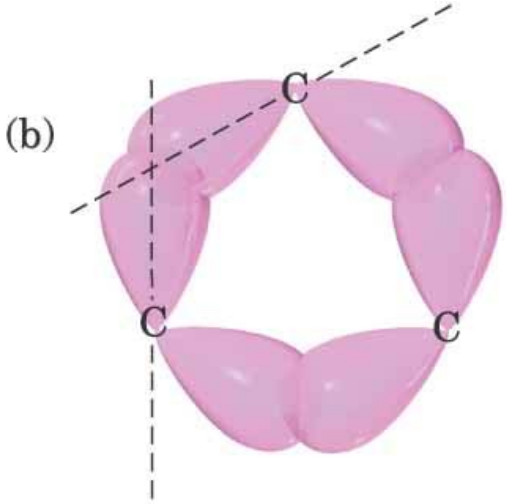
Cyclobutane



Cyclopentane



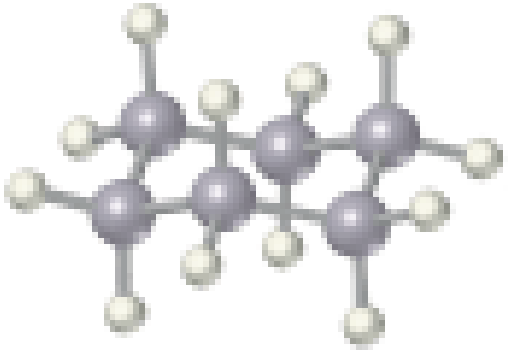
A typical alkane C–C bond

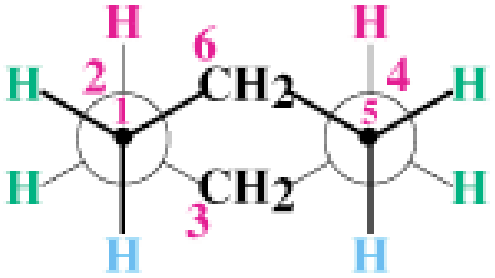


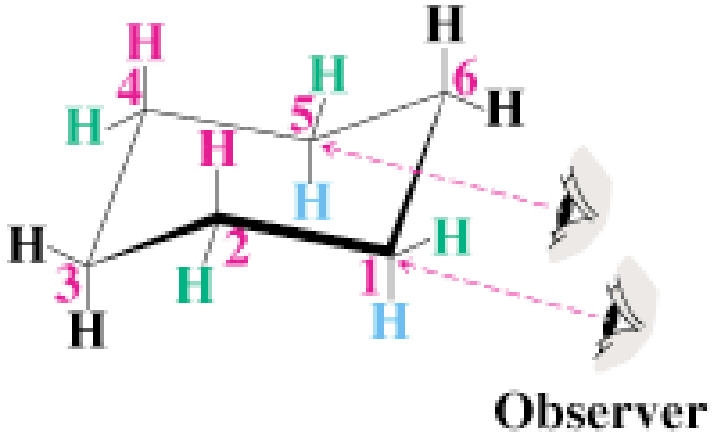
A bent cyclopropane C–C b

4.9 Conformations of Cyclohexane

- Substituted cyclohexanes occur widely in nature
- The cyclohexane ring is free of angle strain and torsional strain
- The conformation has alternating atoms in a common plane and tetrahedral angles between all carbons
- This is called a **chair conformation**





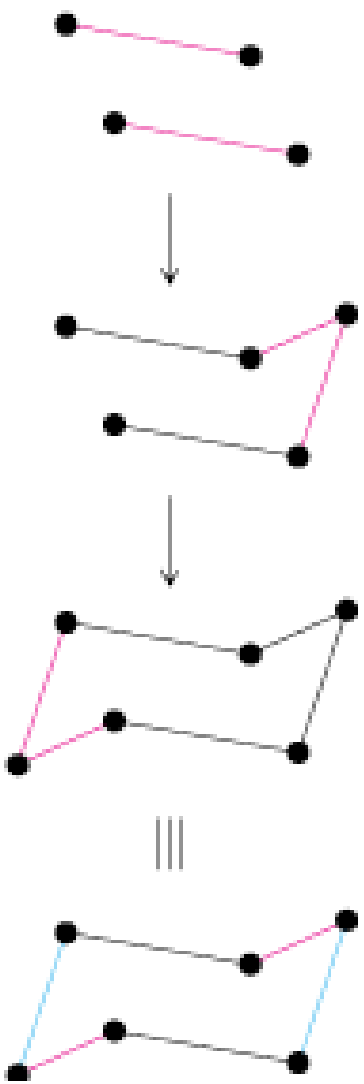


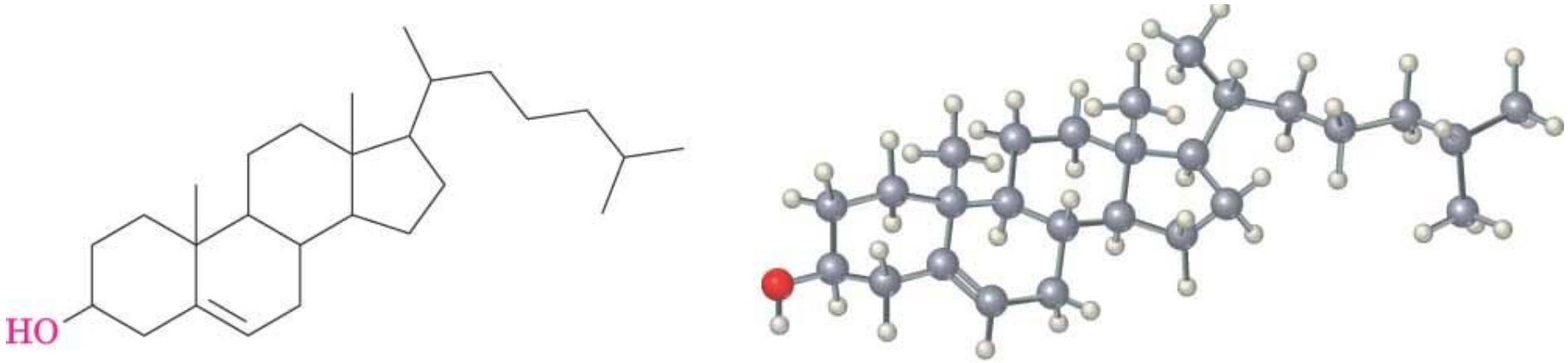
How to Draw Cyclohexane

STEP 1 Draw two parallel lines, slanted downward and slightly offset from each other. This means that four of the cyclohexane carbon atoms lie in a plane.

STEP 2 Locate the topmost carbon atom above and to the right of the plane of the other four and connect the bonds.

STEP 3 Locate the bottommost carbon atom below and to the left of the plane of the middle four and connect the bonds. Note that the bonds to the bottommost carbon atom are parallel to the bonds to the topmost carbon.



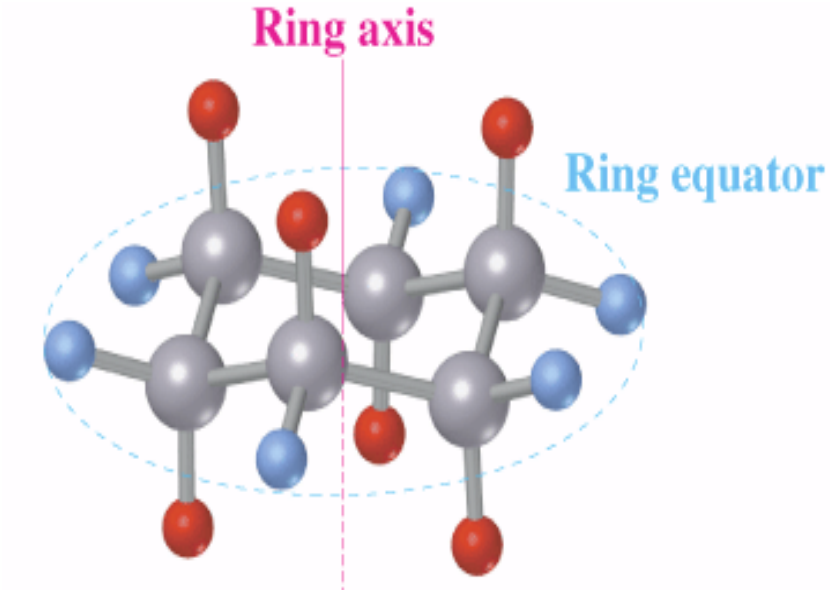


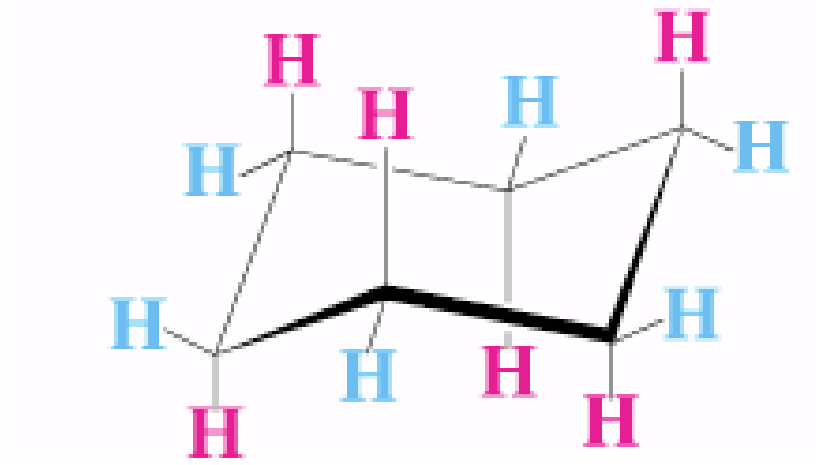
Cholesterol

4.10 Axial and Equatorial Bonds in Cyclohexane

- The chair conformation has two kinds of positions for substituents on the ring: *axial* positions and *equatorial* positions
- Chair cyclohexane has six **axial** hydrogens perpendicular to the ring (parallel to the ring axis) and six **equatorial** hydrogens near the plane of the ring
- Each carbon atom in cyclohexane has one axial and one equatorial hydrogen

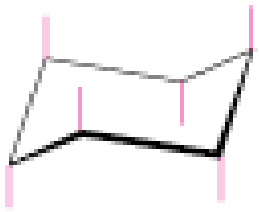
- Each face of the ring has three axial and three equatorial hydrogens in an alternating arrangement



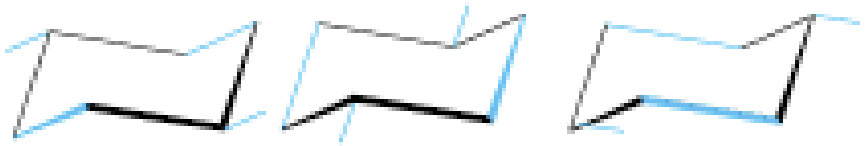


Drawing the Axial and Equatorial Hydrogens

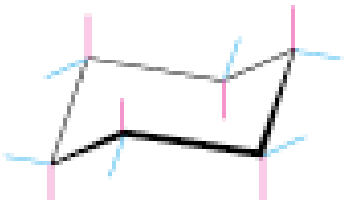
Axial bonds: The six axial bonds, one on each carbon, are parallel and alternate up–down.



Equatorial bonds: The six equatorial bonds, one on each carbon, come in three sets of two parallel lines. Each set is also parallel to two ring bonds. Equatorial bonds alter- nate between sides around the ring.

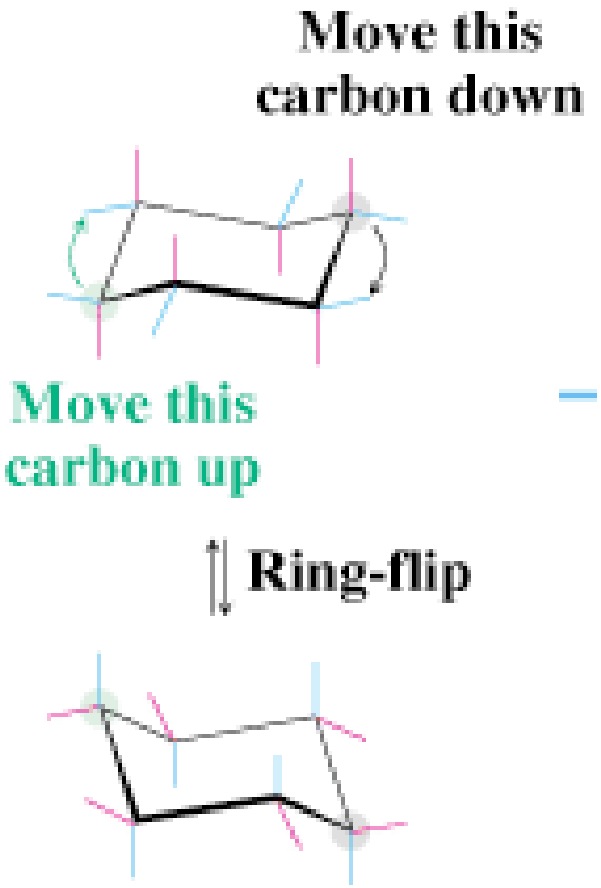


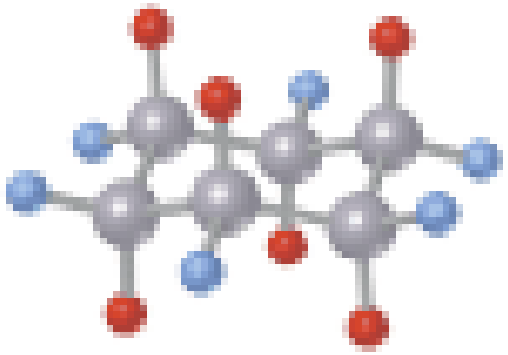
Completed cyclohexane

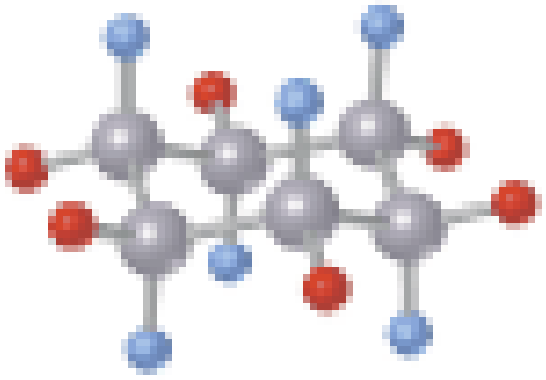


4.11 Conformational Mobility of Cyclohexane

- Chair conformations readily interconvert, resulting in the exchange of axial and equatorial positions by a **ring-flip** (In a ring flip, whatever is up, stays up, whatever is down stays down but axial becomes equatorial

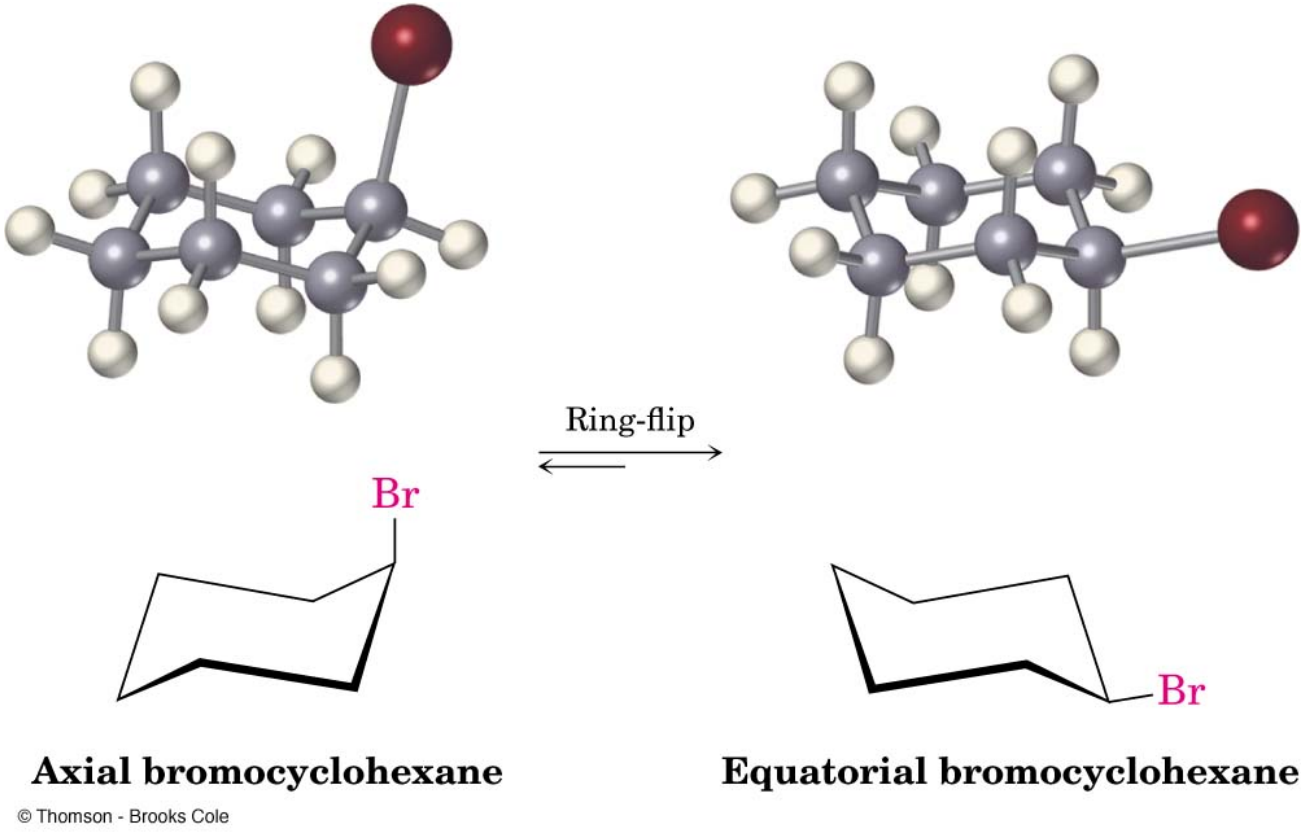






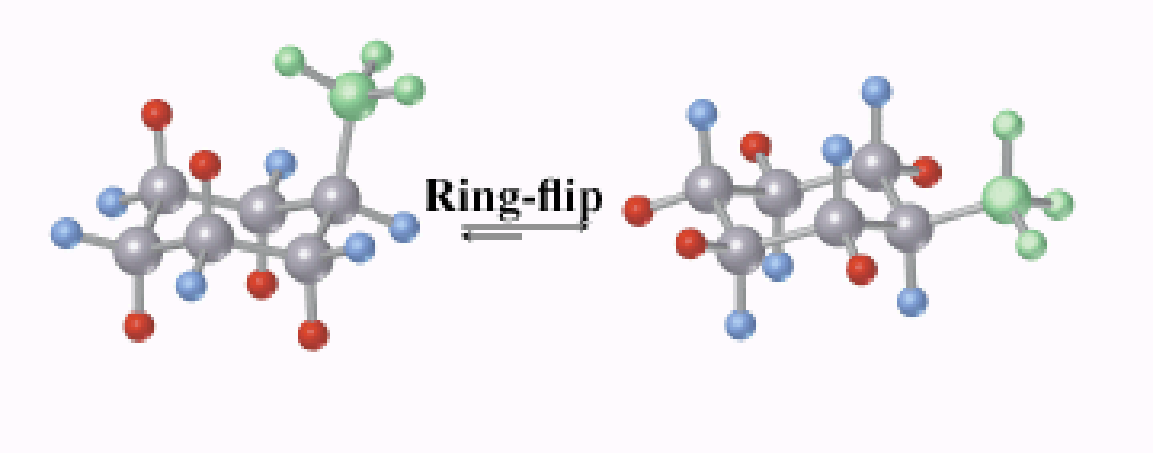
Bromocyclohexane

- When bromocyclohexane ring-flips the bromine's position goes from equatorial to axial and so on
- At room temperature the ring-flip is very fast and the structure is seen as the weighted average, however at very low temperatures, the conformation with equatorial bromine predominates (no 1,3 diaxial interactions).



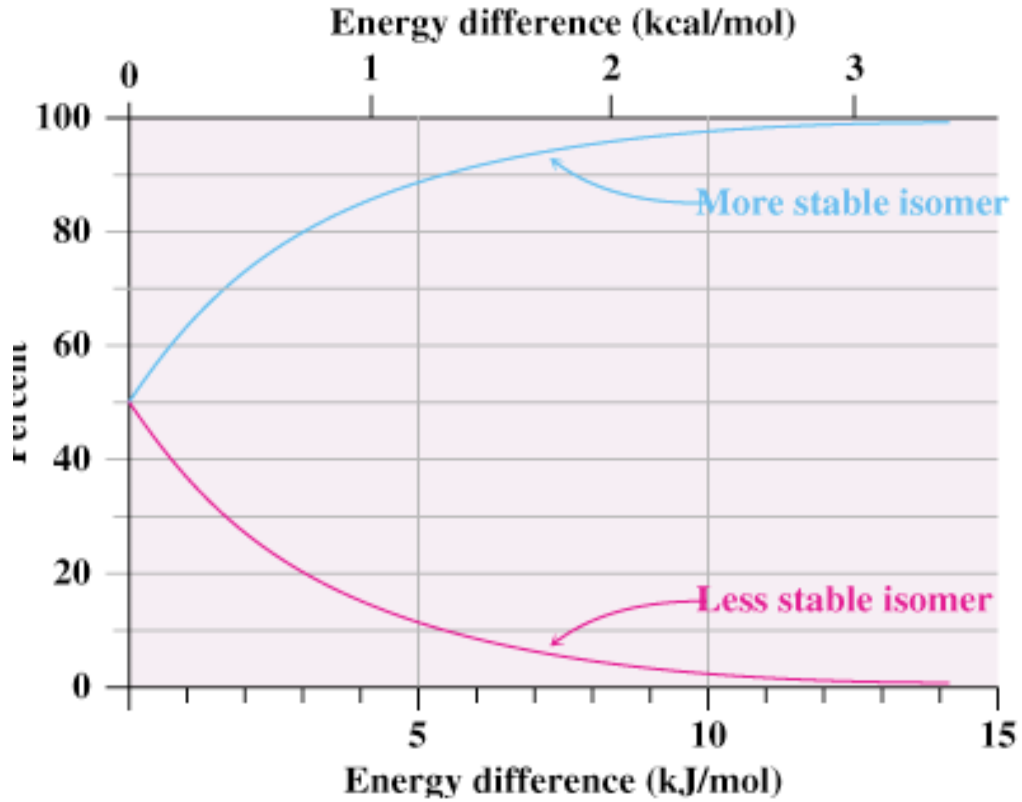
4.12 Conformations of Monosubstituted Cyclohexanes

- The two conformers of a monosubstituted cyclohexane are not equal in energy
- The equatorial conformer of methyl cyclohexane is more stable than the axial by 7.6 kJ/mol



Energy and Equilibrium

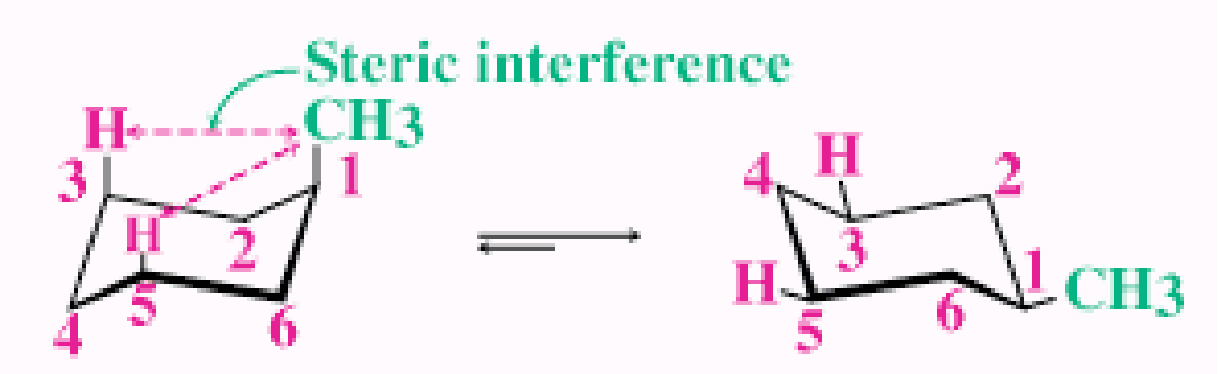
- The relative amounts of the two conformers depend on their difference in energy $\Delta E = -RT \ln K$
- R is the gas constant [8.315 J/(K•mol)], T is the Kelvin temperature, and K is the equilibrium constant between isomers



1,3-Diaxial Interactions

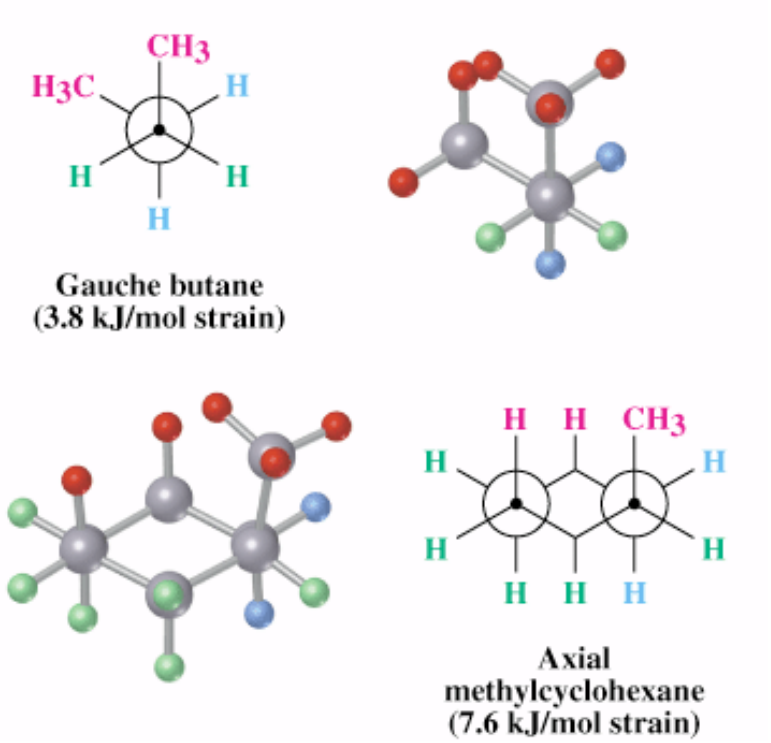
- Difference between axial and equatorial conformers is due to steric strain caused by **1,3-diaxial interactions**

- Hydrogen atoms of the axial methyl group on C1 are too close to the axial hydrogens three carbons away on C3 and C5, resulting in 7.6 kJ/mol of steric strain



Relationship to Gauche Butane Interactions

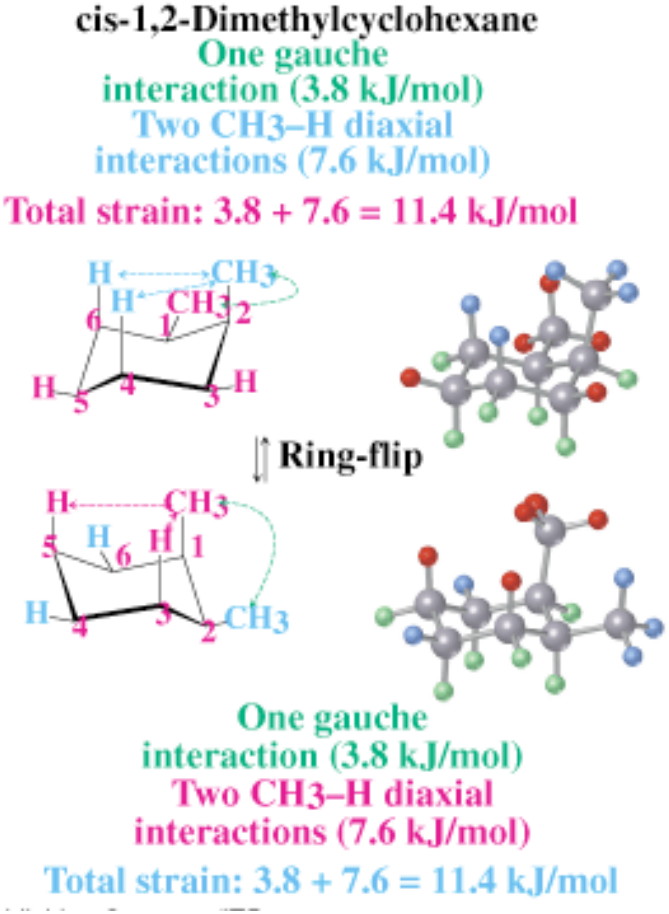
- Gauche butane is less stable than anti butane by 3.8 kJ/mol because of steric interference between hydrogen atoms on the two methyl groups
- The four-carbon fragment of axial methylcyclohexane and gauche butane have the same steric interaction
- In general, equatorial positions give more stable isomer



4.13 Conformational Analysis of Disubstituted Cyclohexanes

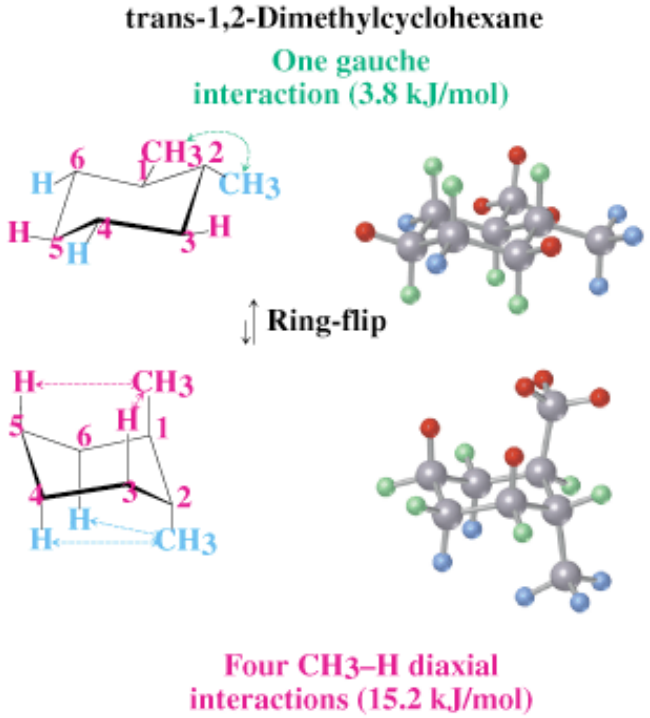
- In disubstituted cyclohexanes the steric effects of both substituents must be taken into account in both conformations
- There are two isomers of 1,2-dimethylcyclohexane. *cis* and *trans*

- In the cis isomer, both methyl groups are on the same face of the ring, and the compound can exist in two chair conformations
- Consider the sum of all interactions
- In cis-1,2, both conformations are equal in energy



Trans-1,2-Dimethylcyclohexane

- Methyl groups are on opposite faces of the ring
- One trans conformation has both methyl groups equatorial and only a gauche butane interaction between methyls (3.8 kJ/mol) and no 1,3-diaxial interactions
- The ring-flipped conformation has both methyl groups axial with four 1,3-diaxial interactions

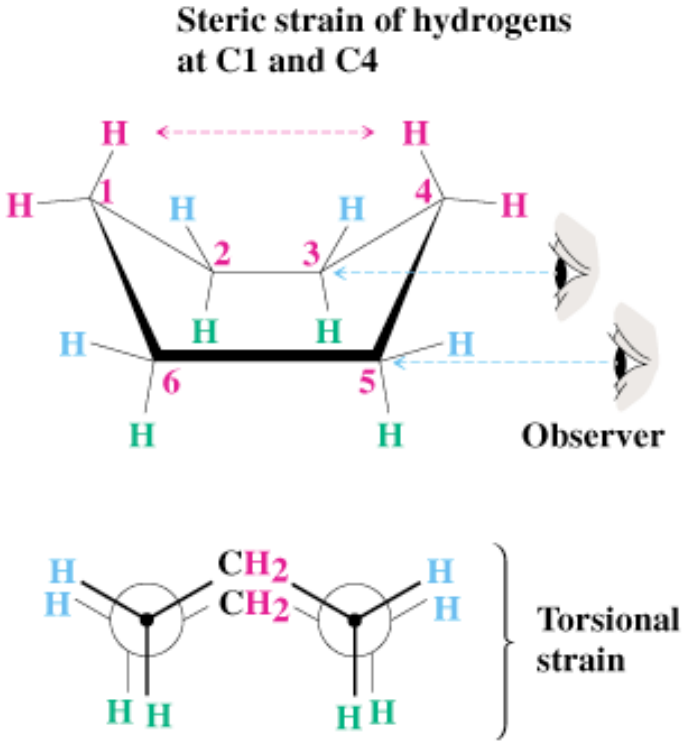


- Steric strain of 4 × 3.8 kJ/mol = 15.2 kJ/mol makes the diaxial conformation 11.4 kJ/mol less favorable than the diequatorial conformation
- *trans*-1,2-dimethylcyclohexane will exist almost exclusively (>99%) in the diequatorial conformation

Tert-butyl cyclohexane exists in one conformation where the t-butyl group is equatorial (locked conformation).

4.13 Boat Cyclohexane

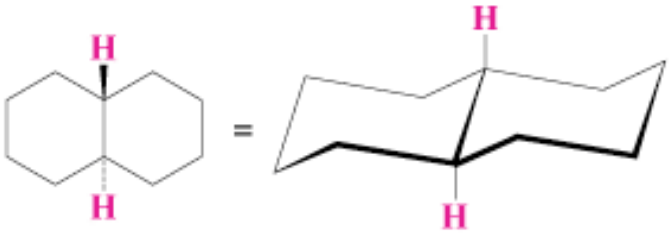
- Cyclohexane can also be in a **boat conformation**
- Less stable than chair cyclohexane due to steric and torsional strain
- C-2, 3, 5, 6 are in a plane
- H on C-1 and C-4 approach each other closely enough to produce considerable steric strain (Flag-pole interaction)
- Four eclipsed H-pairs on C- 2, 3, 5, 6 produce torsional strain
- ~29 kJ/mol (7.0 kcal/mol) less stable than chair



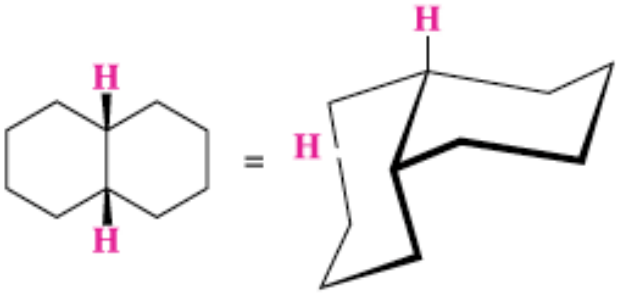
4.15 Conformations of Polycyclic Molecules

- Decalin consists of two cyclohexane rings joined to share two carbon atoms (the *bridgehead* carbons, C1 and C6) and a common bond
- Two isomeric forms of decalin: trans fused or cis fused

- In *cis*-decalin hydrogen atoms at the bridgehead carbons are on the same face of the rings
- In *trans*-decalin, the bridgehead hydrogens are on opposite faces
- Both compounds can be represented using chair cyclohexane conformations
- Flips and rotations do not interconvert cis and trans



trans-Decalin



cis-Decalin

Fused ring systems are widely available in nature; steroids (cholesterol) are but one example.

Construct a model of bicycle[2.2.1]heptane (Norbornane, camphor is a derivative of Norbornane).