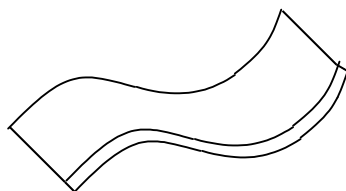
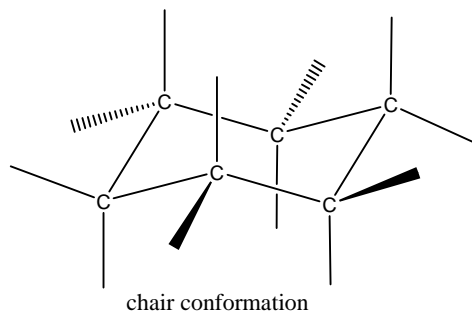


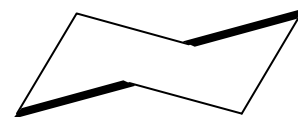
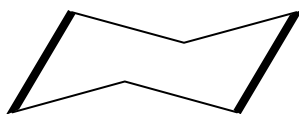
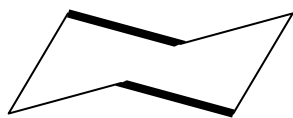
Cyclohexanes

Cyclohexane rings (six atom rings in general) are the most well studied of all ring systems. They have a limited number of, almost strain free, conformations. Because of their well defined conformational shapes, they are frequently used to study effects of orientation or steric effects when studying chemical reactions. Additionally, six atom rings are the most commonly encountered rings in nature. Cyclohexane structures do not choose to be flat. Slight twists at each carbon atom allow cyclohexane rings to assume much more comfortable conformations, which we call *chair conformations*. (Chairs even sound comfortable.) The chair has an up and down shape all around the ring, sort of like the zig-zag shape seen in straight chains (...time for models!).



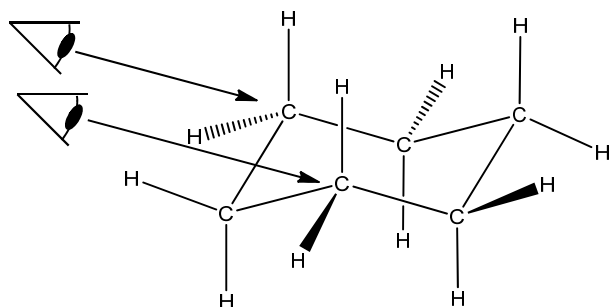
lounge chair - used to kick back and relax while you study your organic chemistry

Cyclohexane rings are flexible and easily allow partial rotations (twists) about the C-C single bonds. There is minimal angle strain since each carbon can approximately accommodate the 109° of the tetrahedral shape. Torsional strain energy is minimized in chair conformations since all groups are staggered relative to one another. This is easily seen in a Newman projection perspective. An added new twist to our Newman projections is a side-by-side view of parallel single bonds. If you look carefully at the structure above or use your model, you should be able to see that a parallel relationship exists for all C-C bonds across the ring from one another.

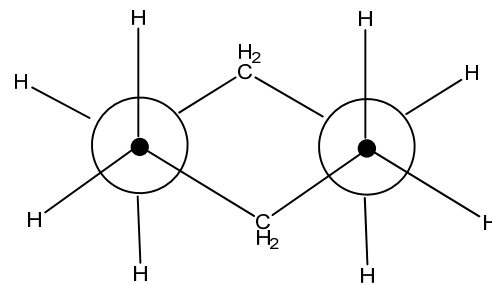


There are three sets of parallel C-C bonds in cyclohexane rings. Any 'set' could be used to draw two parallel Newman projections.

Two simultaneous Newman projection views are now possible as shown below. Remember, that any two bonds on opposite sides of the ring can be used and they can be viewed from front or rear directions.



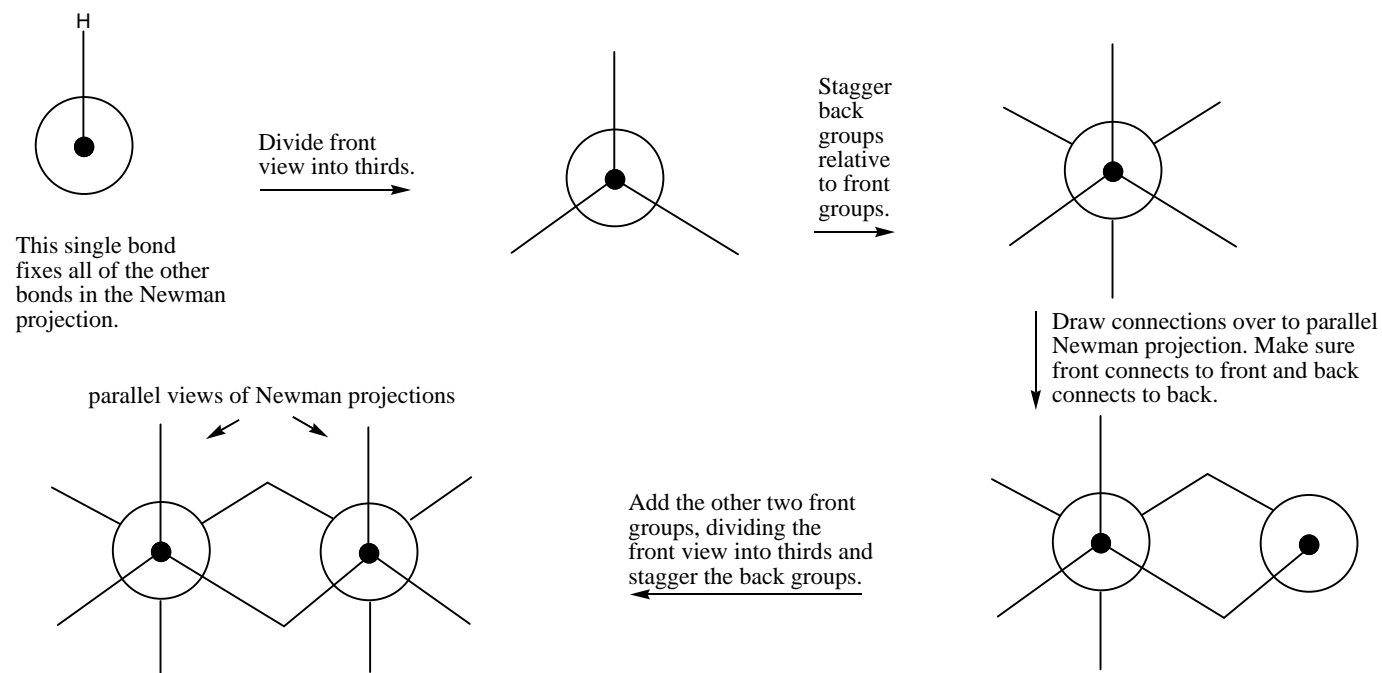
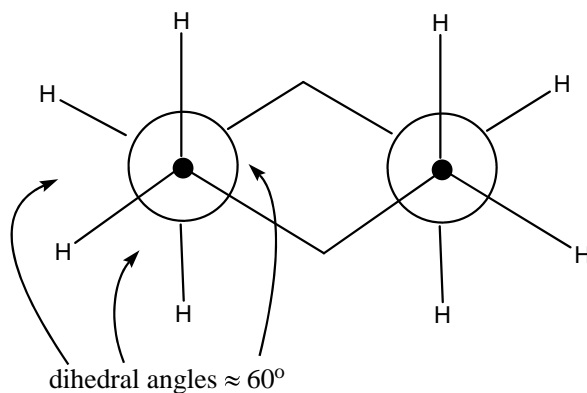
Newman
projection
→



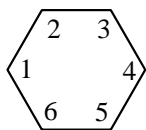
Chair conformations can be viewed down any two parallel bonds (from either side) as two parallel Newman projections. In this example, the view is from the left side.

All groups are staggered in chair conformations of cyclohexane rings.

Once the first bond is drawn in a Newman projection of a chair conformation of cyclohexane ring, all of the other bonds (axial and equatorial) are fixed by the staggered arrangements and the cyclic connections to one another. Once you have drawn all of the bonds in a Newman projection, you merely fill in the blanks at the end of each line, based on the substituents that are present (determined from the name or a 2D drawing).

How to draw a Newman projection of a cyclohexane ring.Ideal dihedral angles of cyclohexane (the real ones are slightly different)

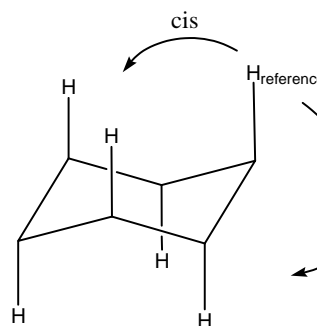
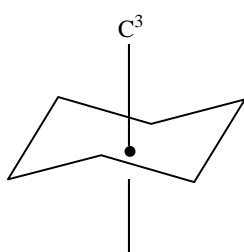
Problem 1 - How many possible Newman perspectives of chairs are possible on the numbered cyclohexane below? Consider all numbers and front/back views. Write them as, C1→C2, C5→C4, etc.)



A Newman projection of a chair conformation of cyclohexane clearly shows that torsional strain is minimized, since all groups are staggered. Additionally, either bond-line or Newman formulas reveal that the two hydrogen atoms at each CH₂ are not the same. Three hydrogen atoms point straight up and three H's point straight down (at alternate positions) relative to the approximate plane of the carbon atoms. Those six parallel C-H bonds are also parallel to the highest axis of symmetry, (which we are ignoring in this book). Because these six C-H bonds are parallel to an axis of symmetry, they are called the axial positions (axial = along an axis). There is one axial position at every carbon atom in the ring and, again if you look carefully, you will see that axial positions alternate pointing up and then pointing down. You should also observe that when they point up they are on the top face of the ring, and when they point down they are on the bottom face of the ring.

Axial positions in cyclohexane rings

A C₃ axis of symmetry means if you rotate the molecule about that axis by 120° the new structure will be indistinguishable from the original structure.



Three axial groups are on the top face. The other two are cis to the reference hydrogen atom in this example.

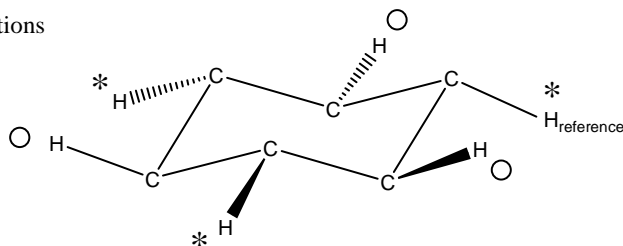
trans

Three axial groups are on the bottom face. They are trans to the reference hydrogen atom in this example.

There are six other hydrogen atoms present, one at each of the carbon atoms in the ring. However, these hydrogen atoms are approximately in the plane of the ring of carbon atoms. These hydrogen atoms all point out, around the perimeter of the ring (...or around the "equator"). These positions are called *equatorial positions* (equator ≈ equatorial). The equatorial positions also alternate around the ring, being on top when axial points down and being on the bottom when axial points up.

These terms (axial and equatorial) create a common point of confusion for students. When students hear that two groups are axial, they often assume they must be the same in all respects, i.e. on the same side (cis). This is true at alternate positions about the ring, but it is not true at adjacent positions or directly across the ring, where they are trans.

Equatorial positions



○ = top side, trans to reference hydrogen atom

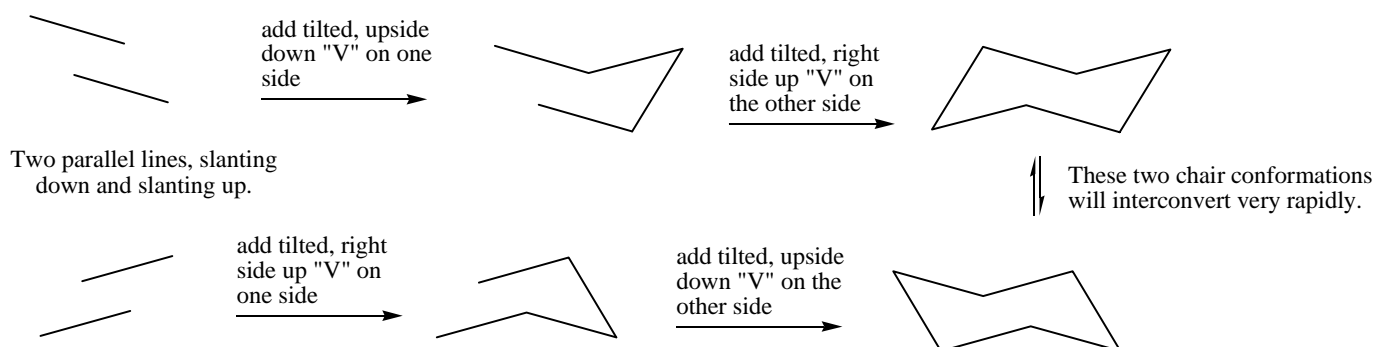
* = bottom side, cis to reference hydrogen atom

Drawing a Cyclohexane

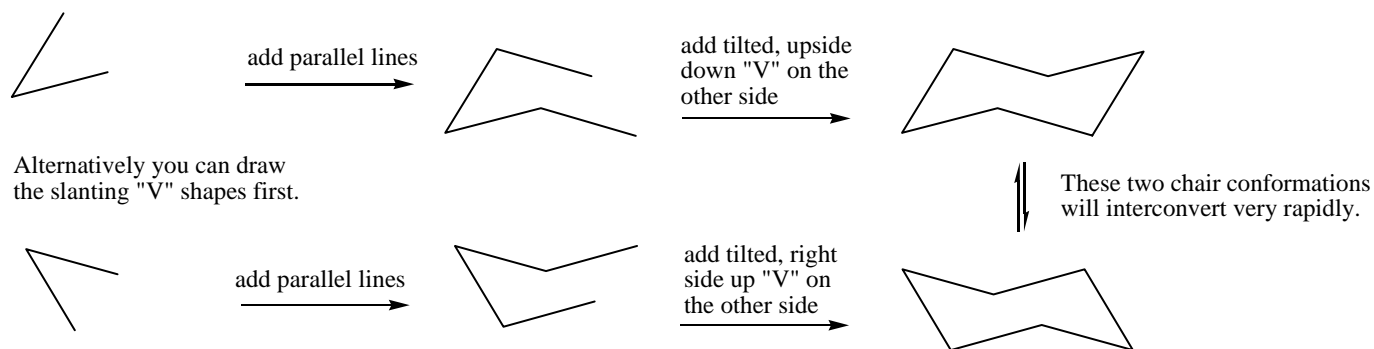
You will need to learn how to draw a cyclohexane ring, with all of its axial and equatorial positions, if you are to ever understand cyclohexane and related ring structures. Once you can draw cyclohexane rings, it is simply fill in the blank to add the substituent atoms (using a name as your guide). You can generate an endless number of substituted possibilities. If you switch out a carbon atom for an oxygen atom and you are set to study the pyranoses of biochemistry (e.g. cyclic glucose). As you work through this section, keep your models by your side.

First you have to generate the outline of the ring. (You should actually practice these steps several times.) This can be done by drawing two parallel lines, slightly off center, tracing slightly up or slightly down. Next a V shape is

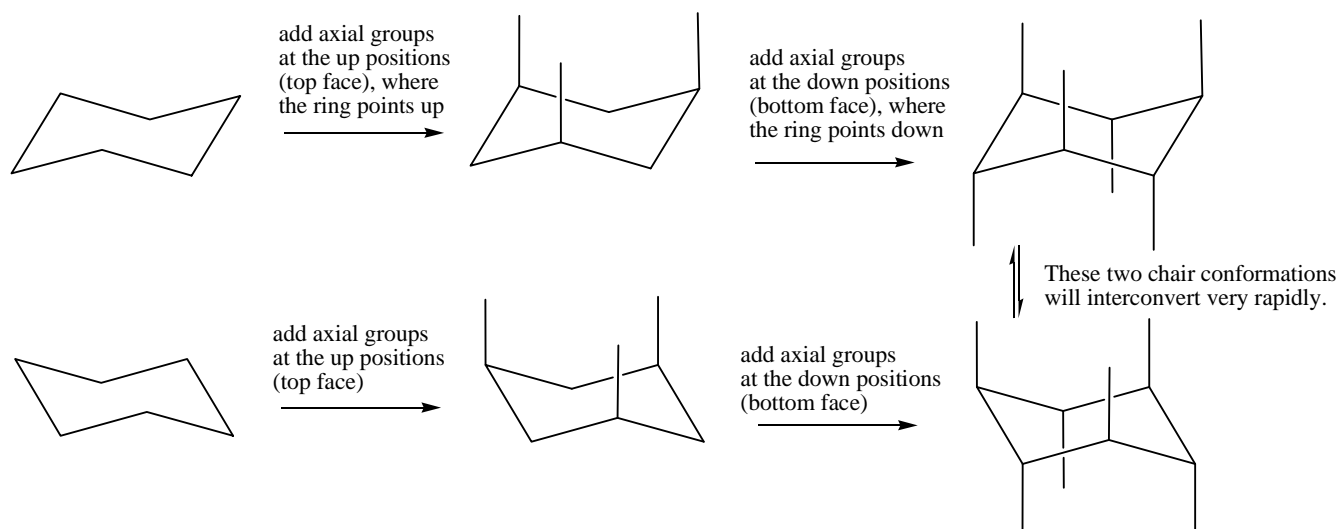
added on both sides so that it points in an opposite sense to the direction of the parallel lines. These two chair conformations are the most common shapes of cyclohexane rings, and interconvert with one another (thousands of times per second).



An alternate strategy is to draw a slanted V shape first, then add the parallel lines in an opposite direction. Then the other V shape is added in the opposite direction to the parallel lines. Use whatever works best for you. Make sure you practice until you can do this with ease.

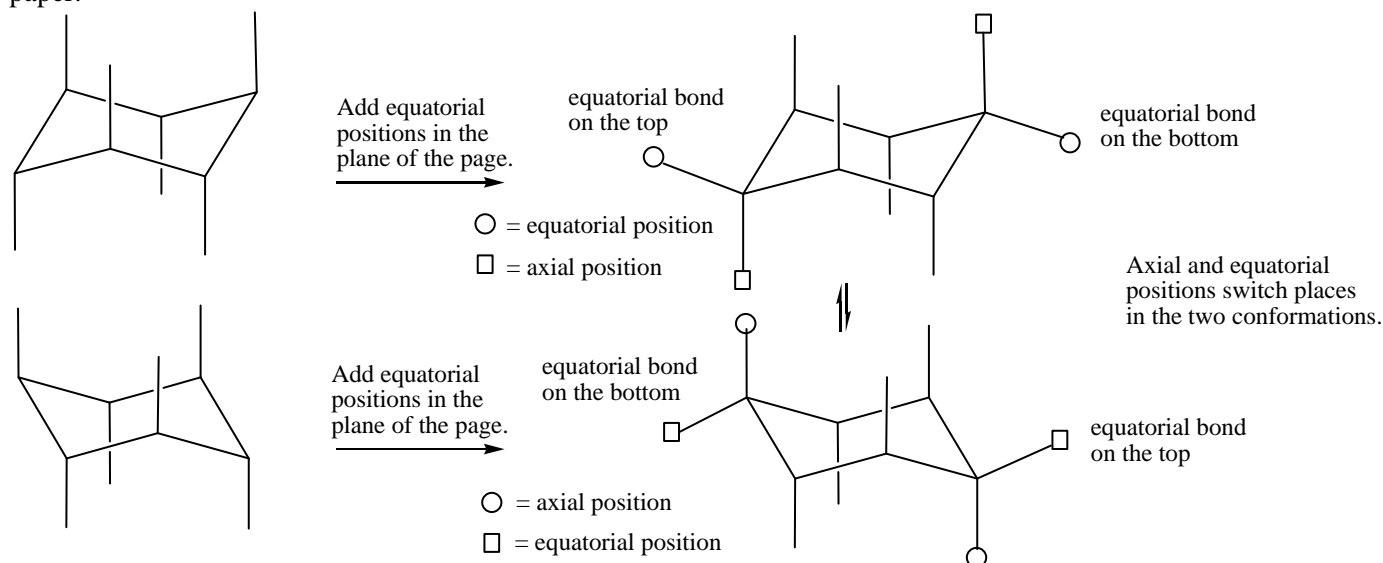


Our next task is to draw in the axial and equatorial positions. The ring is very helpful to us in this regard. The ring always points to the axial positions. If a ring carbon atom is in an up position, the axial position is pointing straight up (on the top of the ring). If a ring carbon atom is in a down position, the axial position is pointing straight down (on the bottom of the ring). The axial positions can now be added to our chair below.

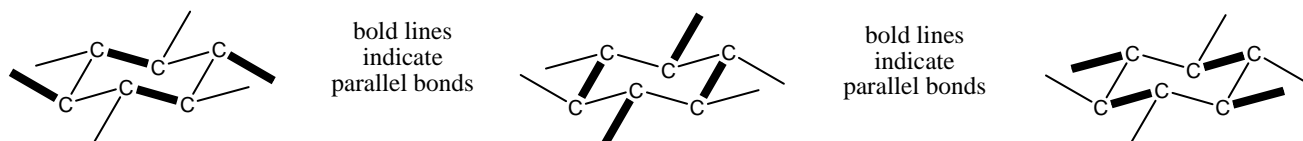


The equatorial positions are added last, about the perimeter (or equator) of the ring. The two opposite positions, in the plane of the paper are the easiest to add since our perspective is a side-on view and they follow the zig-zag shape we expect in straight chains. Notice that one of these equatorial positions is on the top of the ring and one of

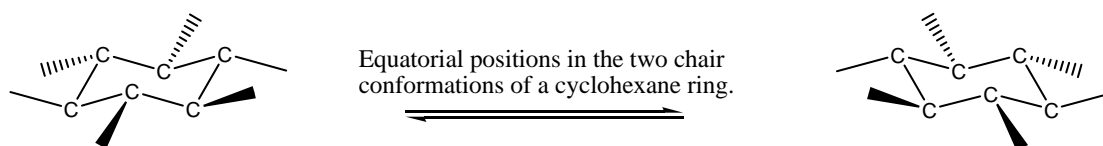
them is on the bottom. They should both be drawn parallel to the ring bonds that are parallel to the plane of the paper.



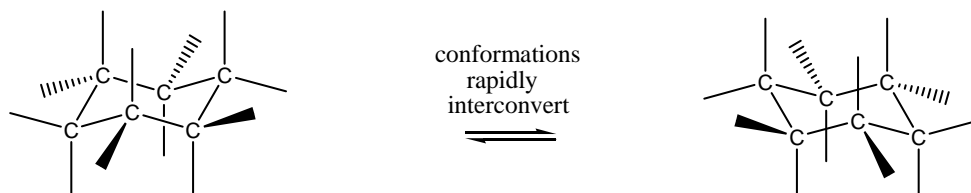
The other equatorial positions require slightly better artistic skills. To represent the equatorial positions coming out of the plane of the page, toward the viewer, wedges are drawn; if projecting behind the page, away from the viewer, dashed lines are drawn. These bonds will be parallel to bonds in the ring already drawn and in fact they have an anti relationship with those parallel bonds (use models). Use the ring bonds to guide you in drawing the equatorial bonds in the ring.



Heavy lines indicate parallel equatorial and ring bonds (above). Use the ring bonds to help you draw the equatorial bonds and then add the proper 3D perspective as simple lines, wedged lines or dashed lines (below).



This is what you need to be able to draw to analyze six atom rings.



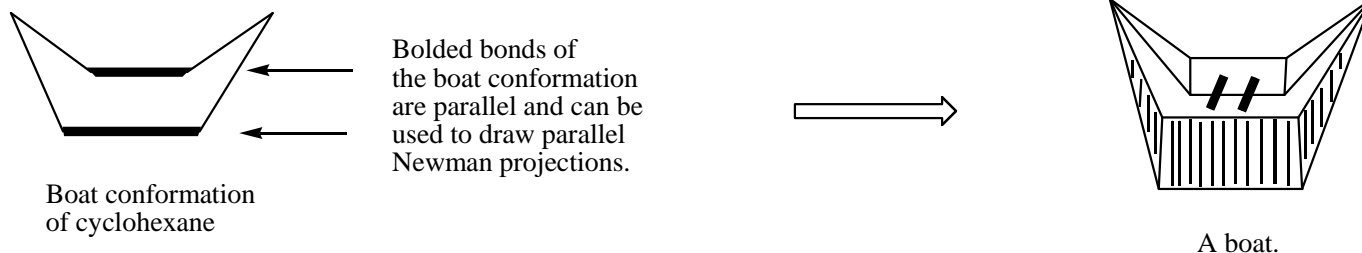
If you practice this several times, you should be able to generate a chair cyclohexane structure in seconds. Substituents can be added as indicated from a chemical name. These two chair conformations are the most common and comfortable of all the conformational possibilities available to a cyclohexane ring. Almost all of your work with cyclohexanes will involve chair conformations.

Boat and Twist Boat Conformations

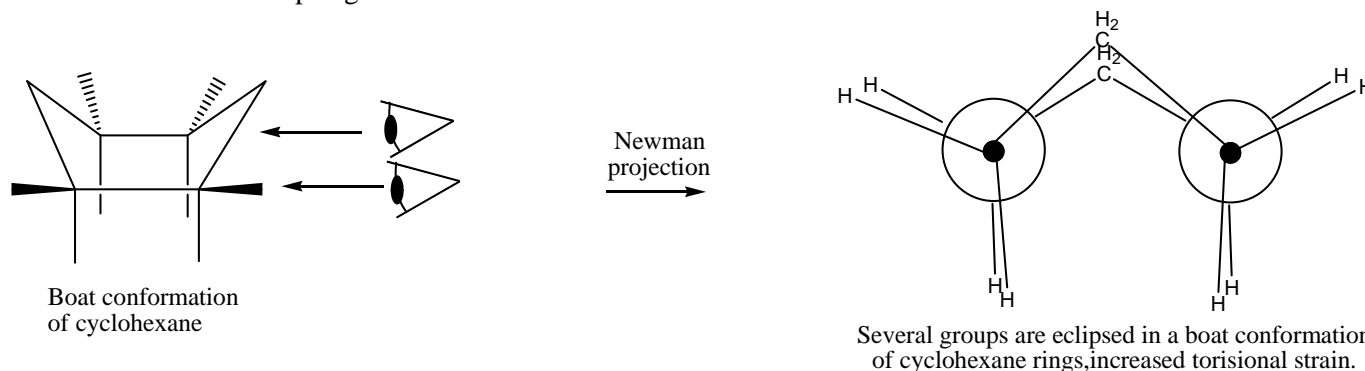
There are additional conformations of cyclohexane rings: boat, twist boat and half-chair conformations. These are high potential energy conformations that are encountered when one chair rotates to the other chair conformation.

Torsional strain and van der Waals strain cause an increase in the potential energy of these conformations. We will take a limited look at the boat conformation (but not the twist boat or half-chair). Occasionally these conformations are found in rigid, fixed structures having cyclohexane subunits, either by design or in nature.

Boat Conformation

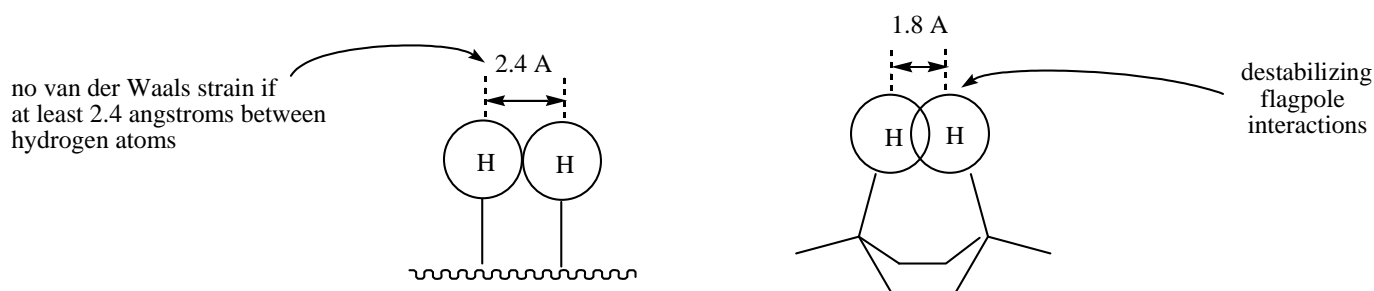


A Newman projection viewing down the two parallel bonds of the boat conformation clearly shows the increased torsional strain from eclipsing interactions.

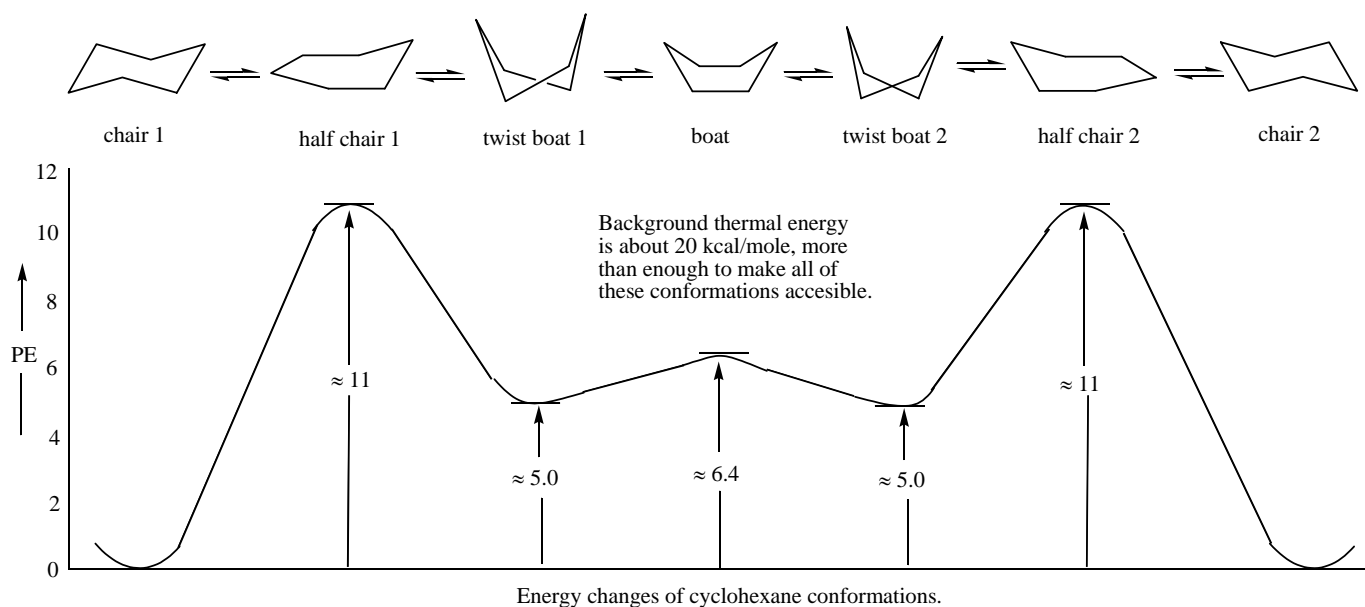


An additional destabilizing feature present in the boat is van der Waals strain between the two hydrogen atoms pointing inward, towards each. These interfering groups are called "flagpole" interactions, and also contribute to the overall ring strain of the boat conformation.

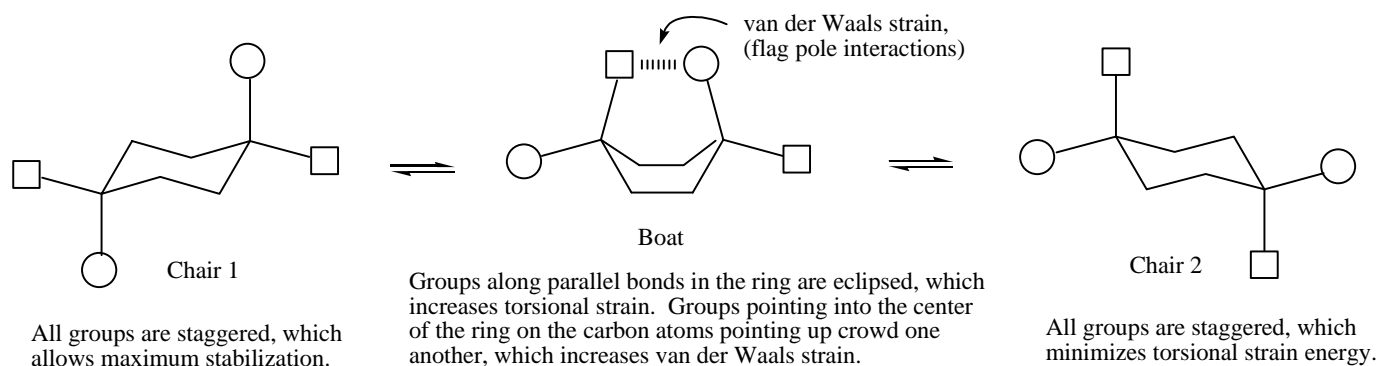
The van der Waals radius for a hydrogen atom is 1.2 Å and represents the radius of a sphere of space occupied by the electron cloud of a hydrogen atom. The nuclei of two hydrogen atoms would be expected to approach no closer than 2.4 Å ($= 2 \times 1.2$ Å) without considerable repulsion. The flagpole hydrogen atoms are 1.8 Å apart in the boat conformation. We classify this as a steric effect.



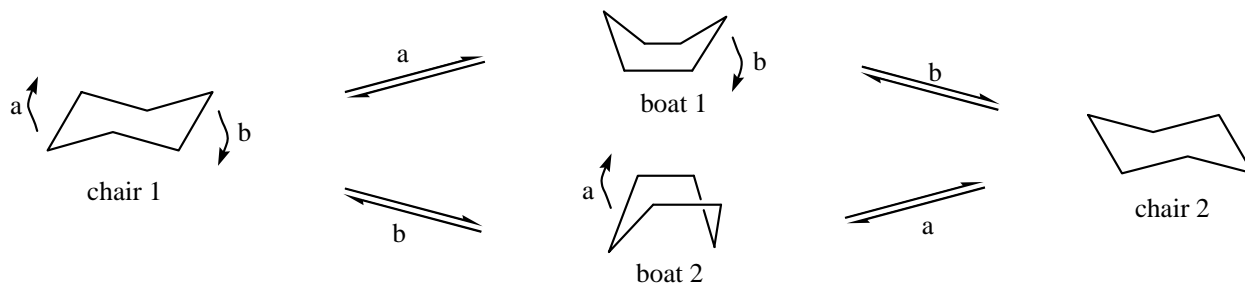
A chair does not immediately become a boat, and then the other chair. There is an even higher transitory conformation, which is called a half chair. Due to the torsional strain and bond angle strain this conformation is even higher in potential energy than the boat. We can consider the half chair as a transition state that exists only on the way to a chair or boat conformation. The potential energy of the half chair is estimated to be about 11 kcal/mole. A potential energy diagram for interconverting the two possible chair conformations would look something like the following.



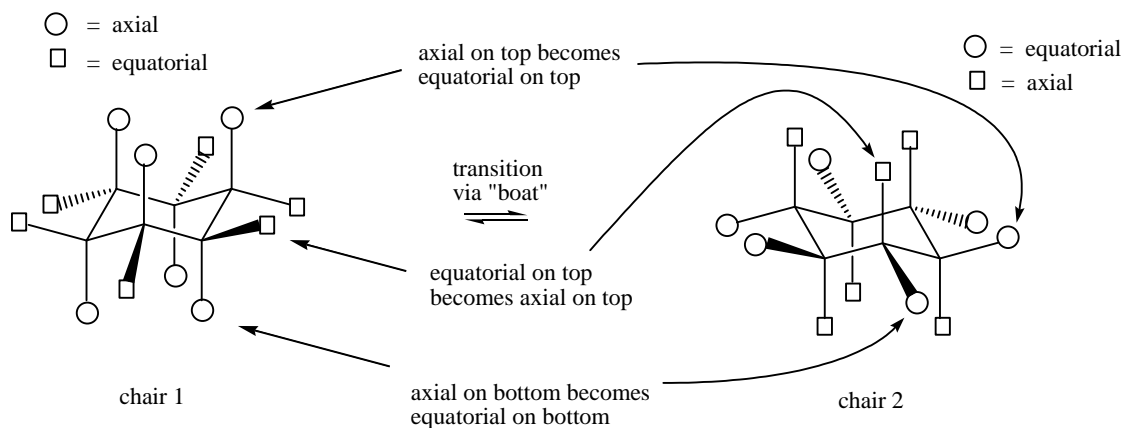
However, we will view the interconversion of the two cyclohexane conformations, simplistically, as chair 1 in equilibrium with chair 2 via the boat conformation.



Equilibration, back and forth, between the two chair conformations is rapid at room temperature and occurs on the order of 80,000 times per second. At lower temperatures interconversion is much slower (there is less thermal background energy). At -40°C the interconversion occurs about 40 times per second, at -120°C interconversion occurs about once every 23 minutes and at -160°C it is estimated to occur once every 23 years. The equilibration can occur in either of two directions as shown below.



Notice that all axial positions (top and bottom) become equatorial positions with the flip-flop of two chairs. Of course, all equatorial positions become axial positions at the same time.

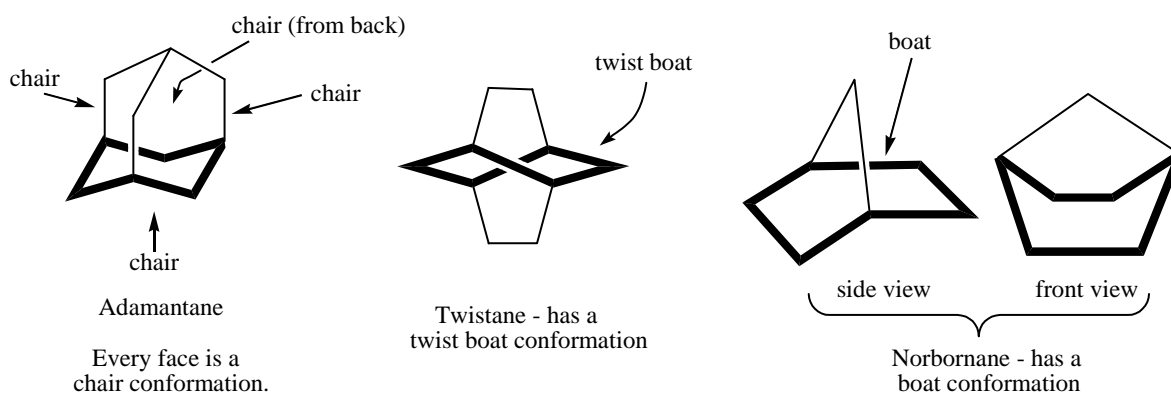


Since the two chair conformations are so much more stable than the boat or half chair over 99.99% of the molecules are in one of the two chair conformations. If all of the ring substituents are hydrogen atoms, there should nearly be a 50/50 mixture of two indistinguishable chair structures.

$$K = \frac{\text{boat}}{\text{chair}} = 10^{\frac{-\Delta G}{2.3RT}} = 10^{\frac{-(6400 \text{ cal/mole})}{(2.3)(2 \text{ cal/mol-K})(298 \text{ K})}} = 10^{-4.60} = 2.1 \times 10^{-5} = \frac{0.002\%}{99.998\%}$$

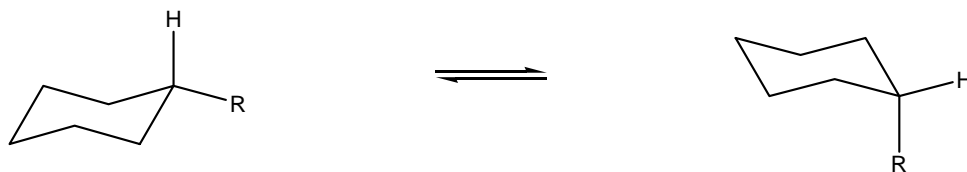
$$K = \frac{\text{chair 1}}{\text{chair 2}} = 10^{\frac{-\Delta G}{2.3RT}} = 10^{\frac{-(0 \text{ cal/mole})}{(2.3)(2 \text{ cal/mol-K})(298 \text{ K})}} = 10^0 = \frac{1}{1} = \frac{50\%}{50\%}$$

Real molecules actually exist that illustrate most of the cyclohexane conformations mentioned, above, as substructures (chair, boat and twist boat). Adamantane has four chair cyclohexane rings in its complicated tricyclic arrangement. Twistane has a good example of a twist boat conformation and is isomeric with adamantane. Norbornane has a boat conformation locked into its rigid bicyclic framework with a bridging CH_2 holding the boat shape in place. Each of these is highlighted below. Your models can help you see this a lot more clearly than these pictures.



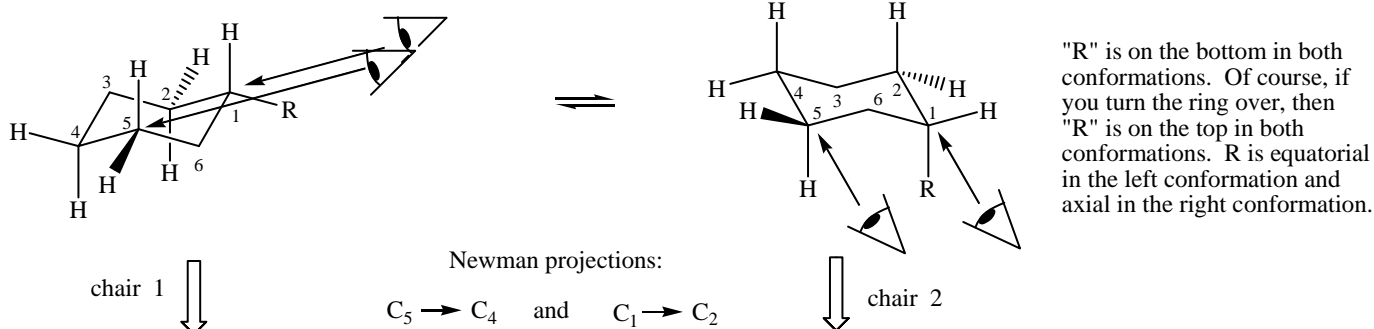
Mono Substituted Cyclohexanes

A single substitution of a hydrogen atom with another group complicates the analysis of cyclohexane conformations. There are still two rapidly equilibrating chair conformations, but they are no longer equal in potential energy.



"R" is on the bottom in both conformations. Of course, if you turn the ring over, then "R" is on the top in both conformations. R is equatorial in the left conformation and axial in the right conformation.

A Newman perspective using the $C_1 \rightarrow C_2$ and $C_5 \rightarrow C_4$ bonds can help to evaluate which of these two conformations is more stable. Both chair conformations have an all staggered orientation about the ring, but chair 2 has gauche interactions of the substituent and the ring, which are not present in chair 1.

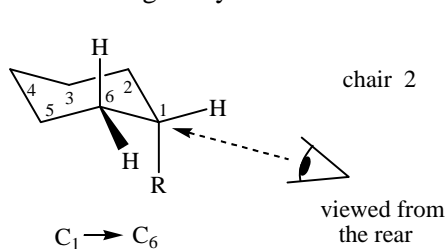


"R" is on the bottom in both conformations. Of course, if you turn the ring over, then "R" is on the top in both conformations. R is equatorial in the left conformation and axial in the right conformation.

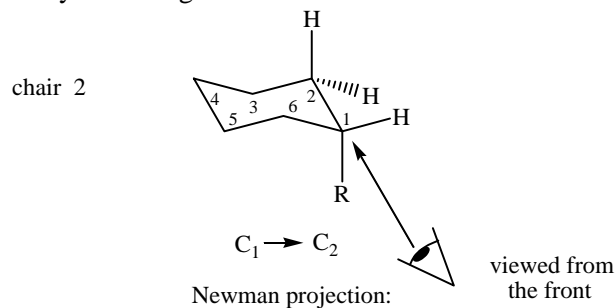
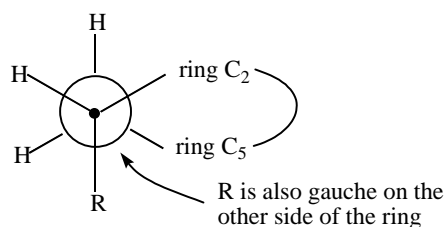
Equatorial "R" is anti to the ring on two sides. Only one shows in this Newman projection.

Axial "R" is gauche to the ring on two sides. Only one shows in this Newman projection.

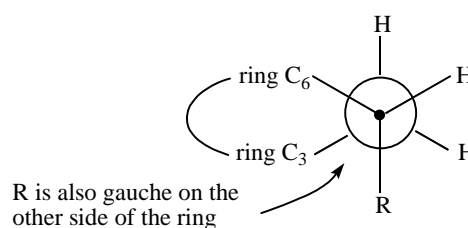
If we view down the $C_1 \rightarrow C_6$ bond and the $C_1 \rightarrow C_2$ bond, it is clear that an axial R substituent is gauche with both sides of the ring. Any axial substituent in a cyclohexane ring really has two gauche interactions.



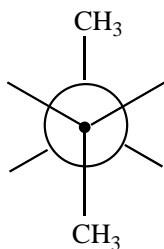
Newman projection:



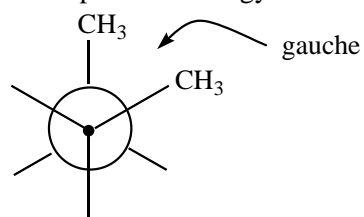
Newman projection:



We have previously seen that a CH₃/CH₃ gauche interaction raises the potential energy about 0.8 kcal/mole.



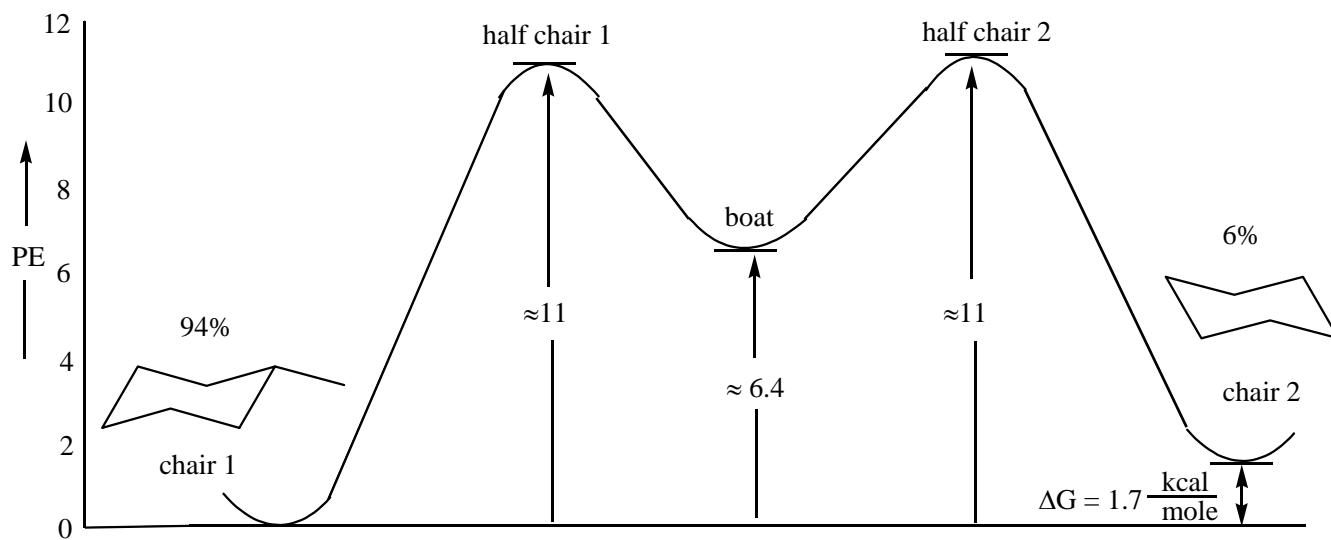
anti CH₃/CH₃ = 0 kcal/mole



gauche CH₃/CH₃ = 0.8 kcal/mole

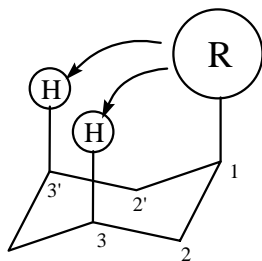
Two such relationships should raise the energy by approximately (2)x(0.8 kcal/mole) = 1.6 kcal/mole. The actual value observed for an axial CH₃ in cyclohexane relative to equatorial is 1.7 kcal/mole, very close to what we expect.

$$K = \frac{\text{chair 2}}{\text{chair 1}} = 10^{\frac{-\Delta G}{2.3RT}} = 10^{\frac{-(1700 \text{ cal/mole})}{(2.3)(2 \text{ cal/mol-K})(298 \text{ K})}} = 10^{-1.2} = 0.058 = \frac{1}{17} = \frac{6\%}{94\%} = \frac{\text{axial CH}_3}{\text{equatorial CH}_3}$$



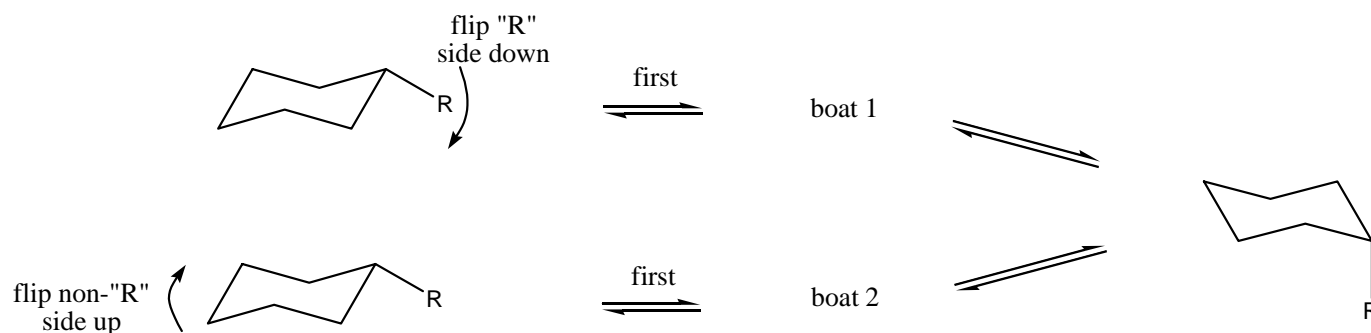
Energy changes of methylcyclohexane conformations.

The two gauche interactions of axial R substituents and the ring carbon atoms in cyclohexane structures, are called 1,3-diaxial interactions. In the axial position, the substituent R, is forced close to the other two axial groups on the same side of the ring. Since these are both three atoms away from the ring carbon atom with the R substituent, the 1,3-diaxial descriptor is appropriate.

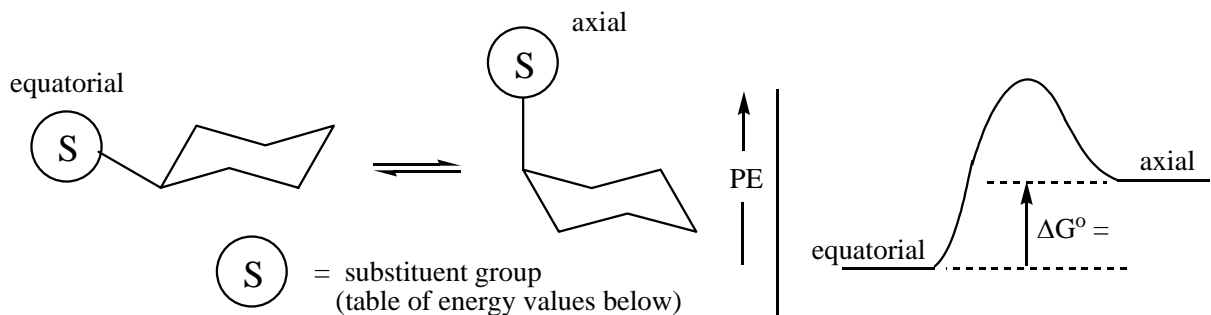


1,3-diaxial interaction
(≈ two gauche interactions)

Problem 2 - Which boat conformation would be a more likely transition state in interconverting the two chair conformations of methylcyclohexane...or are they equivalent? Explain your answer.

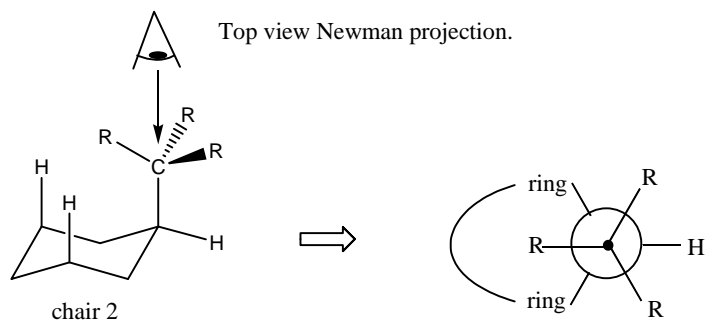
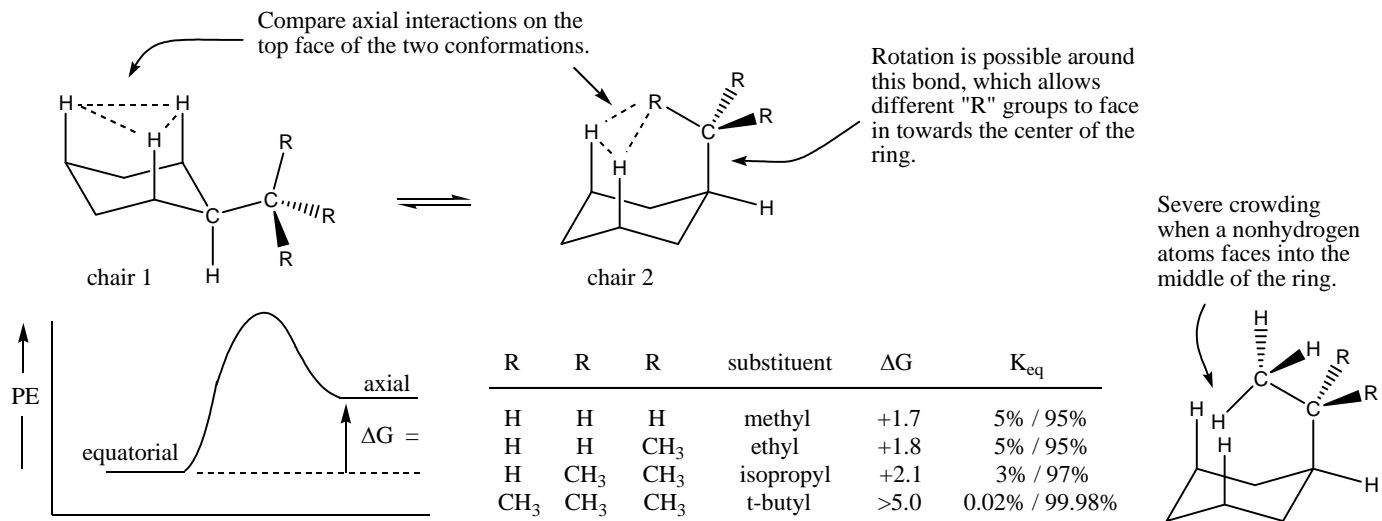
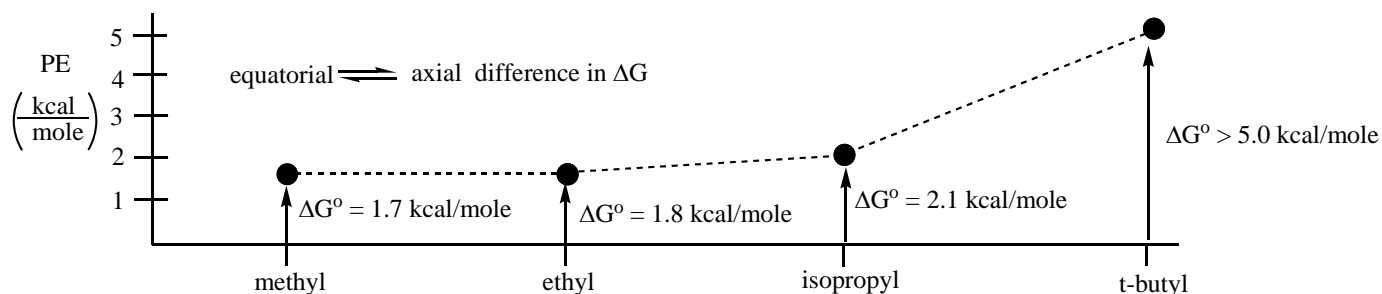
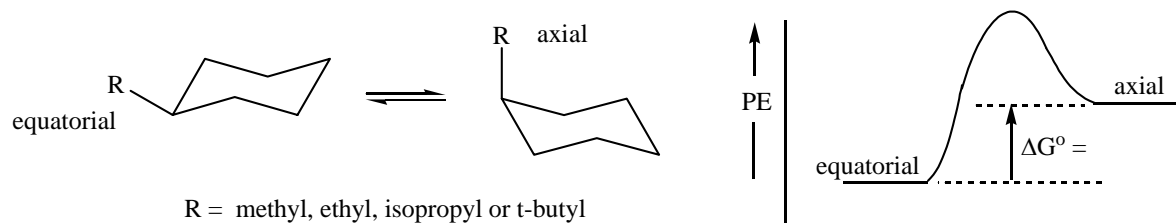


A wide range of substituents has been studied and almost all show a preference for the equatorial position. Several examples are listed in the table below. The actual energy difference between equatorial substituents and axial substituents is often called the A value (axial strain). Larger A values indicate a greater equatorial preference for the substituent due to larger destabilizing 1,3-diaxial interactions (or double gauche interactions).



Substituent	ΔG° (A value)	Substituent	ΔG° (A value)
-H	0.0	-CH ₂ OH	1.8
-CH ₃	1.7	-CH ₂ Br	1.8
-CH ₂ CH ₃	1.8	-CF ₃	2.4
-CH(CH ₃) ₂	2.1	-O ₂ CCH ₂ CH ₃	1.1
-C(CH ₃) ₃	> 5.0	-OH	0.9
-F	0.3	-OCH ₃	0.6
-Cl	0.5	-SH	1.2
-Br	0.5	-SCH ₃	1.0
-I	0.5	-SC ₅ H ₆	1.1
-CH=CH ₂	1.7	-SOCH ₃	1.2
-CH=C=CH ₂	1.5	-SO ₂ CH ₃	2.5
-CCH	0.5	-SeC ₆ H ₅	1.0
-CN	0.2	-TeC ₆ H ₅	0.9
-C ₆ H ₅ (phenyl)	2.9	-NH ₂	1.2(C ₆ H ₅ CH ₃), 1.7(H ₂ O)
-CH ₂ C ₆ H ₅ (benzyl)	1.7	-N(CH ₃) ₂	1.5 (C ₆ H ₅ CH ₃), 2.1(H ₂ O)
-CO ₂ H	0.6	-NO ₂	1.1
-CO ₂ [⊖]	2.0	-HgBr	0.0
-CHO	0.7	-HgCl	-0.2
		-MgBr	0.8

The energy differences in the table between equatorial and axial positions for substituent groups from methyl through ethyl, isopropyl and *t*-butyl appear puzzling. Ethyl definitely is larger than methyl and isopropyl is larger than either of those two, but they all have similar A values. The A value for the *t*-butyl group, on the other hand, suddenly jumps to a much higher energy. Examination of the three dimensional axial conformation provides insight into this observation.



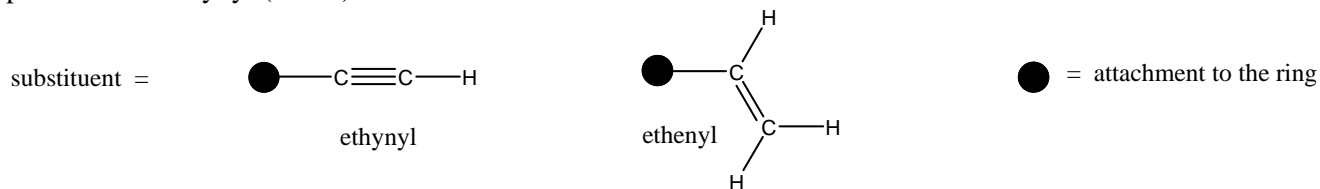
R can be a hydrogen atom pointing into the center of the ring, when the axial substituent is methyl, ethyl and isopropyl. It is not possible when the ring substituent is *t*-butyl. If the *t*-butyl substituent is axial, a methyl has to point into the center of the ring. This is very destabilizing and for the most part, *t*-butyl substituents are in the equatorial position.

In the case of methyl, ethyl or isopropyl there is always a hydrogen atom that can (and most often will) point inward toward the center of the ring. Free rotation is possible about the R₃C-C(ring) bond. Since van der Waals strain is lower for a hydrogen atom pointing toward the middle of the ring than methyl, any substituent from methyl (R = H, R = H, R = H) to ethyl (R = H, R = H, R = CH₃) to isopropyl (R = H, R = CH₃, R = CH₃) will choose an

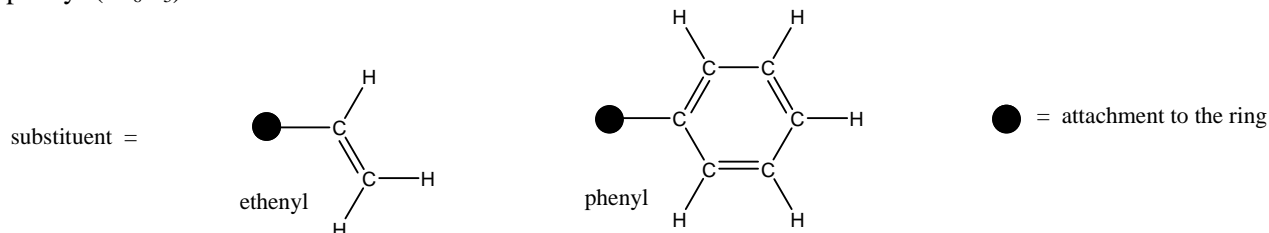
inward pointing hydrogen as its preferred conformation. When the substituent is *t*-butyl ($R = \text{CH}_3$, $R = \text{CH}_3$, $R = \text{CH}_3$), there is no such option. All possible orientations of an axial *t*-butyl point a CH_3 toward the center of the ring, which is extremely destabilizing (easy to see with a model) and chair 1 is overwhelmingly preferred.

Even though an equatorial substituent is preferred for all of the examples above, both chair conformations are present in rapid equilibrium. What varies is the percent of each chair conformation that is present. Even with *t*-butyl as the substituent, a tiny fraction of cyclohexane rings will have a transient, axial *t*-butyl (see the table above).

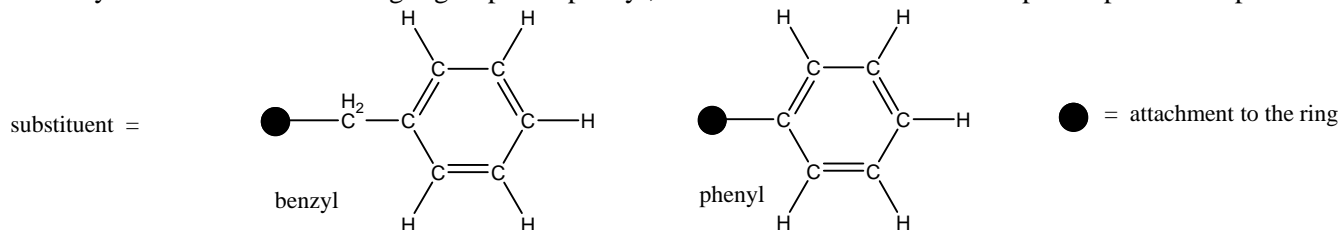
Problem 3 – a. Propose an explanation for why ethenyl ($-\text{CH}=\text{CH}_2$) has a larger preference for the equatorial position than ethynyl ($-\text{CCH}$).



b. Propose an explanation for why ethenyl ($-\text{CH}=\text{CH}_2$) has a smaller preference for the equatorial position than phenyl ($-\text{C}_6\text{H}_5$).



c. Benzyl would seem to be a larger group than phenyl, but has a smaller A value. Propose a possible explanation.

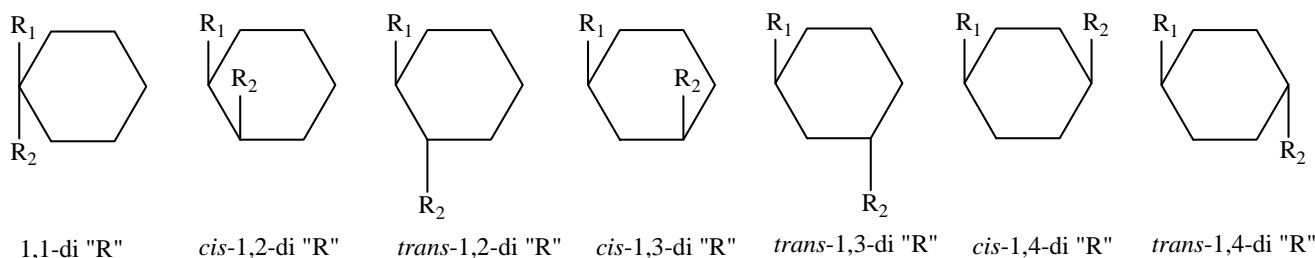


Disubstituted Cyclohexanes

Here is an excellent example of why memorization does not work in organic chemistry. Not only is it easier to learn a limited number of basic principles and logically use them in newly encountered situations, it is down right impossible to memorize every possible situation you might encounter.

When we add a second substituent to monosubstituted cyclohexane rings, the possibilities increase tremendously. Seven flat ring structures are drawn below, which just emphasize the top and bottom positions on the ring. Flat structures can be drawn as time average approximations between two interconverting chairs, although in actuality none of the structures are flat. These structures are only used as a short hand to show that substituents are on the same side or are on opposite sides. In biochemistry they are sometimes called Haworth projections and commonly used with cyclic sugar molecules.

$R_1 = R_2$ $R_1 \neq R_2$ gauche interactions are possible when substituents are 1,2-substituted



Even though we have gone from a single monosubstituted cyclohexane to seven disubstituted cyclohexane rings, the situation is even more complicated yet! Just as our monosubstituted cyclohexane had two chair conformations, there are two possible chair conformations for each of the flat structures shown above. In some cases the two conformations are equivalent in energy, but in other cases one conformation is preferred.

We need a systematic method of analysis or we will quickly become hopelessly lost in the wilderness of flip-flopping cyclohexane rings. I recommend the following strategy for every cyclohexane analysis.

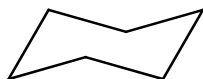
Possible systematic approach to Analyze Cyclohexane Conformations

1. Draw the cyclohexane ring framework as a bond-line formula (chair).
2. Add both axial and equatorial positions. Axials point straight up or down in alternating fashion (the ring points to the axial positions). Equatorials are off to the side (use the axial positions to guide you as to top and bottom positions). Both alternate on top or bottom of the face of the ring as you move around the ring. Use parallel bonds in the ring to guide you where to draw the equatorial bonds.
3. Add in the necessary substituents according to the name of the structure (fill in the blank). It is generally easier to visualize substituents drawn on the extreme left or extreme right carbon atoms of the ring because those bonds will be in the plane of the paper, so these are good places to draw your first substituent.
4. Draw the other conformation by flipping one side up and flip the other side down. All of the axial and equatorial positions will interchange, but the top will still be the top and the bottom will still be the bottom.
5. In addition to 1,3-diaxial interactions look for an extra gauche interactions when substituents are substituted 1,2 (vicinal substitution). We will use gauche values from the table in Topic 5 (page 13) or 0.8 if not available.
6. Evaluate which is the preferred conformation using the available energy values. Use ΔH to calculate a ratio.

$$K = 10^{\frac{-\Delta G}{2.3RT}} \approx 10^{\frac{-\Delta H}{2.3RT}}$$

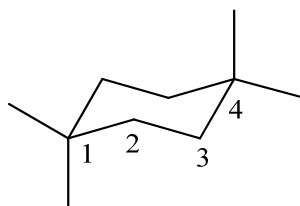
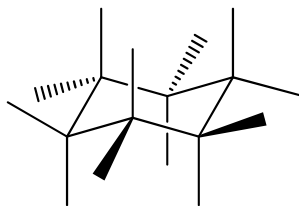
Example 1 *cis* 1,4-dimethylcyclohexane

1. Draw the bond line formula of a chair.



cis 1,4-dimethylcyclohexane

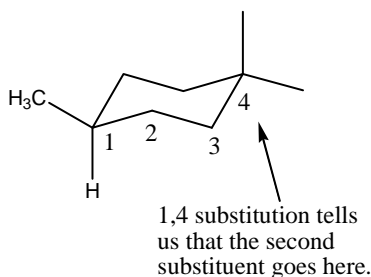
2. Add axial and equatorial positions (ring points axial).



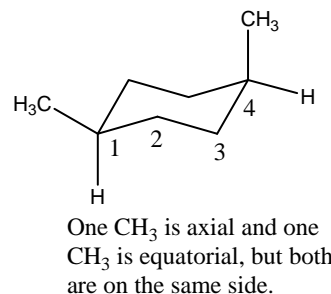
...or just this, if 1,4-disubstituted.

You can simplify this step somewhat by just adding the axial and equatorial positions of the substituted carbon atoms. Include both axial and equatorial positions at substituted positions, even if a hydrogen atom occupies one of them. If you can draw this template structure, you should be able to draw any possible structure.

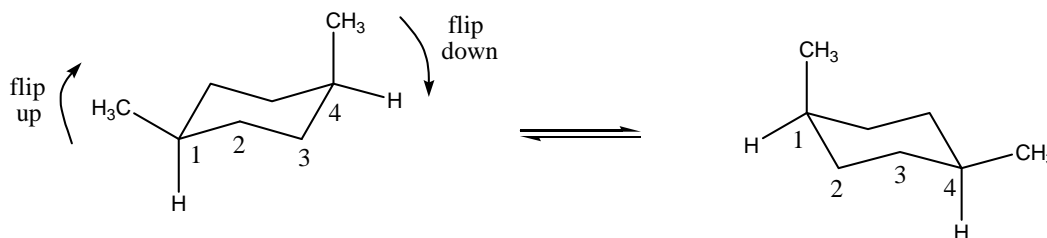
3. Add the indicated substituents. Generally the easiest positions to fill are the positions on the far left and far right carbon atoms (1 and 4, just above), since their representation is drawn in the plane of the page. At least the first substituent should be drawn at one of these positions and then fill in any other substituent(s) as required.



cis = same side, so both CH₃ groups should be on the same side (top side as written in this example). If you turned the structure over, the two methyl groups would still be on the same side, but that side would be the bottom.

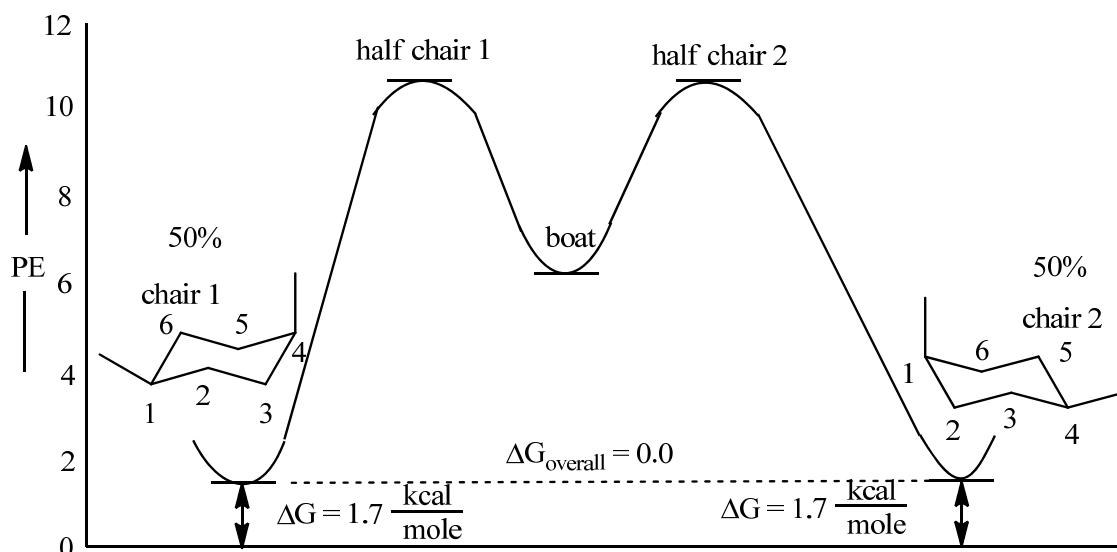


4. Draw the other conformation (flip up, flip down). Axial/equatorial interchange occurs but the structure is still *cis*.



5. There is one axial CH_3 (+1.7 kcal/mole) and one equatorial CH_3 in each conformation.
6. 1,2-gauche interactions are not applicable in this example, since there are no vicinal substituents.
7. Since the two conformations are equivalent in energy we would expect a 50/50 mixture.

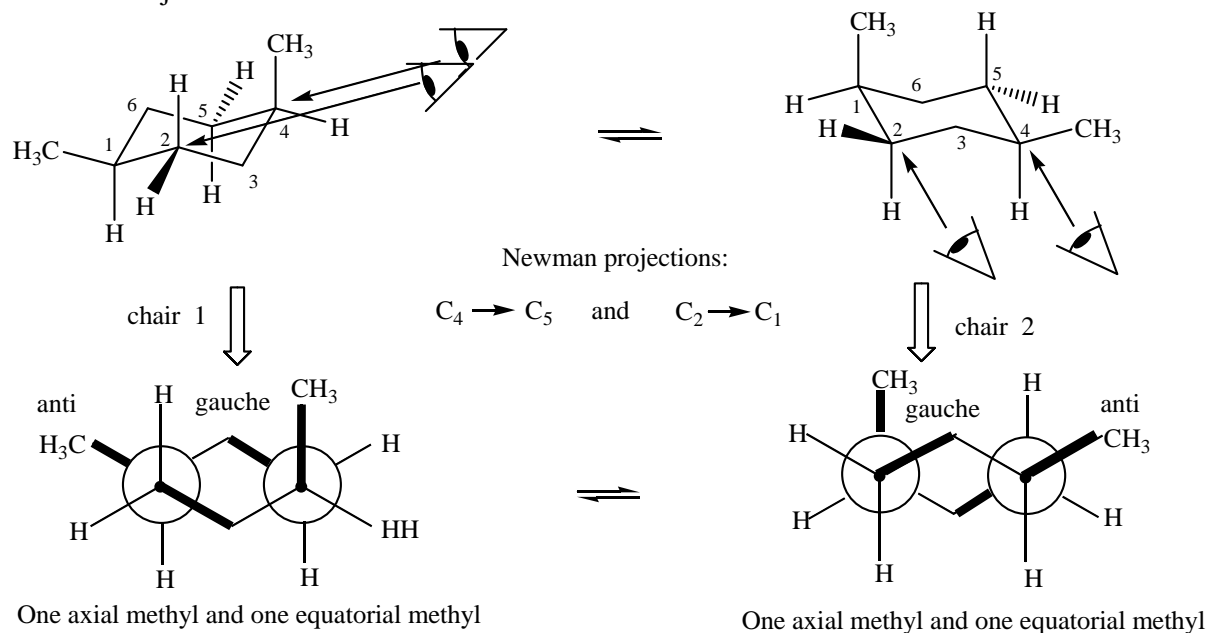
$$K = \frac{\text{chair 2}}{\text{chair 1}} = 10^{\frac{-\Delta G}{2.3RT}} = 10^{\frac{-(0 \text{ cal/mole})}{(2.3)(2 \text{ cal/mol-K})(298 \text{ K})}} = 10^0 = \frac{1}{1} = \frac{50\%}{50\%}$$



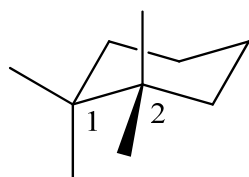
Energy changes of *cis*-1,4-dimethylcyclohexane conformations.

Zero is a strain free cyclohexane reference point with no substituents.

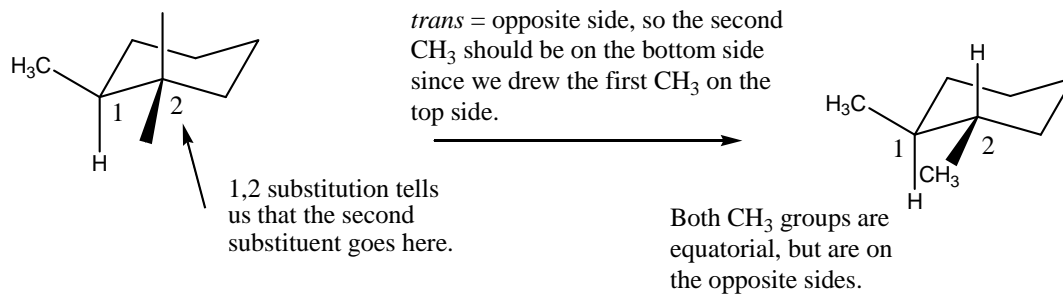
Newman Projections

Example 2 *trans*-1,2-dimethylcyclohexane

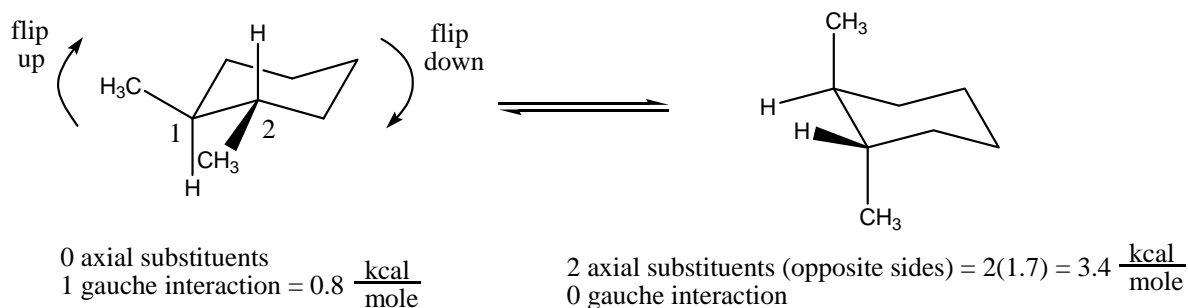
1. See above.
2. Add axial and equatorial positions wherever substituents are present (the ring points to axial).

*trans*-1,2-dimethylcyclohexane

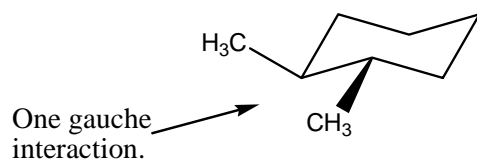
3. Add the indicated substituents.



- 4 & 5. Draw the other conformation and estimate the energy expense of each conformation.

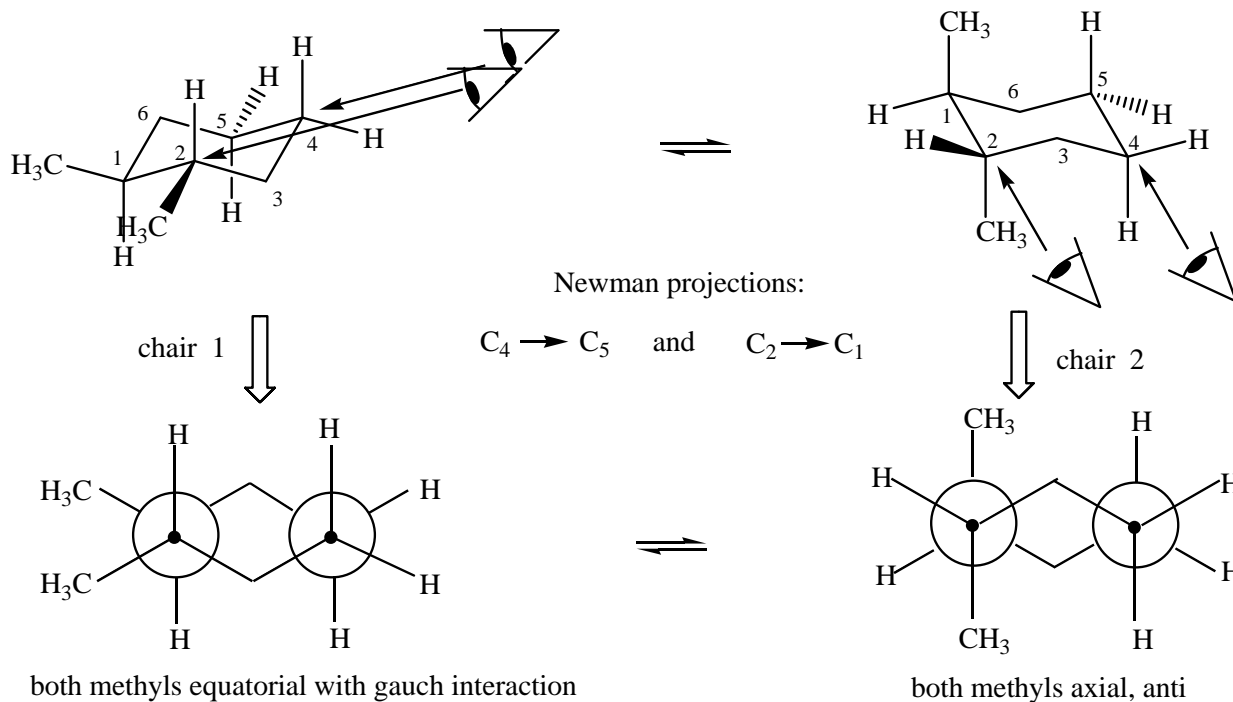
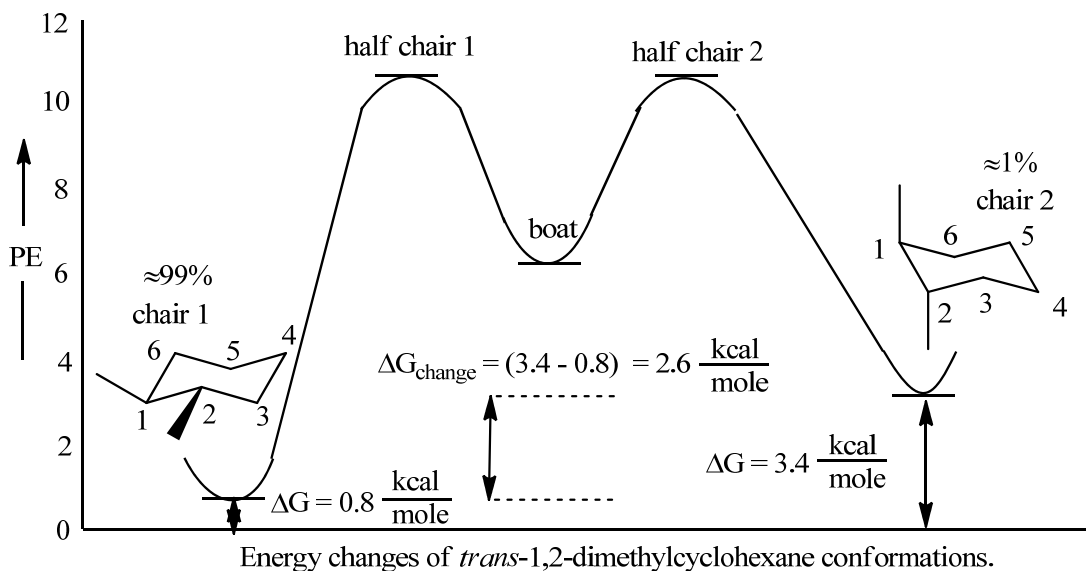


6. Chair 1 has a gauche relationship between the two CH₃ substituents, which increases energy of that conformation by +0.8 kcal/mole.



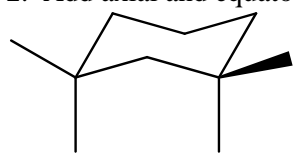
7. The potential energy difference between the two conformations is (3.4 – 0.8) = 2.6 kcal/mole. Use this value to calculate $K_{\text{equilibrium}}$.

$$K = \frac{\text{chair 2}}{\text{chair 1}} = 10^{\frac{-\Delta G}{2.3RT}} = 10^{\frac{-(2,600 \text{ cal/mole})}{(2.3)(2 \text{ cal/mol-K})(298 \text{ K})}} = 10^{-1.9} = \frac{1}{79} = \frac{1.3\%}{98.7\%}$$

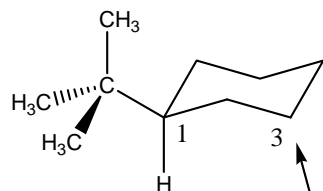


Example 3 *trans*- 1-t-butyl-3-methylcyclohexane

1. See above.
2. Add axial and equatorial positions wherever substituents are present (the ring points to axial).

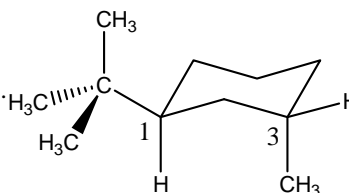
*trans*- 1-t-butyl-3-methylcyclohexane

3. Add the indicated substituents.



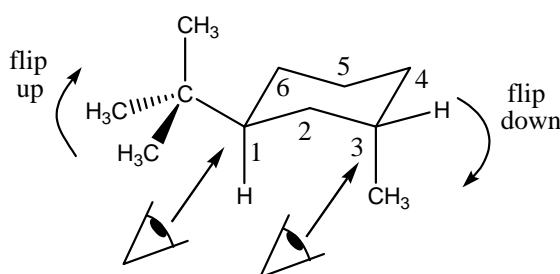
1,3 substitution tells us that the second substituent goes here.

trans = opposite side, so the CH₃ should be on the bottom side since we drew the t-butyl on the top side.

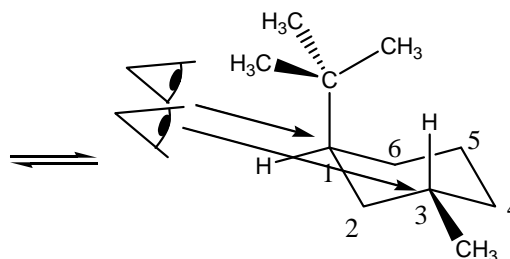


The t-butyl group is equatorial and the CH₃ group is axial, and they are on opposite sides.

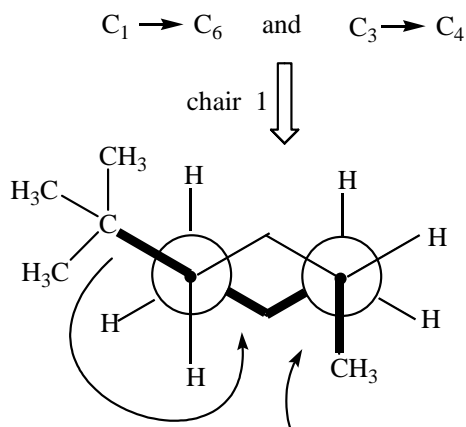
- 4 & 5. Draw the other conformation and estimate the energy expense of each conformation.



1 axial CH₃ substituent = 1.7 $\frac{\text{kcal}}{\text{mole}}$
0 gauche interaction = 0



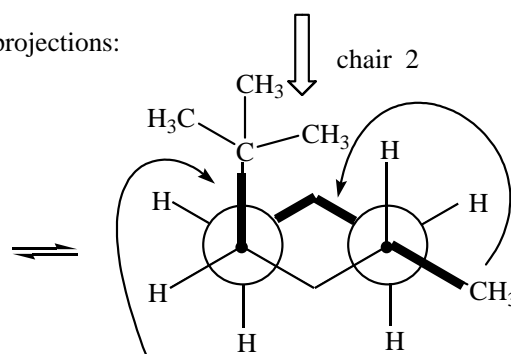
1 axial t-butyl substituent > 5.0 $\frac{\text{kcal}}{\text{mole}}$
0 gauche interaction = 0.0



t-butyl group is anti to the ring.

Axial "CH₃" is gauche to the ring on two sides. Only one shows in this Newman projection.

Newman projections:



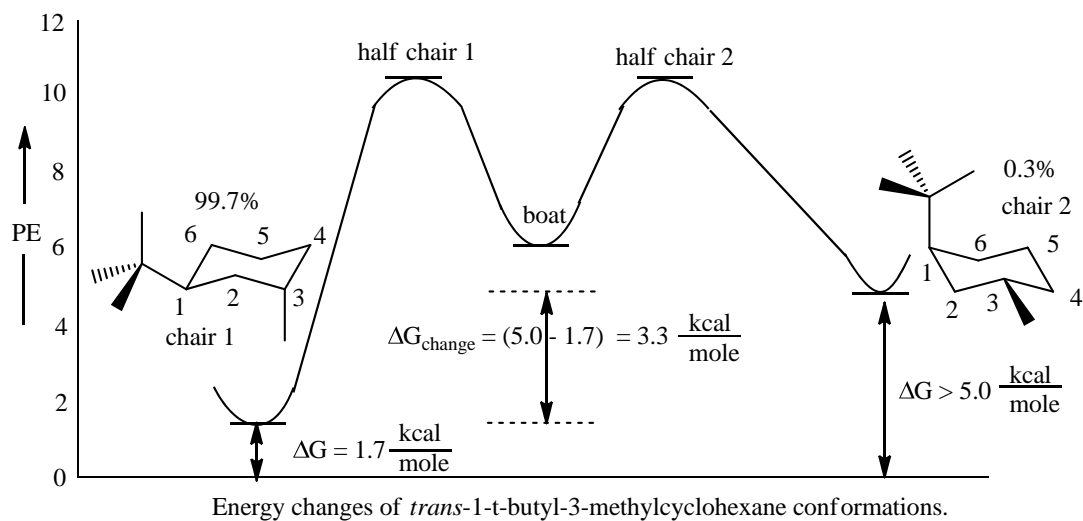
Axial "t-butyl group" is gauche to the ring on two sides. Only one shows in this Newman projection.

Equatorial "CH₃" is anti to the ring on two sides. Only one shows in this Newman projection.

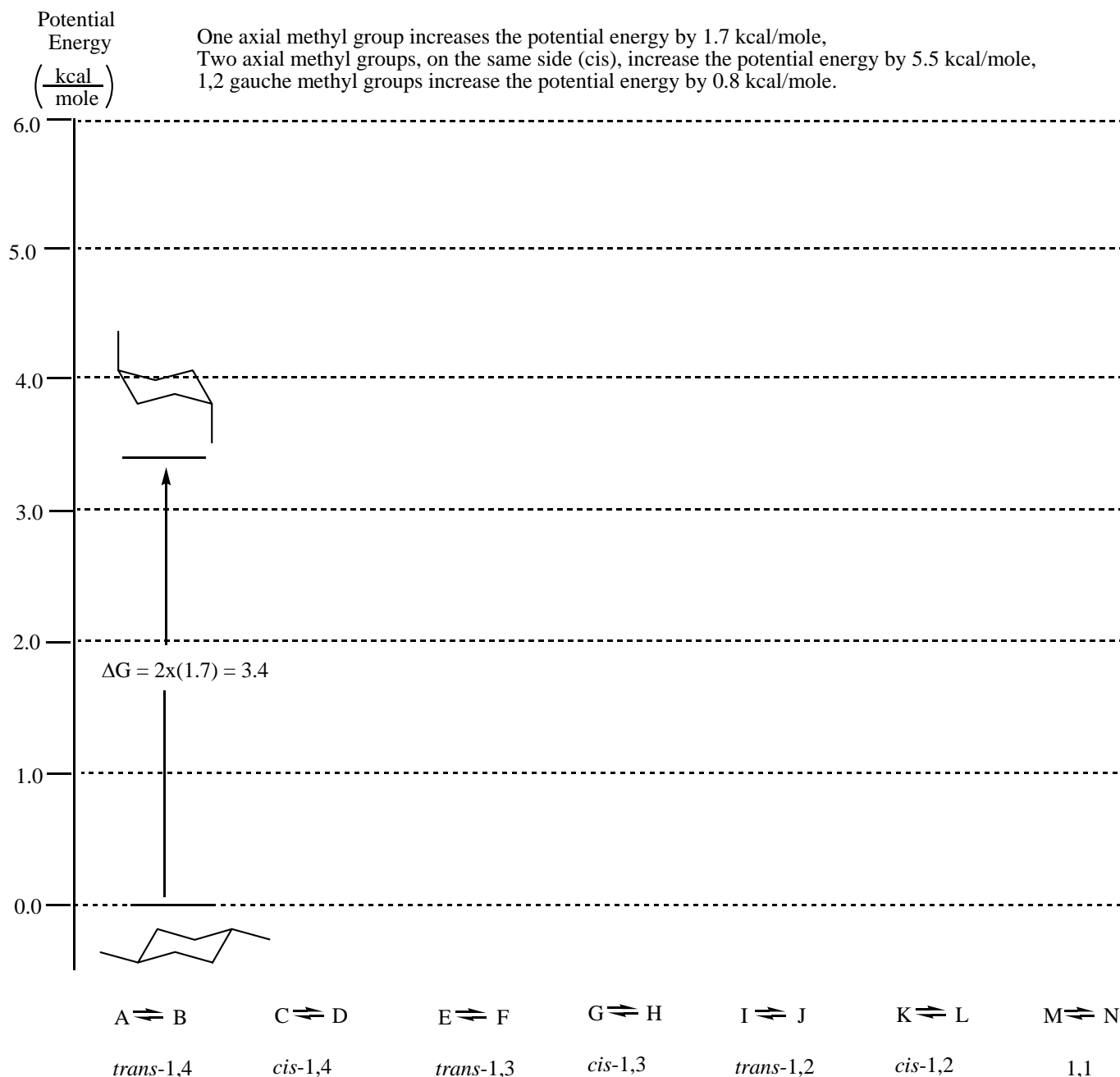
6. Gauche relationships are not applicable because substituents are not 1,2 (vicinal).

7. The potential energy difference between the two conformations is $(5.0 - 1.7) = 3.3$ kcal/mole. Use this value to calculate $K_{\text{equilibrium}}$.

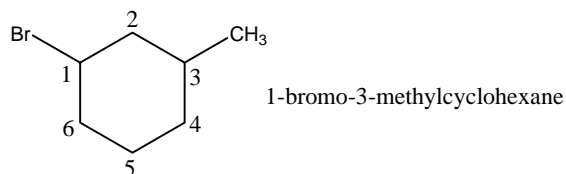
$$K = \frac{\text{chair 2}}{\text{chair 1}} = 10^{\frac{-\Delta G}{2.3RT}} = 10^{\frac{-(3,300 \text{ cal/mole})}{(2.3)(2 \text{ cal/mol}\cdot\text{K})(298 \text{ K})}} = 10^{-0.004} = \frac{1}{255} = \frac{0.3\%}{99.7\%}$$



Problem 4 – Draw all isomers of dimethylcyclohexane and evaluate their relative energies and estimate an equilibrium distribution for the two chair conformations. Use the given energy values for substituted cyclohexane rings. If the two substituents on the ring were different, all 14 conformations below would have different energies!

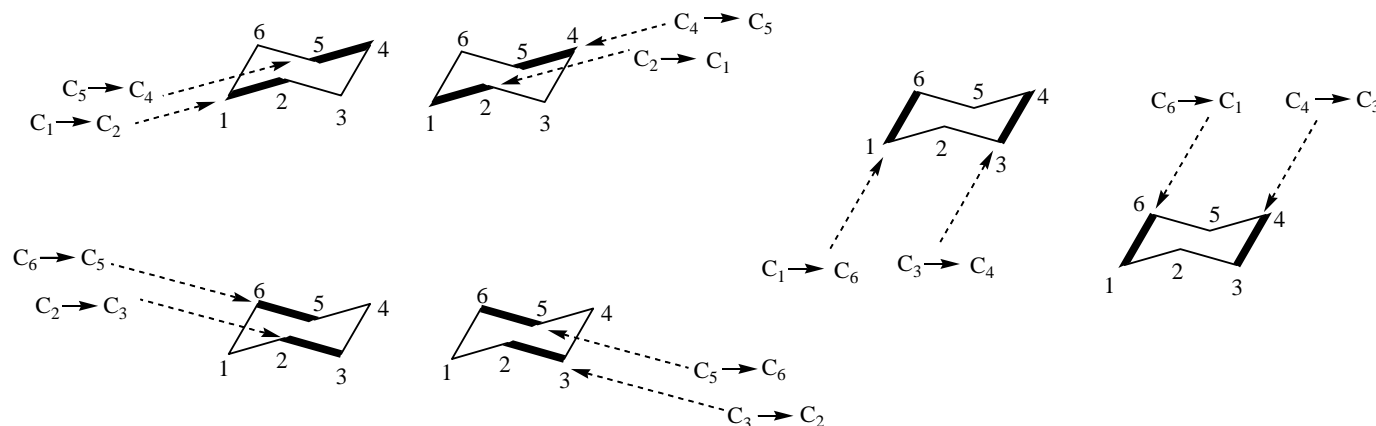


Problem 5 - Both *cis* and *trans* 1-bromo-3-methylcyclohexane can exist in two chair conformations. Evaluate the relative energies of the two conformations in each isomer (use the energy values from the table presented earlier). Estimate the relative percents of each conformation at equilibrium using the difference in energy of the two conformations from your calculations. Draw each chair conformation in 3D bond line notation and as a Newman projection using the $C_1 \rightarrow C_6$ and $C_3 \rightarrow C_4$ bonds to sight down.

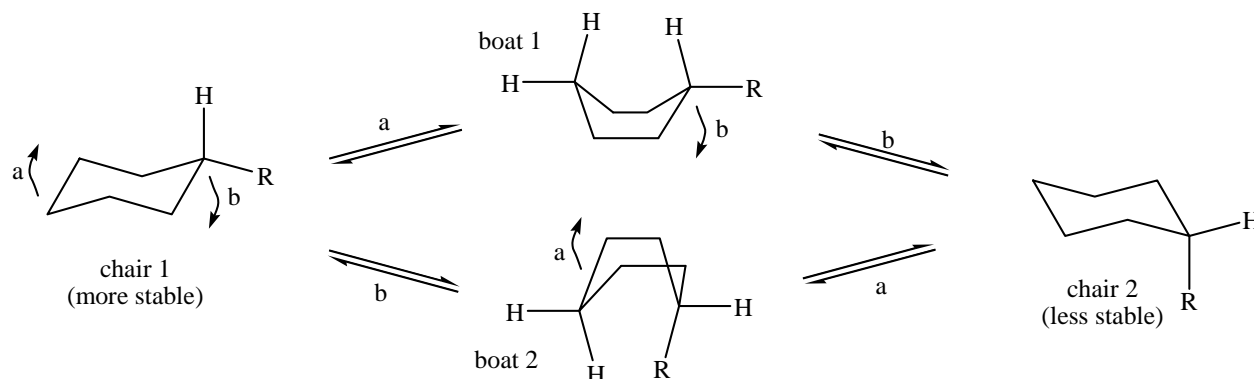


Topic 7 Possible answers to problems

Problem 1 (p 3) - How many possible Newman perspectives of chairs are possible on the numbered cyclohexane below? Consider all numbers and front/back views. Write them as, C1→C2, C5→C4, etc.)



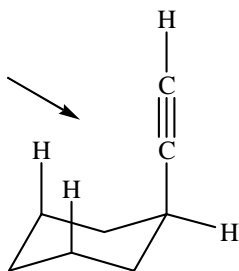
Problem 2 (p 11) - Which boat conformation would be a more likely transition state in interconverting the two chair conformations of methylcyclohexane...or are they equivalent? Explain your answer.



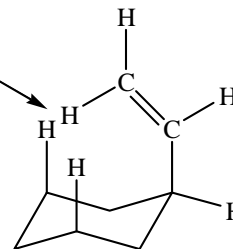
Boat 2 raises the potential energy more than boat 1 because the larger 'R' group is pointing into the middle of the ring causing greater electron-electron repulsion from the crowded positions. Boat 1 keeps the larger 'R' group pointing out away from the rest of the ring until the final flip puts it in the less stable axial position.

Problem 3 (p 13) – a. Propose an explanation for why ethenyl ($-\text{CH}=\text{CH}_2$) has a larger preference for the equatorial position than ethynyl ($-\text{C}\equiv\text{CH}$).

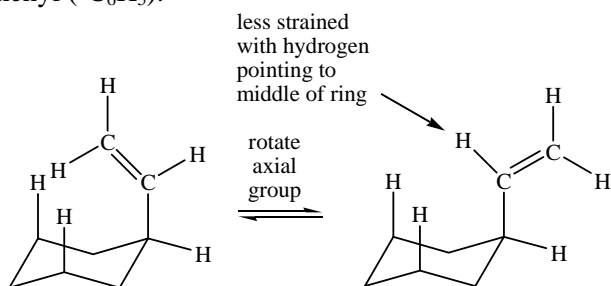
Ethynyl is a sterically smaller group in the axial position because of its linear shape. It is parallel to the other 1,3 diaxial positions causing very little crowding.



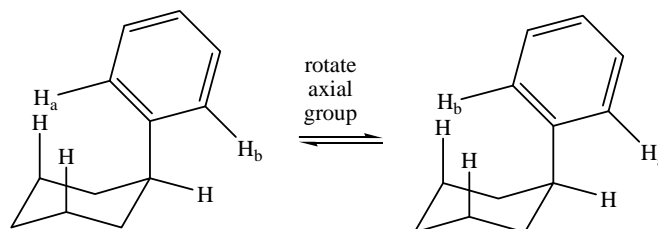
Ethenyl is a sterically larger group in the axial position, causing more severe 1,3 diaxial crowding.



b. Propose an explanation for why ethenyl ($-\text{CH}=\text{CH}_2$) has a smaller preference for the equatorial position than phenyl ($-\text{C}_6\text{H}_5$).

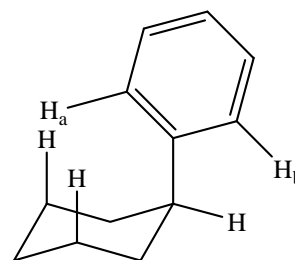
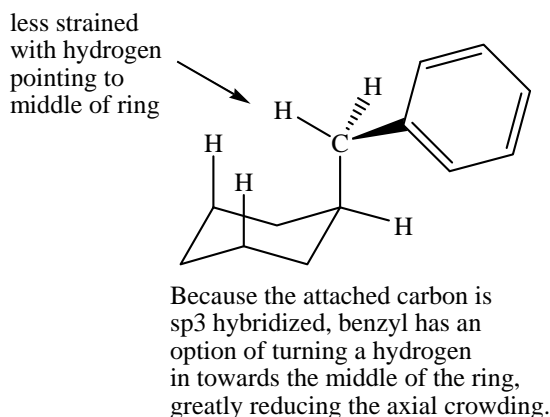


Even when ethenyl is axial it has the option of turning a hydrogen in towards the middle of the ring, greatly reducing the axial crowding.



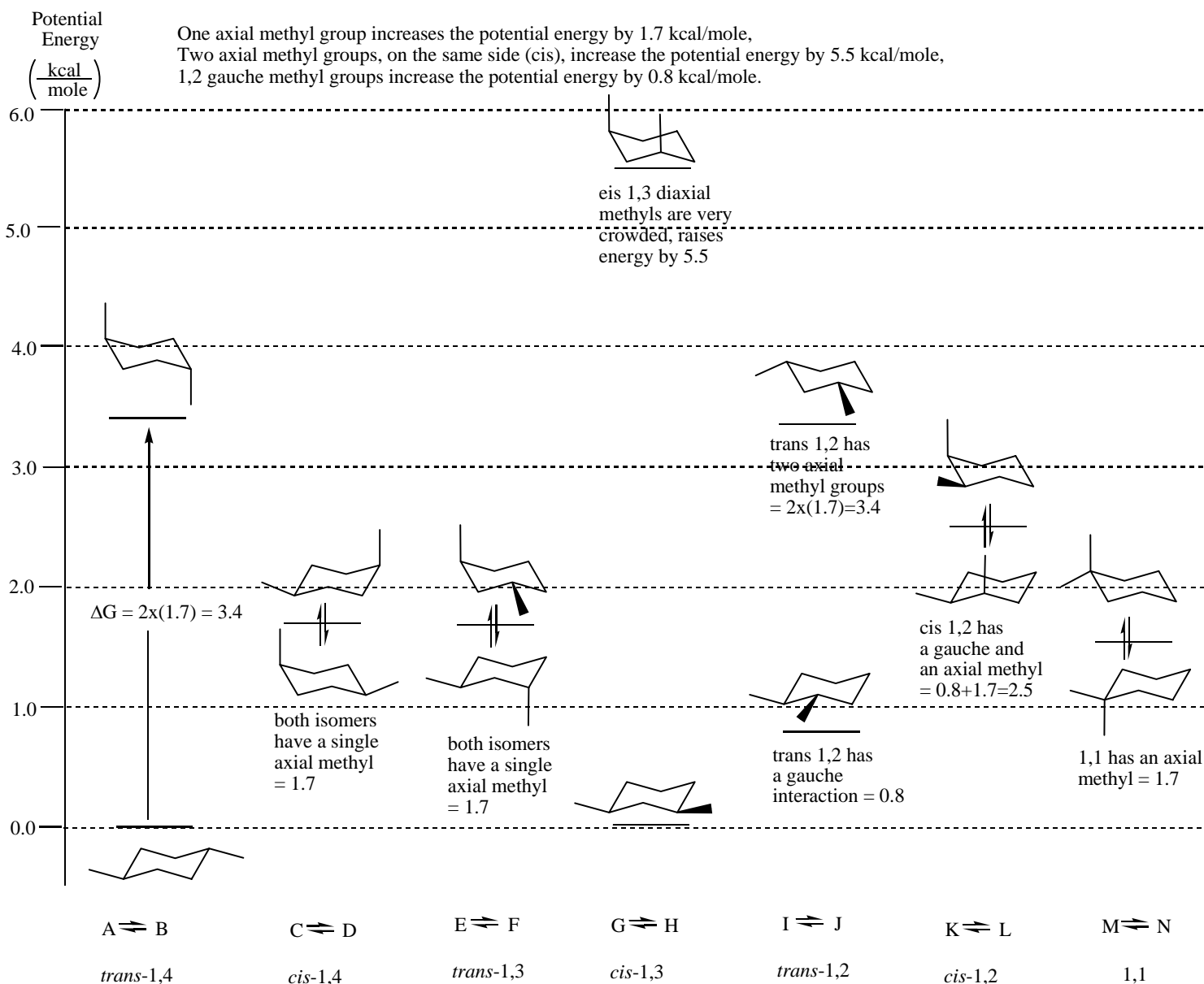
Nothing changes when the phenyl substituent rotates 180°. It is sterically crowded in both positions, so will have larger axial strain (energy).

c. Benzyl would seem to be a larger group than phenyl, but has a smaller A value. Propose a possible explanation.



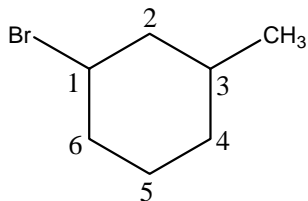
As seen above, phenyl does not have any options for the relief of A strain (1,3 diaxial interactions).

Problem 4 (p 20) – Draw all isomers of dimethylcyclohexane and evaluate their relative energies and estimate an equilibrium distribution for the two chair conformations. Use the given energy values for substituted cyclohexane rings.

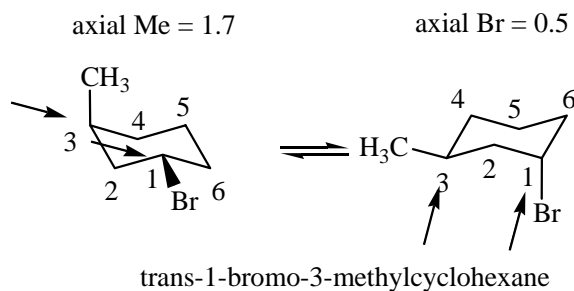


Problem 5 (p 20) - Both *cis* and *trans* 1-bromo-3-methylcyclohexane can exist in two chair conformations. Evaluate the relative energies of the two conformations in each isomer (use the energy values from the table presented earlier). Estimate the relative percents of each conformation at equilibrium using the difference in energy of the two conformations from your calculations. Draw each chair conformation in 3D bond line notation and as a Newman projection using the C₁→C₆ and C₃→C₄ bonds to sight down.

1-bromo-3-methylcyclohexane



$$\Delta H = -1.2 \text{ kcal/mole}$$

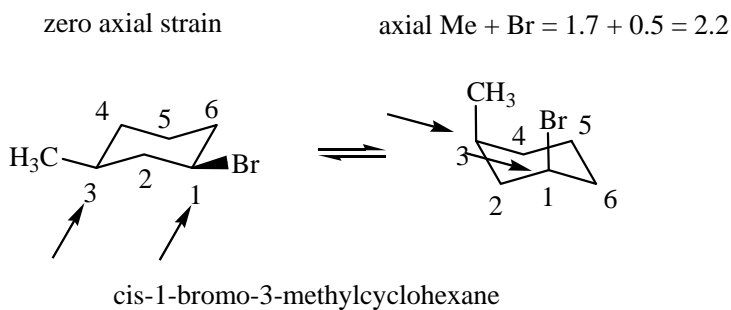


$$K = \frac{\text{chair 2}}{\text{chair 1}} = 10^{\frac{-\Delta G}{2.3RT}}$$

$$= 10^{\frac{-(-1,200 \text{ cal/mole})}{(2.3)(2 \text{ cal/mol-K})(298 \text{ K})}}$$

$$= 10^{+0.9} = \frac{7.4}{1.0} = \frac{88\%}{12\%}$$

$$\Delta H = 2.2 \text{ kcal/mole}$$



$$K = \frac{\text{chair 2}}{\text{chair 1}} = 10^{\frac{-\Delta G}{2.3RT}}$$

$$= 10^{\frac{-(2,200 \text{ cal/mole})}{(2.3)(2 \text{ cal/mol-K})(298 \text{ K})}}$$

$$= 10^{-1.6} = \frac{1}{39} = \frac{2\%}{98\%}$$

