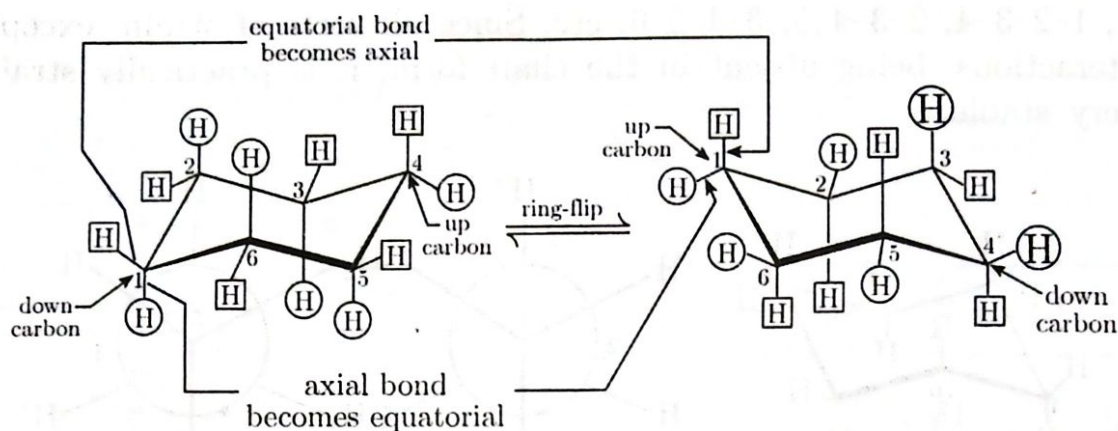


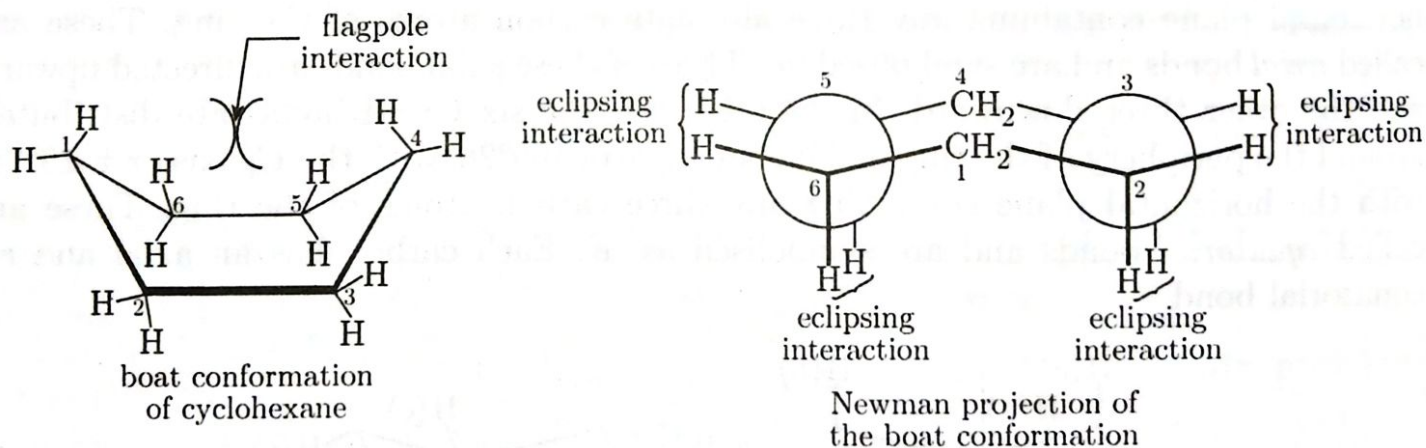
(c) As a result of the ease of rotation about its C—C single bonds, cyclohexane rapidly interconverts between two stable chair conformations. This interconversion is known as ring-flip or ring inversion. When the two chair conformations interconvert, the equatorial bonds become axial while the axial bonds become equatorial. In addition up and down carbons become down and up carbons respectively.



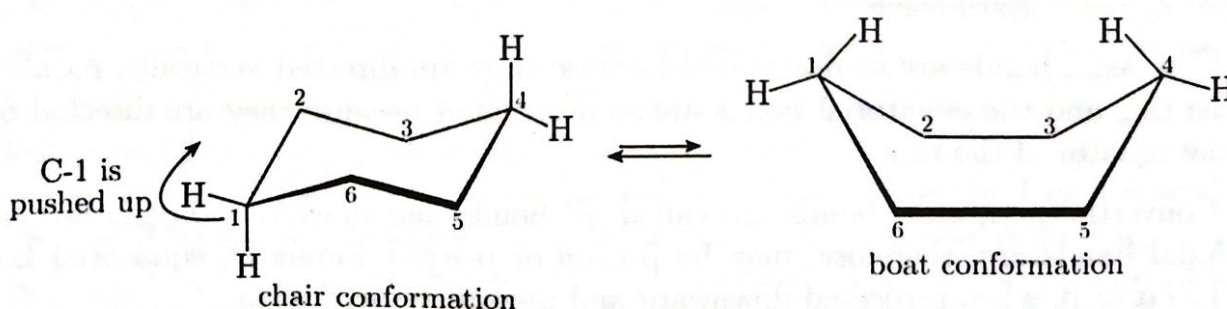
Since the activation energy for the process of ring inversion at room temperature is very low (10.8 kcal/mol), the rate of ring inversion or chair-chair interconversion is very high (approximately 10^5 times per second) at room temperature.

The interconversion can be arrested by cooling cyclohexane to very low temperatures ($\approx 100^\circ\text{C}$).

(d)

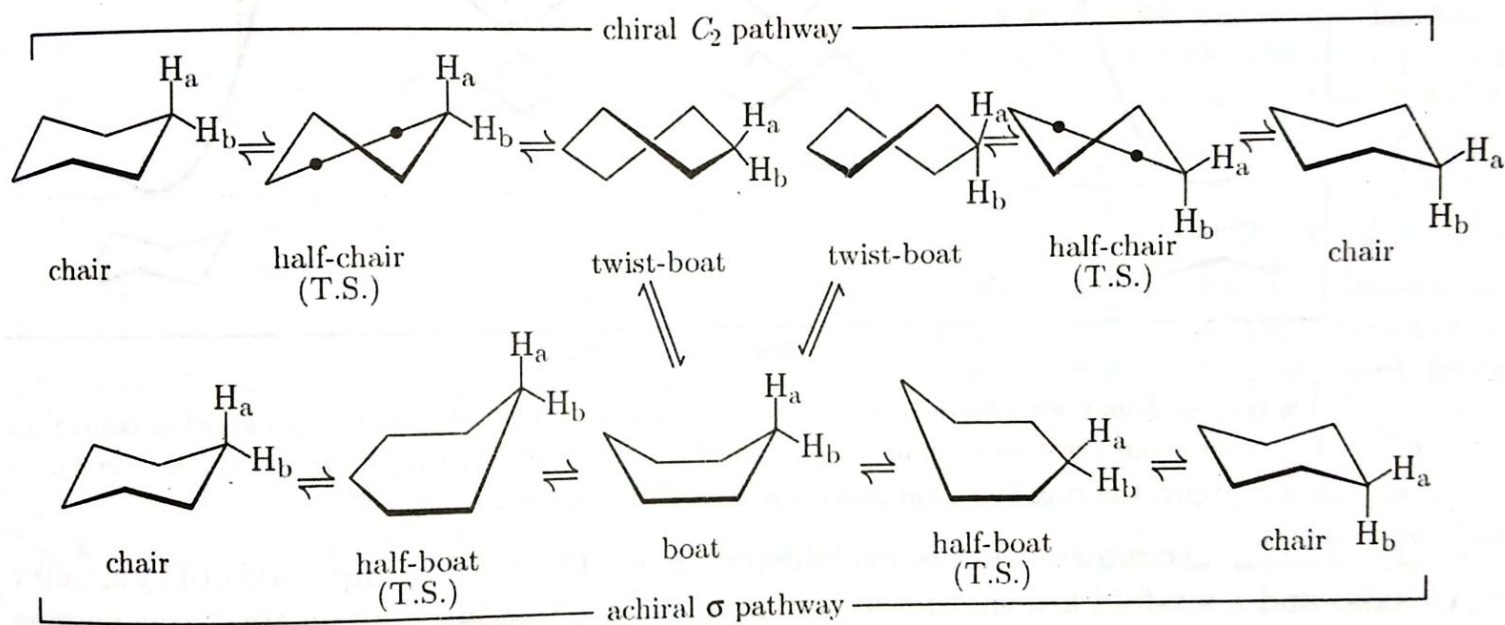


The boat conformation of cyclohexane is formed by “flipping” one end of the chair conformation up (or down). This flip requires only rotation about C—C single bonds.



Like the chair conformation, the boat conformation is free of angle strain. The boat conformation, however, is not free of torsional strain because there is eclipsing of two pairs of hydrogens on each set of gunwale carbons (C-2,C-3 and C-5,C-6). Again, the two flagpole hydrogens (the hydrogens which point upward from the ends of the boat like two flagpoles) on C-1 and C-4 are close enough to each other (which are within 180 pm, less than twice the van der Waals radius of hydrogen, i.e., $120 \times 2 = 240$ pm) to cause van der Waals repulsion (steric strain). This interaction is often called "flagpole" interaction. Torsional strain and "flagpole" interaction cause the boat conformation to have considerable higher energy (6.5 kcal/mole) than the chair conformation, even though the former contains two less *buten-gauche* interactions. Therefore, the boat conformation is less stable than the chair conformation.

(e) Two different pathways (chiral C_2 pathway and achiral σ pathway) have been considered for ring inversion of cyclohexane chair form and these can be shown as follows :



C_2 pathway : The chair conformer may be twisted to get the half-chair conformation (transition state) in which four carbon atoms lie in a plane and the other two alternately above and below the plane. There occurs extensive bond angle deformation accompanied with an increase in torsional strain. The transition state conformation has a C_2 axis but no σ plane. Further change leads to the 'twist-boat' conformation which has no angle strain but suffers from some torsional strain. It corresponds to an energy minimum and is actually a conformer. It leads to a conformation which is the classical boat. The boat conformation in its turn can go back to the original chair or to the inverted chair with equal facility through the enantiomeric twist-boat and half-chair transition state (T.S.) respectively. This pathway is called the C_2 pathway, since C_2 axis of the ground state chair form is retained along the pathway.

σ pathway : The chair form is twisted to an envelope-like half-boat conformation (transition state) with five of the carbon atoms in a plane and the sixth one either above or below it. This conformation has a σ plane and so is achiral. It leads directly to an energy minimum conformation which is the classical boat. The boat conformation in its

turn can go back to the original chair or to the inverted chair equally well through the equivalent half-boat conformation. This pathway is called a σ pathway, since both the half-boat and the classical boat conformations retain the symmetry plane of the chair ground state.