

Chapter 7

Alkenes and Alkynes I: Properties and Synthesis

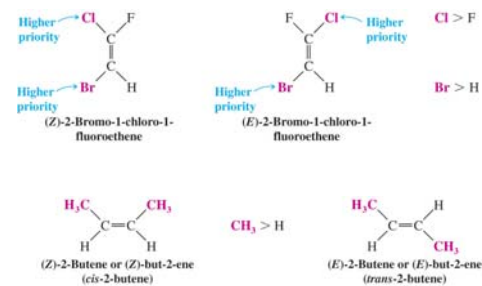
Elimination Reactions of Alkyl Halides

The (E)-(Z) System for Designating Alkene Diastereomers

The Cahn-Ingold-Prelog convention is used to assign the groups of highest priority on each carbon

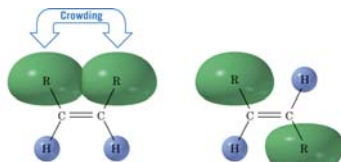
→ If the group of highest priority on one carbon is on the same side as the group of highest priority on the other carbon the double bond is Z (zusammen)

→ If the highest priority groups are on opposite sides the alkene is E (entgegen)



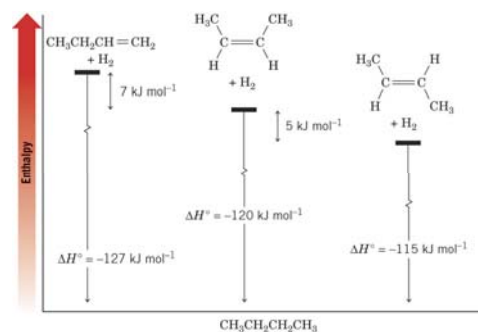
Relative Stabilities of Alkenes

- Generally cis alkenes are less stable than trans alkenes because of steric hindrance



- Heat of Hydrogenation
→ The relative stabilities of alkenes can be measured using the exothermic heats of hydrogenation

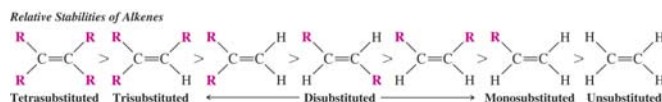
Heats of hydrogenation of three butene isomers



Since product is the same, the difference in ΔH are due to the alkene

Overall Relative Stability of Alkenes

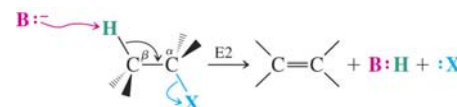
The greater the number of attached alkyl groups (*i.e.* the more highly substituted the carbon atoms of the double bond), the greater the alkene's stability



Synthesis of Alkenes via Elimination Reactions

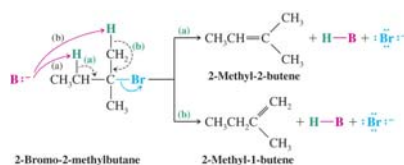
Dehydrohalogenation

- Reactions by an E2 mechanism are most useful
 - E1 reactions can be problematic
- E2 reactions are favored by:
 - Secondary or tertiary alkyl halides
 - Alkoxide bases such as sodium ethoxide or potassium *tert*-butoxide
- Bulky bases such as potassium *tert*-butoxide should be used for E2 reactions of primary alkyl halides



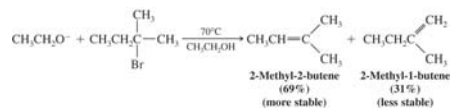
Zaitsev's Rule: Formation of the Most Substituted Alkene

Some hydrogen halides can eliminate to give two different alkenes



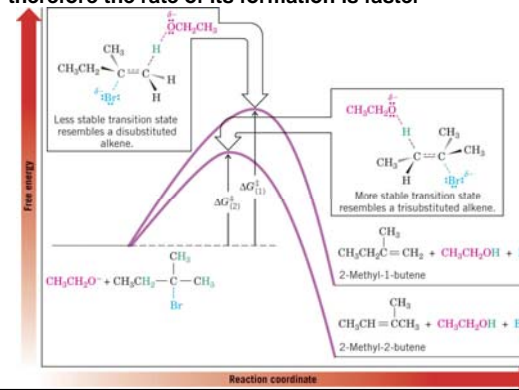
Zaitsev's Rule: when two different alkenes are possible in an elimination, the most highly substituted alkene will be the major product

→ This is true only if a small base such as ethoxide is used



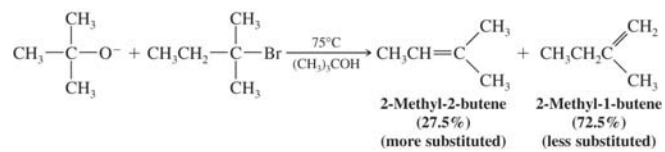
Basis of Zaitsev's Rule: Transition state has double bond character

- ♦ T.S. reflects greater stability of more substituted double bond
- ♦ Example of **Kinetic control**: When one of two products is formed because its free energy of activation is lower and therefore the rate of its formation is faster



Formation of the Least Substituted Alkene Using a Bulky Base

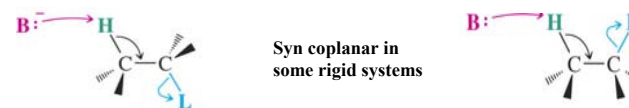
Bulky bases such as potassium *tert*-butoxide have difficulty removing sterically hindered hydrogens and generally only react with more accessible hydrogens (e.g. primary hydrogens)



The Stereochemistry of E2 Reactions

All four atoms (H-C-C-L) must be in the same plane

◆ Anti coplanar orientation is preferred so all atoms are staggered

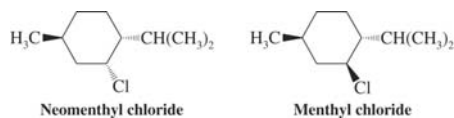


◆ In a cyclohexane ring the eliminating substituents must be diaxial to be anti coplanar



Example of stereochemical requirements

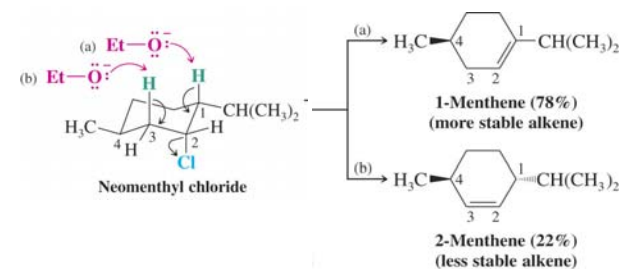
Neomenthyl chloride and menthyl chloride give different elimination products with sodium ethoxide



In neomenthyl chloride, the chloride is in the axial position in the most stable conformation

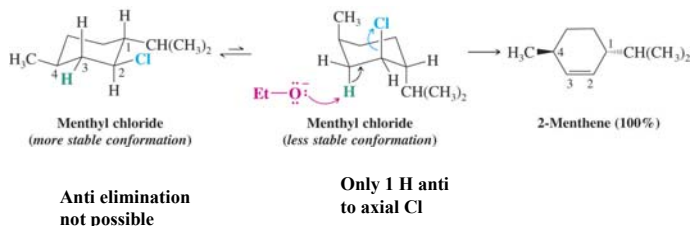
◆ Two axial hydrogens anti to chlorine can eliminate

◆ The Zaitsev product predominates



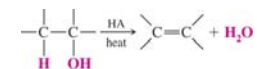
In menthyl chloride the molecule must first change to a less stable conformer to produce an axial chloride

- Elimination is slower
- Can yield only the least substituted (Hoffman) product from anti elimination



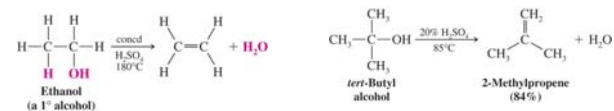
Acid Catalyzed Dehydration of Alcohols

Protonation by acids convert OH into a good leaving group OH_2^+



Typical acids used in dehydration are sulfuric acid and phosphoric acid (where the conjugate base is not a good nucleophile)

Primary alcohols are most difficult to dehydrate, tertiary are the easiest

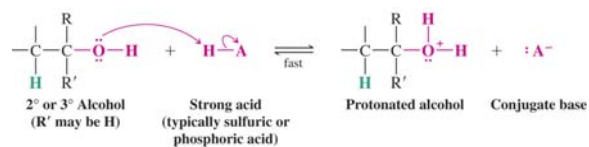


Recall that elimination is favored over substitution at higher temperatures

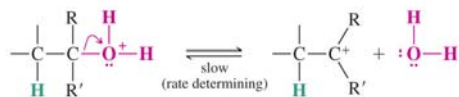
Caveat: Rearrangements of the carbon skeleton can occur

Mechanism for Dehydration of 2° and 3° Alcohols: E1

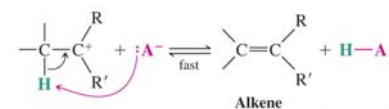
Step 1: protonation of the hydroxy group



Step 2: formation of a carbocation



Step 3: carbocation loses a proton

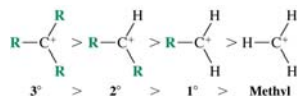


another molecule of the alcohol, a water molecule, or the conjugate base of the acid may accept the proton

Note that only a catalytic amount of acid is required since it is regenerated in the final step of the reaction

Carbocation Stability and the Transition State

Recall the stability of carbocations is:



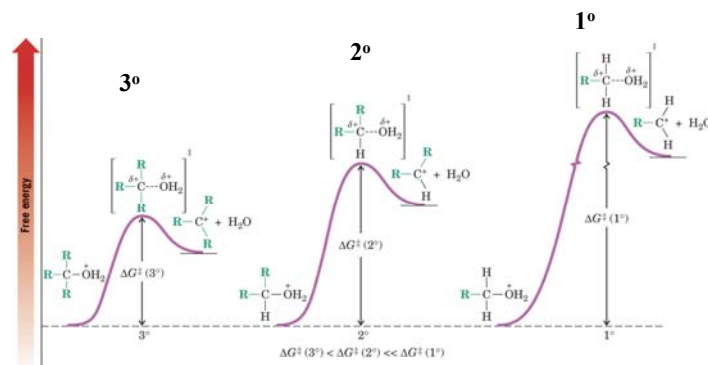
The second step in which the carbocation forms is rate determining

The transition state for this reaction has carbocation character

Tertiary alcohols react the fastest because they have the most stable tertiary carbocation-like transition state in the second step

The relative heights of ΔG^\ddagger for the second step of E1 dehydration

Primary alcohols have a prohibitively large energy barrier

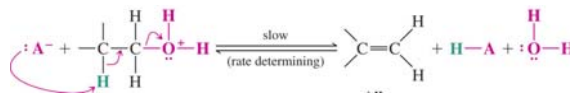


Mechanism for Dehydration of Primary Alcohols is E2

- Primary alcohols cannot undergo E1 dehydration because of the instability of the carbocation-like transition state
- In the E2 dehydration the first step is the same: protonation of the hydroxyl to yield the good leaving group water



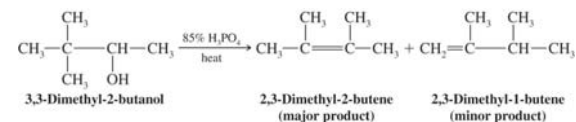
- Unable to form a carbocation, the protonated alcohol waits until some weak base assists in an E2 reaction



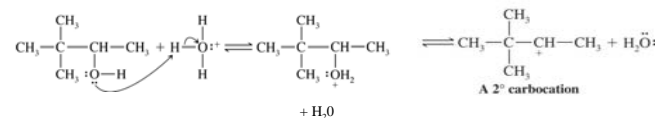
Carbocation Stability and Molecular Rearrangements

Rearrangements During Dehydration of Secondary Alcohols

- Rearrangement of a carbocation occurs if a more stable carbocation can be obtained

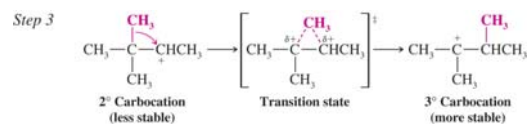


The first two steps are the same as for any E1 dehydration

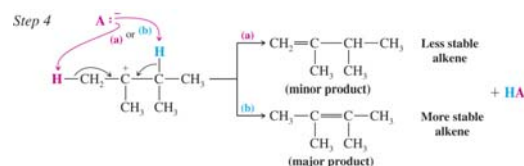


The less stable 2° carbocation rearranges by shift of a methyl group with its electrons to produce more stable 3° carbocation

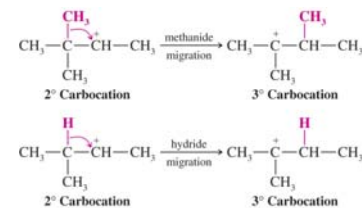
- This is called a **1,2 shift**



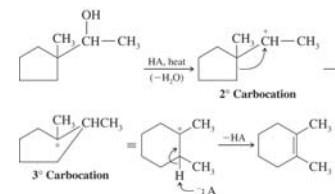
The removal of a proton to form the alkene occurs to give the Zaitzev (most substituted) product as the major one



A hydride shift (migration of a hydrogen with its electrons) can also occur to yield the most stable carbocation

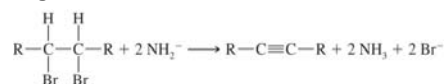


Carbocation rearrangements can lead to expansion of rings

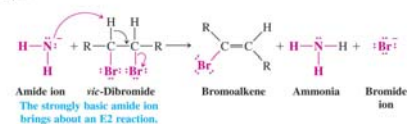


Synthesis of Alkynes by Elimination Reactions

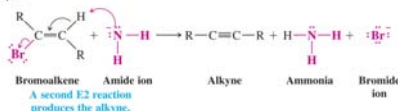
- Alkynes can be obtained by two consecutive dehydrohalogenation reactions of a vicinal dihalide



Step 1

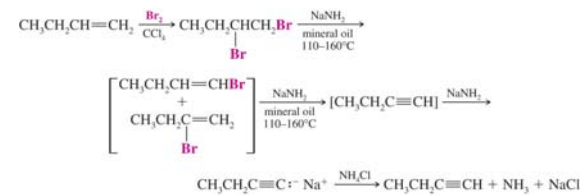


Step 2

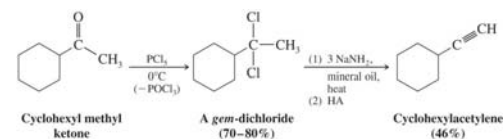


Alkenes can be converted to alkynes

By bromination and consecutive dehydrohalogenation reactions

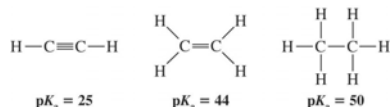


Geminal dihalides can also undergo consecutive dehydrohalogenation reactions to yield the alkyne

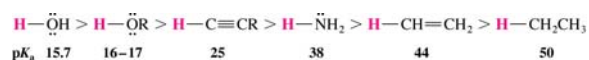


The Acidity of Terminal Alkynes

Recall that acetylenic hydrogens have a pKa of about 25 and are much more acidic than most other C-H bonds

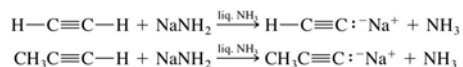


- The relative acidity of acetylenic hydrogens in solution is:



- Acetylenic hydrogens can be deprotonated with relatively strong bases (sodium amide is typical)

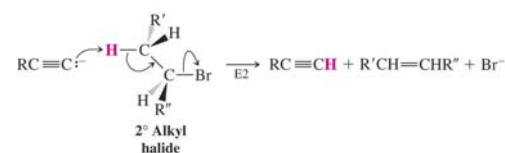
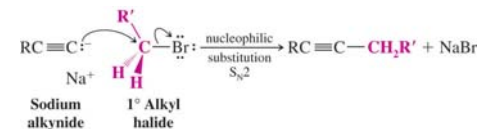
† The products are called alkynides



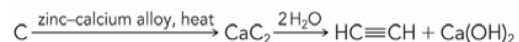
Substitutions on terminal alkynes

- Sodium alkynides can be used as nucleophiles in S_N2 reactions

- New carbon-carbon bonds are the result
- Only primary alkyl halides can be used or else elimination reactions predominate



Generation of acetylene from carbon

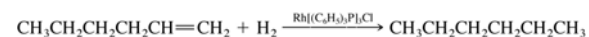
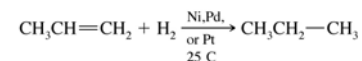
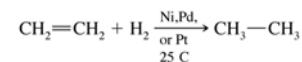


- Big Bang® carbide cannons - at big savings!
- You probably remember these from days of your youth.
- Big Bang cannons have been in continuous production since 1912.
- We offer the most popular models at below factory prices!
- These are great gifts for the junior cannoneer (ages 10 to 100) fun for the whole family

Big Bang cannons are fired by putting water in the barrel housing and then adding a measured amount of Bangsite (carbide powder). The powder dissolves in the water creating acetylene gas. The gas is then ignited by a spark....resulting in a safe and loud BOOM.

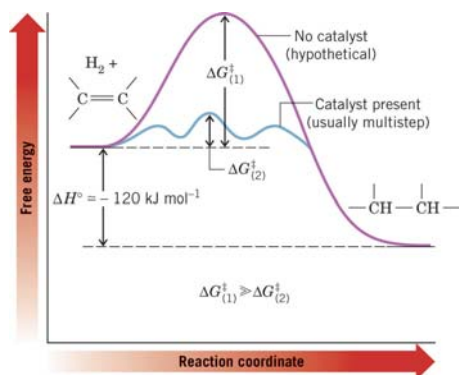
Hydrogenation of Alkenes

- Hydrogen adds to alkenes in the presence of metal catalysts
- Heterogeneous catalysts: finely divided insoluble platinum, palladium or nickel catalysts
- Homogeneous catalysts: catalyst (typically rhodium or ruthenium based) is soluble in the reaction medium
 - Wilkinson's catalyst is Rh[(C₆H₅)₃P]₃Cl
- This process is called a reduction or hydrogenation
 - An unsaturated compound becomes a saturated (with hydrogen) compound

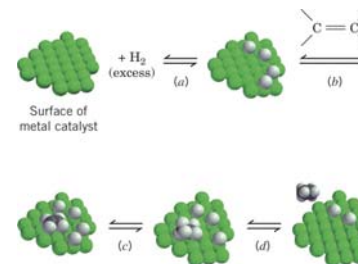


Hydrogenation: The Function of the Catalyst

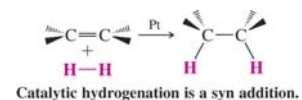
The catalyst provides a new reaction pathway with lower ΔG^\ddagger values



In heterogeneous catalysis the hydrogen and alkene adsorb to the catalyst surface and then a step-wise formation of C-H bonds occurs



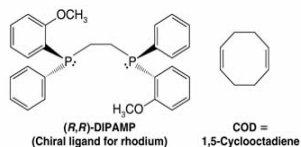
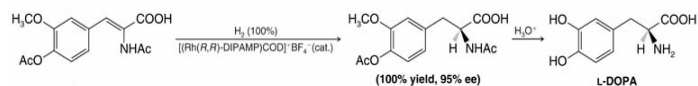
Both hydrogens add to the same face of the alkene (a **syn addition**)



Asymmetric Hydrogenation

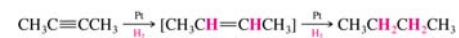
Using chiral versions of Wilkinson's catalyst, can get stereoselectivity

Asymmetric synthesis of L-dopa, drug for treating Parkinson's disease



Hydrogenation of Alkynes

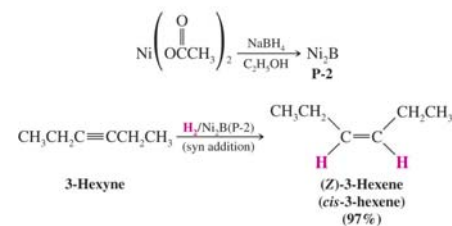
Reaction of hydrogen using regular metal catalysts results in formation of the alkane



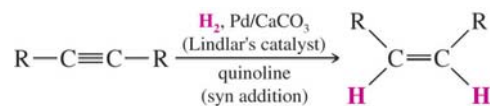
Syn Addition of Hydrogen: Synthesis of *cis*-Alkenes

→ The **P-2 catalyst nickel boride** results in syn addition of one equivalent of hydrogen to a triple bond

→ An internal alkyne will yield a *cis* double bond



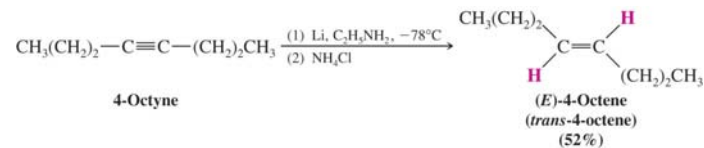
- **Lindlar's catalyst** also directs syn addition, stops with addition of only molecule of hydrogen, and produces *cis*-alkenes from alkynes



Anti Addition of Hydrogen: Synthesis of *trans*-Alkenes

A dissolving metal reaction which uses lithium or sodium metal in low temperature ammonia or amine solvent produces *trans*-alkenes

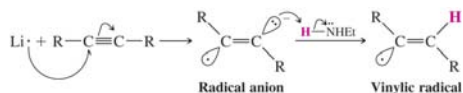
Net **anti addition** occurs by formal addition of hydrogen to the opposite faces of the double bond



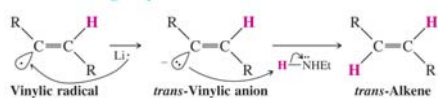
Mechanism has two sequential electron transfers from the metal

Lithium donate an electron to the alkyne (into its anti-bonding orbital!)

This produces a radical anion, which reacts as a base with the amine solvent



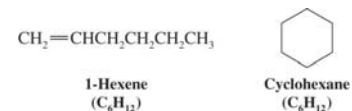
Second electron converts radical to an anion, which again reacts as a base



The vinylic anion prefers to be *trans* and this determines the *trans* stereochemistry of the product

Structural Information from Molecular Formulas

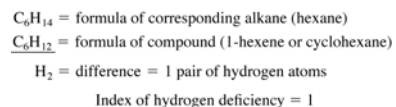
- ♦ Saturated alkane = molecular formula $\text{C}_n\text{H}_{2n+2}$
- ♦ Formula of C_nH_{2n} will have either a double bond or a ring



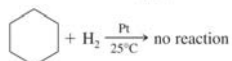
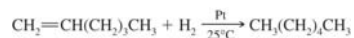
- ♦ A compound with general formula $\text{C}_n\text{H}_{2n-2}$ can have a triple bond, two double bonds, a double bond and a ring or two rings
- ♦ **Index of Hydrogen Deficiency:** the number of pairs of hydrogen atoms that must be subtracted from the molecular formula of the corresponding alkane to give the molecular formula of the compound under consideration

Using the Index of Hydrogen Deficiency (IHD)

- ◆ Example: A compound with molecular formula C_6H_{12}



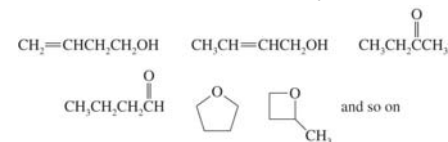
- ◆ Hydrogenation allows one to distinguish a compound with a double bond from one with a ring



- ◆ Compounds Containing Halogens, Oxygen, or Nitrogen
 - For compounds containing halogen atoms, the halogen atoms are counted as if they were hydrogen atoms
 - Example: A compound with formula $C_4H_6Cl_2$
 → This is equivalent to molecular formula C_4H_8 which has IHD=1

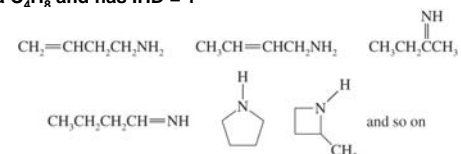
- ◆ For compounds containing oxygen, the oxygen is ignored and IHD is calculated based on the rest of the formula

- Example: A compound with formula C_4H_8O has IHD = 1



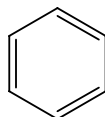
- ◆ For compounds containing nitrogen, one hydrogen is subtracted for each nitrogen and the nitrogen is ignored in the calculation

- Example: A compound with formula C_4H_9N is treated as if it has formula C_4H_8 and has IHD = 1



Benzene and Aromatic Rings

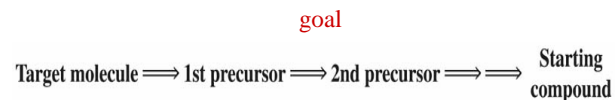
- ◆ Benzene has 3 double bonds and a ring
- ◆ IHD = 4
- ◆ Whenever IHD = 4 or more with a modest number of carbons, consider a aromatic ring



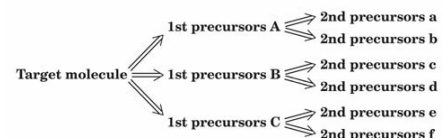
Retrosynthetic Analysis

Organic synthesis is **making complex molecules from simpler ones**

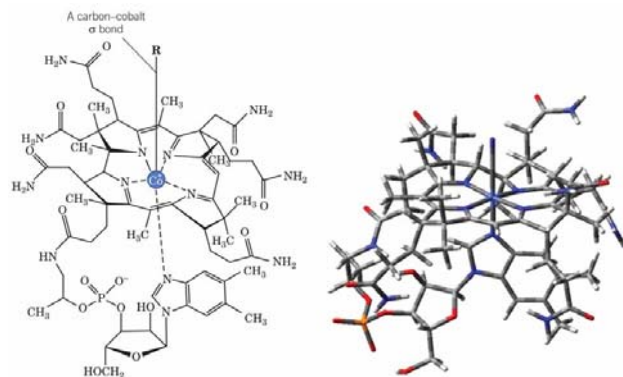
Often we know where we want to finish (complex molecule) but not where to start so we work backwards



Usually need to consider several options so we can optimize



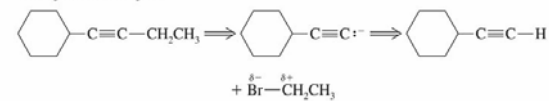
Synthesis target – Vitamin B₁₂



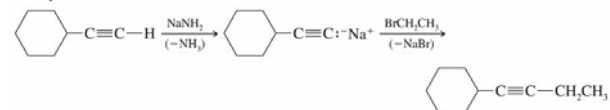
R. B. Woodward, 1972 – 90 steps, 11 years, 100 chemists

Example: synthesis of 1-cyclohexyl-1-butyne

Retrosynthetic Analysis



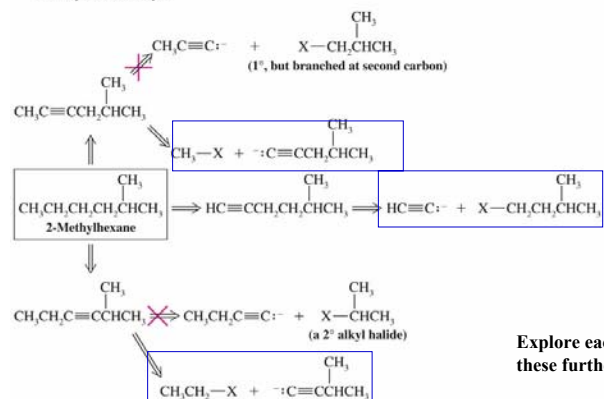
Synthesis



After doing retrosynthetic analysis, we write the normal synthetic sequence and check each step for feasibility

Options for preparing 2-methylhexane: from compounds with fewer carbons

Retrosynthetic Analysis



Explore each of
these further