Organic Chemistry
——Reaction

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考试题型：

一、请给出下列化合物IUPAC的英文名称或写出相应化学结构(每小题1分， 12分)

二、选择题（每题2分，30分)

三、完成下列反应式（每题2分，20分)

四、用指定化合物及简单必要试剂合成下列化合物(每题6分，12分)

五、回答问题(每题5分，20分)

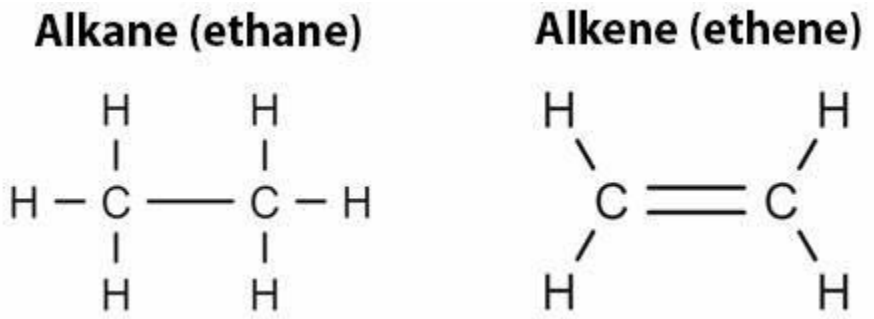
六、给出该反应的合理反应机理(6分)

成绩评定方法： 期末考试成绩(70%)+ 实验成绩 (20%)

+ 平时成绩(10%) + 预习（10%）

有机反应

- **烷烃(alkanes)**
  - 燃烧反应(combustion reaction)
  - 自由基取代反应 Free radical substitution reaction
  - 自动氧化反应（选）Autooxidation reaction
- **烯烃(alkenes)**
  - 氢卤酸(Hydrohalic acid)
  - 水
  - Br的反式加成(*Trans* addition of Br)
  - 降级反应(Downgrade reaction)
  - 硼氢化-氧化反应(hydroboration-oxidation reaction)
- **炔烃(alkynes)**
  - 端氢的酸性(Acidity of terminal hydrogen)
  - 三键的亲核取代反应Nucleophilic Substitution of Triple
  - 炔烃的鉴定
  - 降级反应（Lindlar Reagent）
- **卤代烷(Haloalkanes)**
  - SN1 取代反应(SN1 substitution reaction)
  - SN2取代反应
  - E1 ， E2消除反应(E1, E2 elimination reaction)
- **醇**
  - 酸碱性(Acidity)
  - SN1，SN2取代反应（逆过程水解）
  - 亚硫酰氯(Thionyl)的取代反应
  - E1 E2消除反应
  - 氧化反应
  - 分子间/内脱水反应(Intermolecular/internal dehydration)
  - 威廉森合成法(Williamson Synthesis)
- **醚**
  - 环氧酸反应(epoxy acid reaction)
  - 开环反应(ring opening reaction)
- **苯与苯酚(Benzene and phenol)**
  - 苯的亲电取代反应(Electrophilic substitution reaction of benzene)
  - 苯酚的酸性
- **含氮化合物**
  - 胺的酸碱性质(Acidic and basic properties of amines)
  - 芳胺的制备(Preparation of aromatic amines)
  - 亲核性试剂(Preparation of aromatic amines)



1. 烷烃与烯烃

烷烃的反应活性(Reactivity of alkanes)

when balancing equations for combustion reactions of hydrocarbons, first balance the number of carbons, next balance the number of hydrogens, then balance the number of oxygens. If the equation is still not balanced, consider doubling all coefficients on each side of the equation arrow

$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O \quad \Delta H^\circ = -886\ \text{kJ/mol}(-212\ \text{kcal/mol})$

Methane

$CH_3CH_2CH_3 + 5O_2 \longrightarrow 3CO_2 + 4H_2O \quad \Delta H^\circ = -2{,}220\ \text{kJ/mol}(-530\ \text{kcal/mol})$

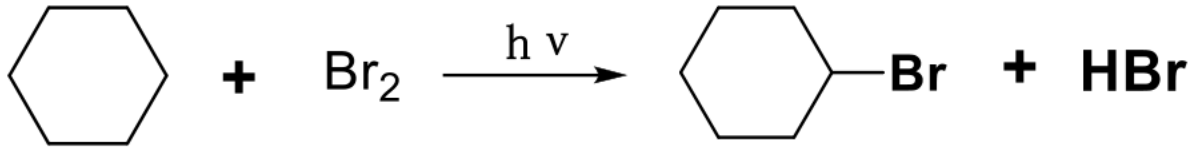
Propane

燃烧反应（氧化反应）
Combustion reaction
(oxidation reaction)

$$C_nH_{2n+2} + \left(\frac{3n+1}{2}\right)O_2 \longrightarrow nCO_2 + (n+1)H_2O$$

烷烃的反应活性(Reactivity of alkanes)

$$CH_4 + Cl_2 \xrightarrow{h\nu} CH_3Cl + HCl$$



链引发 $X_2 \xrightarrow{光或热} 2X\bullet$

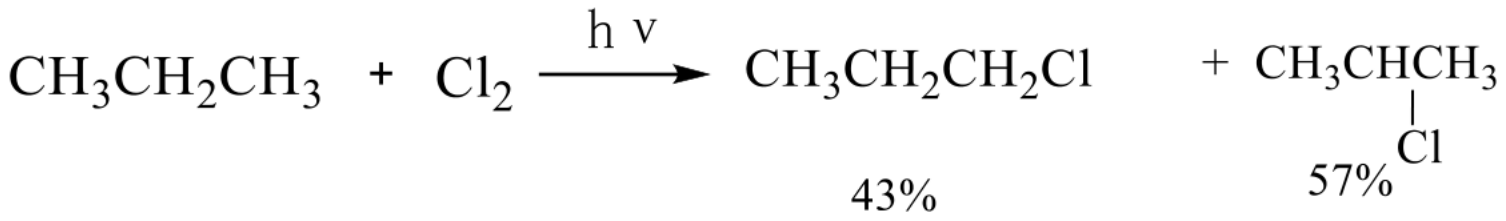
链增长
$$RH + X\bullet \longrightarrow R\bullet + HX$$
$$R\bullet + X_2 \longrightarrow RX + X\bullet$$

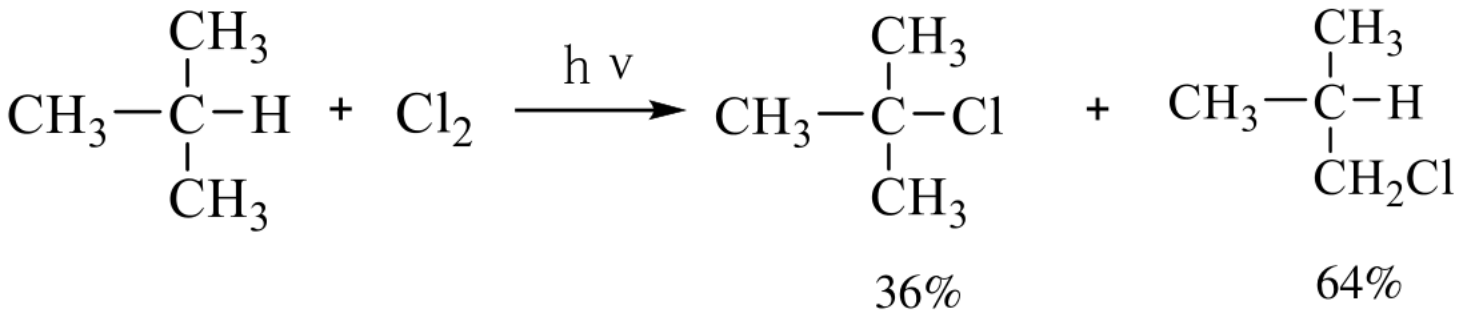
链终止
$$X\bullet + X\bullet \longrightarrow X_2$$
$$X\bullet + R\bullet \longrightarrow RX$$
$$R\bullet + R\bullet \longrightarrow R\text{-}R$$

自由基取代反应(free radical substitution reaction)

1. *hν*或*heat*诱发初始反应
2. 自由基碰撞进行连锁反应
3. 最终以自由基再结合结束

烷烃的反应活性(Reactivity of alkanes)

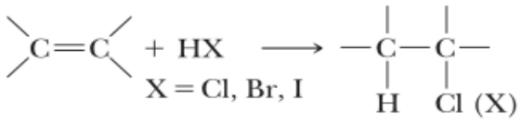
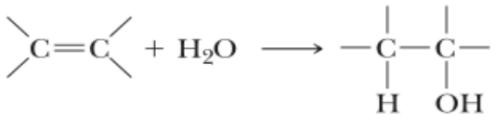
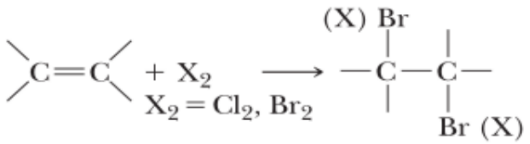
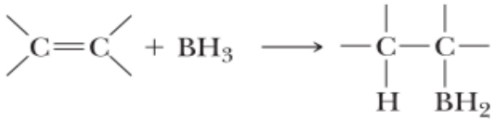
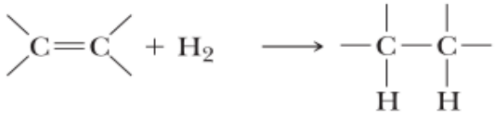




注：
1. 叔碳的$\alpha-H$容易被取代（zi中间体）The $\alpha-H$ of the tertiary carbon is easily substituted (carbenium ion intermediate)
2. 产物的占比也与1° 2° 3° H的占比有关 The proportion of products is related to the proportion of 1° 2° 3° H

烯烃的反应活性(Reactivity of alkanes)

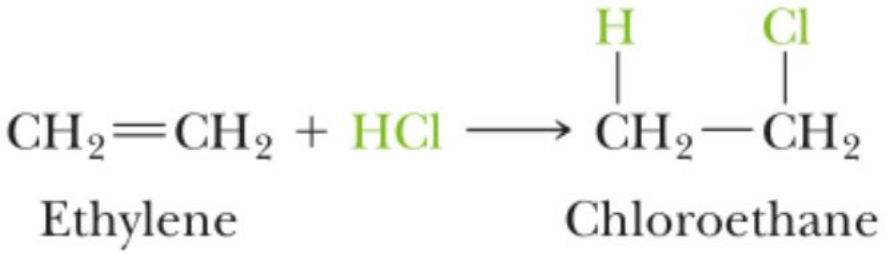
TABLE 5.1 Characteristic Reactions of Alkenes

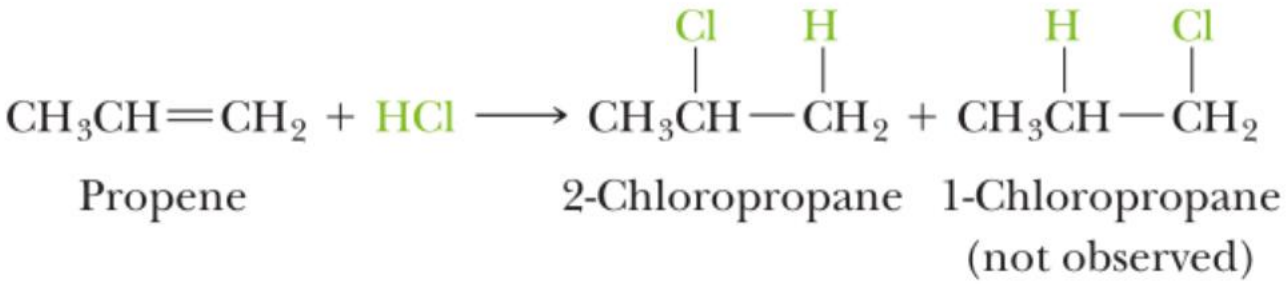
Reaction	Descriptive Name(s)
	Hydrochlorination (hydrohalogenation)
	Hydration
	Bromination (halogenation)
	Hydroboration
	Hydrogenation (reduction)

特征反应

1. 亲电加成
    1. 氢卤酸加成
    2. 酸催化的水加成
    3. 溴、氯的反式加成
2. 硼氢化-氧化反应
3. 催化加氢（降级反应）

烯烃的反应活性(Reactivity of alkanes)

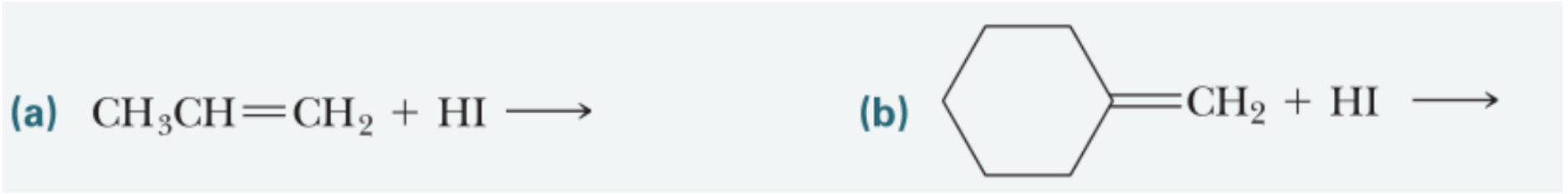




氢卤酸加成(Hydrohalic acid addition)

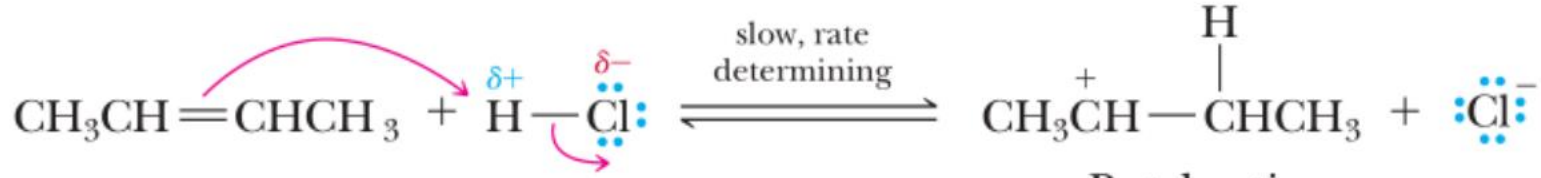
注：

1. 马氏规则(Markov's rule)判断加氢顺序
2. 氯化氢异裂
3. 亲电加成(Electrophilic addition)



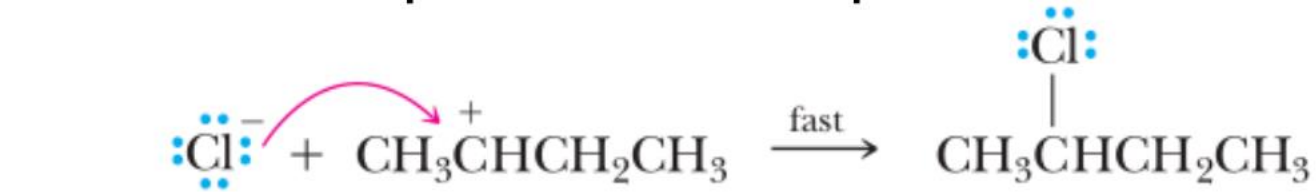
烯烃的反应活性(Reactivity of alkanes)

Step 1: Add a proton. The reaction begins with the transfer of a proton from HCl to 2-butene, as shown by the two curved arrows on the left side of Step 1:



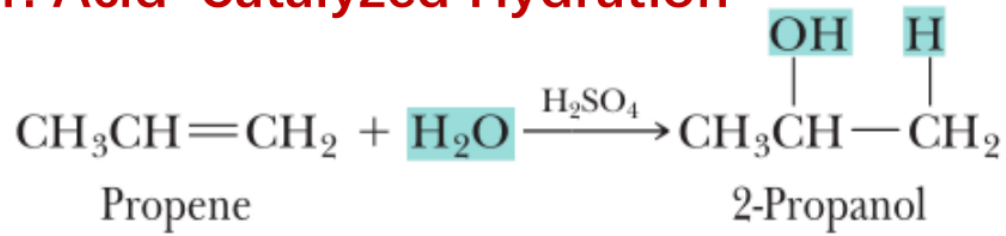
碳正离子中间体

Step 2: Reaction of an electrophile and a nucleophile to form a new covalent bond.



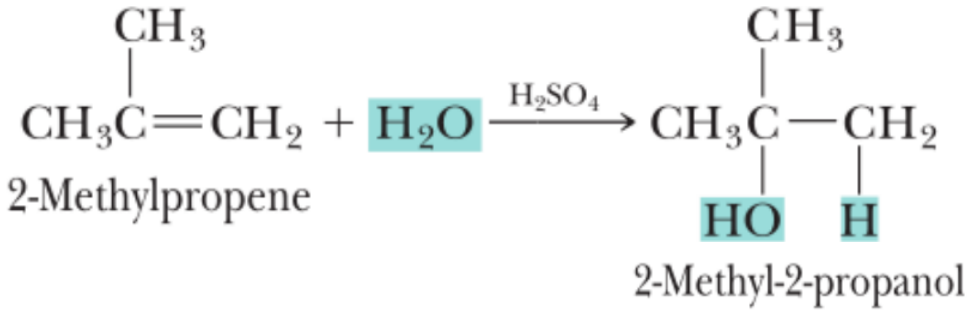
烯烃的反应活性(Reactivity of alkanes)

B. Addition of Water: Acid-Catalyzed Hydration

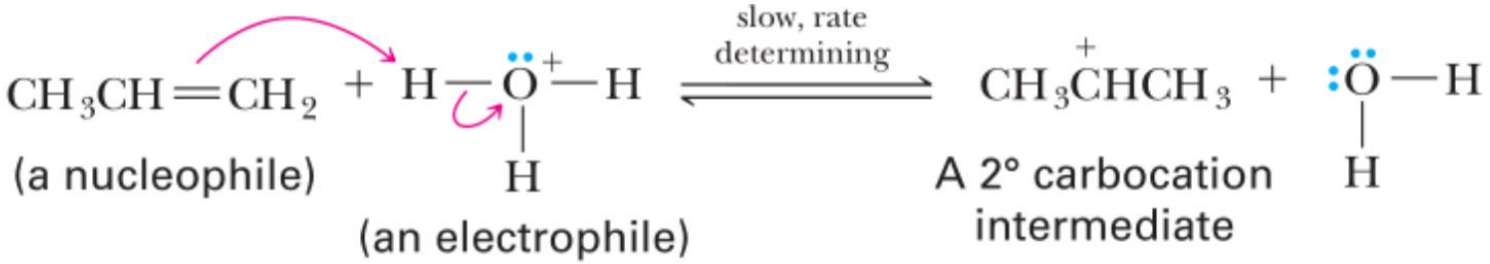


酸催化加氢反应

一般满足**马氏规则**



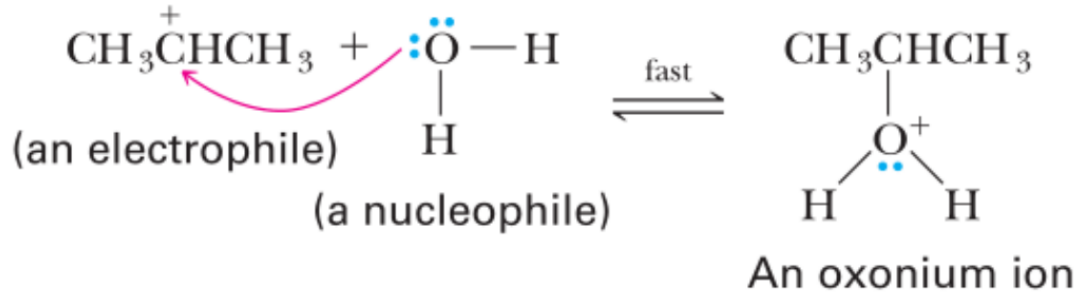
Why we call Acid-Catalyzed Hydration?



提供更多的质子，形成碳正离子（决速步）

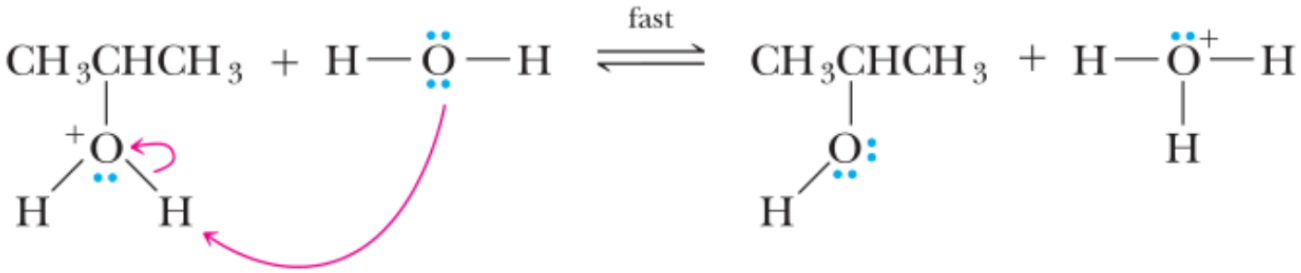
烯烃的反应活性(Reactivity of alkanes)

Step 2: Reaction of a nucleophile and an electrophile to form a new covalent bond.



酸催化水合反应

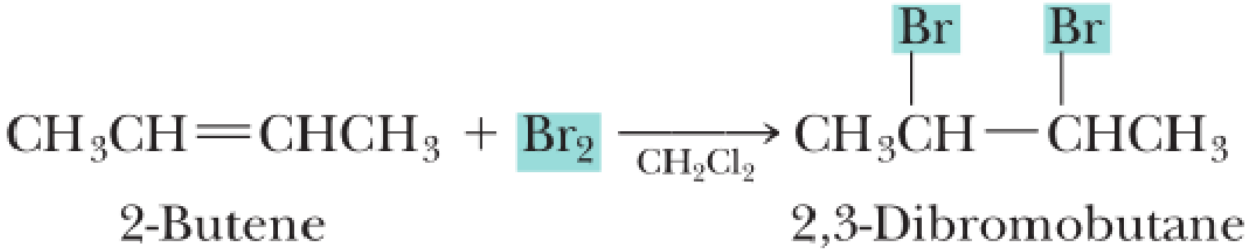
Step 3: take a proton away.

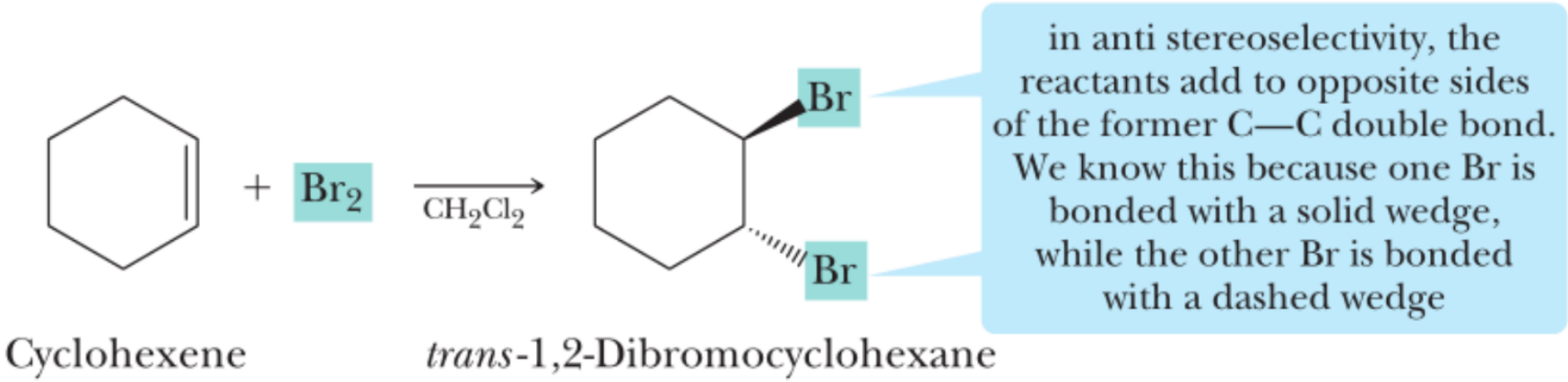


烯烃的反应活性

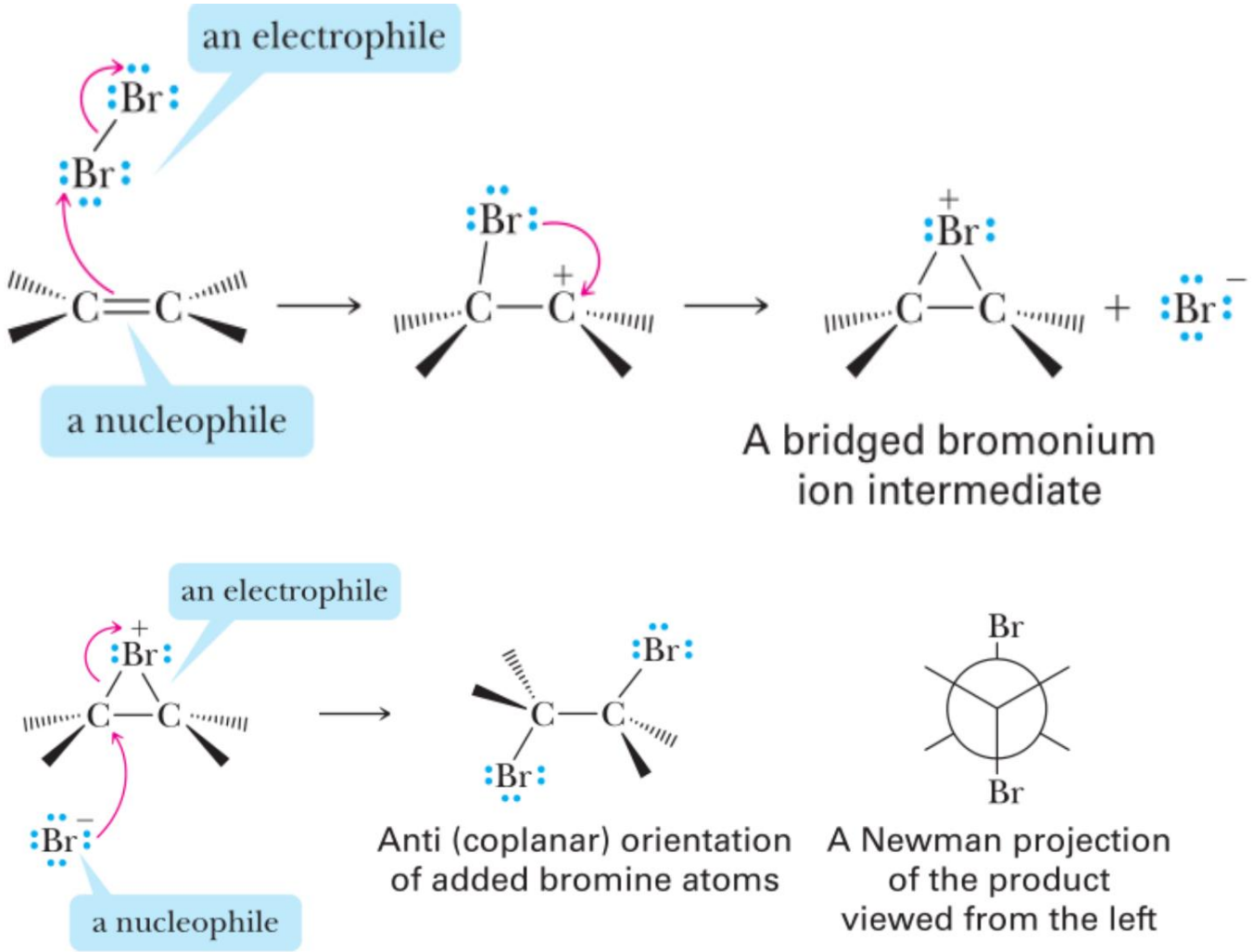
Only trans-compounds could be observed!

只得到反式产物！

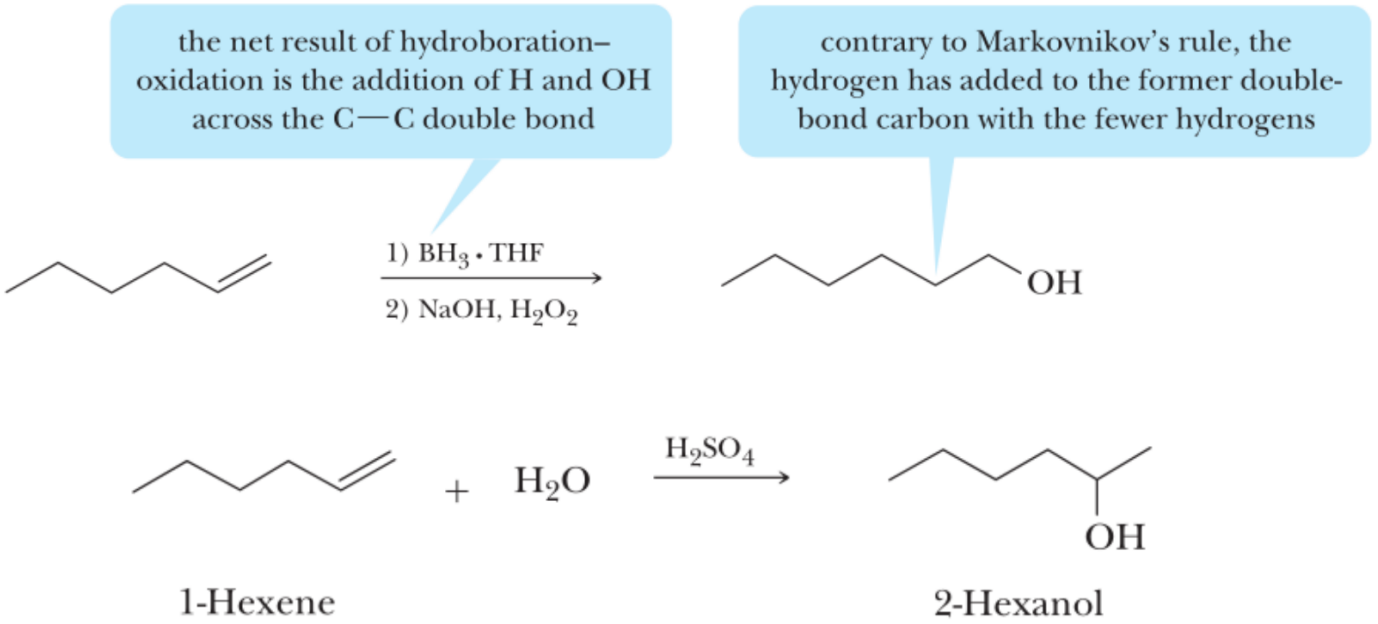




烯烃的反应活性(Reactivity of alkanes)



烯烃的反应活性(Reactivity of alkanes)



- 硼氢化-氧化反应(hydroboration-oxidation reaction)

端位加羟基- 反马氏规则

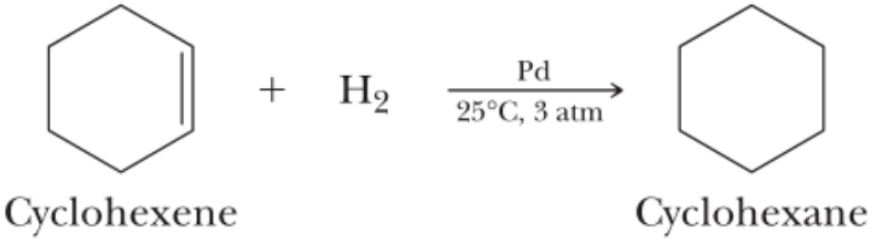
影响因素：**空间位阻效应(Steric hindrance)**

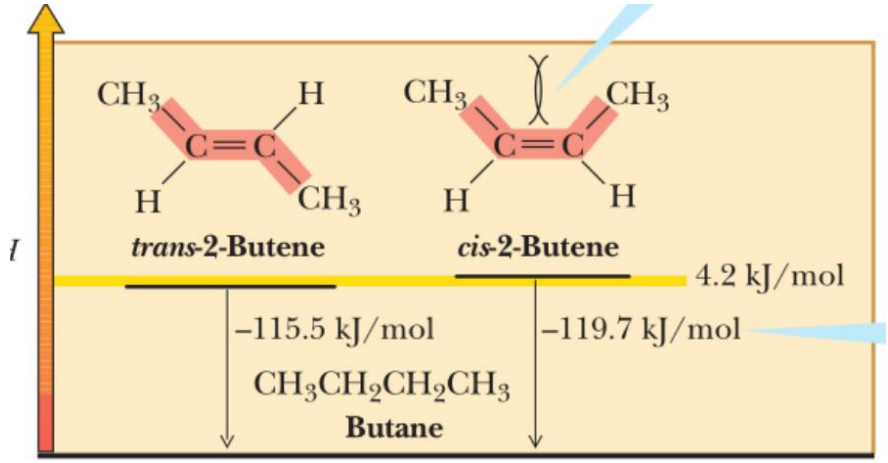
- (Comparison)酸催化的加成反应

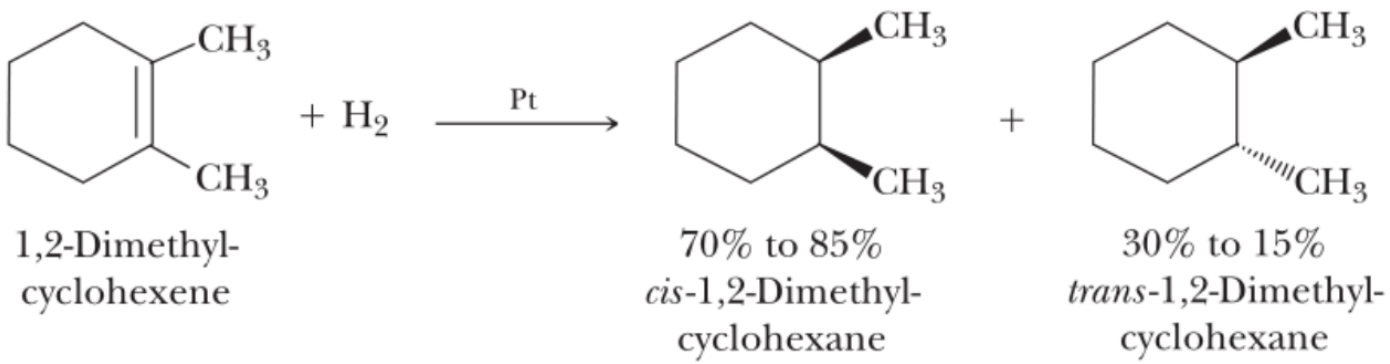
马氏规则加氢

影响因素：**电荷效应**

烯烃的反应活性



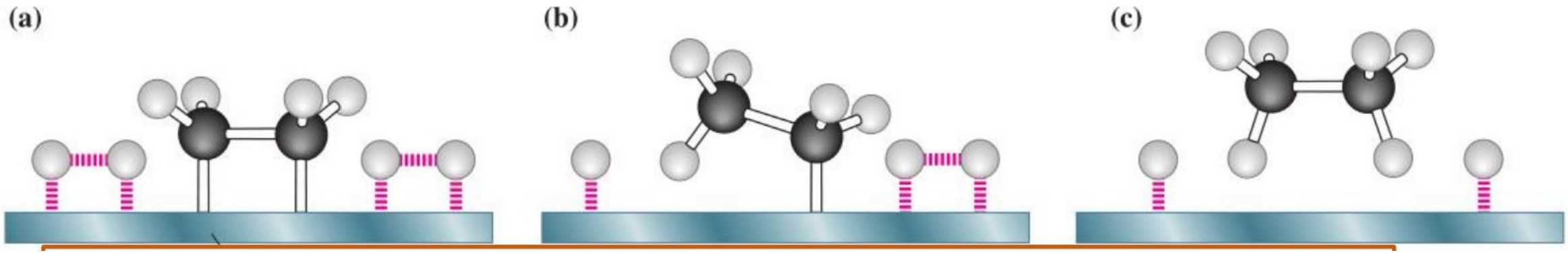




催化加氢反应

- 催化剂：金属催化剂（ Ni、Pd、Pt、Ru、Rh）
- 加成空间结构：顺式（cis）
- 顺式结构能量高（非稳定构象）

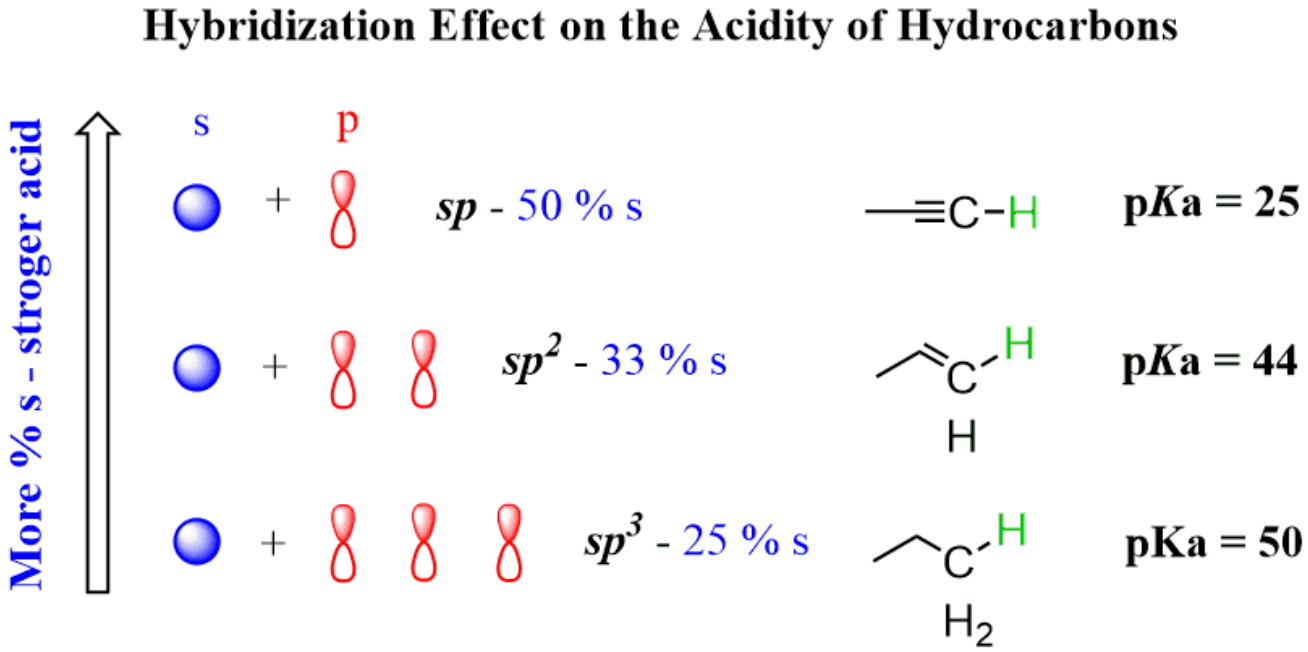
烯烃的反应活性(Reactivity of alkanes)



催化剂表面决定加成产物的空间结构
Catalyst surface determines the spatial structure of addition products.

2.炔烃与卤代烃

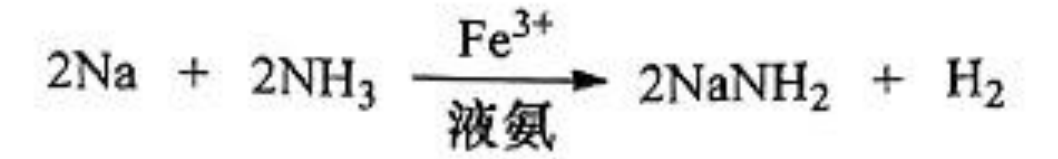
端氢的酸性(Acidity of terminal hydrogen)

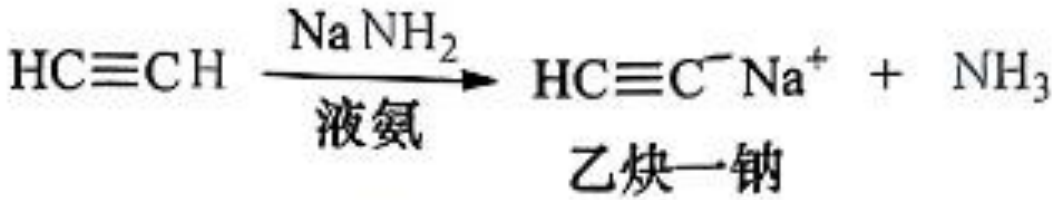


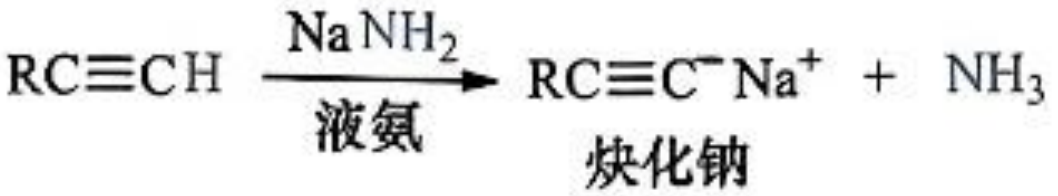
原因：

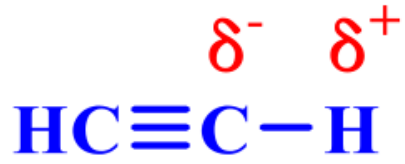
在杂化轨道中S成分越大（吸引力越大），碳原子的电负性就越大，所以在$\equiv C-H$中，形成$C-H$键的电子对比末端烯烃中$C-H$键和烷烃的$C-H$键中的电子对更靠近碳原子，导致末端炔烃中的$C-H$键更容易异裂，释放出质子。

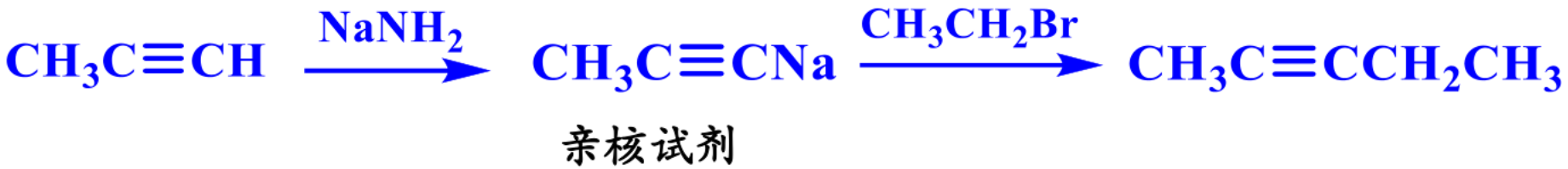
端氢的酸性(Acidity of terminal hydrogen)







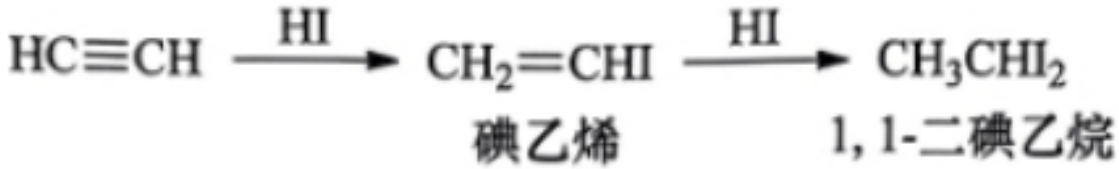




延长碳链反应

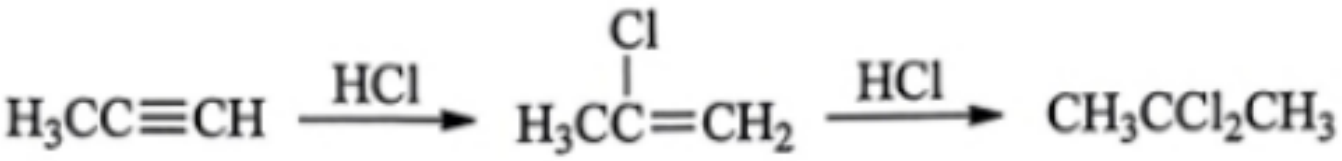
炔烃的亲电加成(Electrophilic Addition of Alkynes)

炔烃与氢卤酸的加成



应用：制备卤代烯

加成规则：一元取代乙炔与氢卤酸的加成反应遵循**马氏规则**



炔烃的亲电加成(Electrophilic Addition of Alkynes)

炔烃与水的加成

应用：常用汞盐做催化剂

加成规则： 遵循马氏规则

注：酸催化反应

炔烃的鉴定(Identification of alkynes)

用于鉴定炔烃官能团

不能使用**催化加氢的量**鉴别烯烃与炔烃！

$$HC{\equiv}CH + 2Ag(NH_3)_2NO_3 \longrightarrow AgC{\equiv}CAg\downarrow + 2NH_4NO_3 + 2NH_3$$

乙炔银（白色）

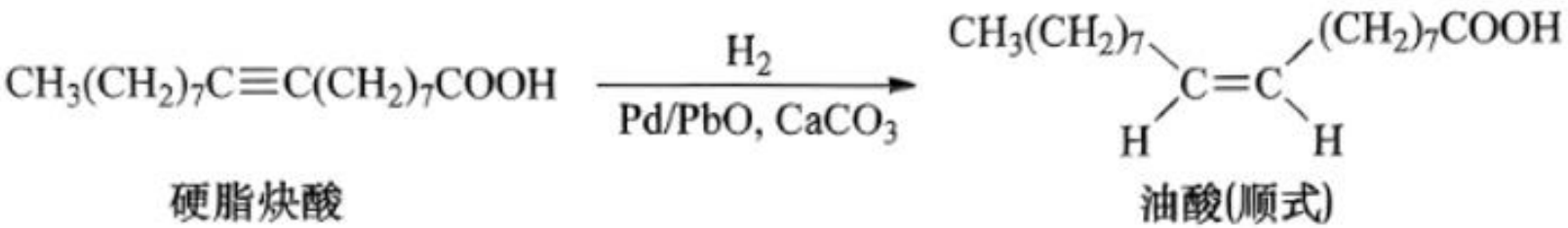
$$HC{\equiv}CH + 2Cu(NH_3)_2Cl \longrightarrow CuC{\equiv}CCu\downarrow + 2NH_4Cl + 2NH_3$$

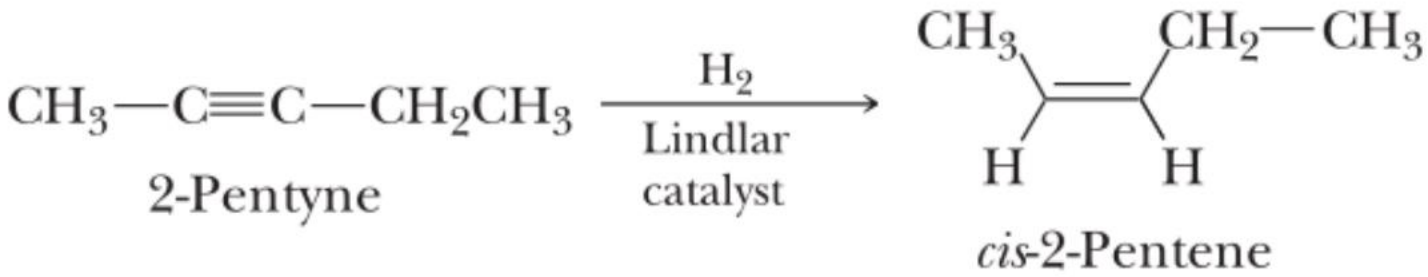
乙炔亚铜（红色）

炔烃的还原(Alkyne Reduction)

催化氢化/降级反应（得顺式cis加氢产物）

使用$Lindlar$试剂进行反应，炔烃只加$1mol\ H$即得Z型烯烃

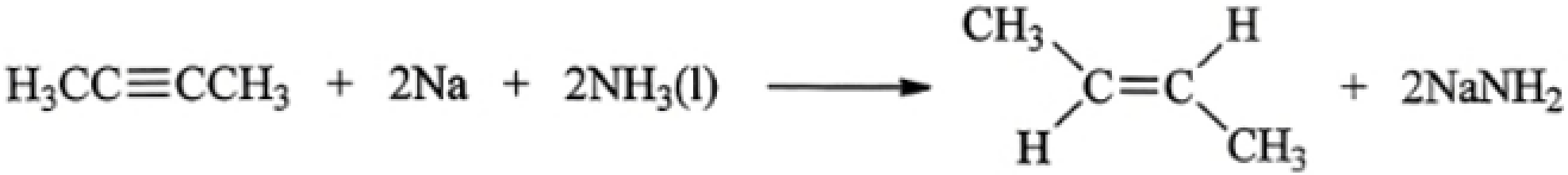




炔烃的还原(Alkyne Reduction) – 拓展

碱金属和液氢还原（得反式*trans*加氢产物）

在液氢中使用金属钠还原，主要生成E型烯烃衍生物



卤代烷的反应活性(Reactivity of haloalkanes)

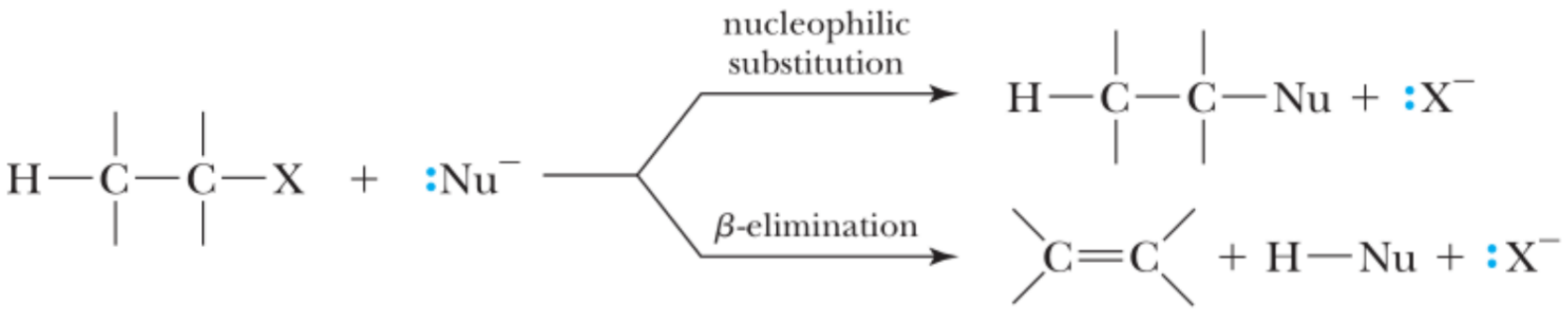
亲核取代反应 Nucleophilic Substitution Reaction

相互竞争

1. SN1 取代反应
2. SN2 取代反应

β－ 消除反应 β-Elimination Reaction

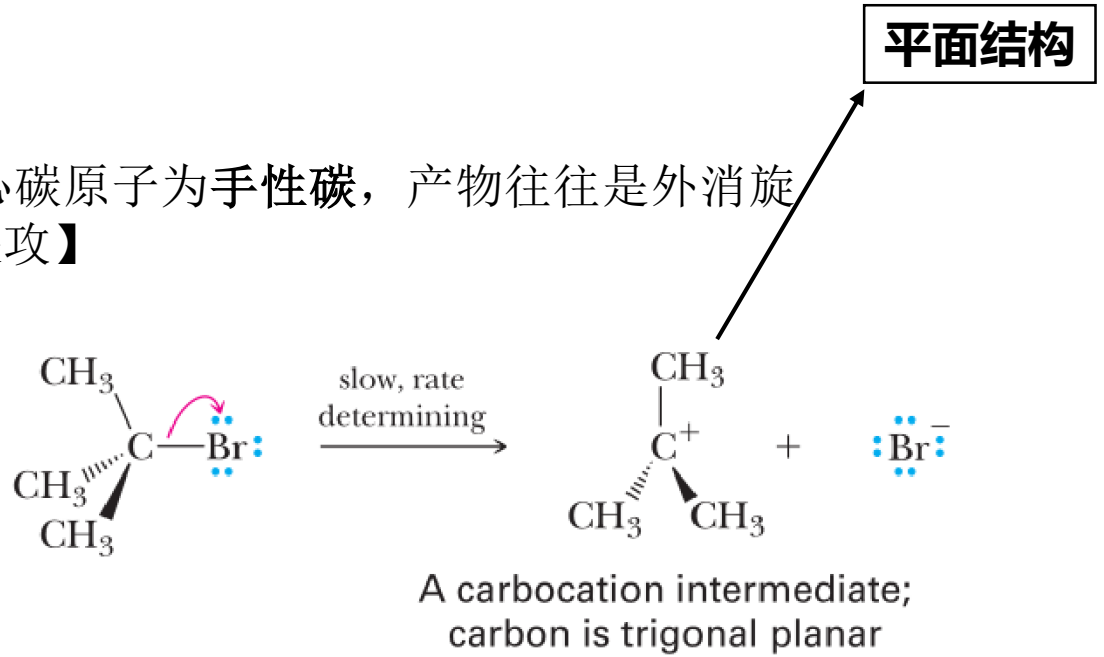
1. E1 消除反应
2. E2 消除反应



SN1 取代反应(SN1 Substitution Reaction)

$$(CH_3)_3\mathrm{C}-Br+OH^-\rightarrow(CH_3)_3\mathrm{C}-\mathrm{OH}+Br^-$$

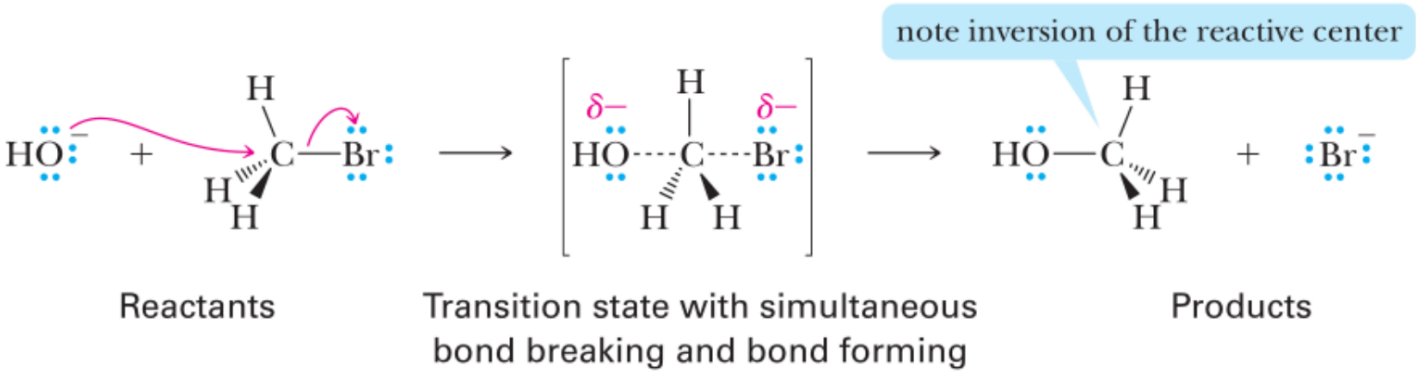
- 在立体化学上的特征是：若中心碳原子为**手性碳**，产物往往是外消旋体（ Racemate ）【两个方向进攻】
- 两步反应



SN2 取代反应(SN2 Substitution Reaction)

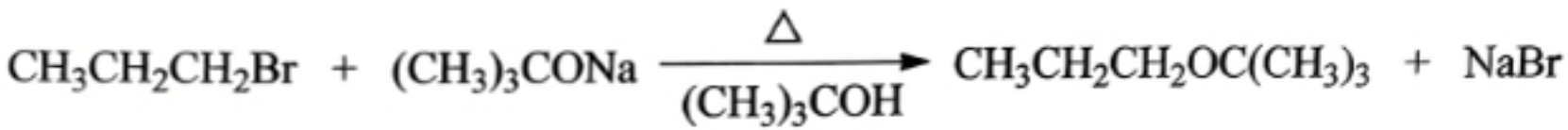
$$CH_3\mathrm{Br} + OH^- \rightarrow CH_3OH + Br^-$$

- 在立体化学上的特征是：若中心碳原子为手性碳，产物生成时中心碳原子的构型**完全翻转**。（瓦尔登翻转 Walden flip ）
- 一步反应



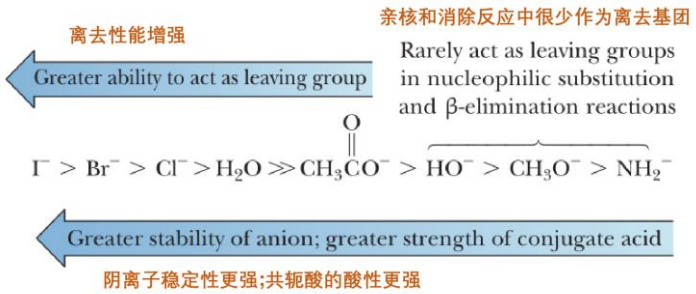
SN1&2 取代反应的应用

制备不对称醚的常用方法



制备腈的主要方法

SN1 vs. SN2



S_N1反应特点

1、两步完成

2、反应速度只与RX有关

3、中间体C^+(重排产物)

4、产物可能存在外消旋化

S_N2反应特点：

1、一步完成

2、反应速度和RX、 亲核试剂有关

3、无中间体

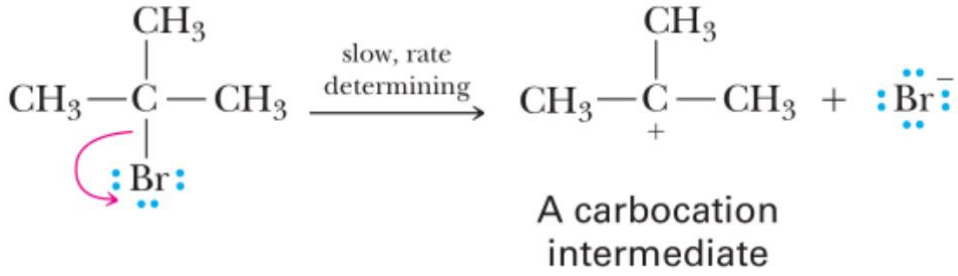
4、产物构型翻转（瓦尔登转化）

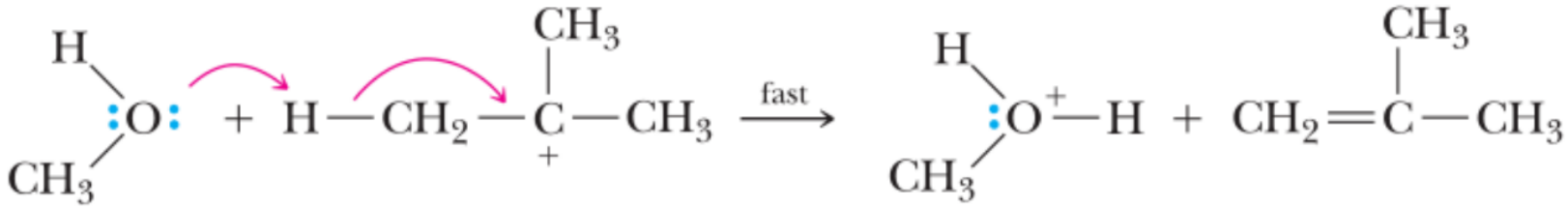
- **碳正离子越稳定**，越倾向于SN1；RX结构越简单，越倾向于SN2；叔卤代烷主要进行SN1反应，伯卤代烷主要进行SN2反应
- 亲核试剂的**亲核性**影响SN2反应；
- 离去基团的离去能力越强，共轭酸的**酸性越强**，对SN1和SN2都是有利的；
- **质子溶剂**（能与负离子形成强的氢键的溶剂）有利于SN1，**偶极溶剂**（分子中的氢与分子内原子结合牢固、不易给出质子的溶剂）有利于SN2，并且增加溶剂的极性能够加速卤代烷的解离，利于SN1，在SN2中，若亲核试剂带**负电荷**，那么增加溶剂的极性不利于SN2

E1 消除反应(E1 Elimination Reaction)

$$(CH_3)_3C-Br+(CH_3)_3CONa/(CH_3)_3COH \rightarrow (CH_3)_2C=CH_2$$

- 稳定碳中间体利好反应发生（伯碳一般不发生E1消除反应）
- 弱碱容易发生E1消除反应（无法直接夺取H）
- 两步反应
- 产物遵循扎伊采夫规则，即含氢较少的β碳提供氢原子

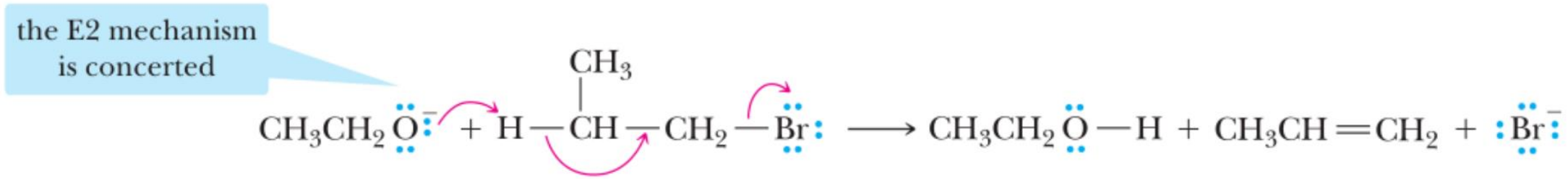




E2 消除反应(E2 Elimination Reaction)

$$CH_3CH_2\mathrm{Br} + (CH_3)_3CON\,a/(CH_3)_3\,COH \rightarrow CH_2 = CH_2$$

- **伯碳**一般更容易发生E2消除反应
- **强碱**容易发生E2消除反应（直接夺取H）
- 一步反应
- 产物遵循扎伊采夫规则



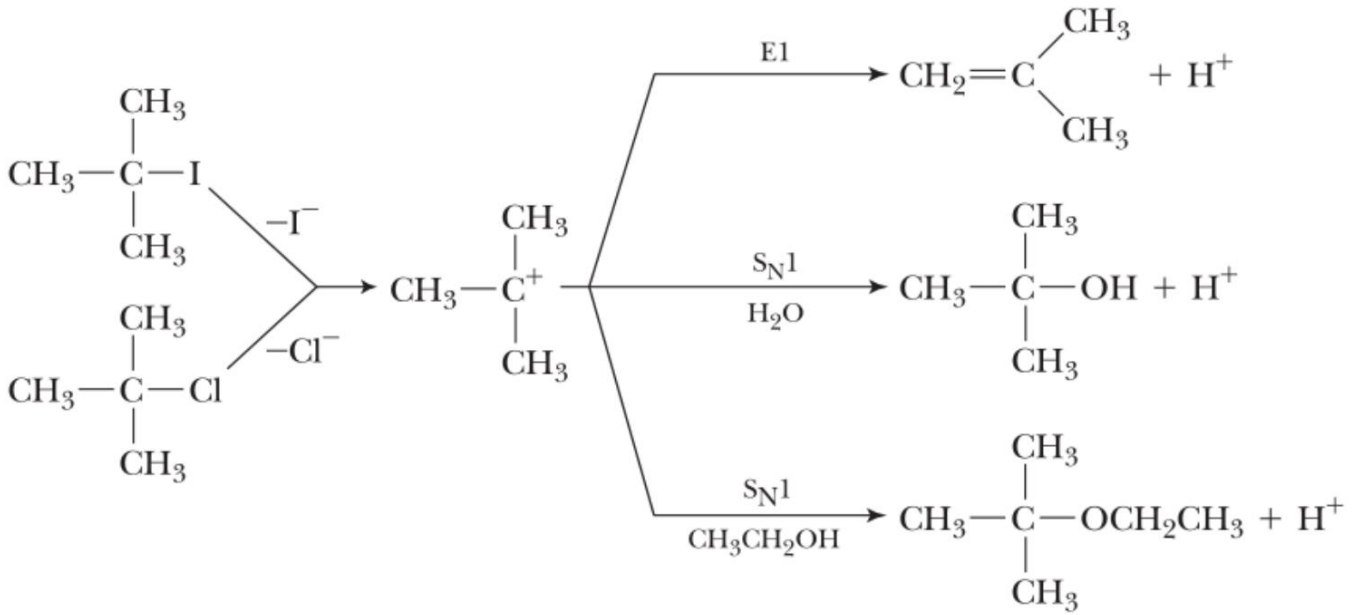
E1 vs. E2

TABLE 7.6 Summary of E1 versus E2 Reactions of Haloalkanes

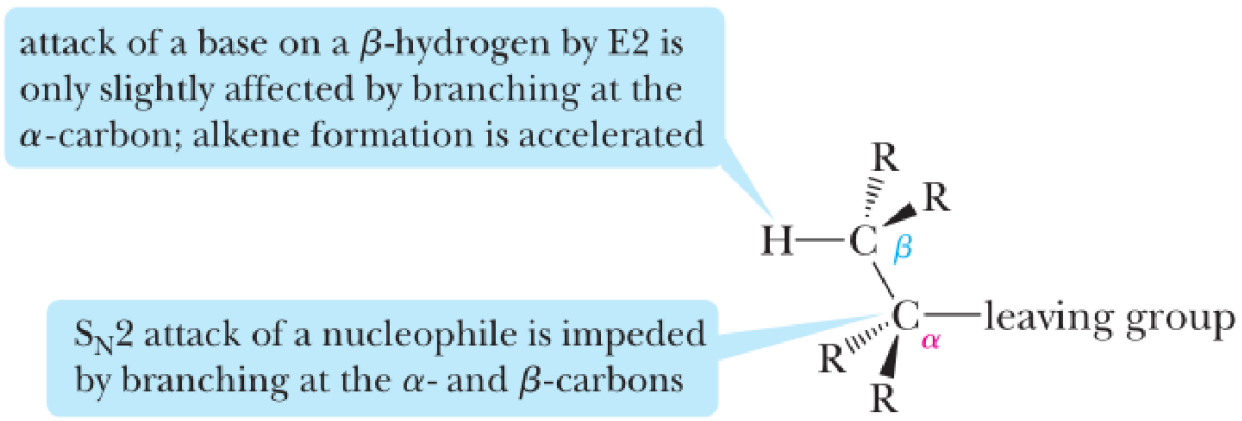
Haloalkane	E1	E2
Primary RCH_2X	E1 does not occur. Primary carbocations are so unstable that they are never observed in solution.	E2 is favored.
Secondary R_2CHX	Main reaction with weak bases such as H_2O and ROH.	Main reaction with strong bases such as OH^- and OR^-.
Tertiary R_3CX	Main reaction with weak bases such as H_2O and ROH.	Main reaction with strong bases such as OH^- and OR^-.

SN1 vs. E1

- E1与SN1竞争，E2与SN2竞争，**温度**越高，越有利于β-消除反应
- E1与SN1竞争：试剂的**亲核性强**、**空阻小**对SN1有利，试剂的碱性强、空阻大对E1有利



SN2 vs. E2



- $\alpha - C/\beta - C$上支链增加，位阻增加，更有利于E2
- 亲核性强有利于SN2，碱性强有利于E2

卤代甲烷无消除

碳正离子不稳定

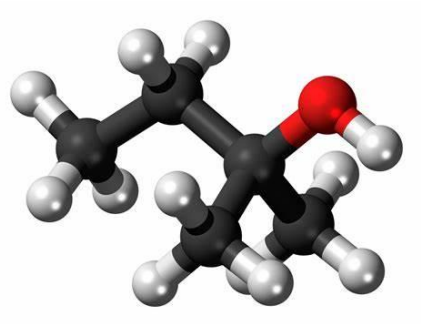
伯碳正离子无法稳定形成

Summary

位阻过大（不影响E2）

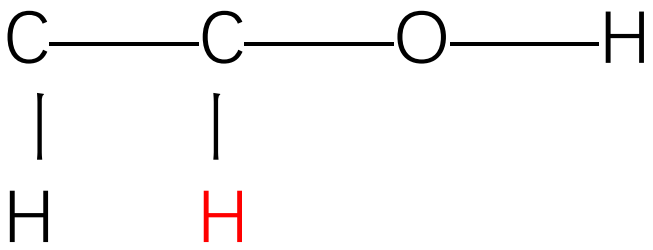
TABLE 7.7 Summary of Substitution versus Elimination Reactions of Haloalkanes

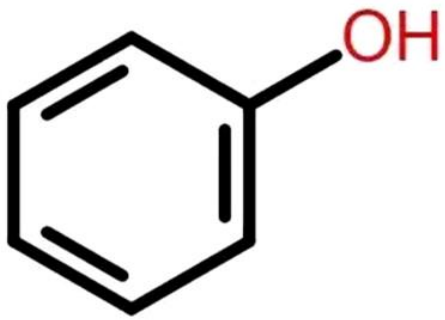
Halide	Reaction	Comments
Methyl	S_N2	The only substitution reactions observed.
CH_3X	~~S_N1~~	S_N1 reactions of methyl halides are never observed. The methyl cation is so unstable that it is never formed in solution.
Primary RCH_2X	S_N2	The main reaction with strong bases such as OH^- and EtO^-. Also, the main reaction with good nucleophiles/weak bases, such as I^- and CH_3COO^-.
	E2	The main reaction with strong, bulky bases, such as potassium *tert*-butoxide.
	~~$S_N1/E1$~~	Primary cations are never formed in solution; therefore, S_N1 and E1 reactions of primary halides are never observed.
Secondary R_2CHX	S_N2	The main reaction with weak bases/good nucleophiles, such as I^- and CH_3COO^-.
	E2	The main reaction with strong bases/good nucleophiles, such as OH^- and $CH_3CH_2O^-$.
	$S_N1/E1$	Common in reactions with weak nucleophiles in polar protic solvents, such as water, methanol, and ethanol.
Tertiary R_3CX	~~S_N2~~	S_N2 reactions of tertiary halides are never observed because of the extreme crowding around the 3° carbon.
	E2	Main reaction with strong bases, such as HO^- and RO^-.
	$S_N1/E1$	Main reactions with poor nucleophiles/weak bases.



3.醇的化学性质

结构分析





苯宝宝装个醇

1.酸性 (Acidity)

2.亲核性 (Nucleophilicity)

3.α-C的亲核取代 (α-C Nucleophilic substitution)

4.β-H的消除(β-H Elimination)

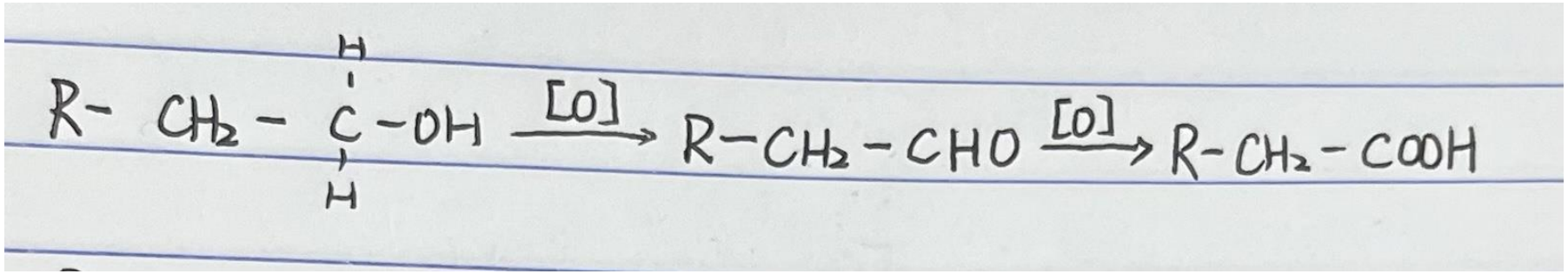
5.α-H的氧化 (α-H Oxidation)

酸性 (Acidity)

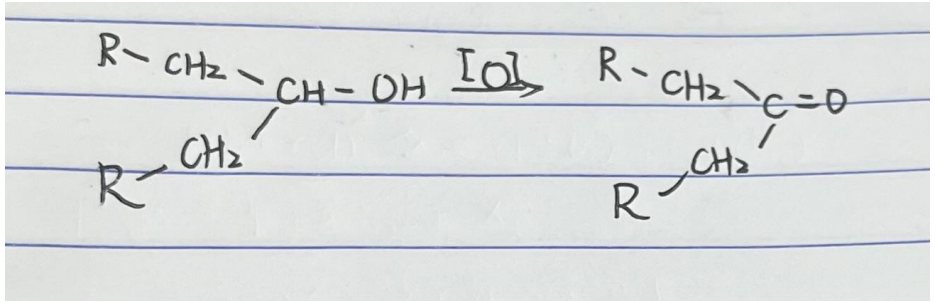
- pK_a=15.5
- $2ROH + 2Na \longrightarrow 2RONa + H2\uparrow$
- The O atom：结合正电荷(Cation)的能力
  - 亲核试剂
  - 结合质子

氧化反应(Oxidation Reaction)

伯醇的氧化(Primary alcohol)



仲醇的氧化(Secondary alcohol)

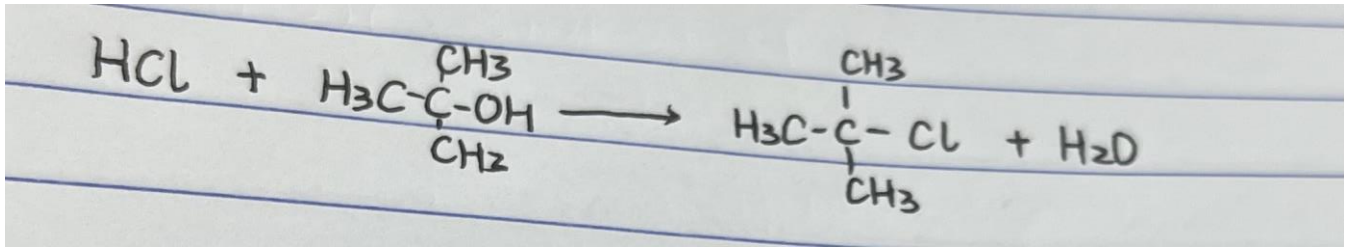


Selective Oxidation of PCC
PCC的选择氧化性

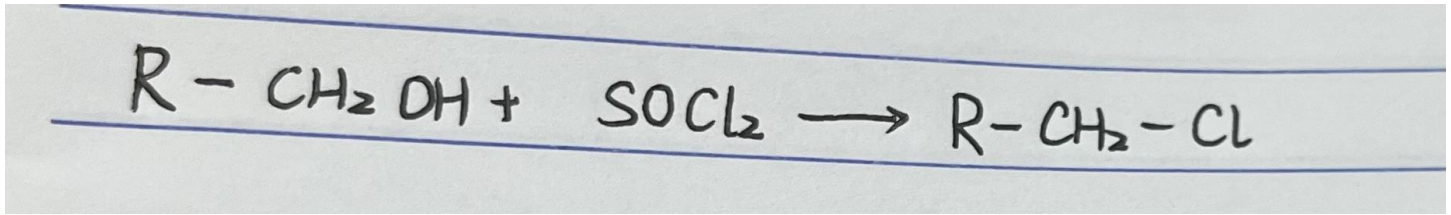
叔醇（Tertiary alcohol）不氧化!

取代反应(Substitution reaction)：

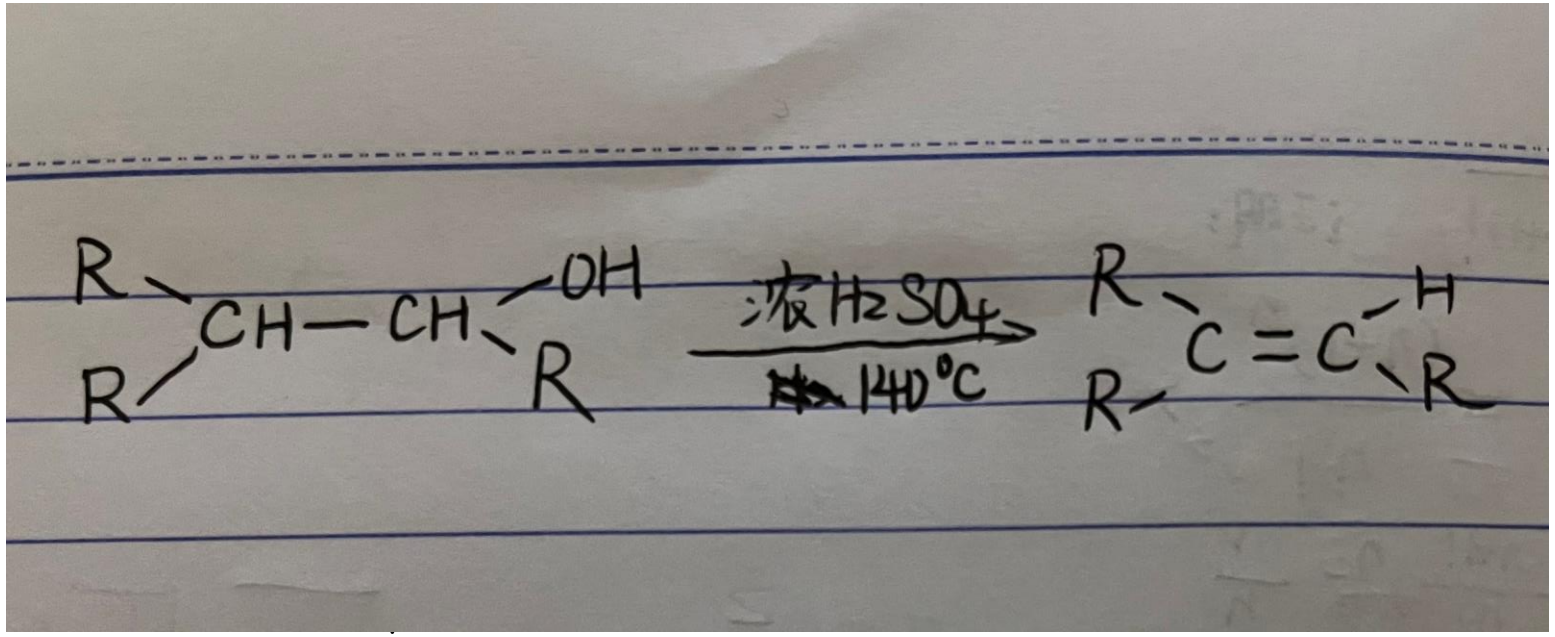
- 与卤素的亲核取代**(Nucleophilic Substitution of Halogen)**



- 与亚硫酰氯的取代**(Substitution of thionyl chloride)**



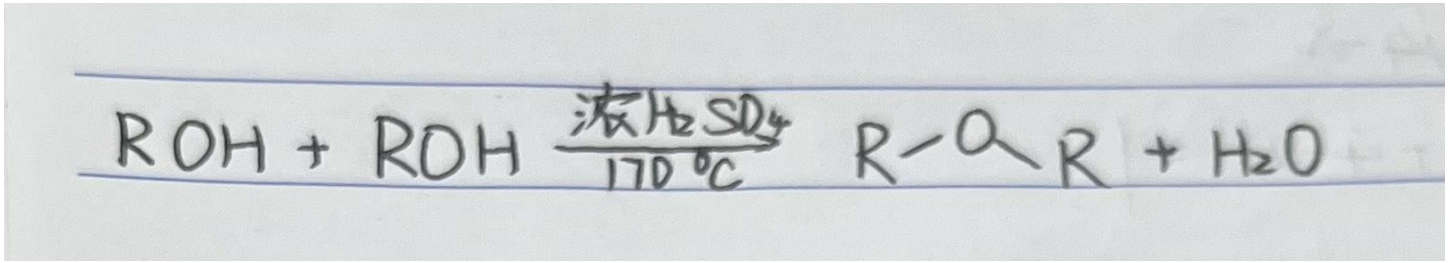
消除反应(Elimination Reaction)



Zaitsev Rule（$\sigma-\pi$ interaction)

脱水反应(dehydration reaction)

- 分子间脱水(intermolecular dehydration)



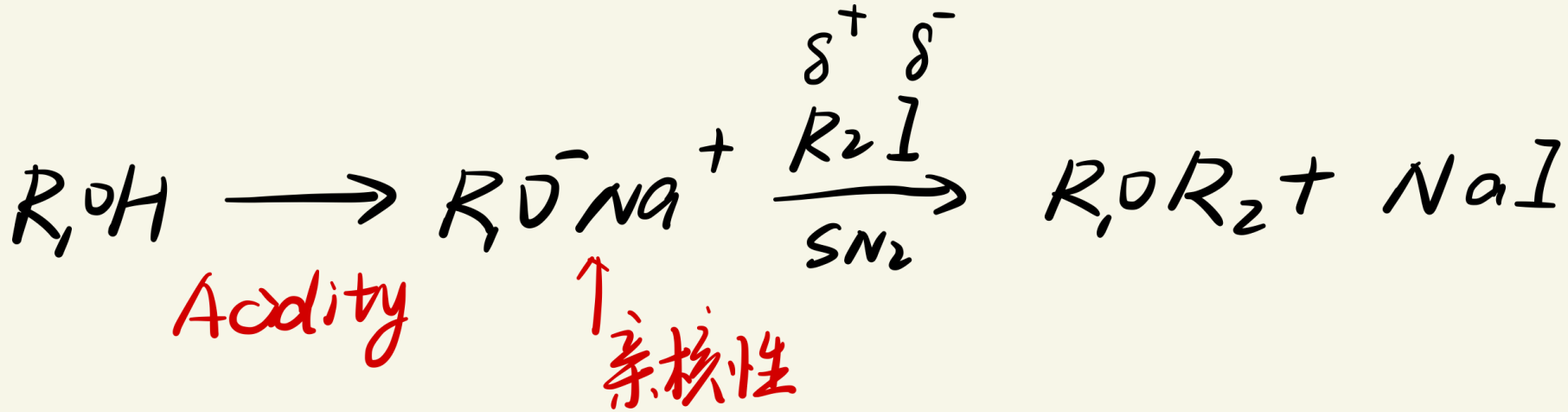
此方法用于制备**对称**的醚。

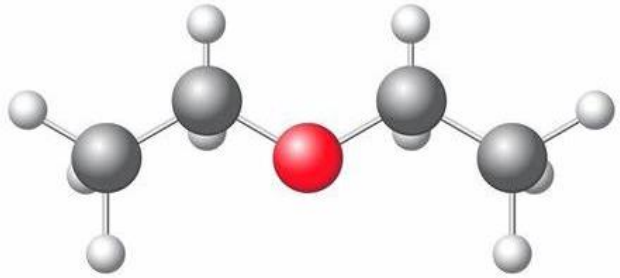
- 分子内脱水(intramolecular dehydration)

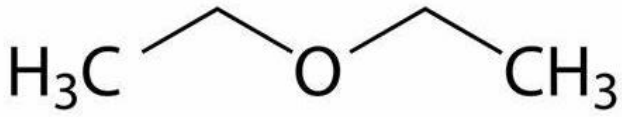
威廉斯合成(Williams synthesis)

制备不对称醚的方法

1. 利用醇1的酸性
2. 利用醇钠的亲核性
3. 醇1负离子与卤代烷发生SN2亲核取代反应



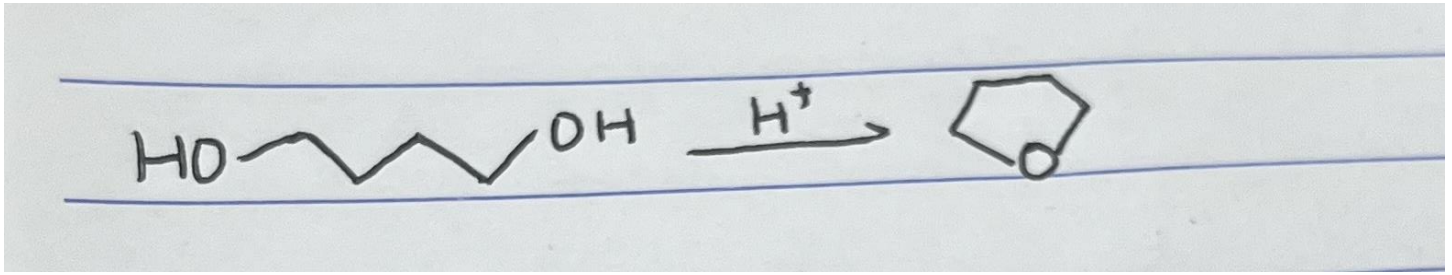




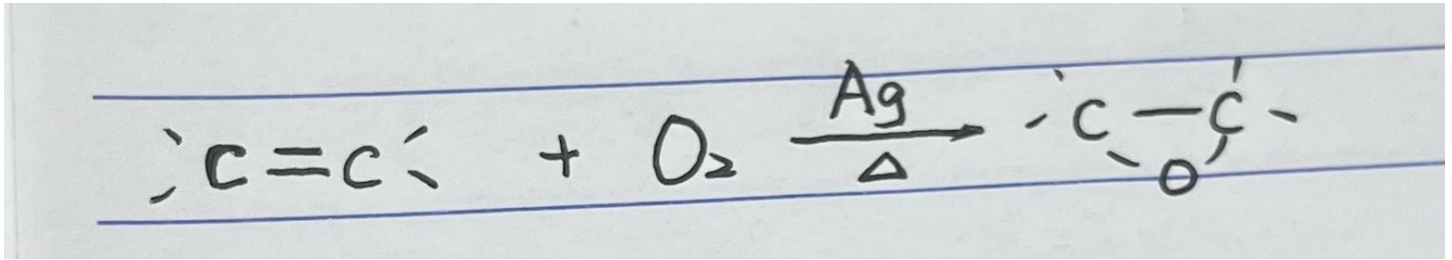
4.醚(Ether)的化学性质

环氧烷的合成(Synthesis of Alkylene Oxide)

- 二醇脱水

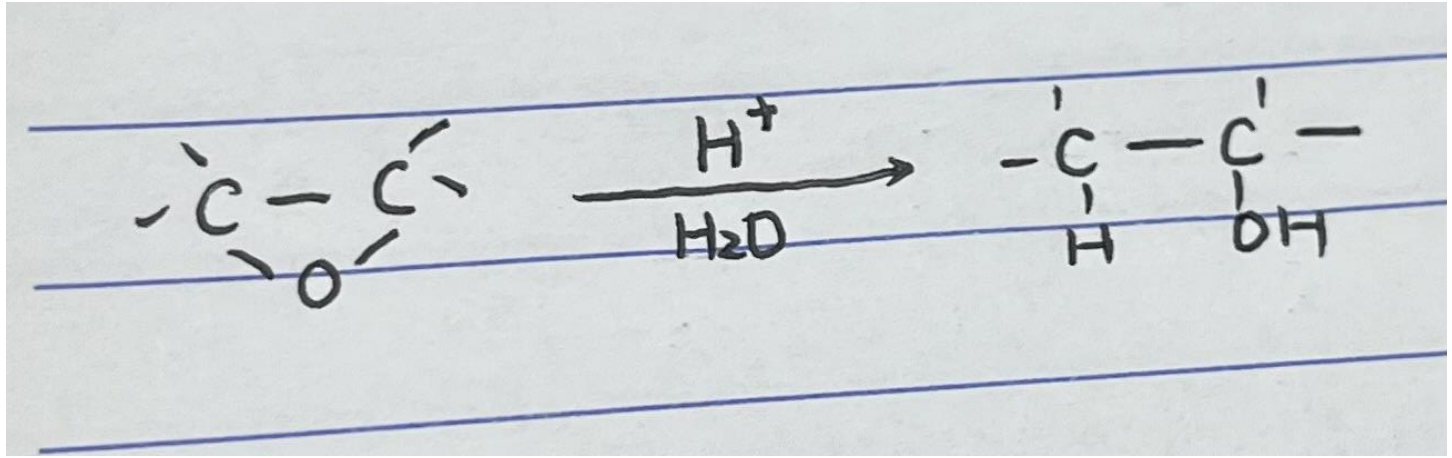


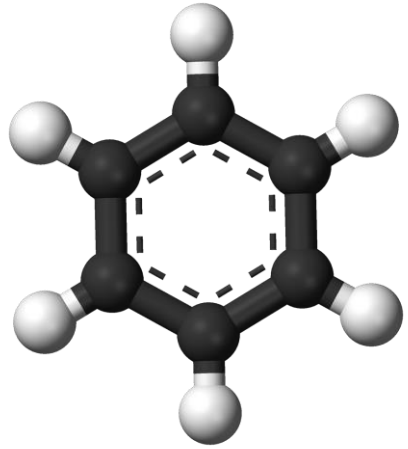
- 烯烃在特殊条件下氧化



开环反应(Ring Opening Reaction)

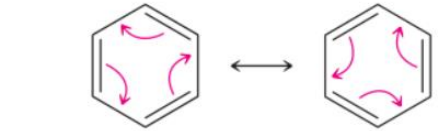
三元环不稳定，更容易开环



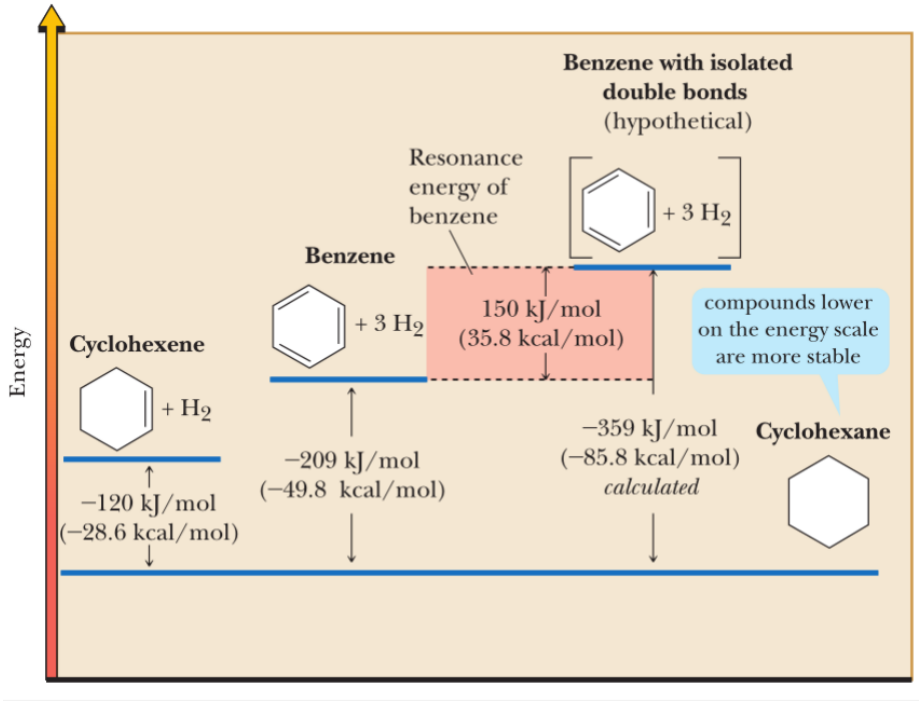


5.芳烃(Benzene)及其衍生物

结构特征



Benzene as a hybrid of two equivalent contributing structures



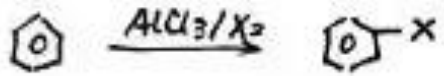
- **芳香性：**芳香族化合物高不饱和度，易取代难加成，有特殊稳定性（共轭能）的性质；

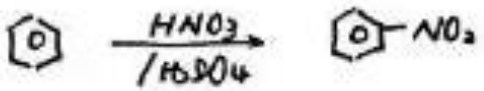
- **休克尔规则：**满足以下三个条件的分子常有芳香性：
  a. 平面环状分子；
  b. 每个原子都有一个2p轨道；
  c. 2p轨道电子数为（4n+2）

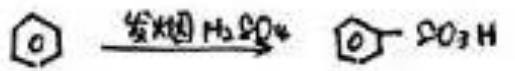
苯的亲电取代反应 (Electrophilic substitution reaction of benzene)

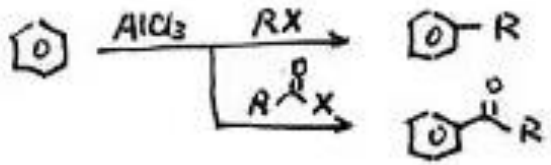
- 卤代(Halogenation)：在**三氯化铁或三氯化铝**催化下，卤素（主要指**氯溴**）取代氢生成卤代苯
- 硝化(Nitration)：与**混酸（硝酸和硫酸的混合物）**反应，取代氢生成硝基苯
- 磺化(Sulfonation)：与**发烟硫酸**（极浓硫酸或溶有三氧化硫的硫酸）反应，取代氢生成苯磺酸
- 傅克烷基化反应(Friedel-Crafts Alkylation)在三氯化铝或三氯化铁催化下，卤代烷取代氢生成烷基苯 （要求苯环**富电**，苯环上有吸电基时不反应）
- 傅克酰基化反应(Acylation)：在**三氯化铝或三氯化铁**催化下，酰卤取代氢生成酰基苯（同样要求苯环**富电**）
- 其他反应(Other Reactions)：在磷酸或硫酸催化下，**烯烃**或**醇**作烷基化试剂，生成烷基苯

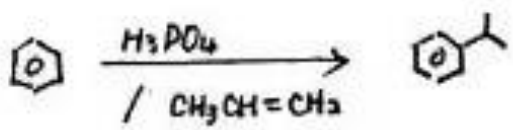
2. 苯的亲电反应1图.

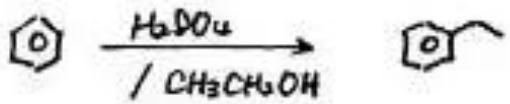
1) 

2) 

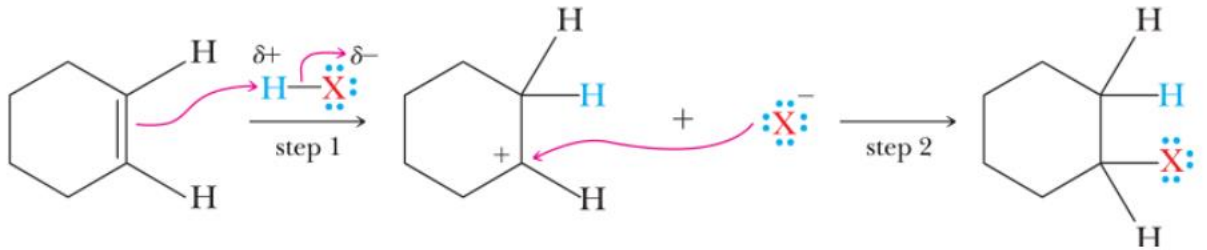
3) 

4) 

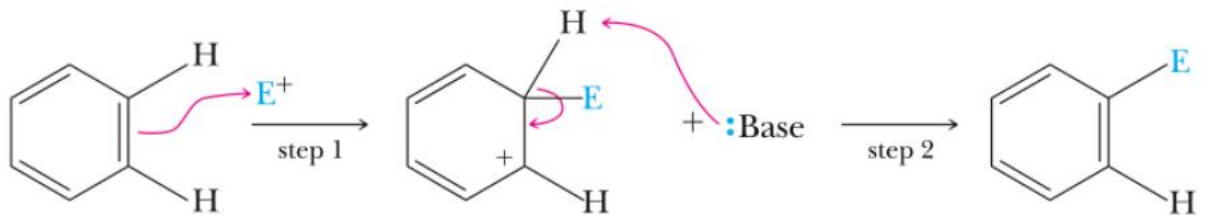
5) 



Addition to an Alkene

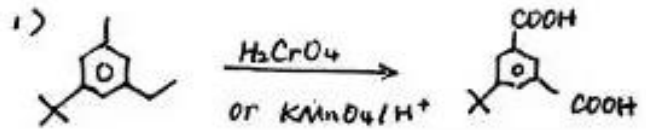


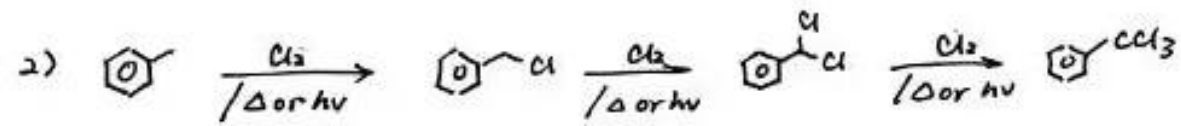
Electrophilic Aromatic Substitution



苯甲位氢的反应(α-C Benzene Hydrogen Reaction)

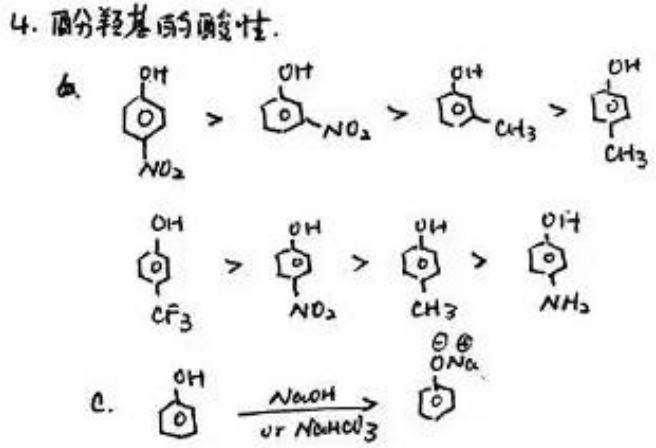
- **氧化**
  - 苯甲位有氢的烷基可被**强氧化剂**（高铬酸，酸性高锰酸钾等）氧化成苯甲酸形式；
  - 苯甲位**无氢**的烷基（如叔丁基）不发生此反应
- **卤代**
  - 在加热或光照条件下，与卤素发生**自由基取代反应**，苯甲位氢逐个被卤原子取代

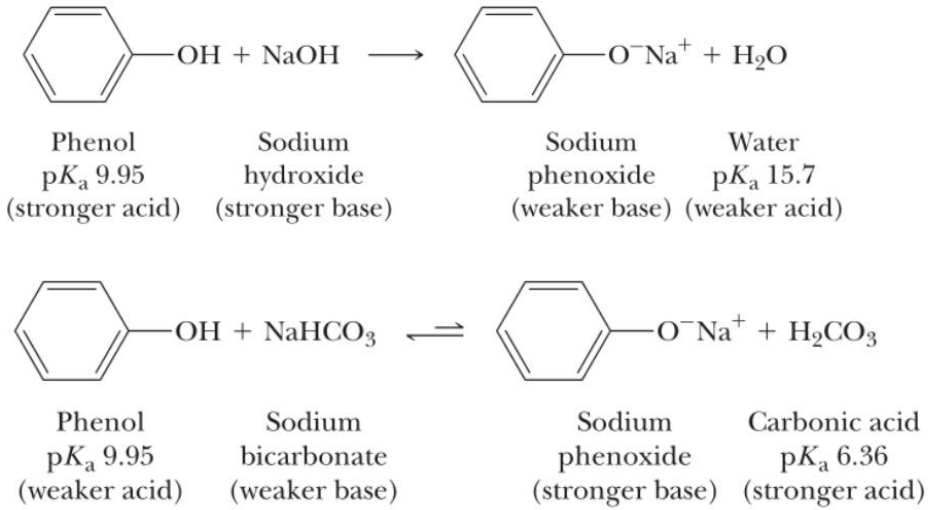




酚的化学活性(Chemical Activity of Phenols)

- **酸性**
  - 苯酚 $pKa = 10$
  - 苯环上**取代基**对酚羟基酸性的影响：
    - 弱 邻对位给电基<间位给电基<间位吸电基<邻对位吸电基 强
    - 弱 强给电基<弱给电基<弱吸电基<强吸电基 强
  - 可以与氢氧化钠，碳酸氢钠反应生成苯氧化钠
  - 苯环上的反应同上，羟基作给电基。



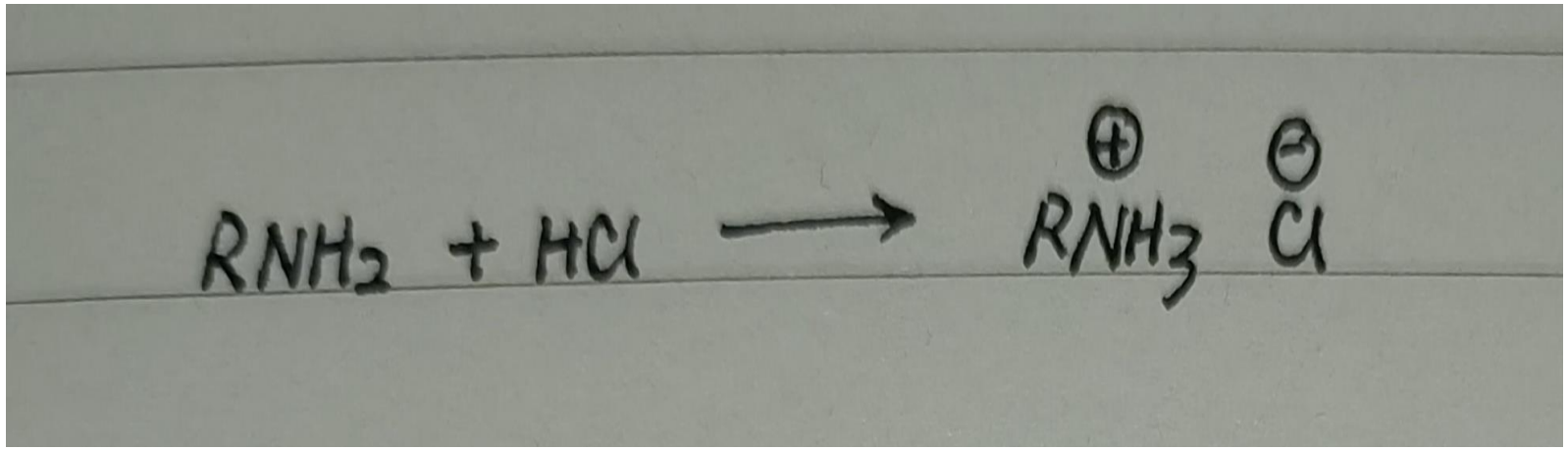


胺的酸碱性质(Acidic and basic properties of amines)

1. 在**水溶液**中，碱性 脂肪胺＞氨＞芳香胺；
2. 其中脂肪胺碱性 2°＞1°＞3°（3°胺碱性较弱主要由于**溶剂化效应和空阻效应**）
3. 芳香胺碱性 $PhNH_2$＞$(Ph)_2NH$＞$(Ph)_3N$；
4. 苯环上取代基对芳胺碱性的影响：
   - 碱性强 邻对位给电基＞间位给电基＞间位吸电基＞邻对位吸电基 碱性弱
   - 碱性强 强给电基＞弱给电基＞弱吸电基＞强吸电基 碱性弱

胺的酸碱性质(Acidic and basic properties of amines)

- 胺可与无机酸反应生成铵盐

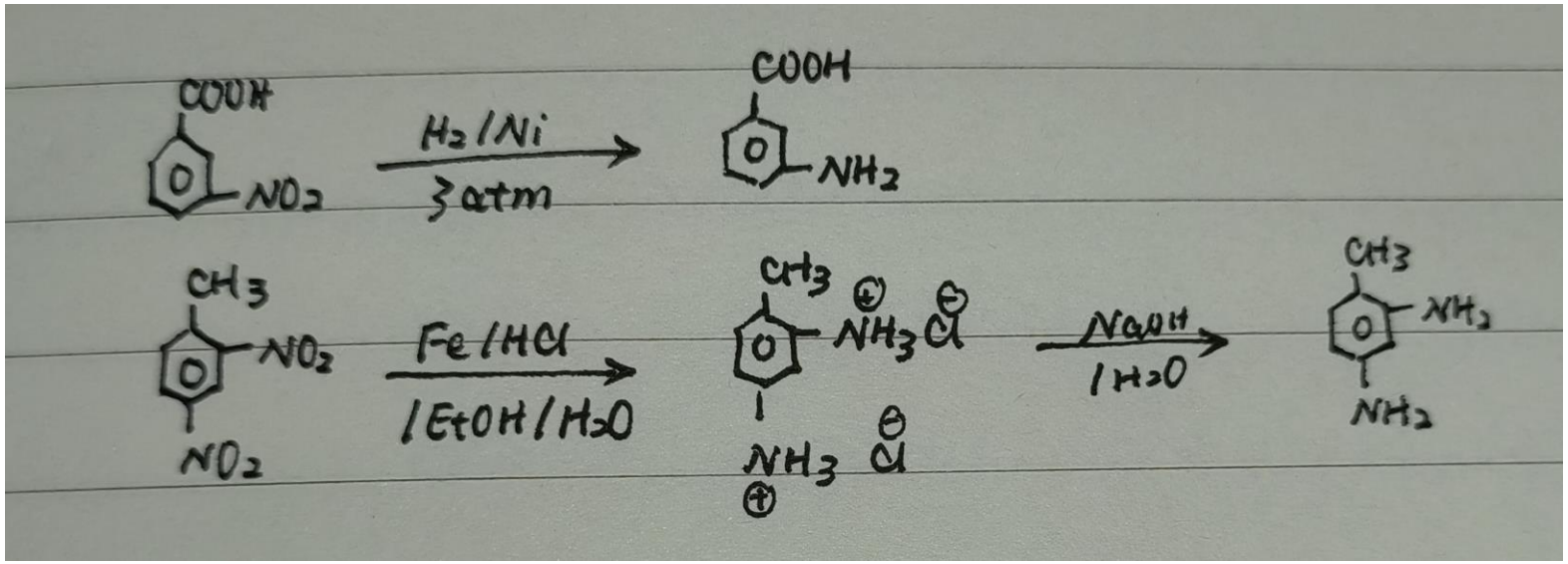


芳胺的制备 (Preparation of aromatic amines)

芳胺的制备（**硝基还原为氨基**）

1. 在3atm和镍催化作用下，氢气还原硝基为氨基
2. 乙醇水溶液中，盐酸和铁还原硝基为氨基

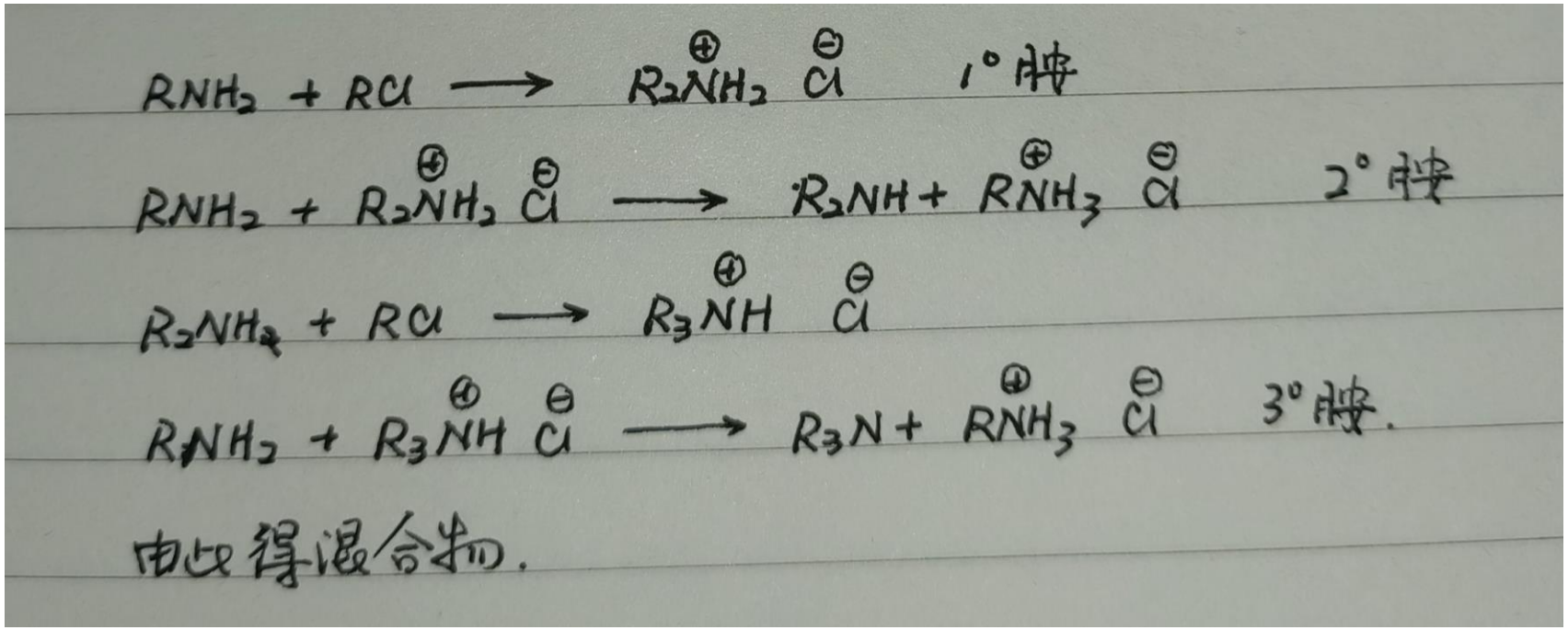
制备芳胺时应当注意基团定位效应，考虑基团进攻苯环的先后顺序



亲核试剂(Work as Nucleophile)

一级脂肪胺和卤化烃的反应
- 亲电试剂与亲核试剂反应
- 质子与亲核试剂反应

由此会得各级胺的**混合物**，制备上无意义。



例题

1.写出S_{N1}, S_{N2},E_1,E_2反应的反应机理

例题

2. 乙酰水杨酸（阿司匹林）制备实验中，浓硫酸的作用