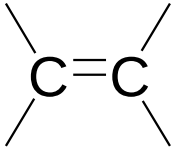
台灣大學開放式課程

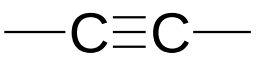
有機化學乙

蔡蘊明　教授

Chapter 7
Alkenes and alkynes: synthesis



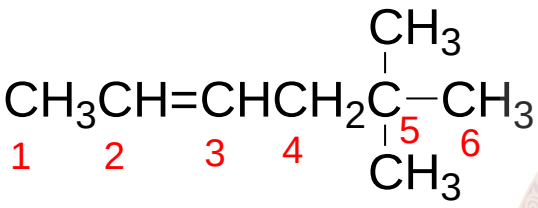
alkenes
also called olefins



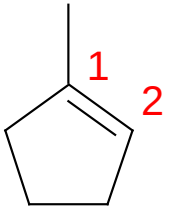
alkynes
common name: acetylenes

※ Nomenclature

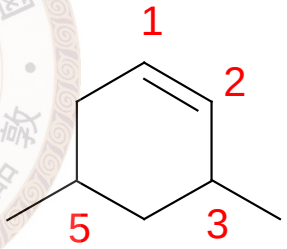
✓ Alkene　　IUPAC: ane → ene



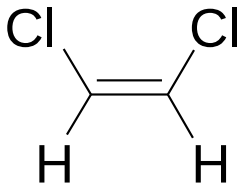
5,5-dimethyl-2-hexene
(5,5-dimethylhex-2-ene)



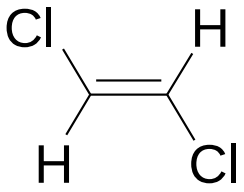
1-methylcyclopentene



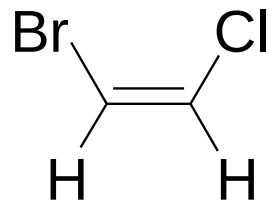
3,5-dimethylcyclohexene



cis-1,2-dichloroethene

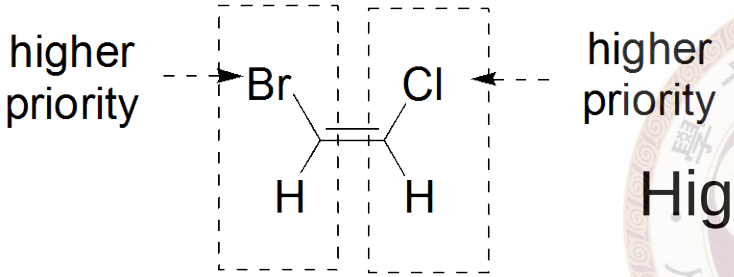


trans-1,2-dichloroethene

Q: 

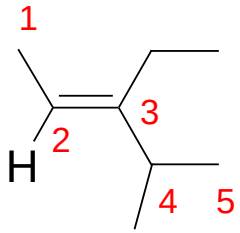
cis or trans?

The (*E*), (*Z*) designation:

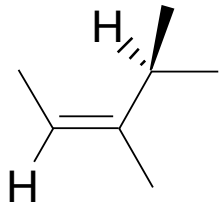


Higher priority at the same side: *(Z)*
at the opposite side: *(E)*

例

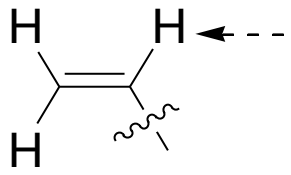


(*E*)-3-ethyl-4-methyl-2-pentene

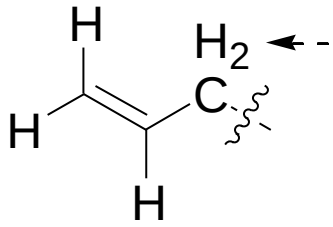


(*Z*)-(*S*)-3,4-dimethyl-2-hexene

As substituent:



vinylic hydrogen

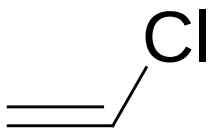


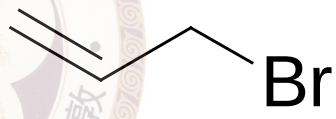
allylic hydrogens

a vinyl group

an allyl group

例





chloroethene

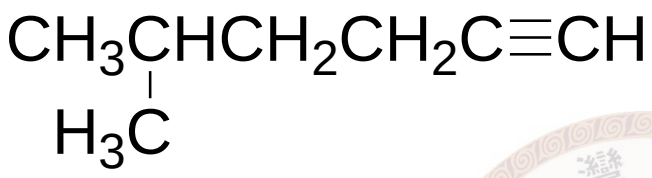
3-bromopropene

common name:
vinyl chloride

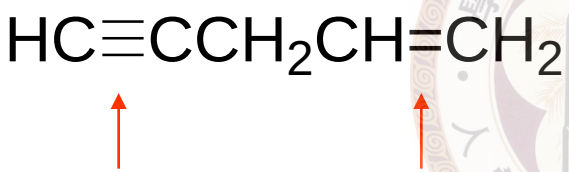
common name:
allyl bromide

✓ Alkyne IUPAC: ane → yne

IUPAC:



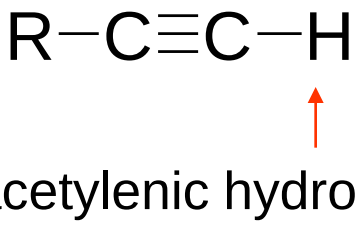
5-methyl-1-hexyne



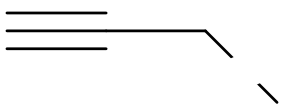
1-penten-4-yne
(or pent-1-en-4-yne)

parent smaller #

Class name:
enyne

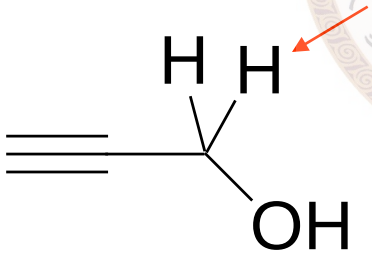


A monosubstituted acetylene
or 1-alkyne
or terminal alkyne



A propargyl group

例

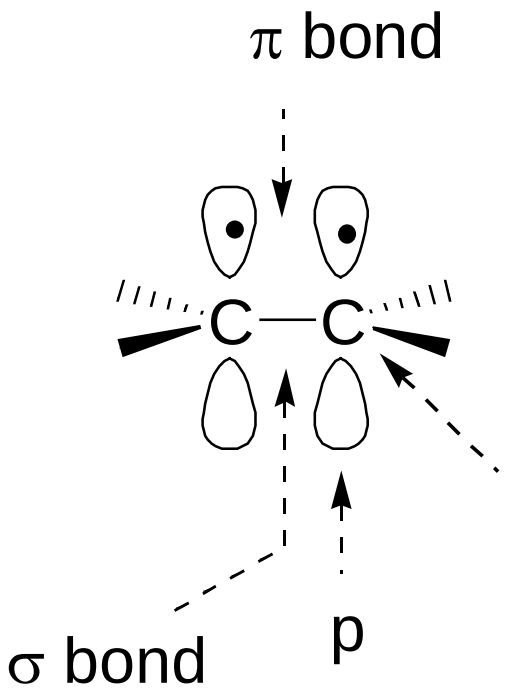


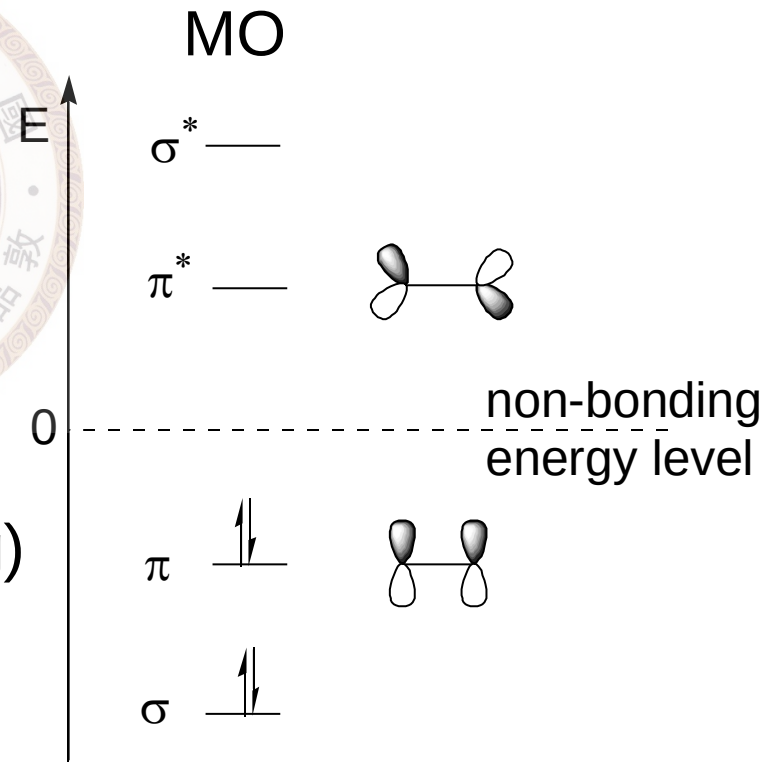
Propargyl alcohol

※ Physical properties, structure and bonding

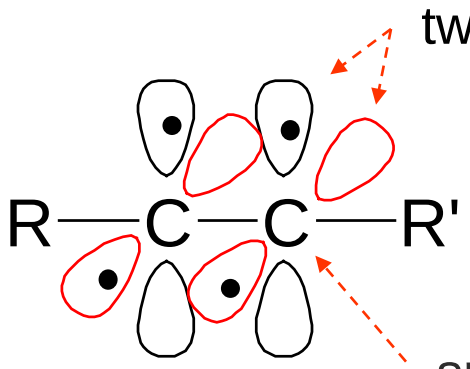
In general:
non-polar, water insoluble, more reactive than alkanes

✓ Alkenes





✓ Alkynes

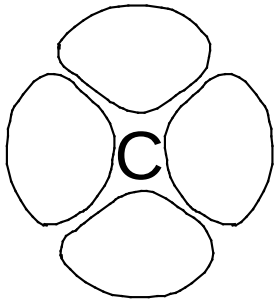


two orthogonal p orbitals ⟹ two orthogonal π systems

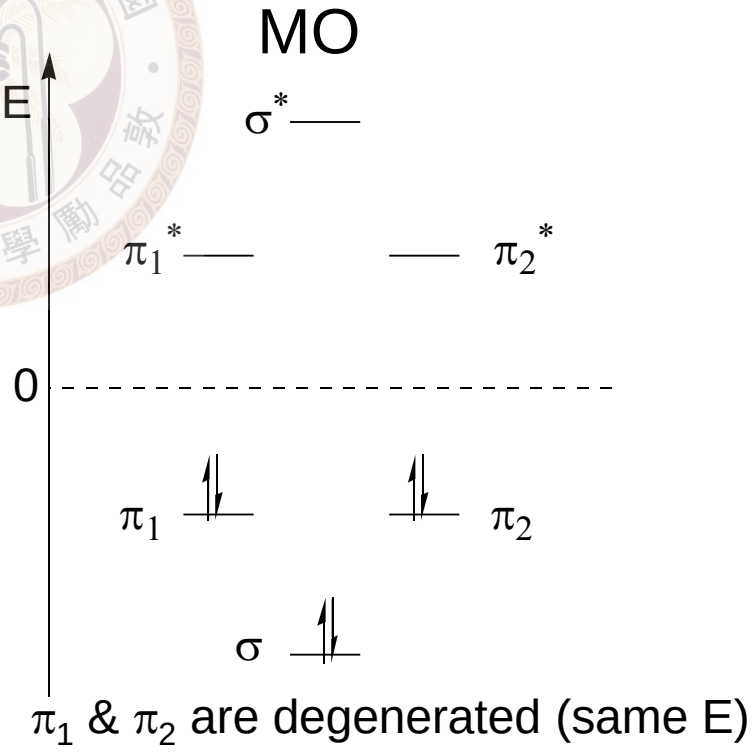
linear shape

sp (for σ bonding)

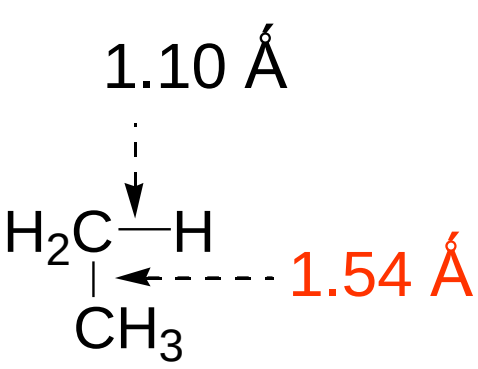
End on view:

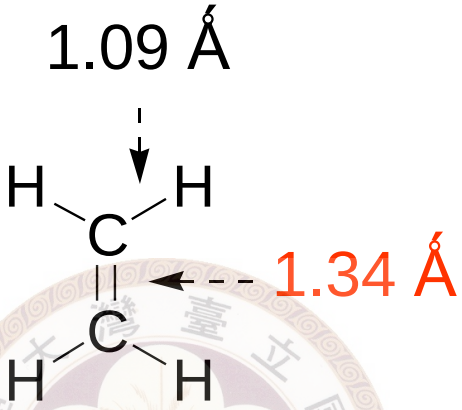


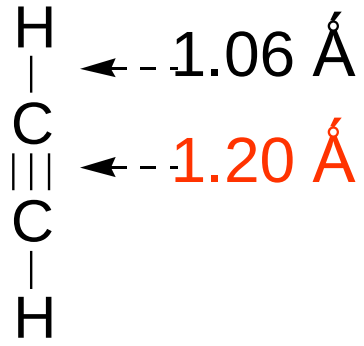
cylindrical



◎ Bon length







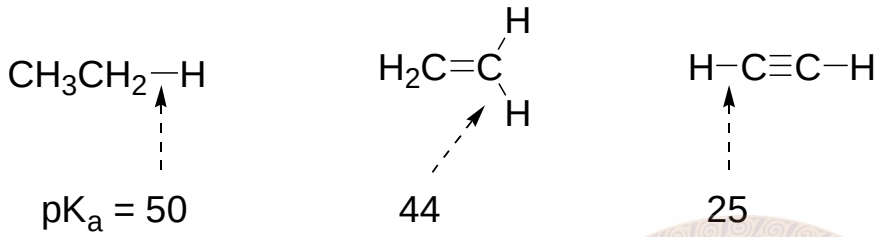
C-C σ bond:

sp^3-sp^3 sp^2-sp^2 sp-sp

higher s character ⇨ shorter bond

C-H σ bond: same trend

★ Acidity



Recall:

$$HA \rightleftharpoons H^+ + A^- \qquad K_a = \frac{[H^+][A^-]}{[HA]}$$

Why?

The power of s character

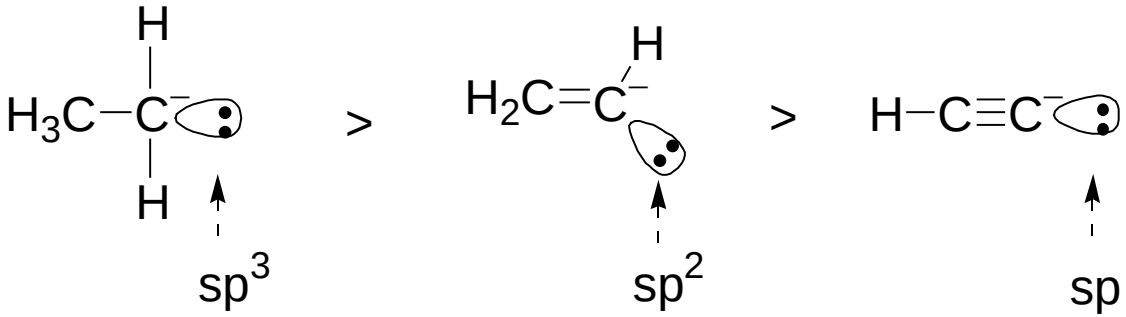
sp

more s character

(orbital electronegativity is higher)

anion is more stabilized

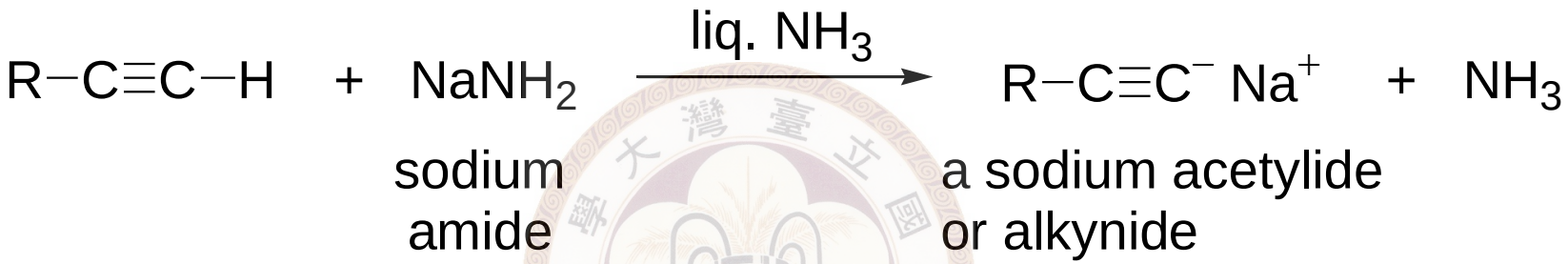
Rel. basicity:



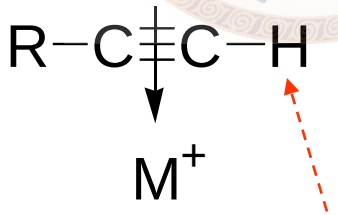
Compare with others:

H_2O > ROH > R-C≡C-H > H_2N-H > CH_2=CH_2 > CH_3CH_3

pK_a	15.8	16-17	25	38	44	50



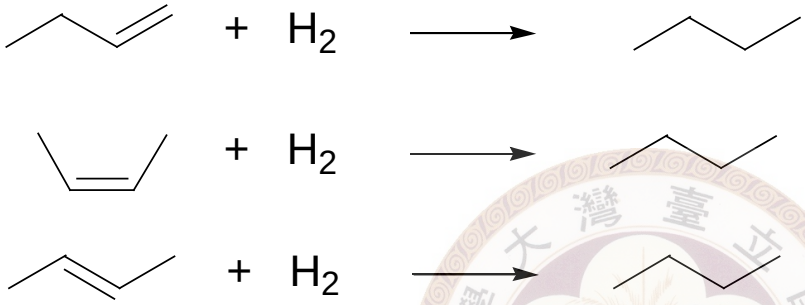
When complexed with transition metal ion:

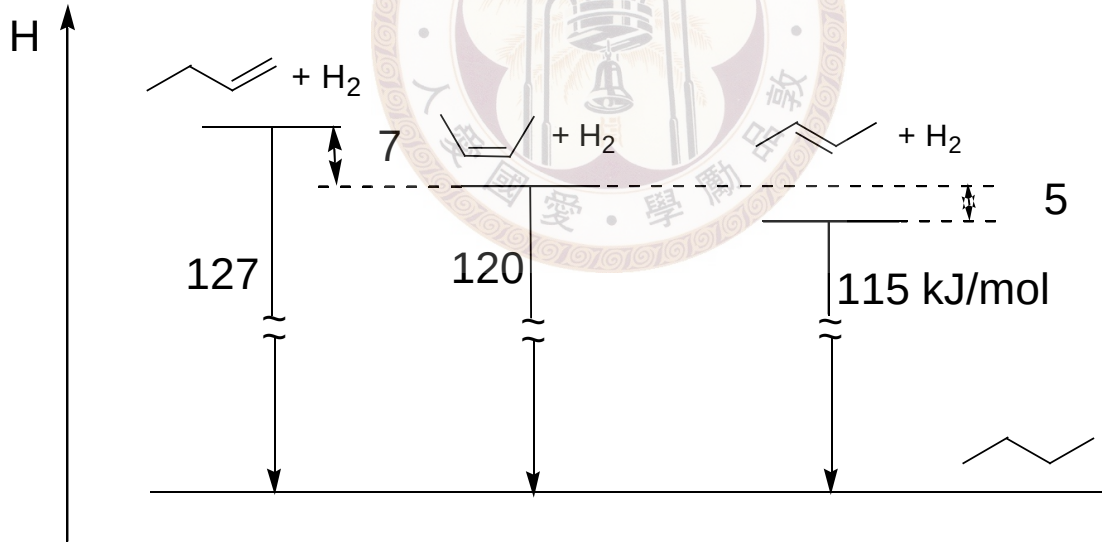


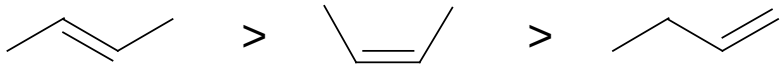
becomes more acidic
due to the adjacent positive charge

※ The stability of alkenes

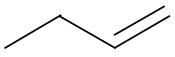
◎ Heat of hydrogenation



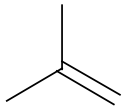


Rel. stability:  >

◎ Heat of combustion



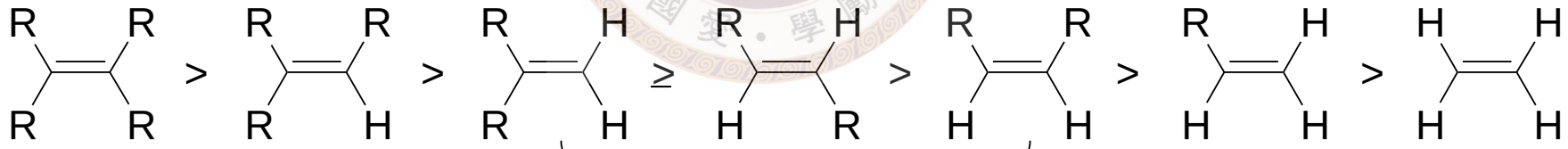
+ $6O_2$ ⟶ $4CO_2$ + $4H_2O$ $\Delta H^o = -2729$ kJ/mol



+ $6O_2$ ⟶ $4CO_2$ + $4H_2O$ $\Delta H^o = -2714$ kJ/mol

More stable by 15 kJ/mol

★ Overall relative stability:



tetrasubstituted tri- disubstituted mono- un-

R: alkyl group

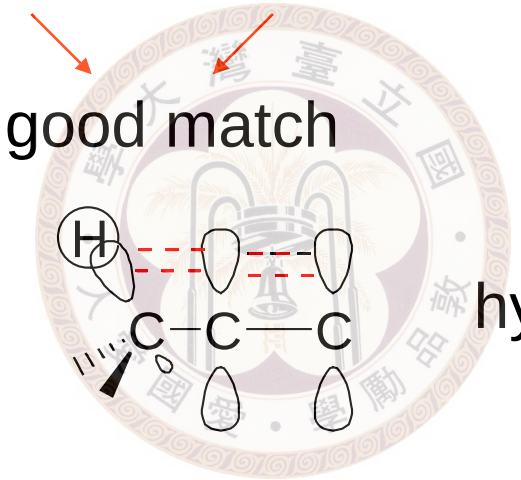
★ Points to remember:

✓ More R → more stable

Reason:

R: donates e^- sp^2 orbital: more e^- demanding

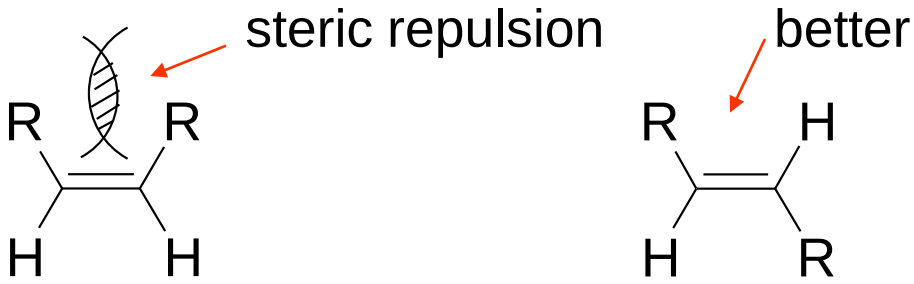
MO view:



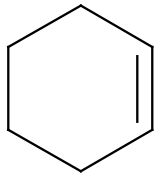
hyperconjugative stabilization

✓ Trans is more stable than cis

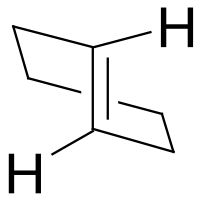
Reason:



◎ Cycloalkenes



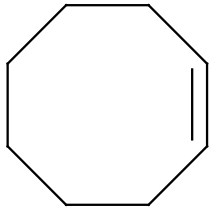
cyclohexene



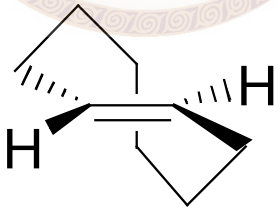
trans-cyclohexene

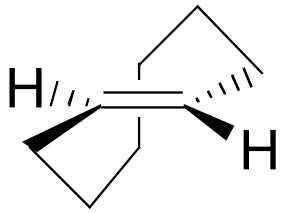
very strain, very unstable

Number of carbon < 6 → only cis



cis-cyclooctene

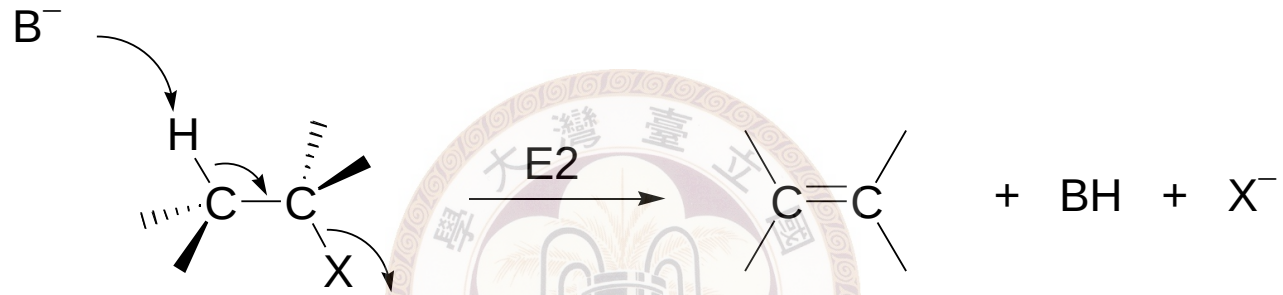




trans-cyclooctene (chiral)

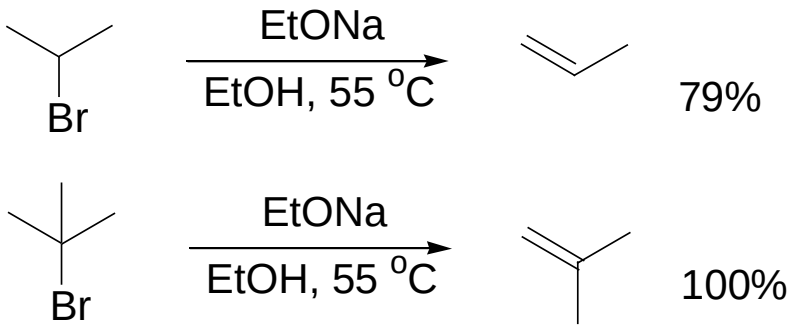
※ Dehydrohalogenation

E2 preffered
(E1 → more side product)

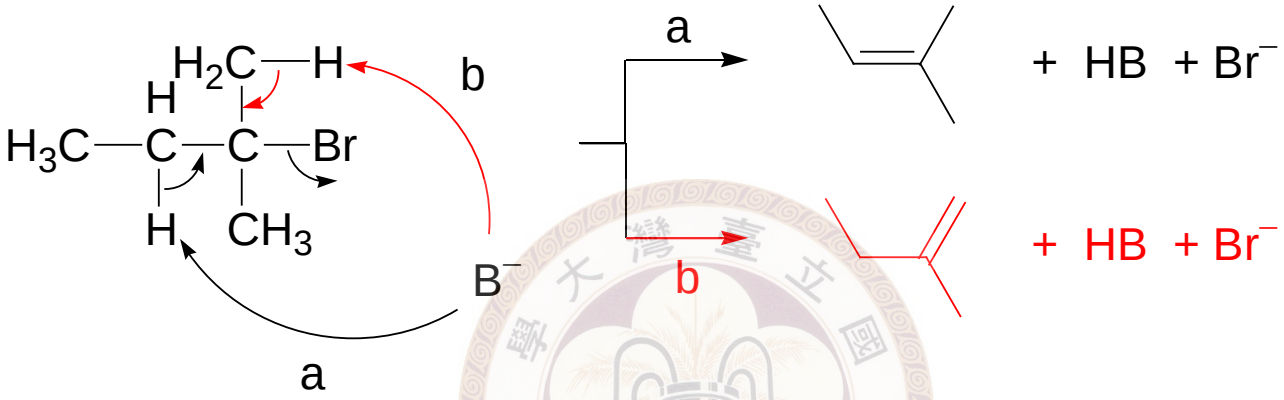


use a strong base: NaOEt, *t*-BuOK, · · · ·
high conc.
high temp.
nonpolar solvent if possible

例

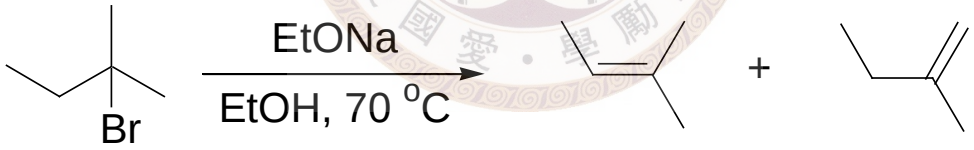


◎ Regioselectivity: Zaitsev's rule
位置選擇



Zaitsev's rule: the more stable alkene will be major

例

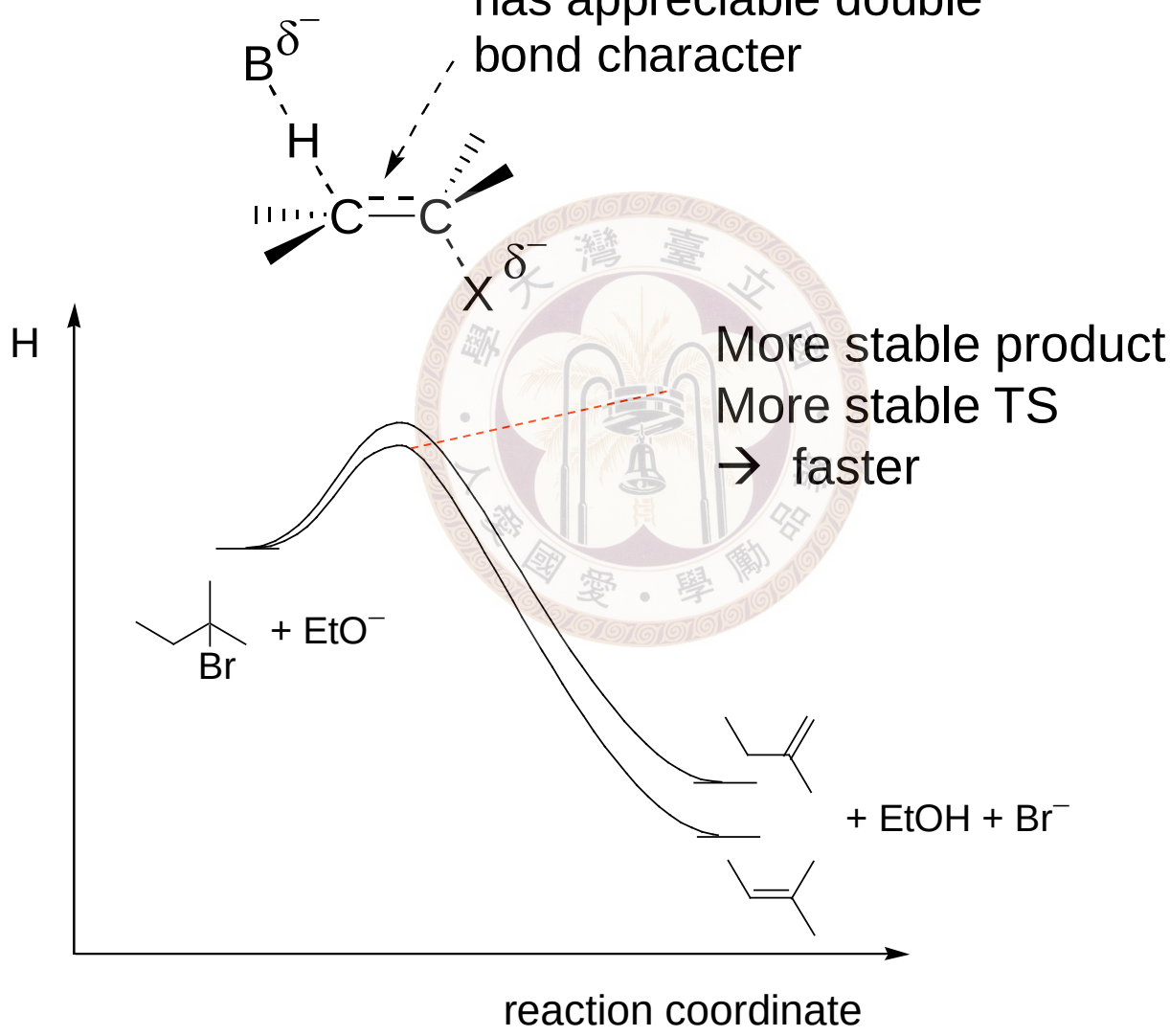


69:31

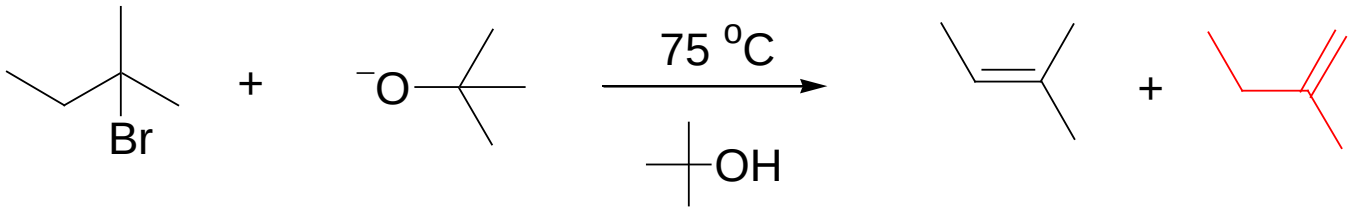
more stable
(trsubstituted)

◎ The reason of Zaitsev's rule

TS:



Exception:



27.5:72.5

Reason: steric

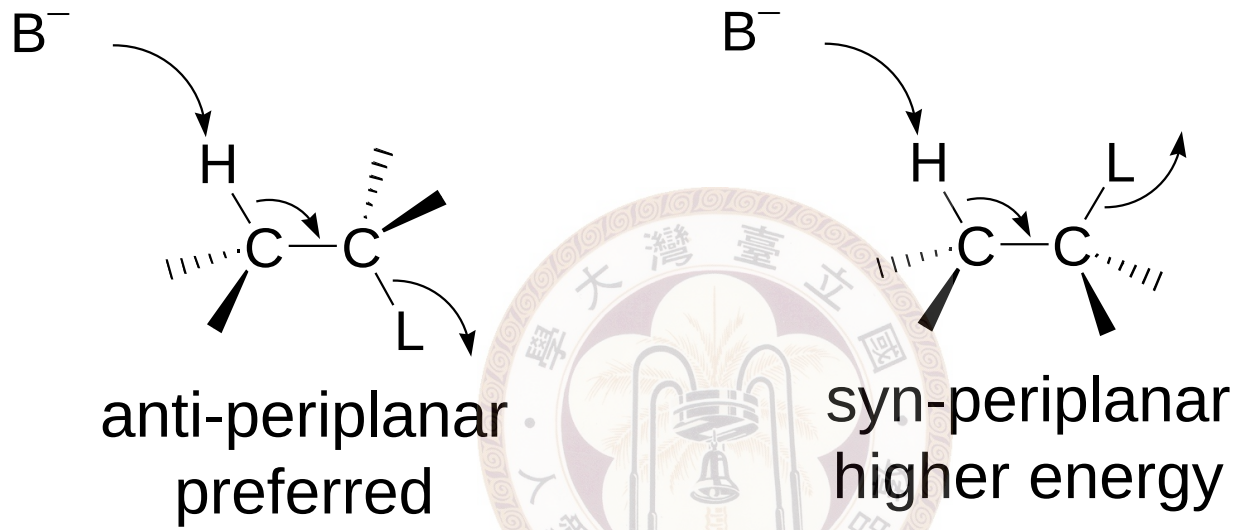
the base is very hindered

abstracts the less crowded 1° hydrogen

Formation of the less substituted alkene

⟹ Hoffmann orientation

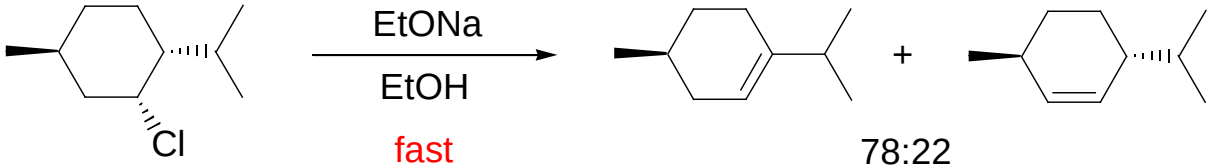
★ Stereochemical requirement



anti-periplanar
preferred

syn-periplanar
higher energy

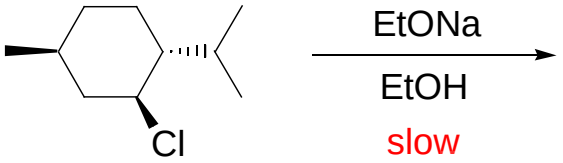
例



neomenthyl chloride

fast

78:22



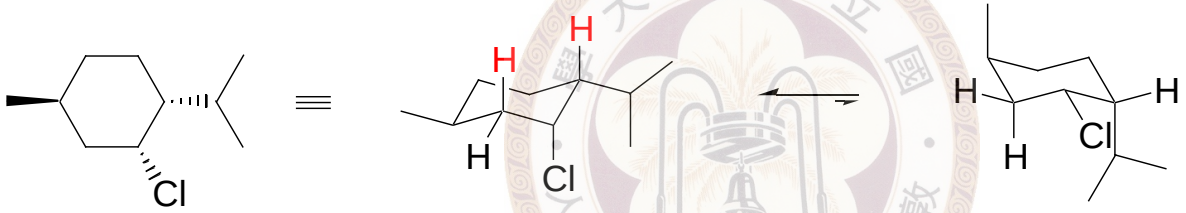
menthyl chloride

slow

0:100

Why?

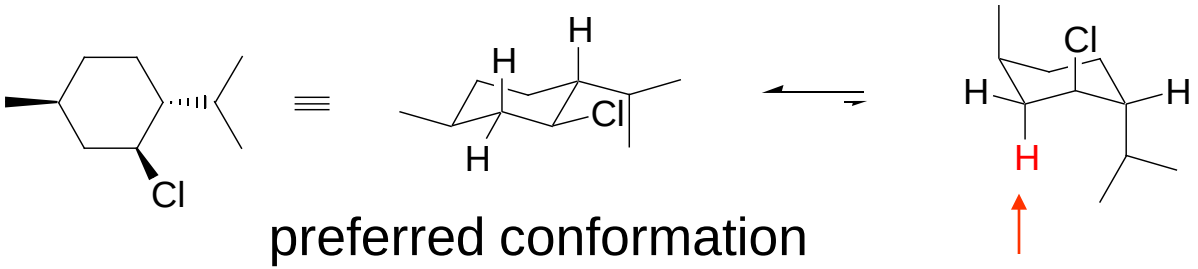
Ans:



preferred conformation

adopts anti-periplanar TS easily

→ Fast and follows Zaitsev's rule



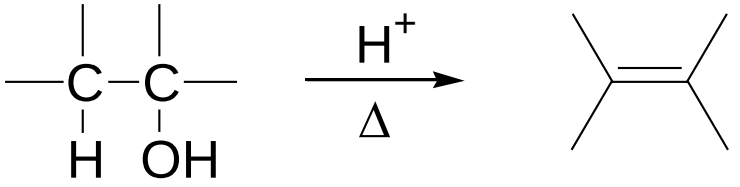
preferred conformation

no H can obtain anti-periplanar relationship with Cl

only this H is anti to Cl

⇨ Hoffmann orientation

※ Dehydration of alcohols



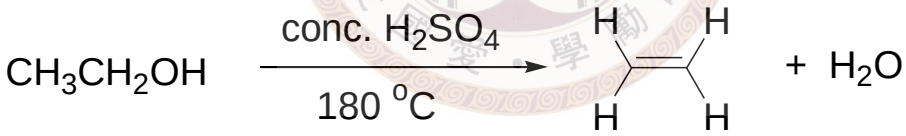
Acid catalyzed

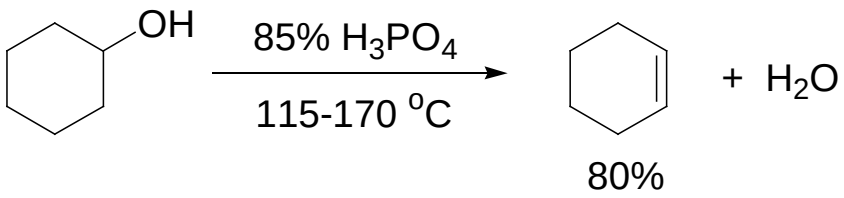
◎ Ease of dehydration

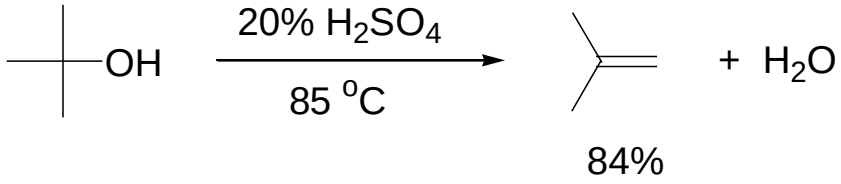
$3^o > 2^o > 1^o$

requires high conc. & high T

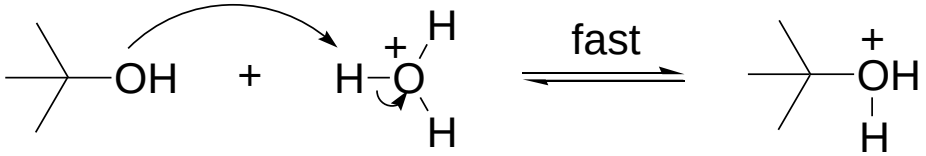
例





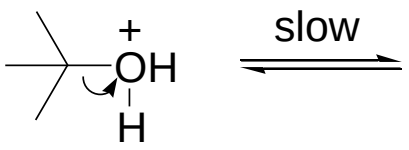


◎ Mechanism: E1 process for 2º and 3º alcohols



hydronium ion

a protonated alcohol or alkyloxonium ion



Carbocation formation in RDS

More stable cation

→ more stable TS

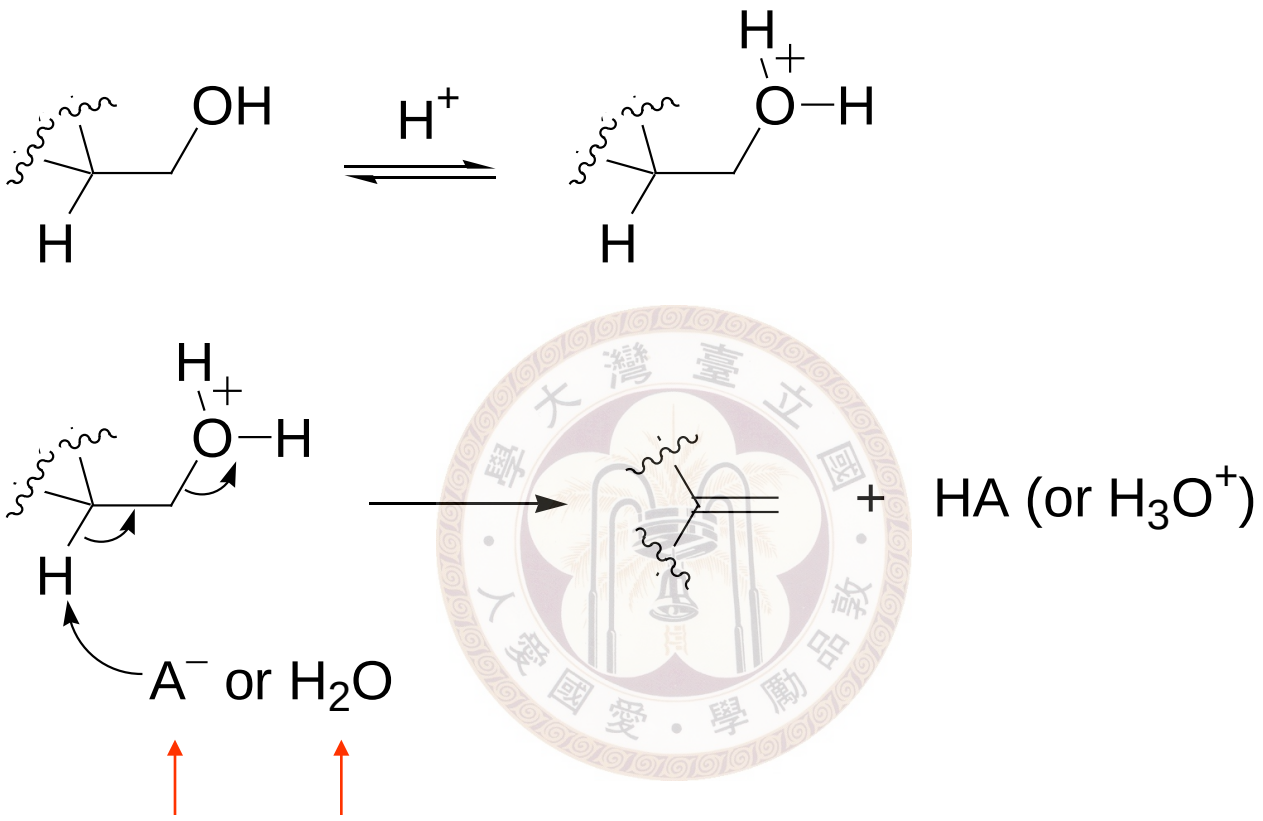
→ faster reaction

or ROH

← Catalyst is regenerated

*Equilibrium: remove water drives the reaction to the right (the reverse reaction is the addition of water to olefins)

◎ E2 mechanism for 1º alcohols

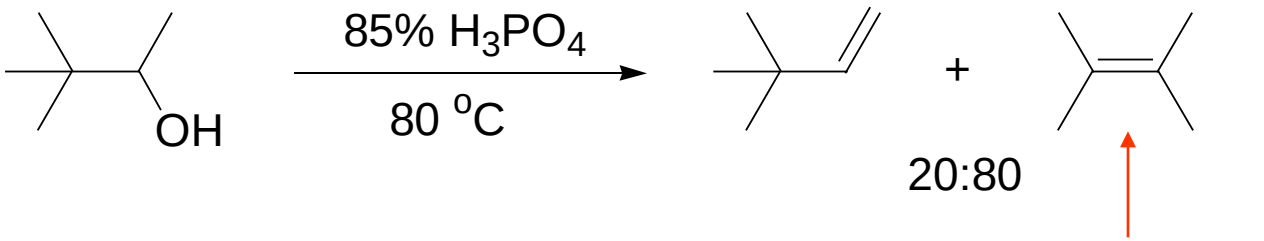


Weak base

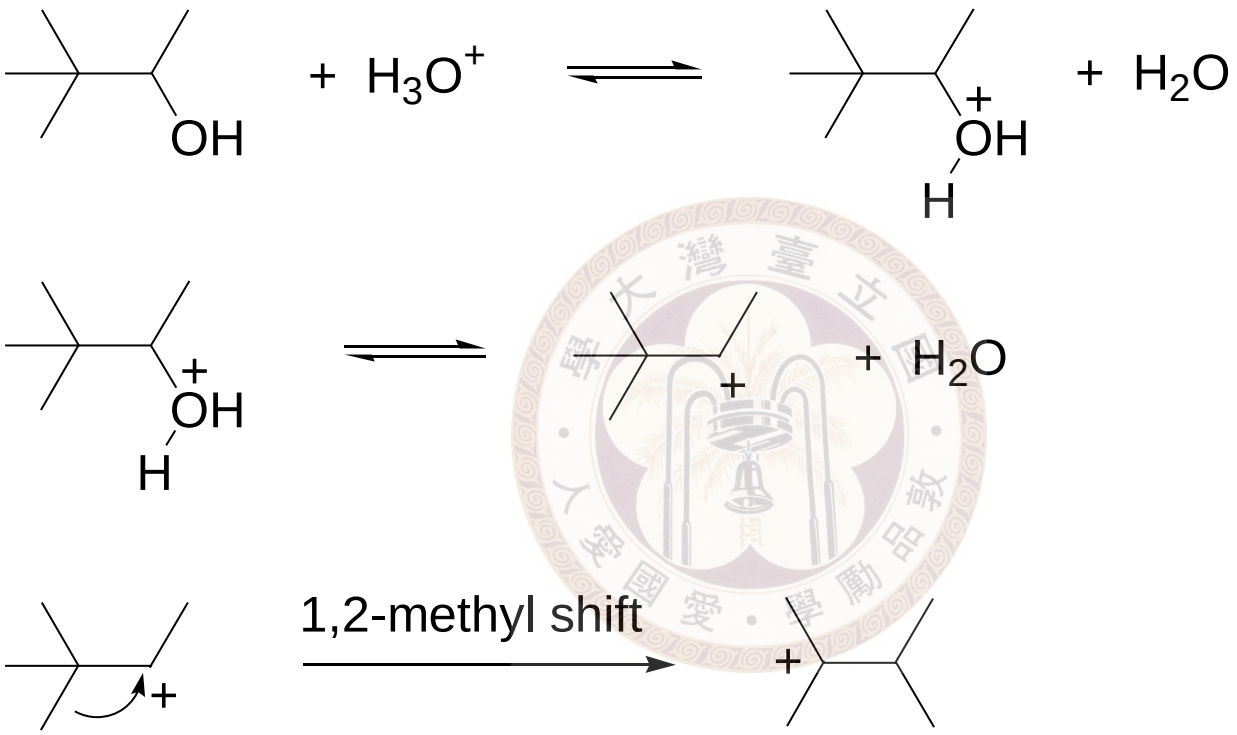
Requires harsh condition

◎ Rearrangement occurs

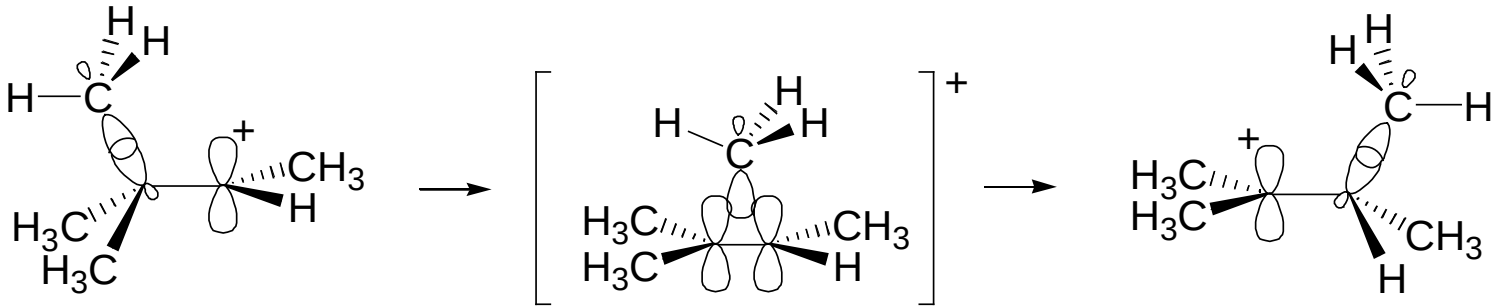
例

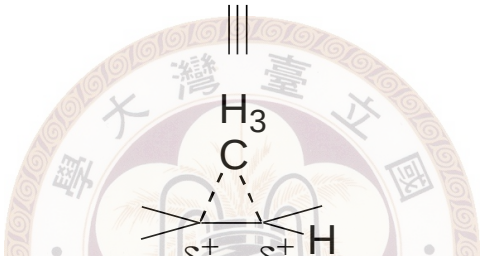


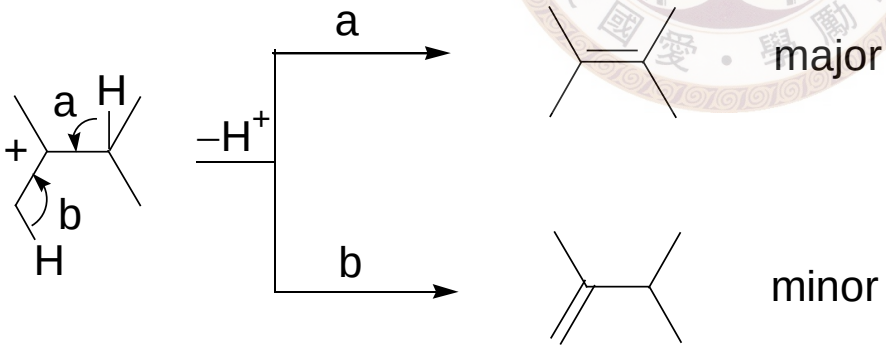
※ Rearrangement of carbocation



Driving force: formation of a more stable carbocation ($2^o \rightarrow 3^o$)

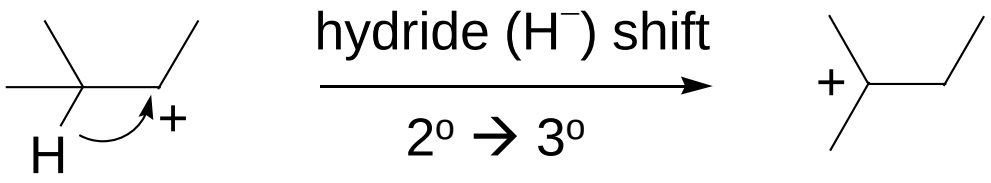


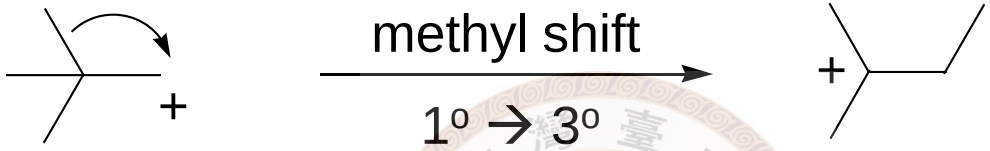


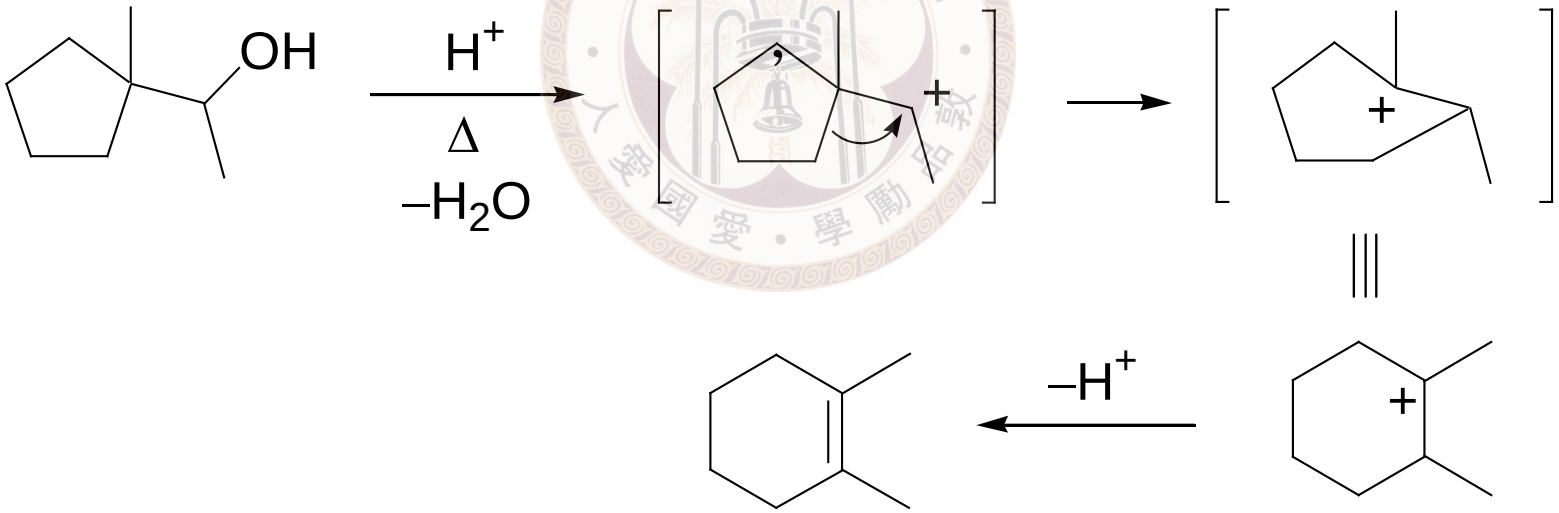


follows
Zaitsev's rule

例

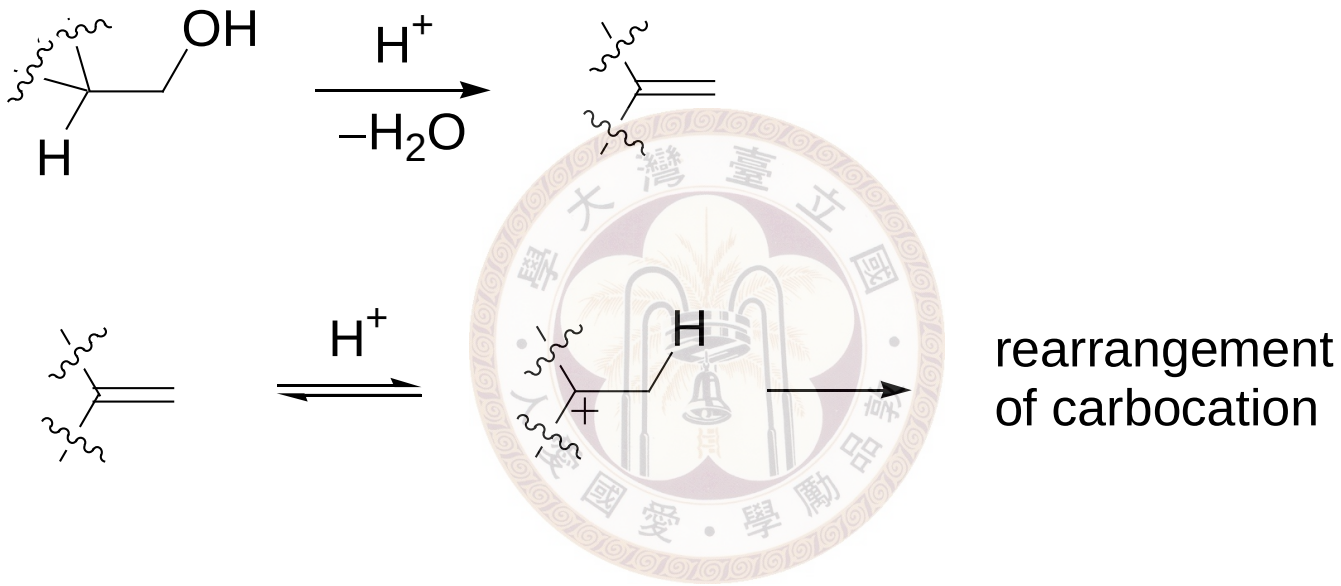






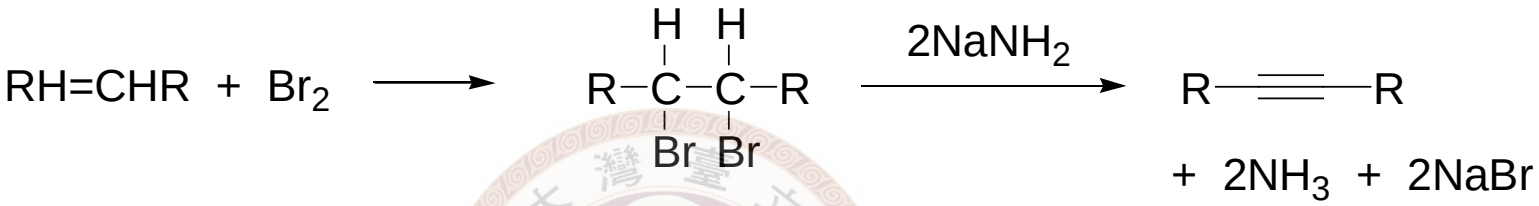
◎ Primary alcohols

rearrangement through olefin products

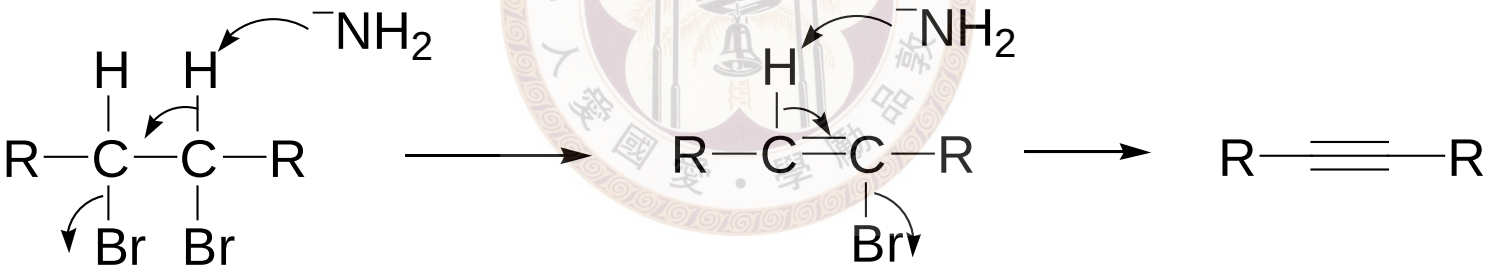


※ Preparation of alkynes

◎ By elimination



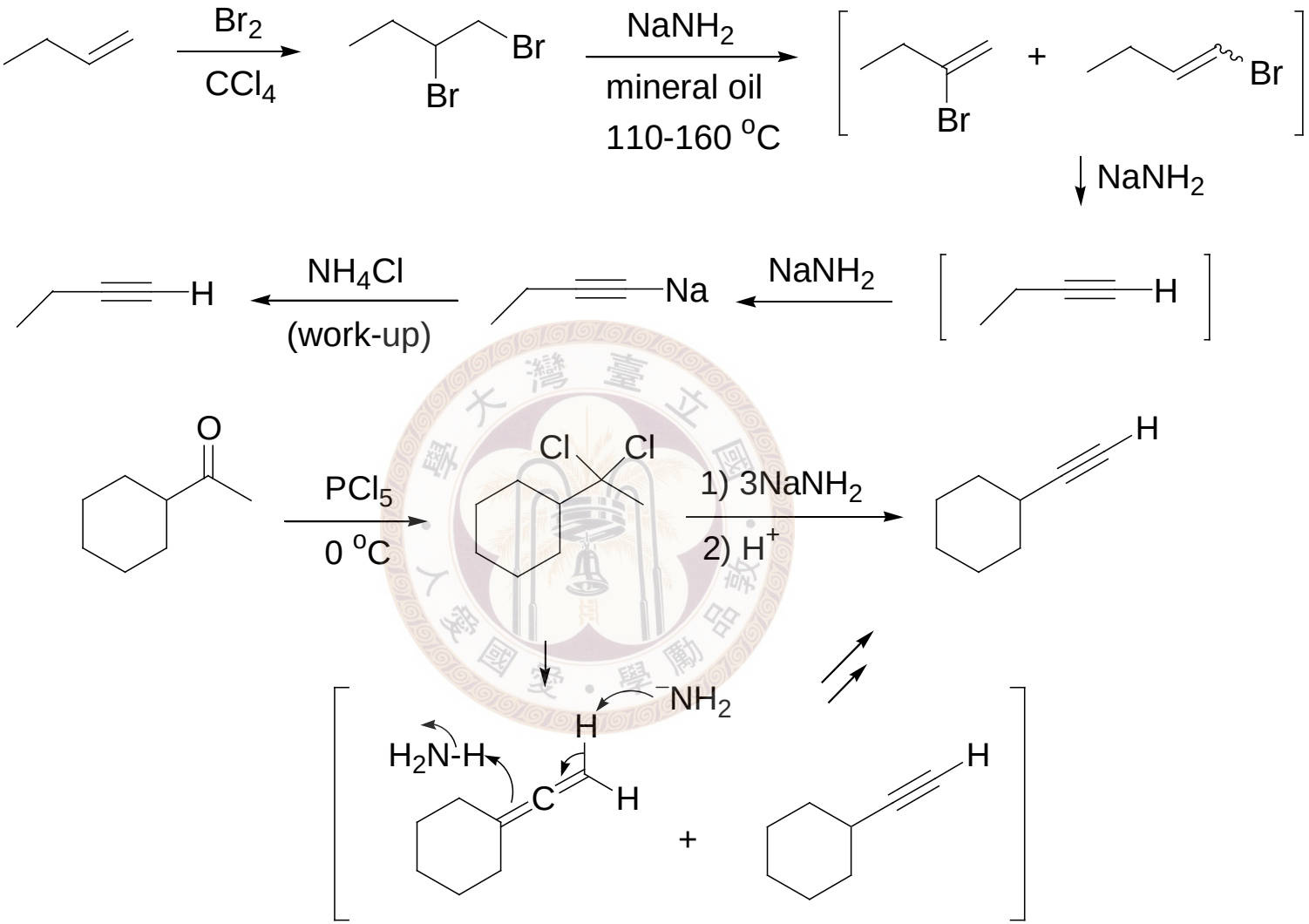
Mechanism:



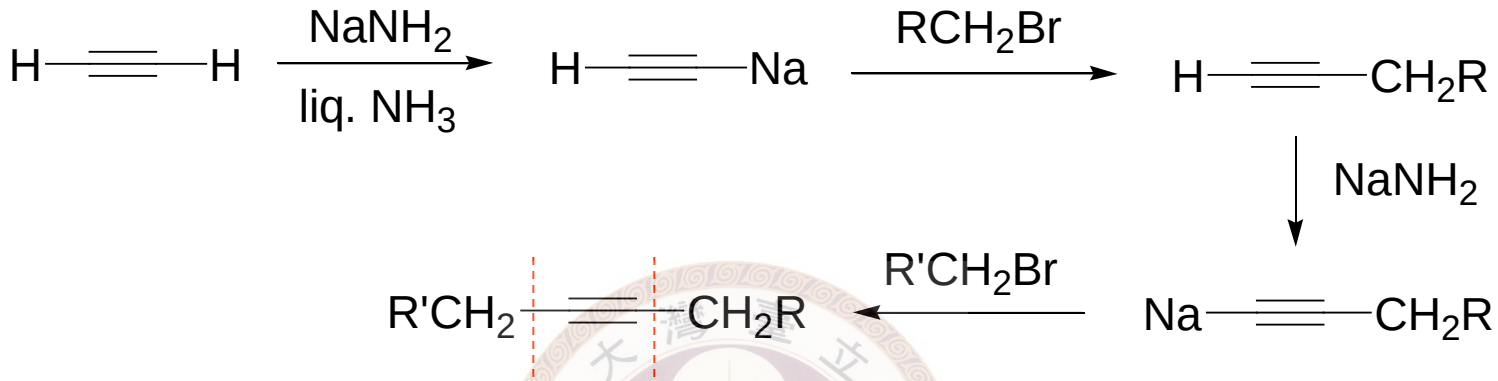
t-BuOK can be used in this step

a strong base is required in this step (vinyl C-H bond is stronger)

例


Br2
CCl4
Br
Br
NaNH2
mineral oil
110-160 °C
Br
+
Br
NaNH2
H
NH4Cl
(work-up)
Na
NaNH2
H
O
PCl5
0 °C
Cl
Cl
1) 3NaNH2
2) H+
H
H2N-H
H
C
H
−NH2
+
H

◎ From acetylide



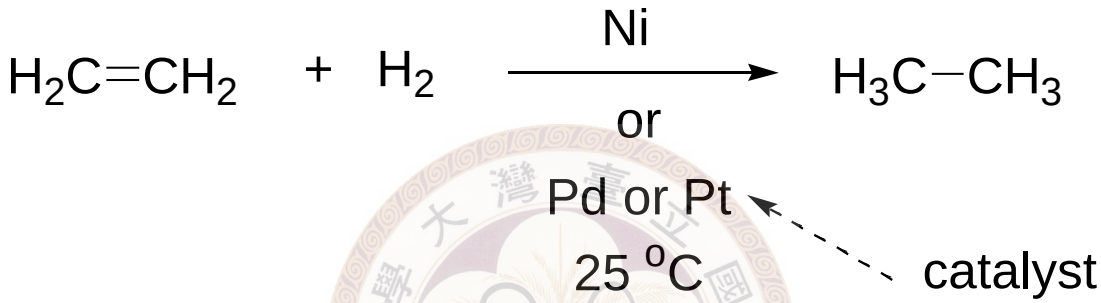
✓Only work with 1º halide

✓ 2º, 3º halides → elimination (acetylides are strong base)

✓ S_N2 with inversion of configuration

※ Hydrogenation (氫化)

◎ Alkenes



A catalytic hydrogenation (an addition reaction)

unsaturated → saturated

break: C-C π form: two C-H σ

H-H σ

Overall: exothermic $\Delta H \sim -120$ kJ/mol

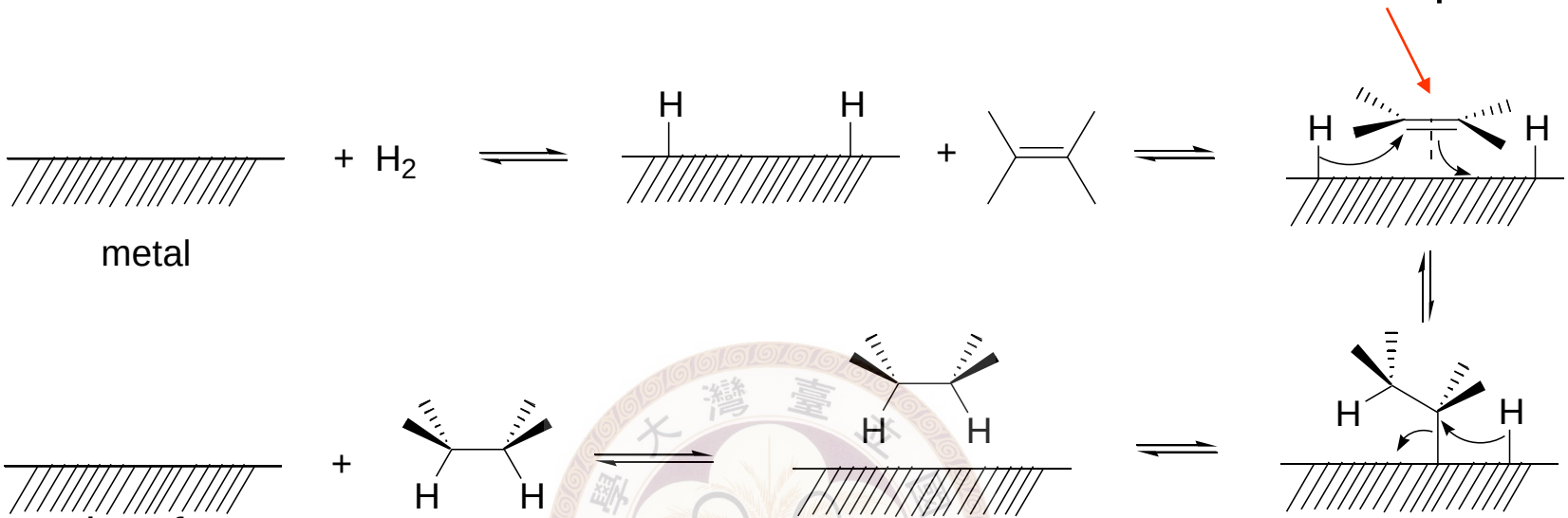
However, E_a is high → catalyst is required

Pd/C: palladium on charcoal is often used

Other metals: Pt (PtO_2), Rh, Ru, Ni

Mechanism:

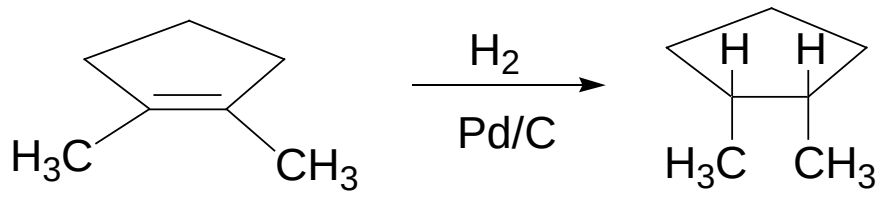
forms a π complex



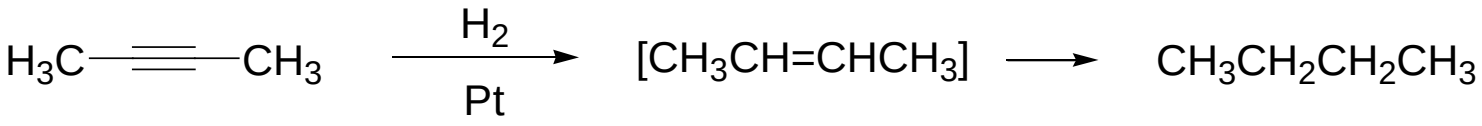
★ Stereochemistry: syn addition of the two hydrogens

syn anti

例

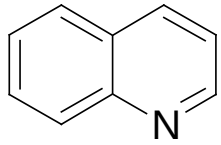


◎ Alkynes

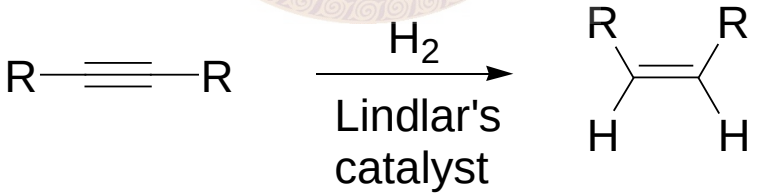


★ Stop at alkene:

✓ The Lindlar's catalyst:

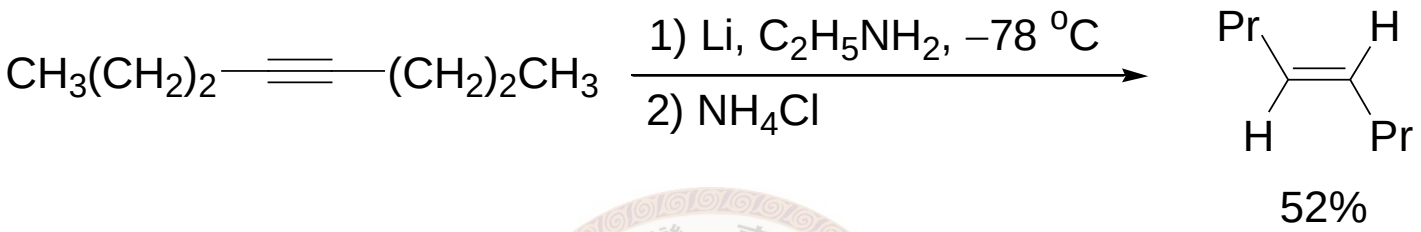
H_2, $Pd/CaCO_3$, Pb^{2+} or quinoline ≡ 

used as catalyst poison
(bind the active site or change the surface structure)



syn addition → cis alkene

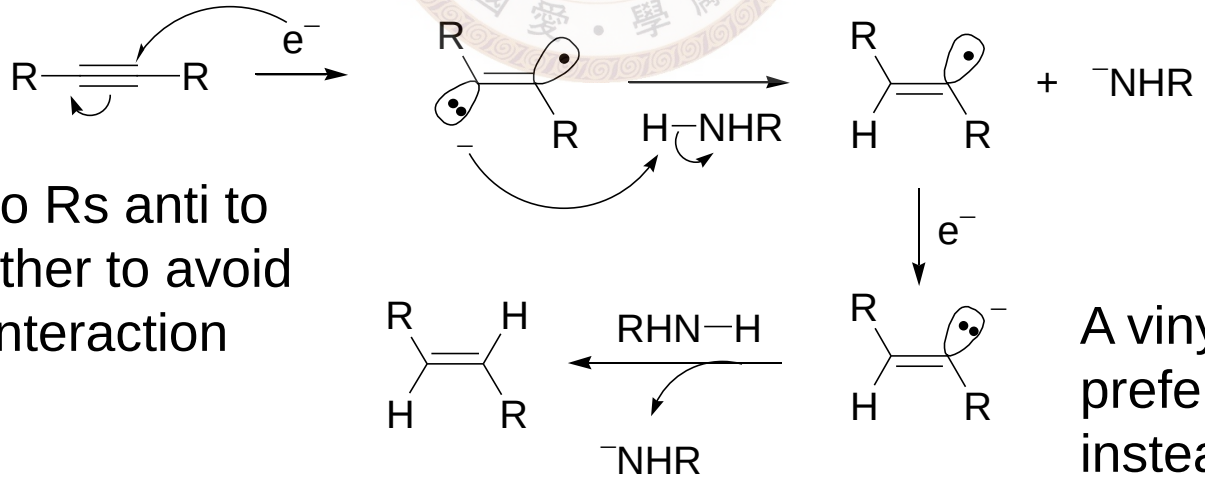
※ Dissolving metal reduction



Other reagents: $Li/NH_{3(l)}$, $Na/NH_{3(l)}$

Note: normal double bond is not reduced

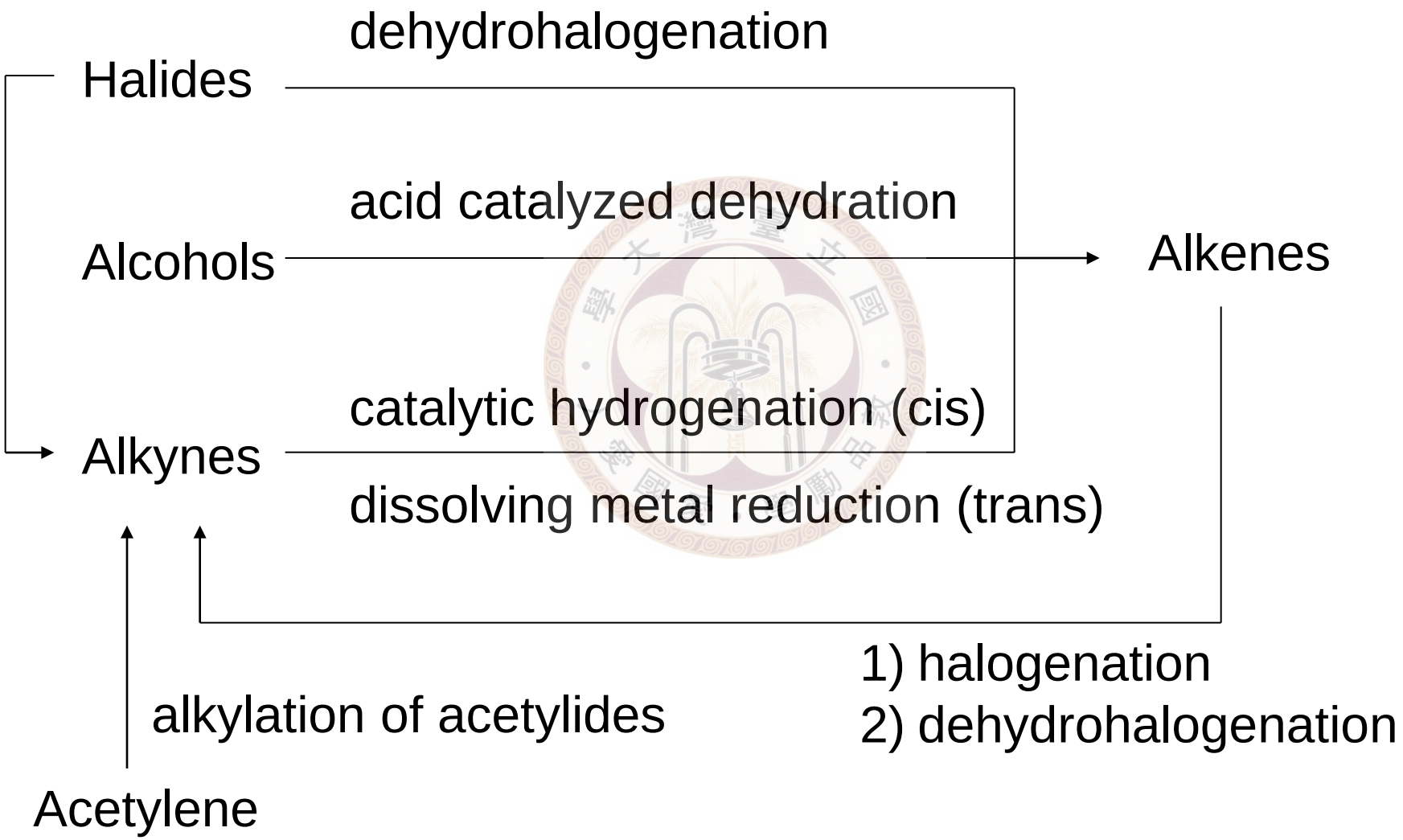
Mechanism:



The two Rs anti to each other to avoid steric interaction

A vinylic anion prefers sp^2 instead of p

※ Summary



★ Take good cares about mech., regio- and stereoselectivity

※ Planning organic synthesis: retrosynthetic analysis

Retrosynthetic analysis:
planning backward through bond disconnections

Create a flowchart:

Target molecule ⟹ 1st precursor ⟹ 2nd precursor ⟹ ⟹ Starting material

Analyze:

- Efficiency
  - Number of steps
  - Overall yields
- Economics
- Safety
- Waste issues

Case study: synthesis of