

Synthèse organique et chimie de composés d'éléments non transitionnels et de métaux de transition

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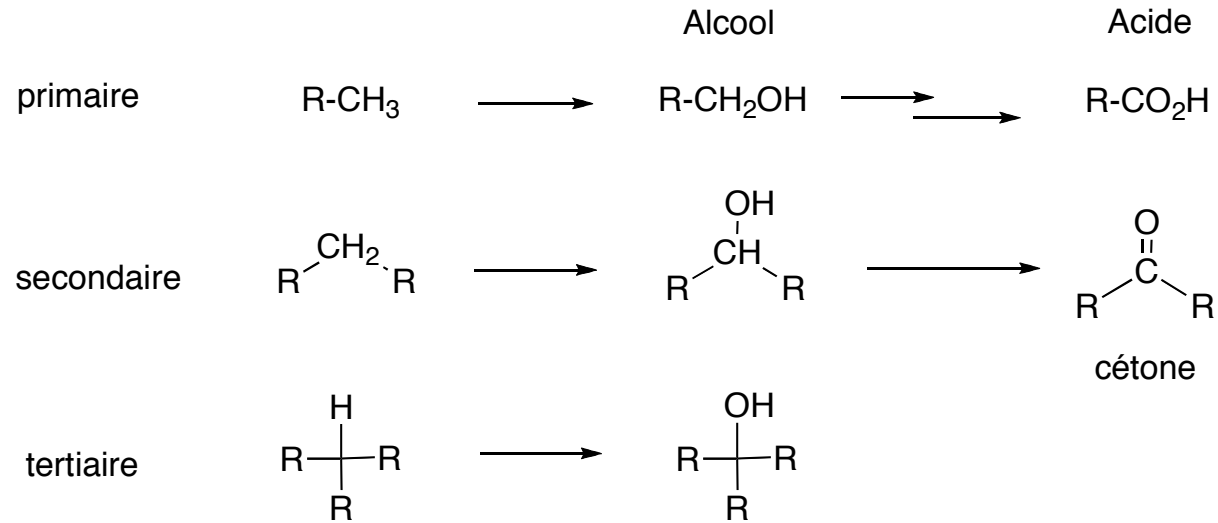
Chapitre 4 : Métaux de transition et synthèse organique

C) Oxydation des hydrocarbures

- I) Généralités
- II) Des alcanes
- III) Des arènes
- IV) Des oléfines et des positions allyliques (benzyliques)

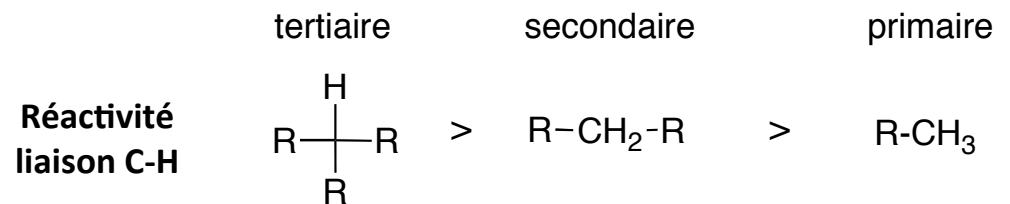
Oxydation des alcanes

Alcanes : le plus difficile



Problèmes:

- S'arrêter à l'alcool sans aller au delà (contrôle)
- liaison C-H est stable et peu réactive
- la sélectivité

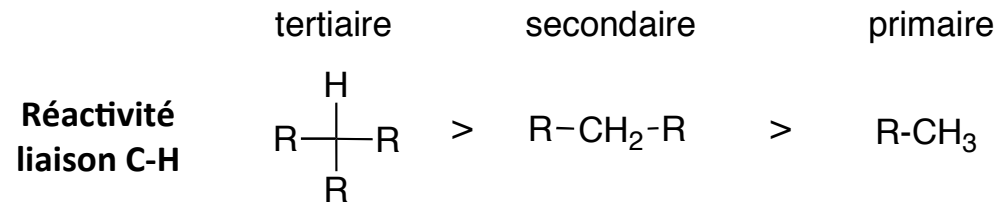
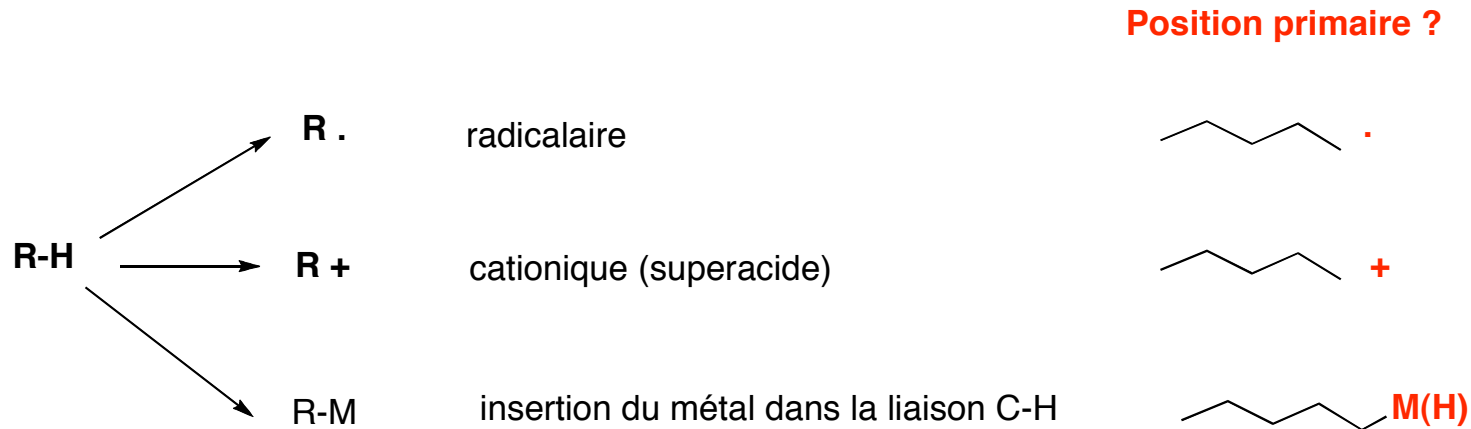


Energie de liaison : 91 kcal/mol 95 kcal/mol 98 kcal/mol

Oxydation des alcanes



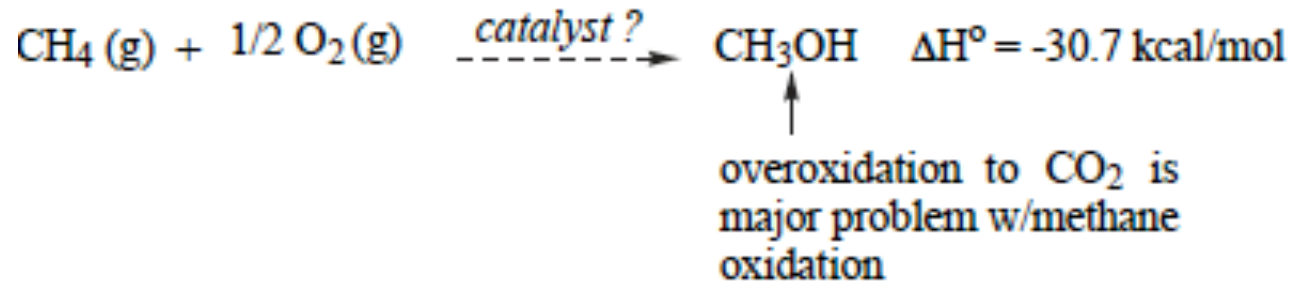
3 mécanismes d'activation possibles de la liaison CH



Energie de liaison :	91 kcal/mol	95 kcal/mol	98 kcal/mol
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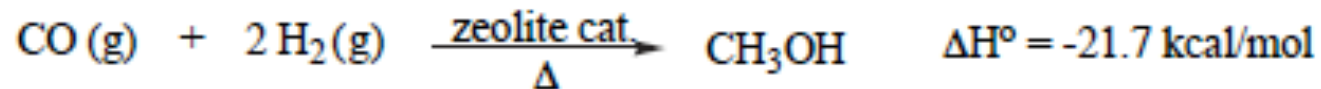
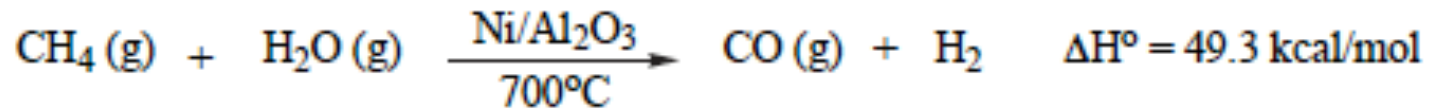
Oxydation des alcanes

La transformation du méthane en méthanol : Un enjeu économique majeur :



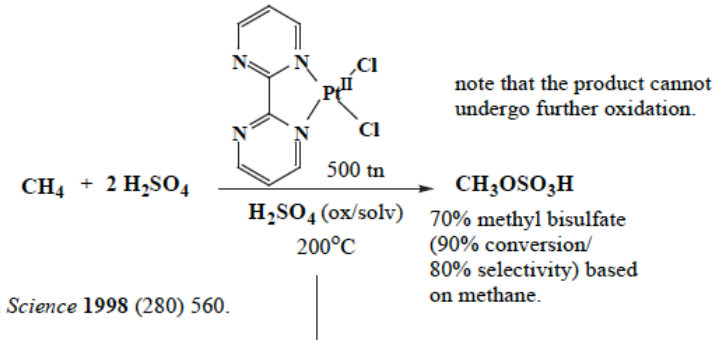
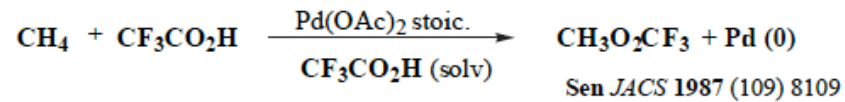
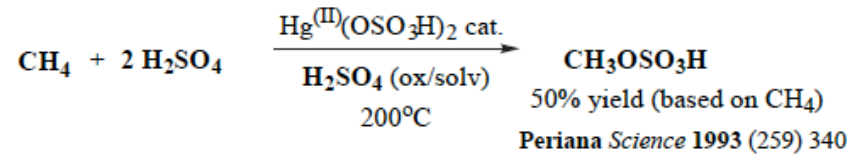
Procédé actuel:

Current industrial process consumes significant amounts of energy:

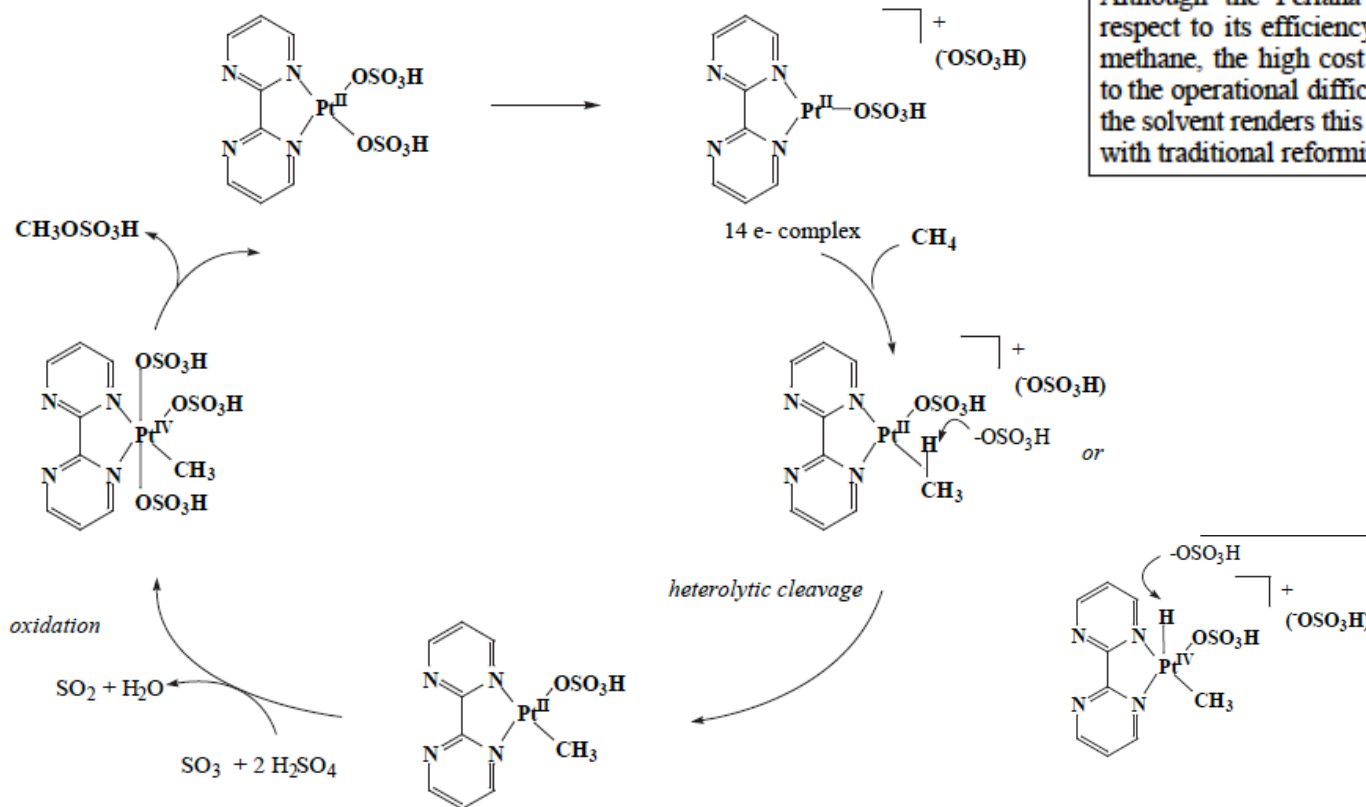


Comment améliorer le système ?

Oxydation des alcanes



Mécanisme proposé

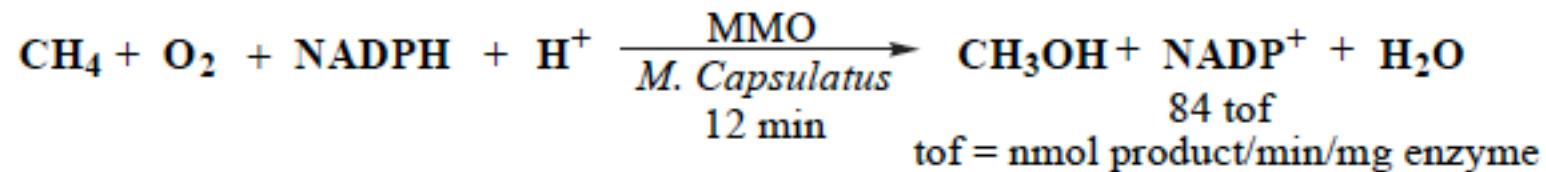


Oxydation des alcanes

En s'inspirant de la nature

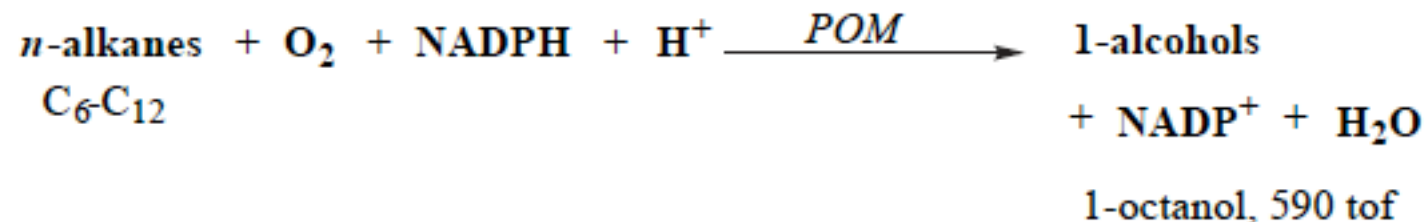
Methane Mono-Oxygenase (MMO):

MMO oxidizes methane to methanol with 100% chemoselectivity (no overoxidized product results).



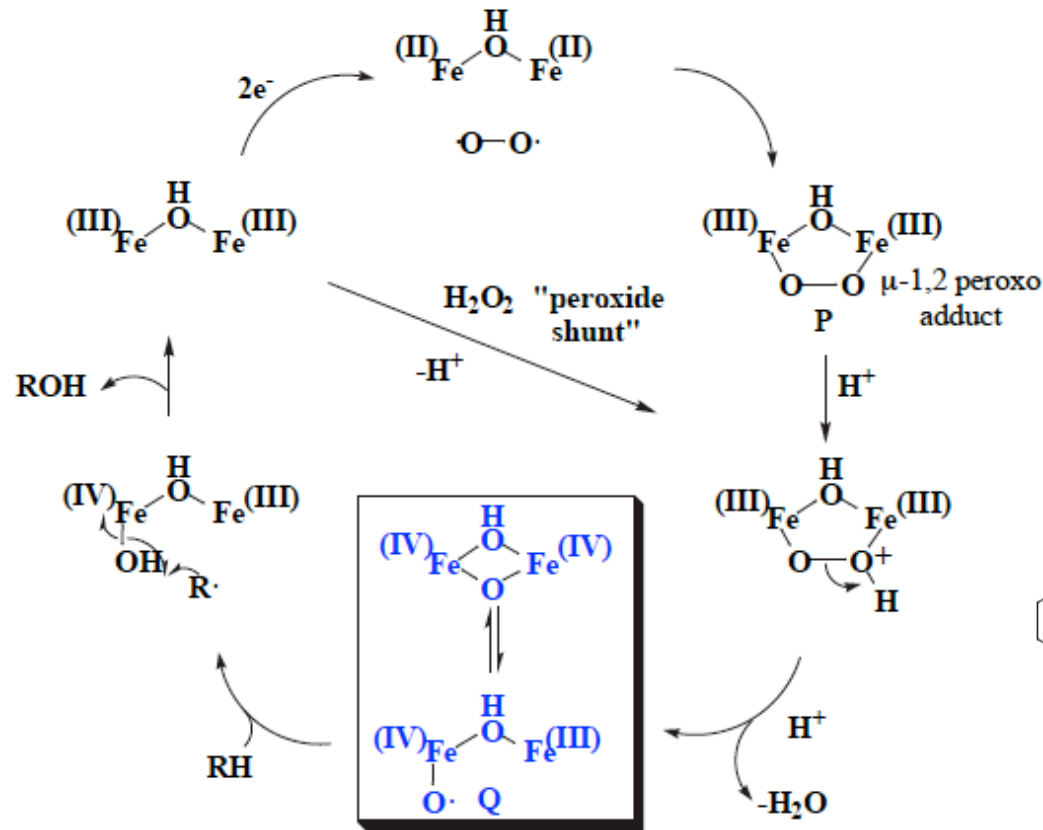
Pseudomonas Oleovorans Mono-Oxygenase (POM):

Oxidizes linear alkanes with 100% regio- and chemoselectivity



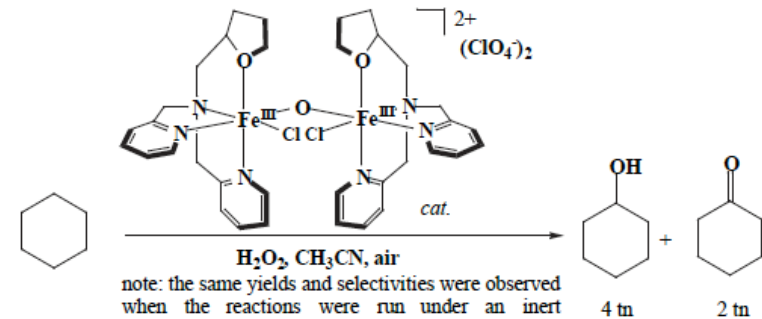
Oxydation des alcanes

Mécanisme proposé d'oxydation catalysé la méthane monooxygénase



The second iron in MMO transiently stabilizes intermediate Q by supplying an e^- to fill the oxygen atom's octet. This avoids energetically unfavorable $\text{Fe}(\text{V})$ intermediates.

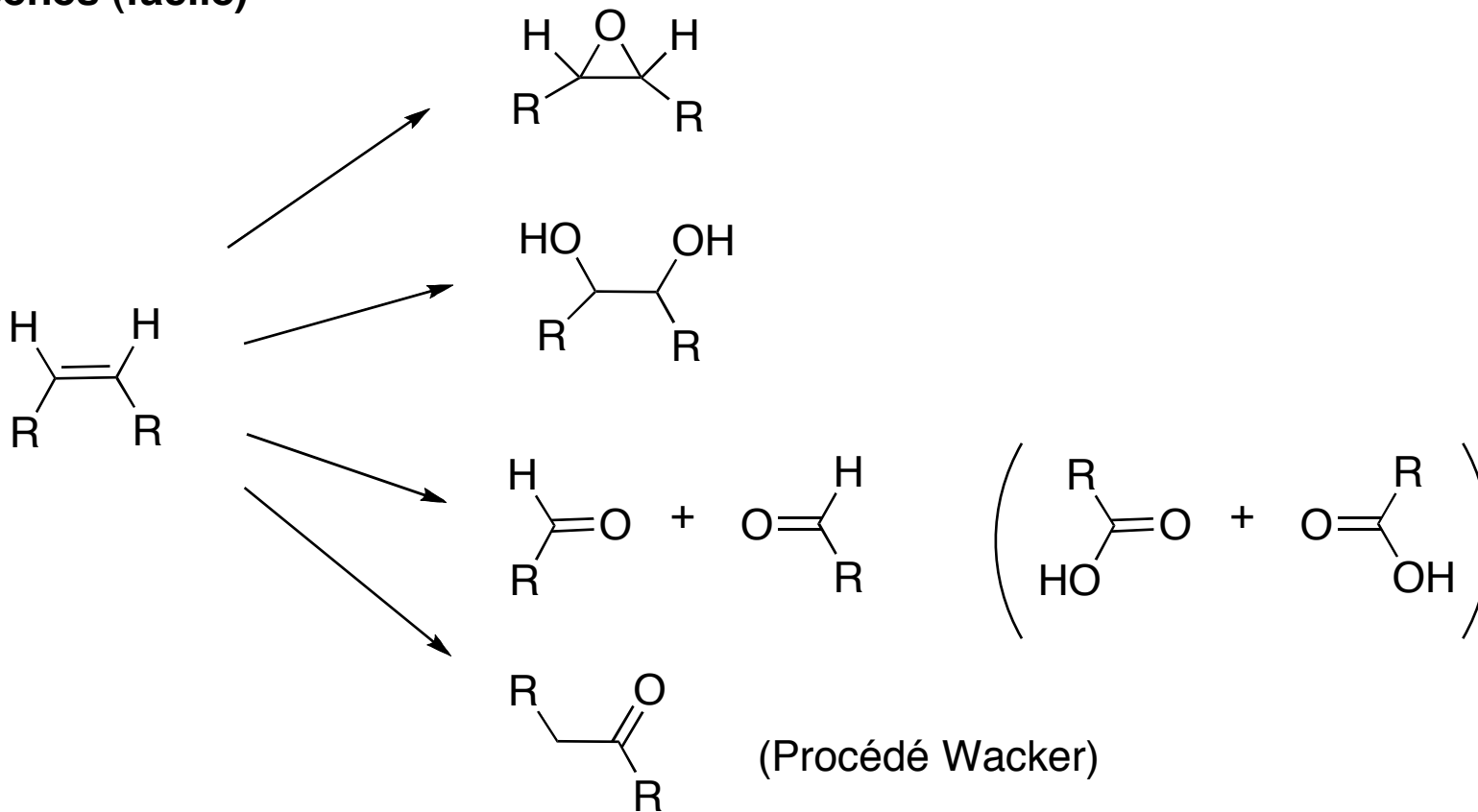
Exemple de catalyseur synthétique



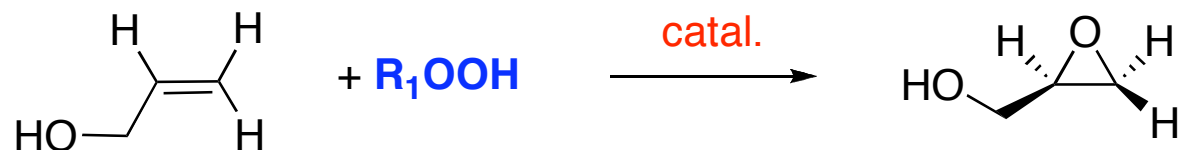
note: the same yields and selectivities were observed when the reactions were run under an inert atmosphere (Ar) or in air. This indicates that free radicals, propagated with O_2 , are not acting as the oxidant. Nishida *Chem. Lett.* 1995 885.

Oxydation des alcènes

Alcènes (facile)



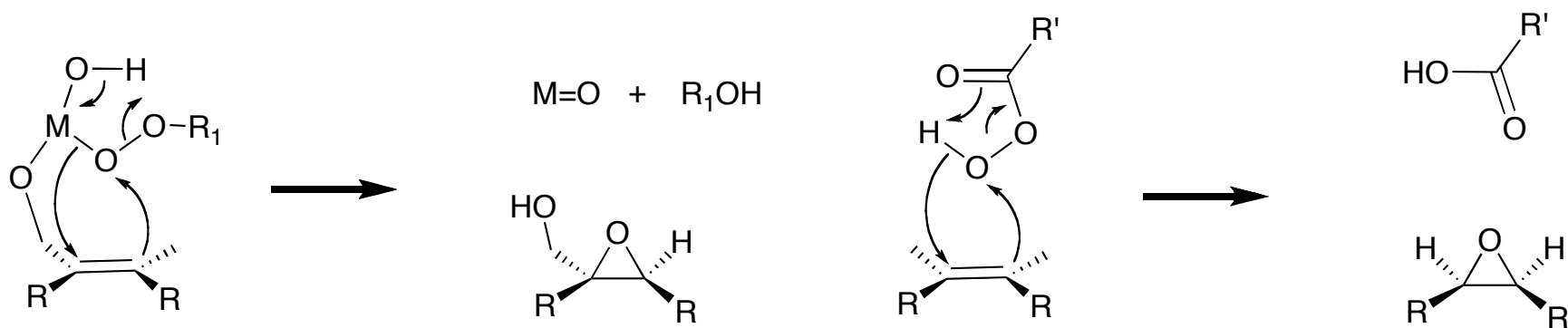
Epoxydation des oléfines allyliques



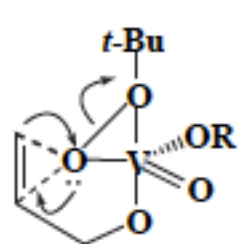
$R_1 = R'CO$ (peracide), **alkyle (hydroperoxyde, ex t-BuOOH)**, H (eau oxygéné)

Catalyseur : complexes d⁰, métal oxophile acide de Lewis dur
ex: $Ti(OR)_4$, V_2O_5

Analogie avec le mécanisme d'époxydation des alcènes par les peracides

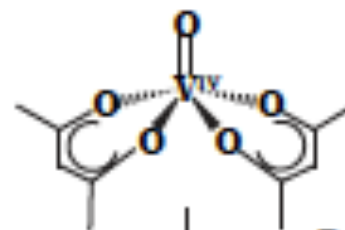
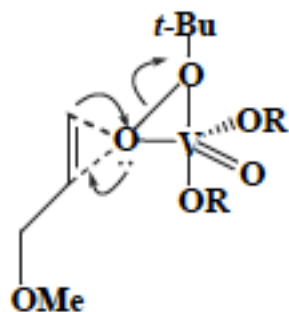


Epoxydation des oléfines allyliques

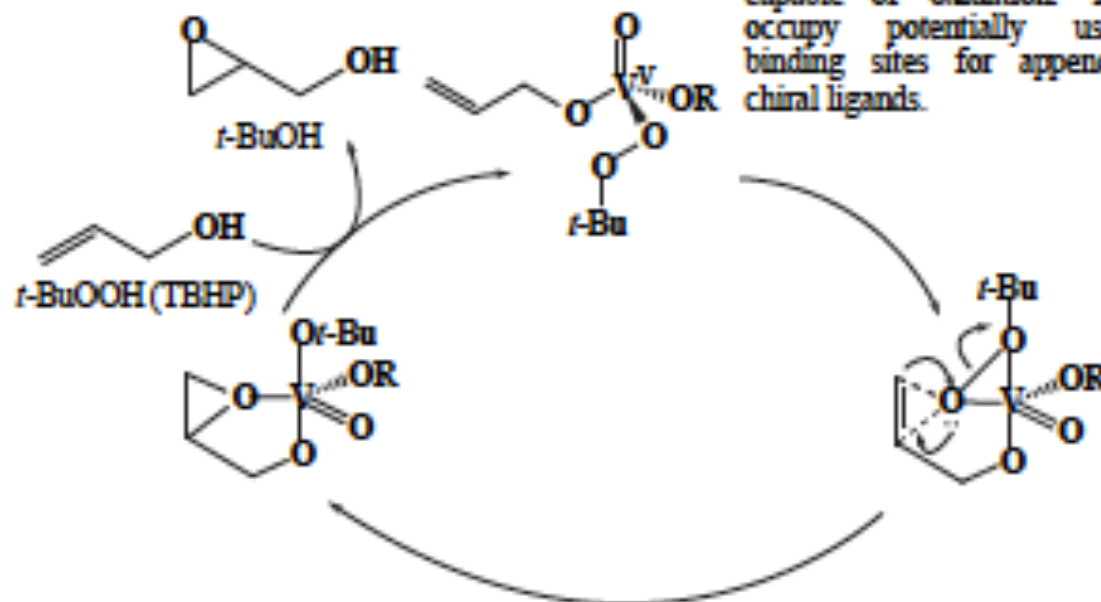


1000 x faster

vs.



Bystander oxo ligands are present in many early d^0 metals capable of oxidation. They occupy potentially useful binding sites for appending chiral ligands.



Sharpless *Alchimica Acta* 1979 (12), 63.

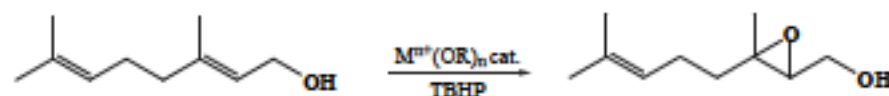
Epoxydation des oléfines allyliques

The Sharpless epoxidation

For all metals capable of effecting catalytic epoxidation of allylic alcohols with TBHP, only Ti displayed ligand accelerated catalysis. All other systems were strongly inhibited or entirely deactivated with added tartrate ligand.

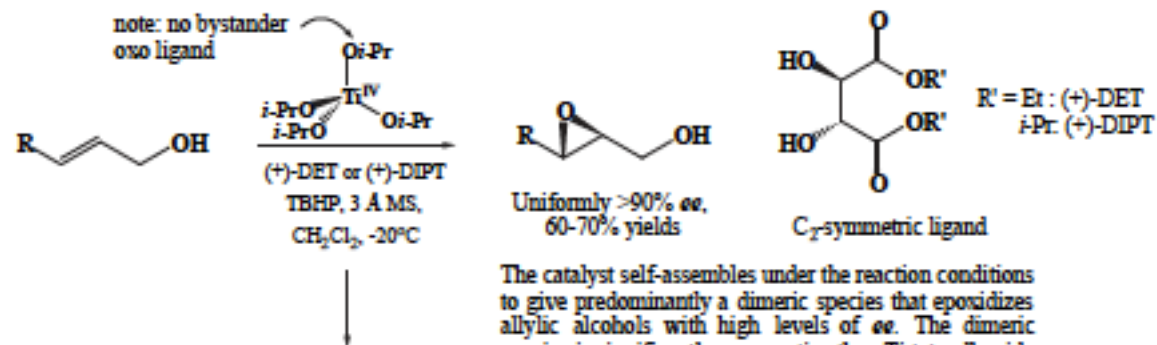
Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn				
Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd				
La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg				
Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lw

Sharpless *ACIEE* 2002 (41) 2024.



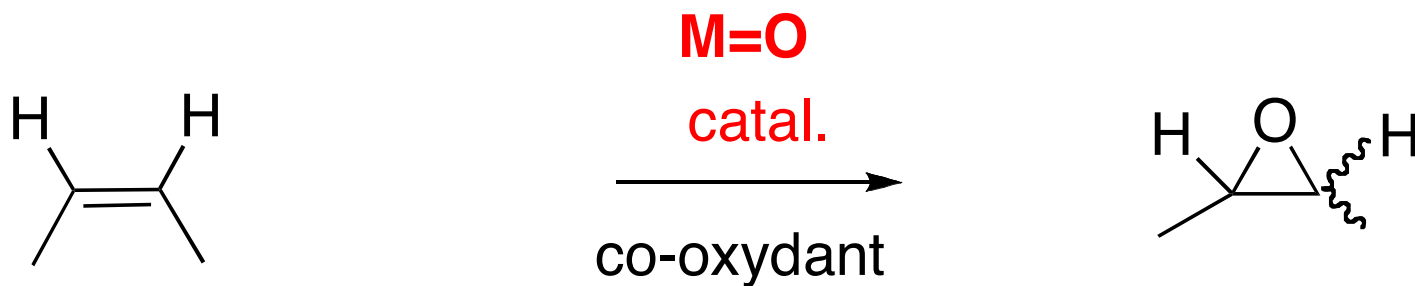
Synthèse asymétrique

Mechanism

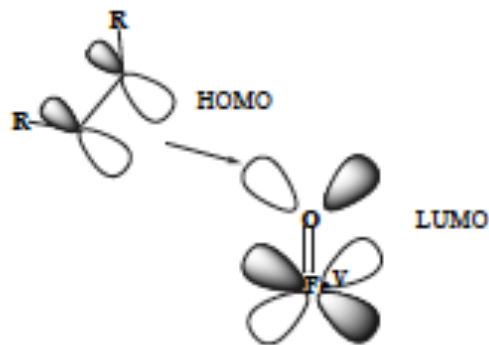


The catalyst self-assembles under the reaction conditions to give predominantly a dimeric species that epoxidizes allylic alcohols with high levels of ee. The dimeric species is significantly more active than Ti tetraalkoxide alone or Ti-tartrates of other than 1:1 stoichiometry which lead to zero or low ee products (respectively).

Epoxydation des oléfines

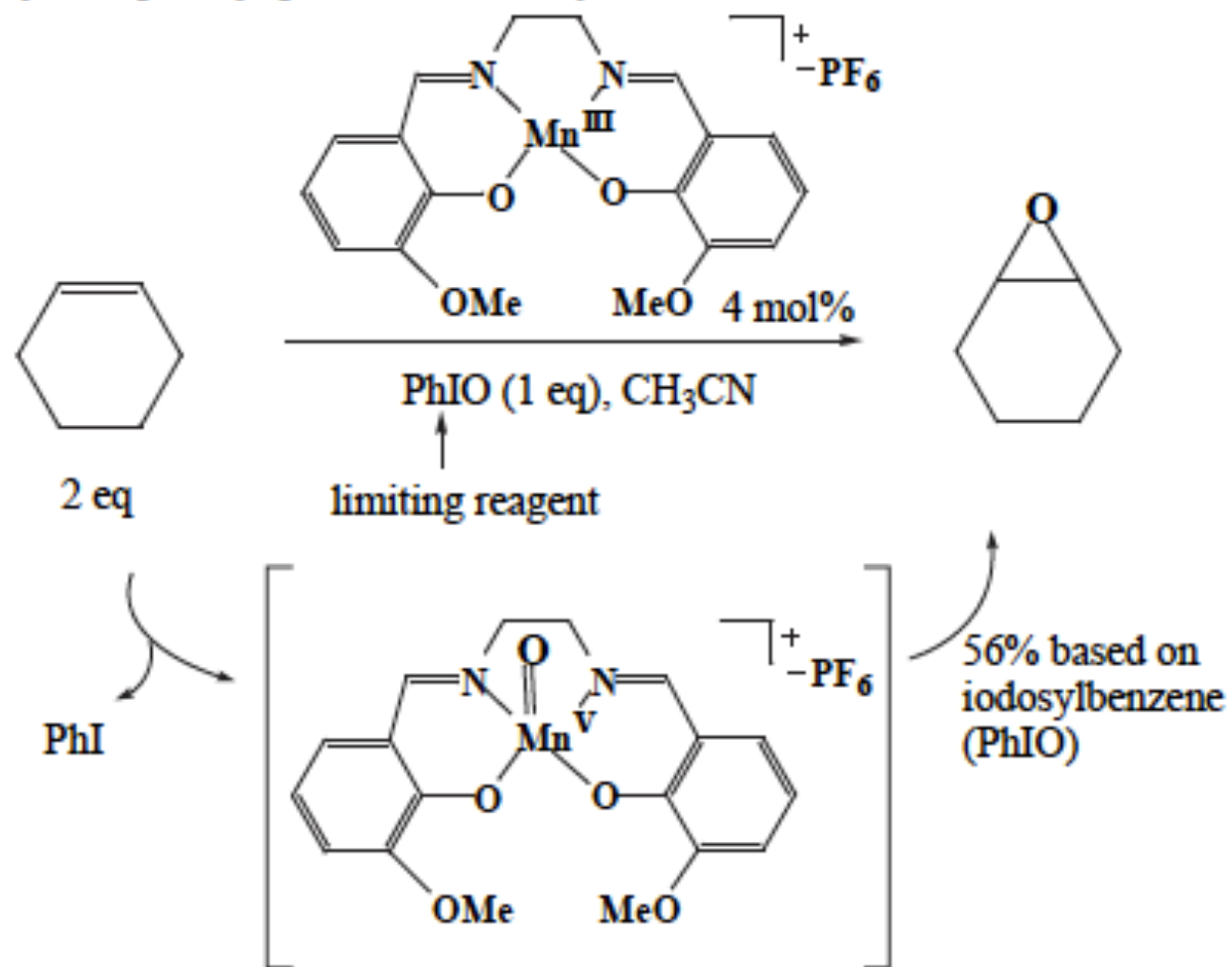


Catalyseur : métal haut degré d'oxydation, Fe, Mn, Os



Epoxydation des oléfines Jacobsen

The first report of epoxidation activity:

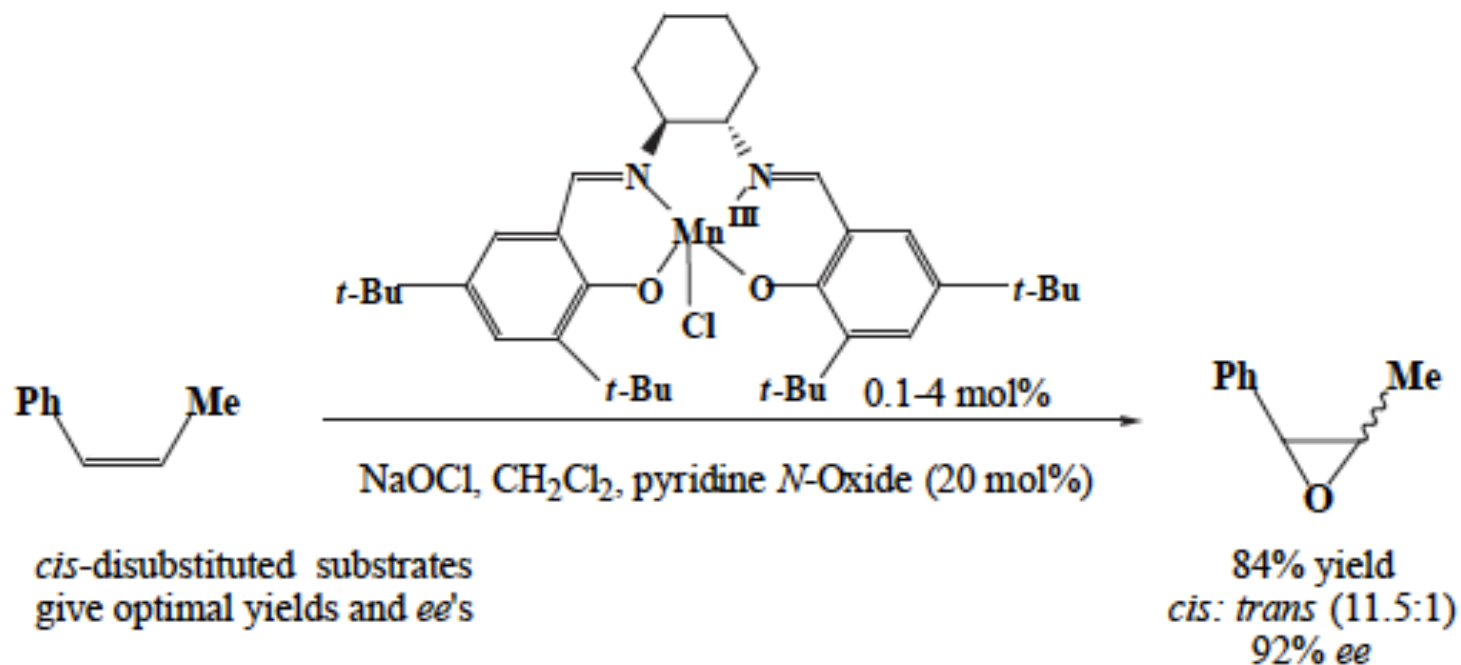


Kochi *JACS* 1986 (108) 2309.

Epoxydation des oléfines Jacobsen

Application en synthèse asymétrique (difficulté isomérisation cis-trans- mécanisme radicalaire!)

The Jacobsen epoxidation



Jacobsen *JACS* 1990 (112) 2801.

Jacobsen *JACS* 1991 (113) 6703.

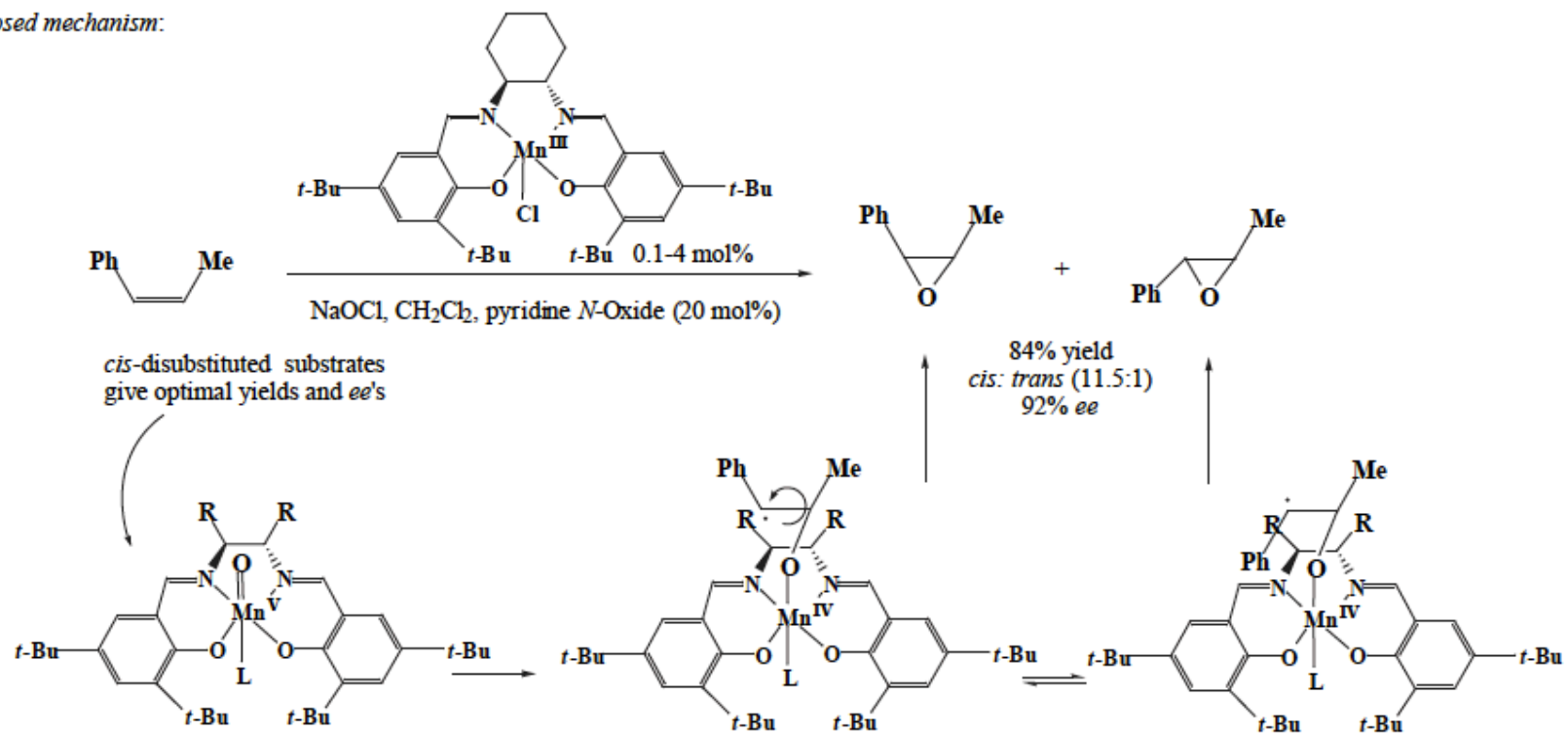
Jacobsen *JOC* 1991 (56) 2296.

Jacobsen *TL* 1996 (37) 3271.

Epoxydation des oléfines Jacobsen

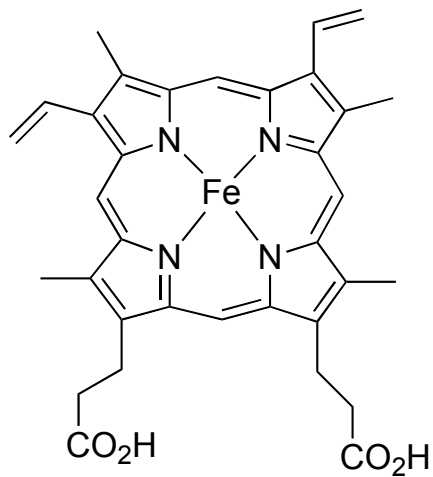
Mechanism

Proposed mechanism:

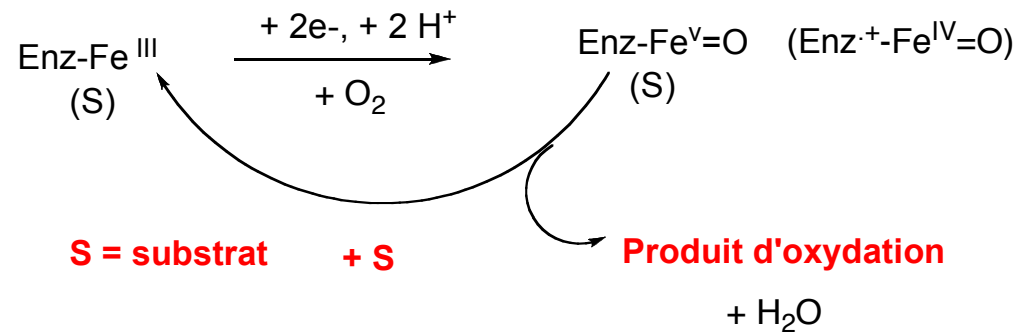


Epoxydation des oléfines

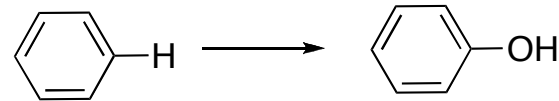
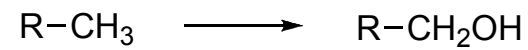
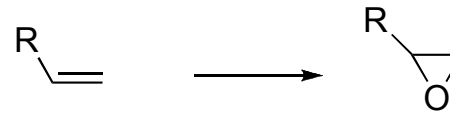
En s'inspirant de la nature: monooxygénase à CP450



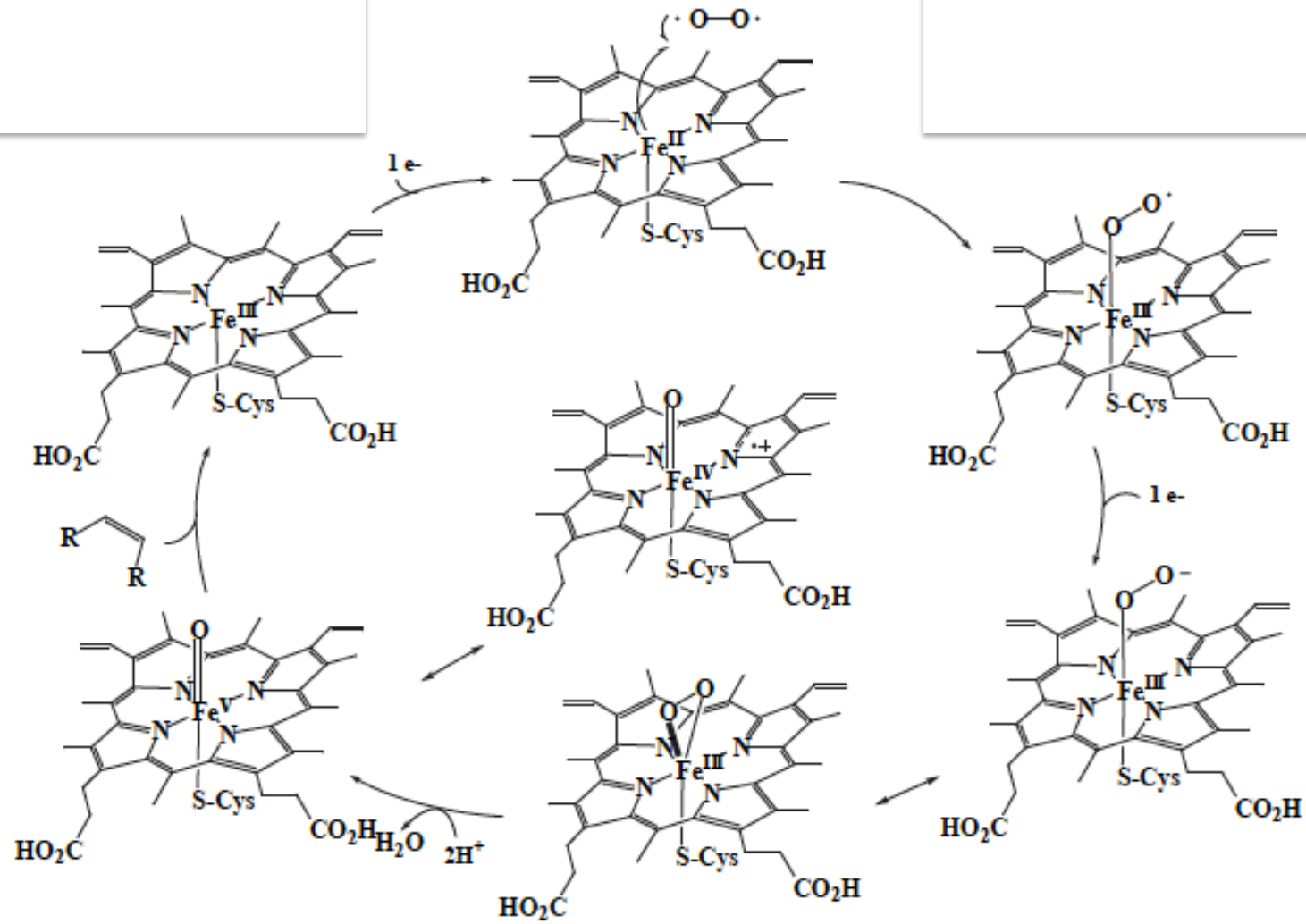
Cytochrome P-450



Exemples :

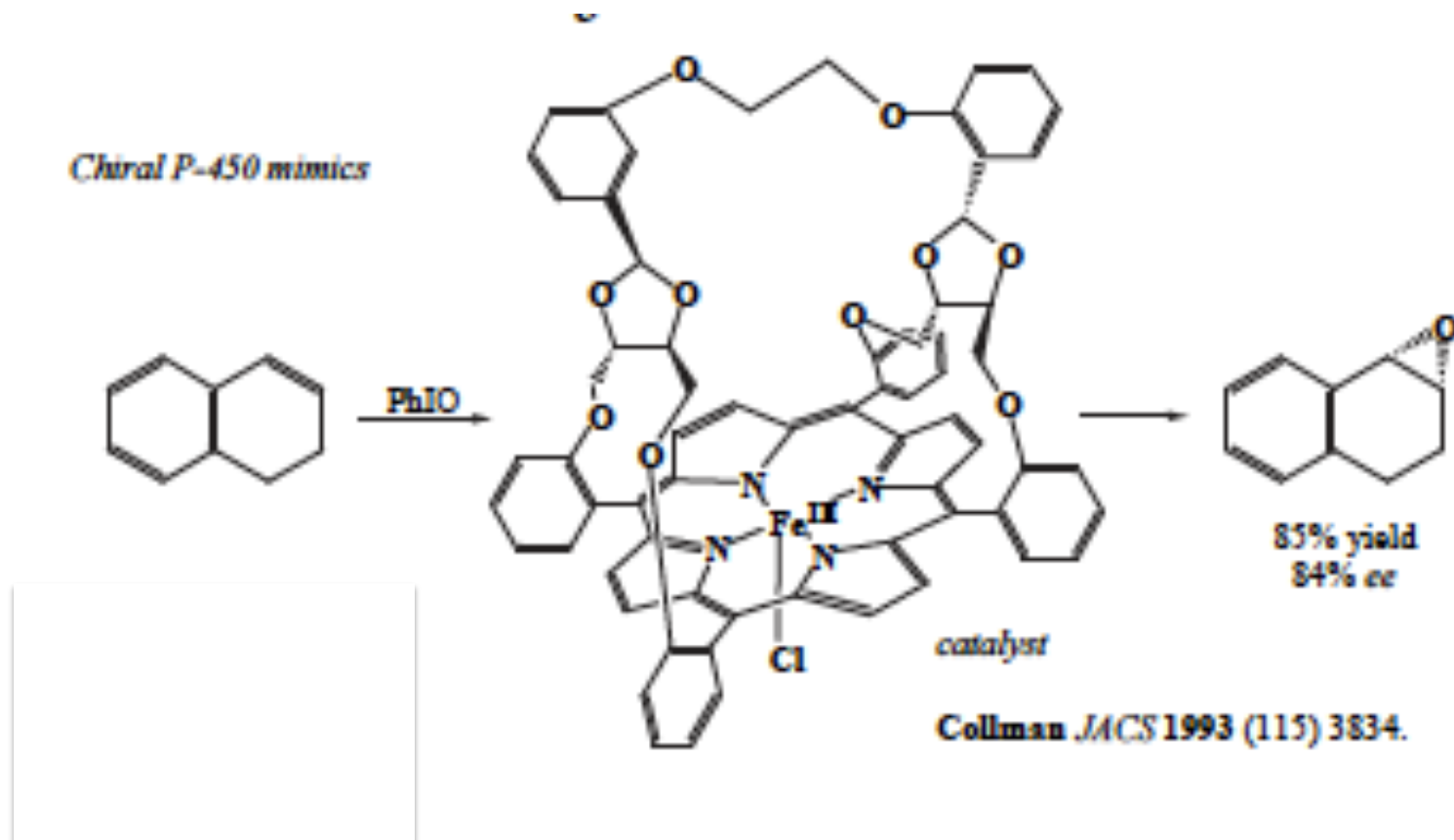


Cycle catalytique : monooxygénase à CP450

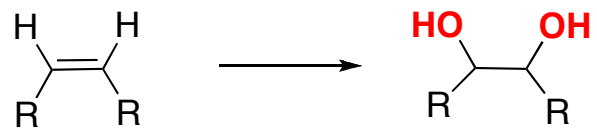


Epoxydation des oléfines

En s'inspirant de la nature : monooxygénase à cytochrome P450

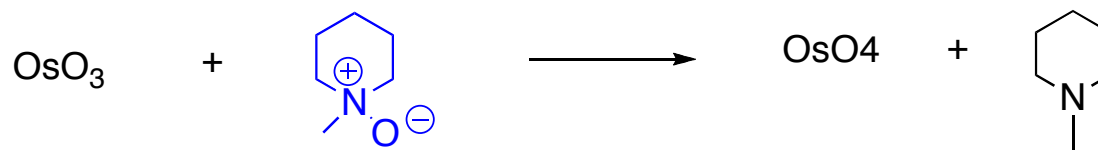
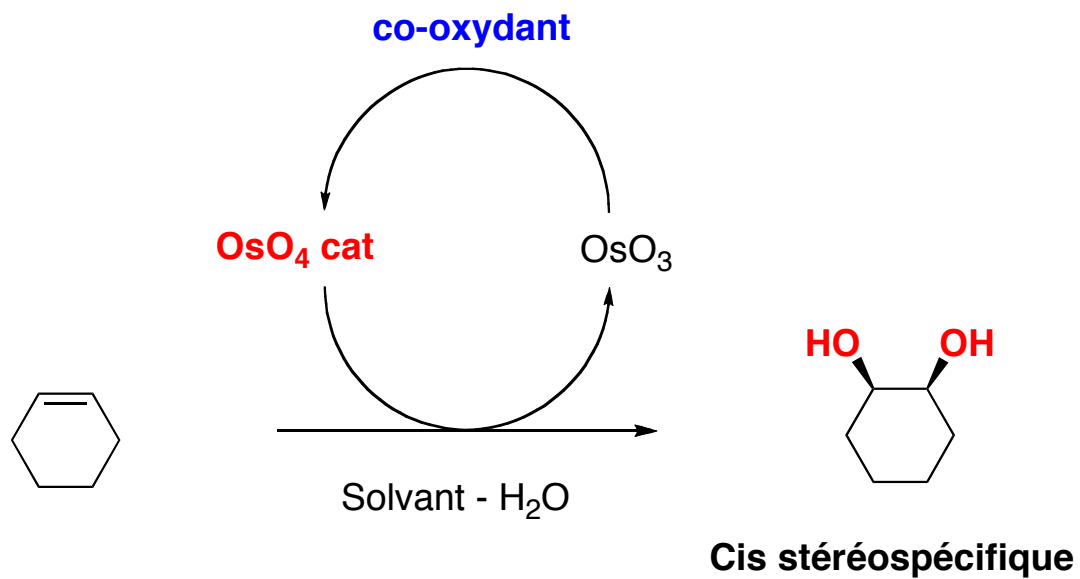


Dihydroxylation des alcènes



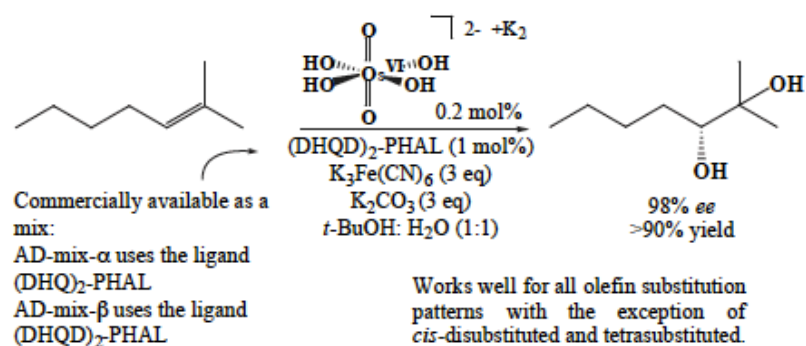
Oxydant : KMnO_4 , OsO_4

Exemple



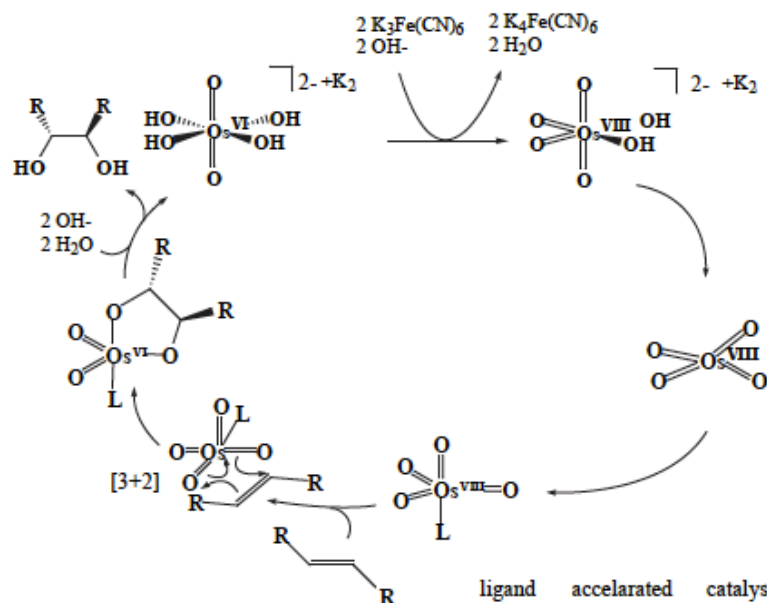
co-oxydant: ex. NMO

Cis dihydroxylation de Sharpless (synthèse asymétrique)



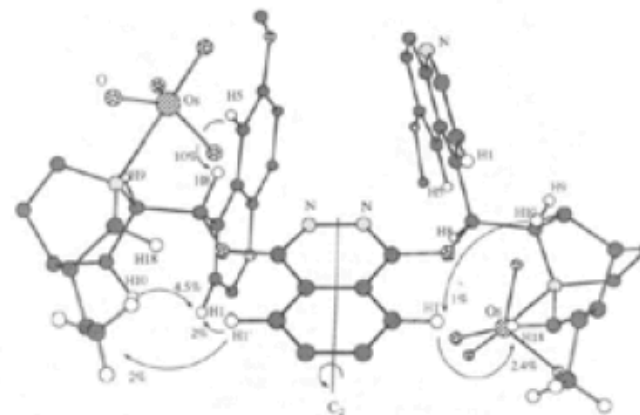
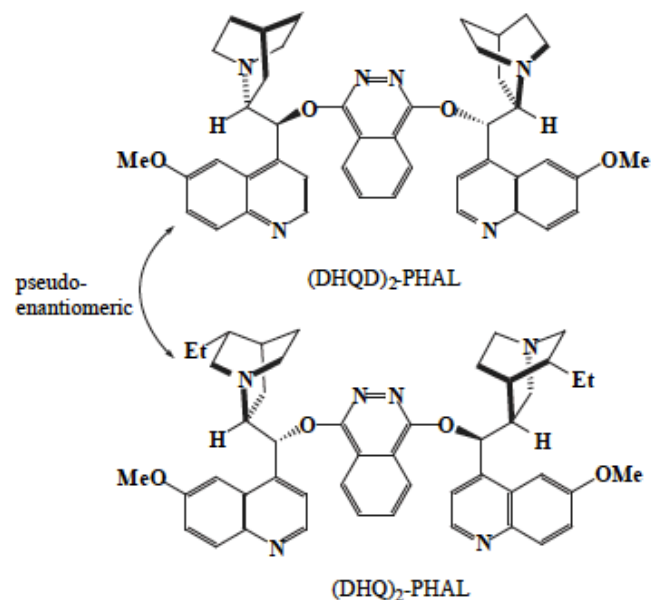
Sharpless *JOC* 1992 (57) 2768.

General mechanism: Sharpless *Chem. Rev.* 1994 (94) 2483.



Evidence favors the [3+2] mechanism vs. [2+2]:
 Corey *TL* 1996 (28) 4899.
 Houk, Sharpless, Singleton *JACS* 1997 (119) 9907.

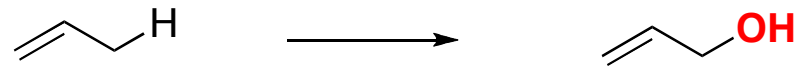
ligand accelerated catalysis: although OsO₄ is capable of dihydroxylating olefins, the ligand bound complex does so at a much greater rate.



The enzyme-like binding cleft is especially well suited for π -stacking with aromatic substrates. Large rate accelerations are observed for aromatic substrates with the phalazine class of ligands.

Corey *JACS* 1993 (115) 2861, 12579.
 Sharpless *JACS* 1994 (116) 1278.

Oxydation allylique



**Oxydant: oxyde métallique, insertion
liaison C-H, activation radicalaire**

Ex : SeO₂

