

# Chapter 10. Concerted Pericyclic Reactions

- Continuous reorganization of electrons via **cyclic TS**
  - ◆ cycloaddition, electrocyclic reactions, sigmatropic rearrang.
- Cycloaddition reactions: [📖 834-5](#)
  - ◆ [2+2] & [2+4] (Diels-Alder & 1,3-dipolar cycloaddition)
  - ◆ Woodward-Hoffmann rules: orbital symmetry rules
    - based on the FMO theory; [📖 837 top Table](#) & [📖 836 middle](#)
    - Möbius system: supra-antarafacial interaction; [📖 836 bottom](#)
    - the selection rules based on aromaticity of TS: [📖 837 middle](#)
    - orbital correlation diagrams: plane of symmetry; [📖 837](#) & [838](#)

# Diels-Alder [D-A] Reactions (I)

- $[4\pi_s+2\pi_s]$  cycloaddition: *s-cis* diene + dienophile
  - ◆ stereospecific syn (cis) addition: [📖 839 middle](#)
  - ◆ asynchronous process: unsymmetrical alkenes; [📖 840 top](#)
    - ionic intermediates: opposite electronic substituents; [📖 840 mid](#)
  - ◆ endo addition: Alder rule, modest selectivity; [📖 841](#)
    - favored by electronic but disfavored by steric effects; [📖 841 mid](#)
  - ◆ steric vs electronic effects with dienes: [📖 842](#)
    - C-1: Me [increased by e<sup>-</sup>-releasing] vs t-Bu [decreased by steric]
    - butadiene: small diMe at C-2/3 [increase] vs large di-t-Bu [no reaction]

# Diels-Alder [D-A] Reactions (II)

## □ Substituent effects: electronic vs steric

- ◆ reactivity of dienes & dienophiles: [845](#) & [843](#) (844 Sch. 10.2)
  - normal e<sup>-</sup> demand: diene-ERG & dienophile-EWG; [846 Fig. 10.4](#)
  - HOMO of diene (Nu) & LUMO of dienophile (E<sup>+</sup>): [846 Fig. 10.6](#)
  - inverse e<sup>-</sup> demand: diene-EWG & dienophile-ERG; [846 Fig. 10.4](#)
- ◆ regioselectivity: orbital coefficients of FMOs; [847 Fig. 10.5](#)
  - favored bonding between the atoms with larger coefficients
  - typical regioselectivity: [a resonance](#); [846 Scheme 10.3](#)
  - contrary regioselectivity to the resonance consideration: [848 top](#)
  - exceptions with 2-substituted diene: [848 middle](#)









# Diels-Alder [D-A] Reactions (III)

- Acid catalysis: Lewis acids; [lowering energy of LUMO](#)
  - ◆ increased reactivity & selectivity (orbital distortion): [849](#)
    - inverse electron demand: LUMO of the diene; [850 top](#)
  - ◆ metal cation effect: stepwise mechanism; [850 middle](#)
    - rate increase in polar solvents: enforced hydrophobic interaction & possible H-bonding lowering the LUMO of the dienophile
- Scope and applications: [861 Scheme 10.4 A & B](#)
  - ◆ useful dienophiles: benzoquinones; [862 top](#)
    - ketene equivalents: [862](#); ethylene equivalent: [863](#); acetylene equivalents: [863](#); allene equivalent: [863](#)
  - ◆ useful dienes: Danishefsky's diene & others; [864](#)








# Diels-Alder [D-A] Reactions (IV)

- Enantioselective D-A: how to make chiral environment
  - ◆ chiral auxiliaries: stoichiometric & acid-catalyzed; [📖 865](#)
    - pantolactone: 92% *si* with / 64% *re* without  $\text{TiCl}_4$ ; [📖 866 top](#)
    - oxazolidinone: with Lewis acids; [📖 866 bottom](#)
  - ◆ chiral catalysts: a chiral ligand with a metal cation/a boron atom
    - bis-oxazoline with  $\text{Cu}^{2+}$ : *re* attack; [📖 867 & 868 Fig. 10.11](#)
    - oxazaborolidine: *exo* selectivity; [📖 868 middle](#)
- Intramolecular D-A: length of a tether; [📖 869 bottom](#)
  - ◆ conformations of a tether: Lewis acid; [📖 869 top & 871 top](#)
  - ◆ bridged bicyclics: [📖 871-2 & 📖 873 Scheme 10.5](#)







# 1,3-Dipolar Cycloaddition Reactions (I)

- $[4\pi_s+2\pi_s]$  cycloaddition: 1,3-dipole+dipolarophile;  [874](#)
- ◆ rates of 1,3-dipoles: various dipolarophiles;  [876 Table 10.3](#)
  - relative reactivity of diazo 1,3-dipoles: ambiphilic;  [877 Table 10.4](#)
  - reactivity of aryl azides:  $\rho > 0$  (nucleophilic alkenes) vs  $\rho < 0$  (electrophilic alkenes) ;  [878 Fig. 10.13](#)
- ◆ syn addition: stereospecific with dipolarophiles;  [878 bottom](#)
  - a mixture of endo vs exo isomers:  [879 top](#)
- ◆ regioselectivity: FMO analysis & orbital coeff.;  [882 Fig. 10.16](#)
  - some exceptions with dominant steric over electronic control
  - Computational results match the FMO analysis:  [882 Fig. 10.17](#)

# 1,3-Dipolar Cycloaddition Reactions (II)

- Applications: inter-/intramolecular;  [885](#) [Scheme 10.7](#)
- ◆ pyrazolines: intermediates for cyclopropane;  [884 top](#)
- ◆ introduction of heteroatoms: nitrones;  [884 middle](#)
- ◆ generation of 1,3-dipoles from aziridines:  [885 bottom](#)
- ◆ catalysis: enhancing the reactivity of the electrophilic reactant
  - electronically controlled: complexation to alkene;  [886 bottom](#)
  - competitive binding to 1,3-dipole by Lewis acids:  [887](#) [Fig. 10.18](#)
    - increased selectivity for '*ortho*' and *exo* TS
- ◆ enantioselective catalysis: activation of dipolarophiles;  [888](#)

# [2+2] Cycloaddition Reactions









- $[2\pi_a+2\pi_s]/ [2\pi_s+(2\pi_s+2\pi_s)]$ : concerted;  889 [Fig. 10.19](#)
  - ◆ *cis*-2,3-disubstituted butanones: stereo-/regio-;  [890 top](#)
    - [asynchronous bonding](#): trans<cis<cyclic<acyclic diene<cyclic diene
    - acid chloride & R<sub>3</sub>N: intramolecular reaction;  [891 top](#)
    - Staudinger ketene cycloaddition: stepwise;  [892 top](#)
  - ◆ non-concerted alkene/alkene addition: zwitterionic;  [891 mid](#)
    - stereochemistry: non-specific in polar solvents
  - ◆ ketene dimerization: facile;  [890 bottom](#)



# Electrocyclic Reactions (ER) (I)

- Stereospecific reversible reaction: [📖 892 & 894](#)
  - ◆ FMO analysis: HOMO of polyenes; [📖 894-5 Fig. 10.21 & 10.22](#)
    - allowed process: butadiene-conrotatory vs hexatriene-disrotatory
  - ◆ orbital correlation diagram: [symmetry](#); [📖 896-7 Fig. 10.23 & 24](#)
    - plane of symmetry-disrotation vs axis of symmetry-conrotation
  - ◆ aromaticity of TS: basis set orbitals of polyenes; [📖 898 & 899](#)
    - Hückel system -  $4n+2$  vs Möbius system -  $4n$
  - ◆ orbital symmetry rules: the same as in D-A; [📖 900 middle](#)
    - energy relationships of ER of some polyenes: [📖 901 Fig. 10.27](#)
  - ◆ rotation of substituents: inward vs outward; [📖 901 & 902](#)
    - ERG-outward vs EWG-inward: catalysis; [📖 902 middle](#)











# Electrocyclic Reactions (ER) (II)

- Applications: ring opening/closing;  [906 Sch. 10.8](#)
  - ◆ [ring opening](#): stereospecific formation of alkenes
  - ◆ [ring closing](#): stereospecific introduction of substituents
  - ◆ Dewar benzene: preparations;  [903 bottom](#) & [904 top](#)
    - high energy barrier for conrotatory opening:  [904 middle](#)
    - stable cyclobutenes:  [893 top & middle](#)
- ER of ions: observing the orbital symmetry rules
  - ◆ cyclopropyl cations: disrotation to allyl cations;  [907](#)
    - rate-limiting concerted ring opening & ionization:  [907](#) & [908](#)
  - ◆ pentadienyl cations: conrotation; Nazarov reaction,  [909](#)
    - pentadienyl & heptatrienyl anions:  [910 top](#)







# [1,n]-Sigmatropic Rearrangements

- Migration of a  $\sigma$  bond along a  $\pi$ -system: [📖 913 Sch. 10.9](#)
  - ◆ suprafacial vs antarafacial migration:  $[\sigma,\pi]$ -; [📖 912 top](#)
  - ◆ generalized orbital symmetry rules: [📖 912 middle](#)
- [1,3]-/[1,5]-/[1,7]-hydride & alkyl shifts
  - ◆ aromaticity of TS: basis set orbitals; [📖 914-5 Fig. 10.31 & 10.32](#)
    - 1,3-hydride shift: antarafacially allowed but too strained; [📖 912 bot](#)
  - ◆  $E_a = 27-42$  kcal/mole: [📖 917](#)
    - facile [1,7]-H shift: 20.2 & 19.2 (antarafacial); [📖 918 & 919](#)
    - comparison of  $E_a$  [1,3]-/[1,5]-/[1,7]-H shifts: [📖 919 Fig. 10.36](#)

# [3,3]-Sigmatropic Rearrangements

- [3,3]-sigmatropic rearrangements:  921 [Scheme 10.10](#)
  - ◆ Hückel system,  $6 \pi e^-$ : supra & retention, chair/boat;  [920 top](#)
- Cope rearrangements: 1,5-dienes;  [920 bottom](#)
  - ◆ equilibrium control: toward more stable side;  [920 middle](#)
  - ◆ stereoselectivity: specific & selective (chair TS);  [922 middle](#)
    - chirality transfer: retention of the stereochemistry;  [922 bottom](#)
  - ◆ *cis*-divinylcyclopropane: rearrangement  $< -40 \text{ }^\circ\text{C}$ ;  [928 bottom](#)
    - high energy process for vinylcyclopropane:  [929 top](#)
    - degenerate rearrangement: [homotropilidine](#) (NMR) & [bullvalene](#)
  - ◆ substituent effects: [oxy-Cope](#) & [anionic oxy-Cope](#);  [931-2](#)
    - lowering  $E_a$  by  $e^-$ -donation & equilibrium toward to the carbonyl
- Claisen & other rearrangements: facile;  [933-7 & 938](#)

# [2,3]-Sigmatropic Rearrangements

- Neutral & anionic types:  [940](#) [Scheme 10.11](#)
- ◆ facile: good leaving group ( $X^+$ ) & anionic ( $Y^-$ );  [939 top](#)
- ◆ stereochemistry: *E*-alkenes via endo;  [941 middle](#)
  - Wittig rearrangement: cyclic TS;  [943 bottom](#)
- ◆ applications:  [941](#) &  [942](#)