7. Образование циклов

·Общие подходы к синтезу циклических молекул, понятие о циклизации и циклоприсоединении, способы сборки циклов

·Особенности реакций циклизации: правила Болдуина

·Трехчленные циклы: циклопропаны, азиридины, оксираны

·Четырехчленные циклы: циклобутаны, оксетаны

·Циклизации «анион-алкен/алкин», «радикал-алкен/алкин», «катион-алкен/алкин»

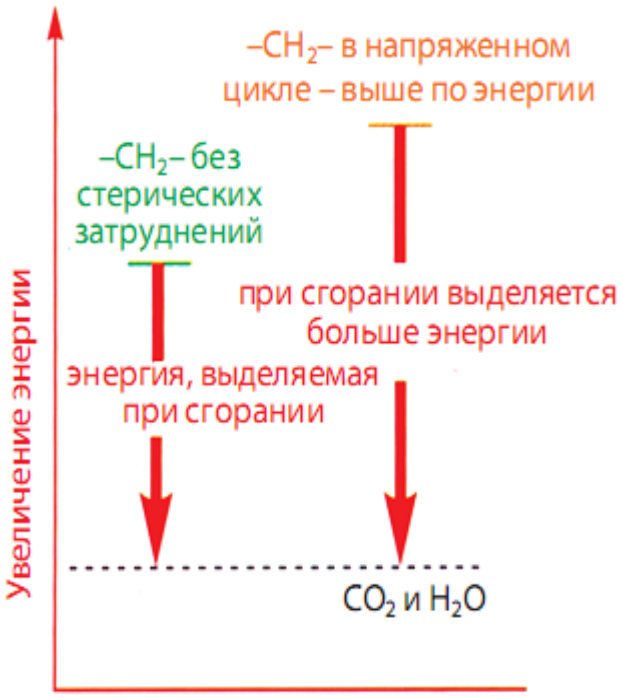
·Пятичленные циклы

·Шестичленные циклы

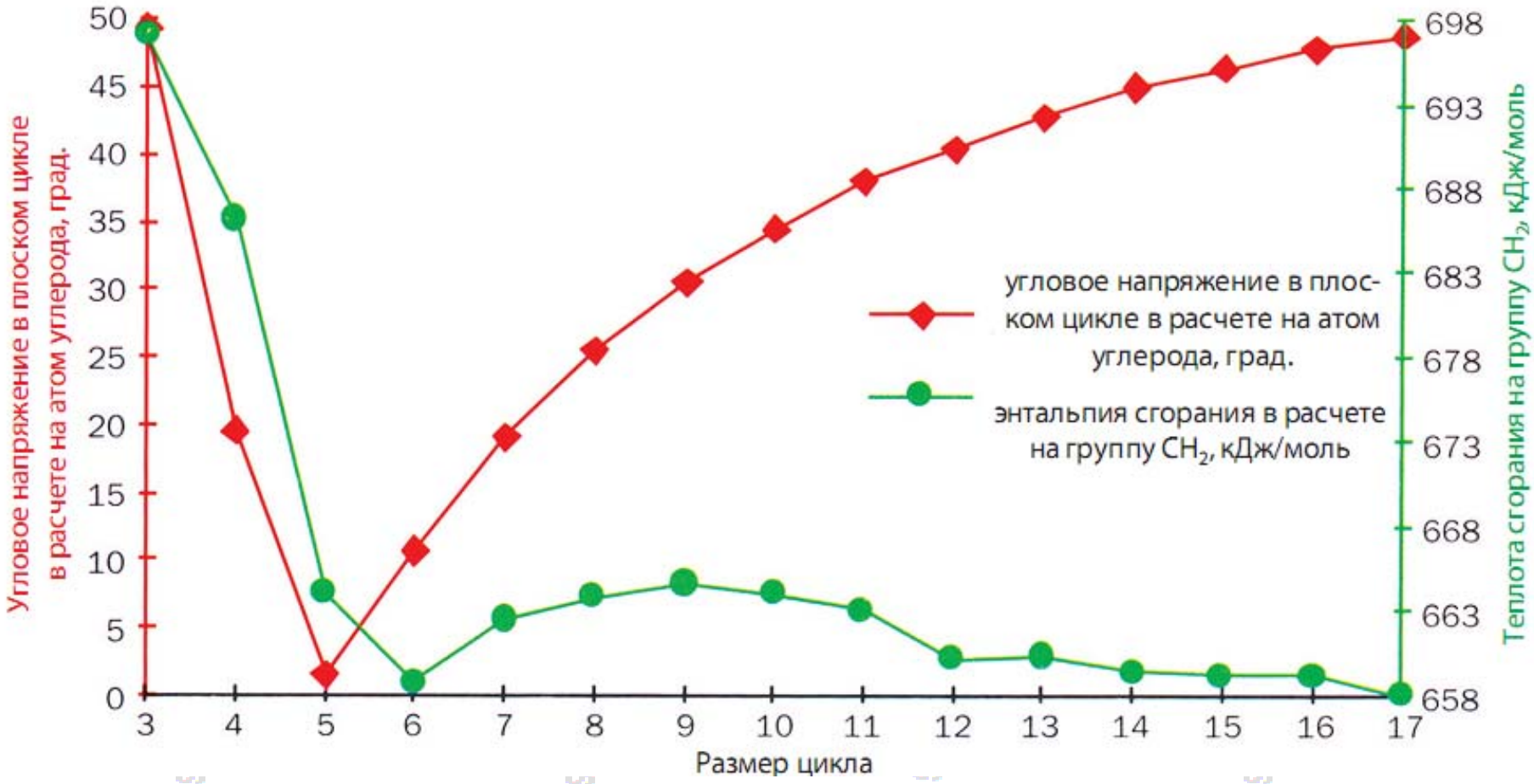
Общая энергия напряжения является суммой трех основных составляющих: углового напряжения, напряжения заслоненных, противостоящих С-Н связей и так называемого трансаннулярного напряжения. Угловое напряжение (синонимы напряжение углерод-углеродных связей или напряжение Байера) вызвано растяжением или сжатием валентных углов и отклонением их от тетраэдрического $109^{o}28'$. Напряжение заслоненных С-Н связей (синонимы торсионное напряжение или напряжение Питцера) по своей природе аналогично отталкиванию атомов водорода в заслоненной конформации этана и других предельных углеводородов для двух соседних заслоненных С-Н связей; энергии этого взаимодействия оценивается приблизительно в 1 ккал/моль. Трансаннулярное напряжение или напряжение Прелога обусловлено взаимодействием в пространстве двух или большего числа атомов водорода при атомах углерода на противоположных концах цикла. Его следует принимать во внимание, главным образом, для средних циклов C_8-C_{11}.

Таблица 18.2. Теплоты сгорания некоторых линейных алканов

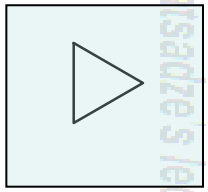
Линейный алкан	n в $CH_3(CH_2)_nCH_3$	$-\Delta H_{сгорания}$, кДж/моль
Этан	0	1560
Пропан	1	2220
Бутан	2	2877
Пентан	3	3536
Гексан	4	4194
Гептан	5	4853
Октан	6	5511
Нонан	7	6171
Декан	8	6829
Ундекан	9	7487
Додекан	10	8148



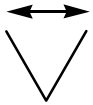
Образование циклов



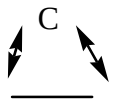
Напряжение по Питцеру и Прелогу



Циклизация

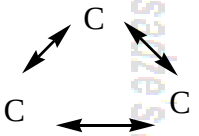


Циклоприсоединение

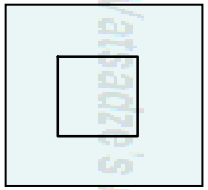


[1+2]

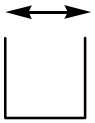
Циклоприсоединение



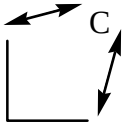
[1+1+1]



Циклизация

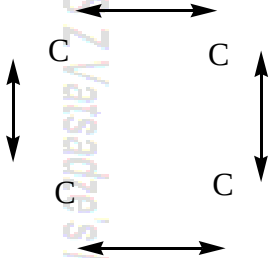


Циклоприсоединение



[1+3]

[2+2]



[1+1+1+1]

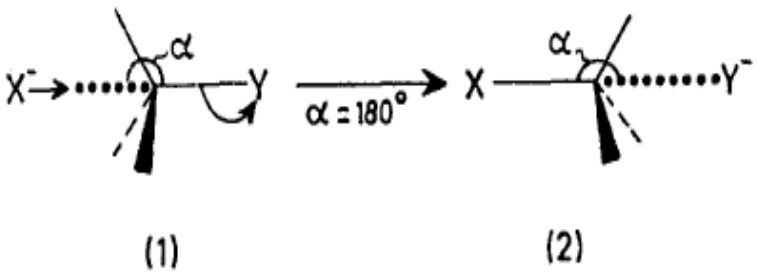


FIGURE 1: *Tet.*

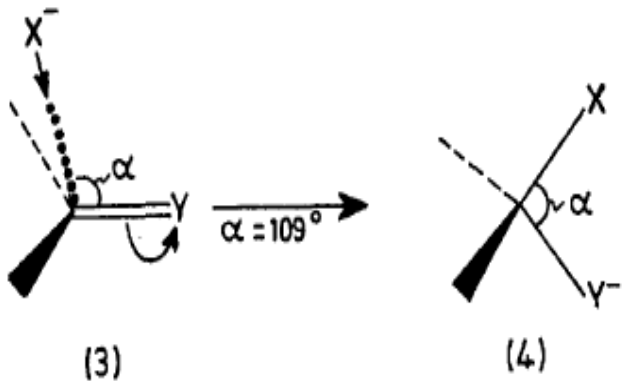


FIGURE 2: *Trig.*

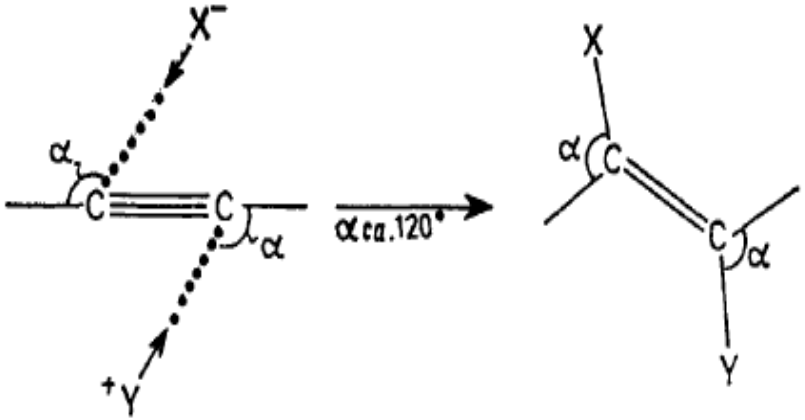
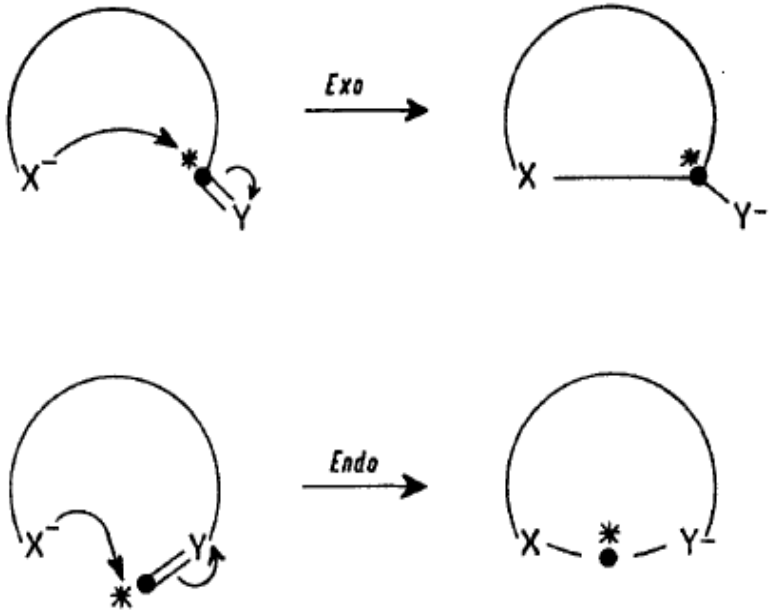


FIGURE 3: *Dig.*

- Правила Болдуина

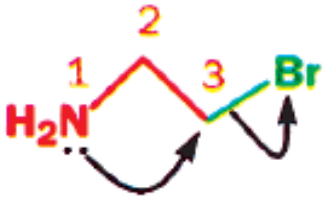
Образование циклов

RING-FORMING reactions are important and common processes in organic chemistry. I now adumbrate a set of simple rules which I have found useful in predicting the relative facility of different ring closures. I believe these

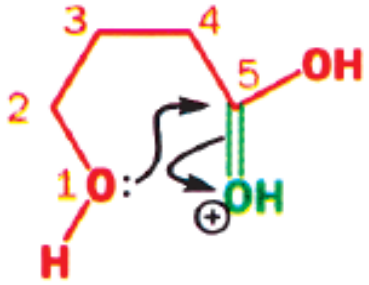


SCHEME 1

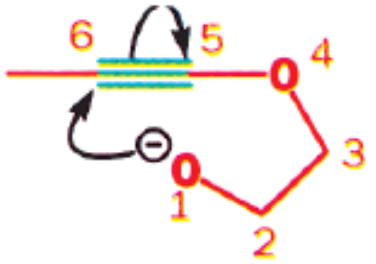
will be useful to organic chemists, especially in planning syntheses. Also these rules indicate certain experiments which may be helpful to define more precisely their limits. The rules are of a stereochemical nature and it is likely that unambiguous cases of all the possibilities I will discuss are as yet unknown.



3-экзо-тет

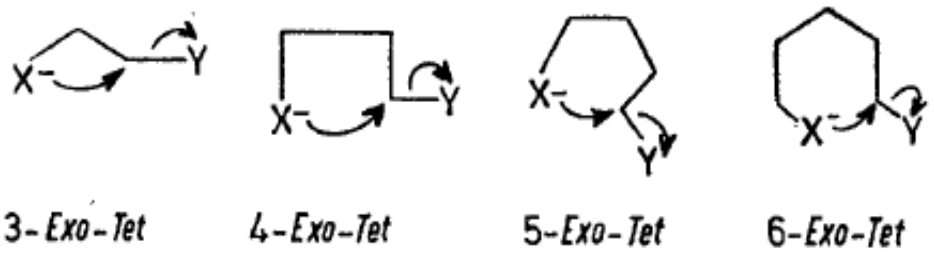


5-экзо-триг

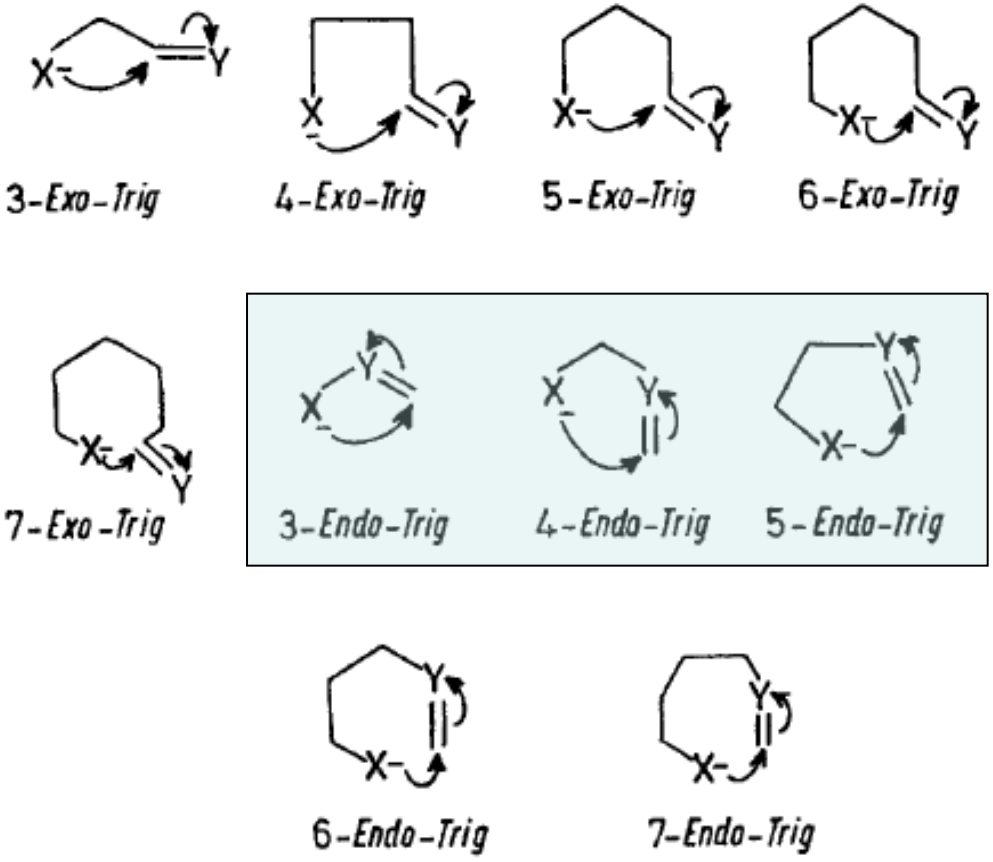


6-эндо-диг

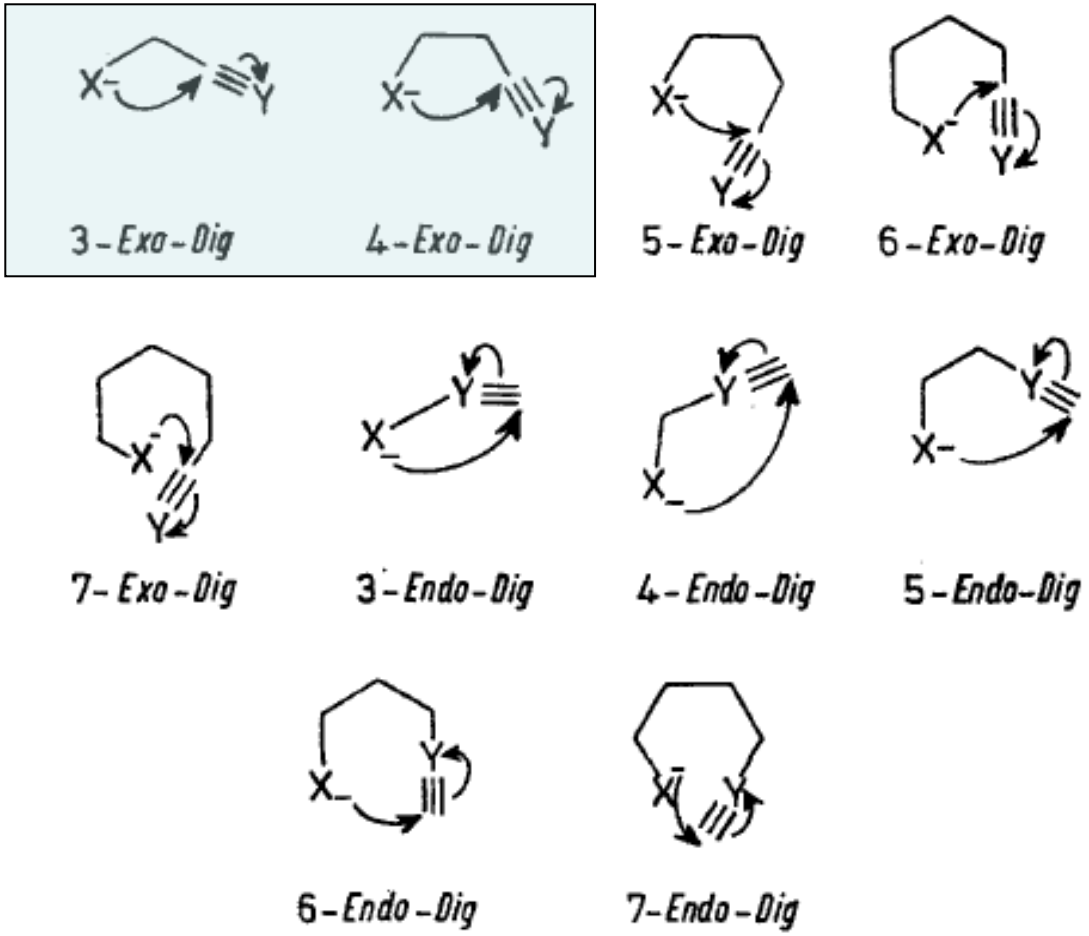
343 J.Chem.Soc., Chem.Comm., 1976, 734-736



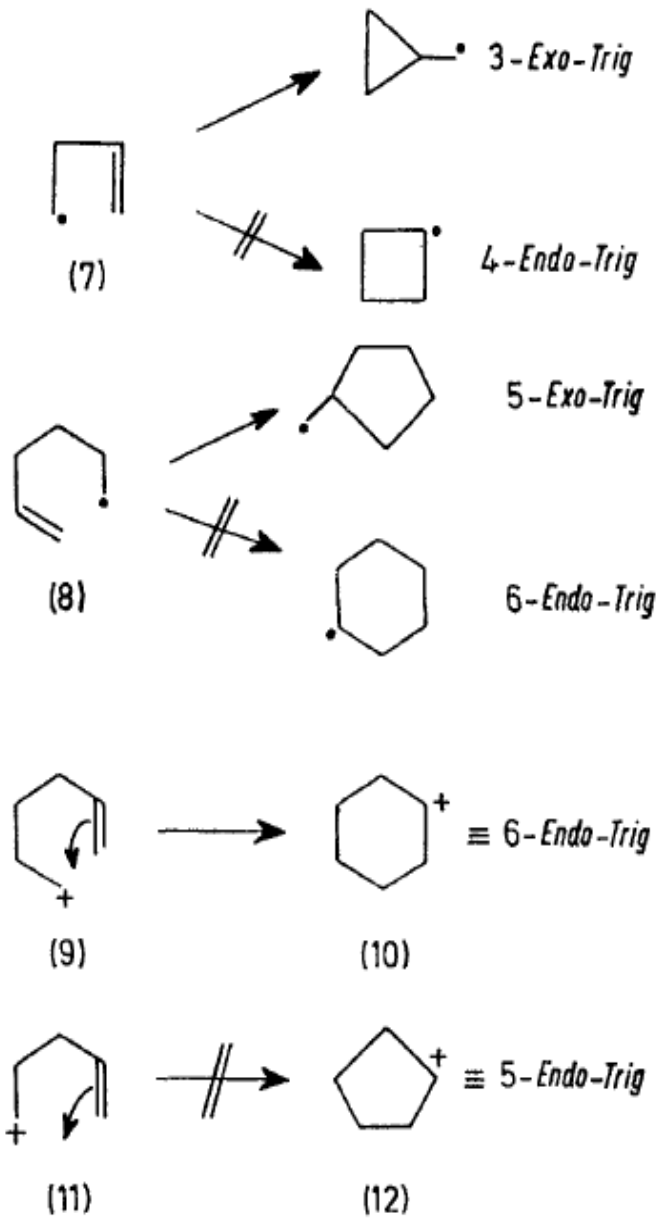
Scheme 2: Tetrahedral



SCHEME 3: Trigonal

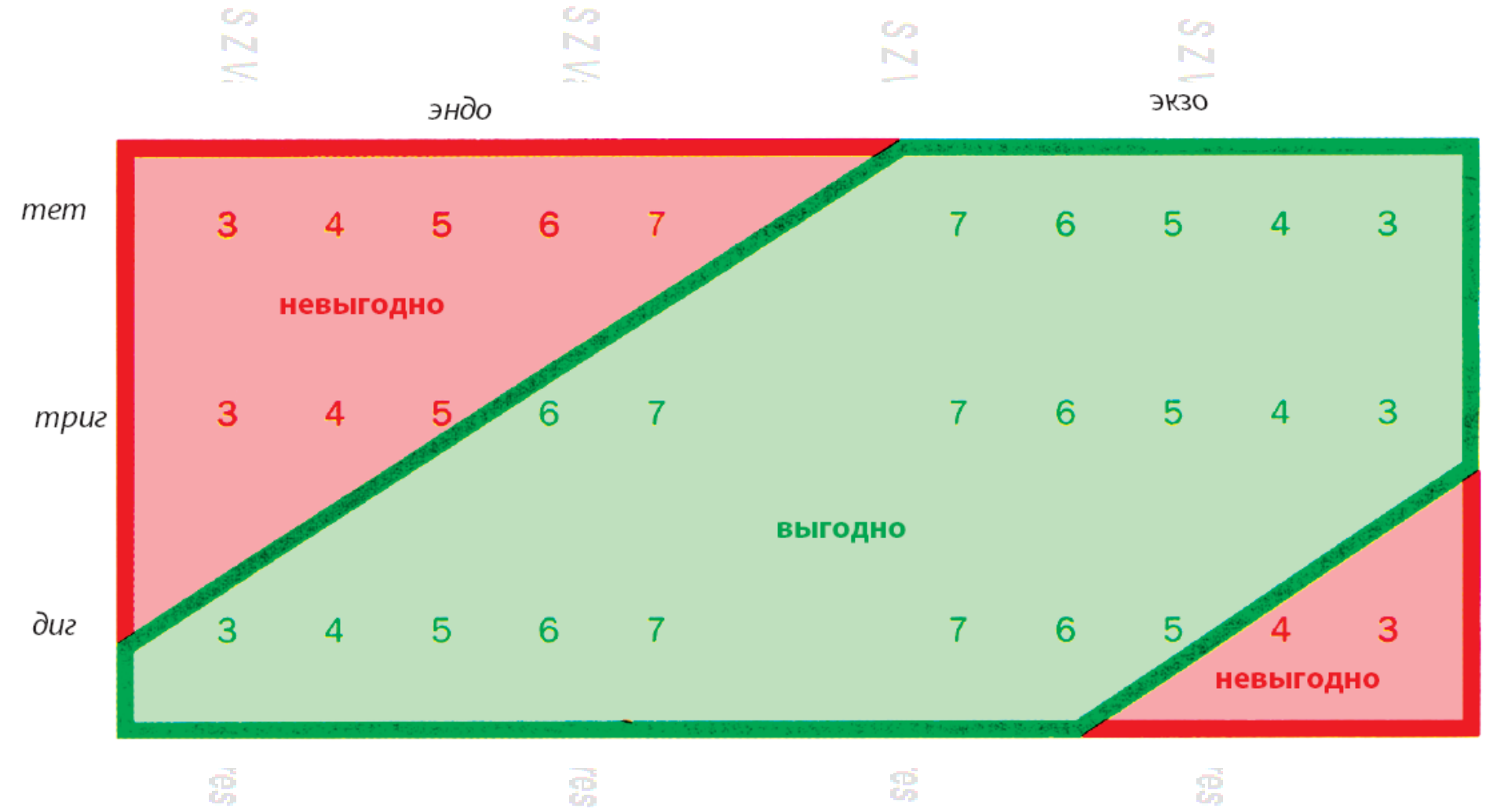


SCHEME 4: Digonal



- Правила Болдуина

Образование циклов



1. **Циклопропаны:**
- **реакция Симмонса-Смита**
- **диазосоединения**
- **илиды серы**
- **S_N2-реакции**

2. **Эпоксиды:**
- **надкислоты, гидропероксиды, диоксираны**
- **галогенгидрины**
- **конденсация Дарзана**
- **илиды серы**

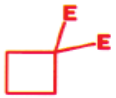
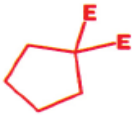
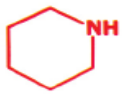
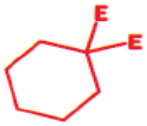
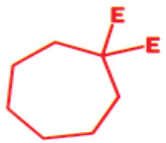
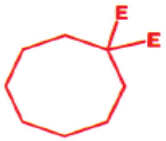
- эпоксидирование, катализ. переходными металлами

3. Азиридины:
-нитрены
- S_N2-реакции

- S_N2 замыкание цикла

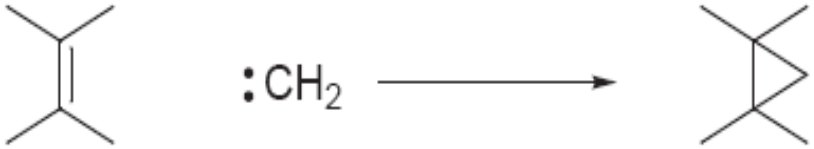
- S_N2 замыкание цикла

Таблица 42.3. Скорости реакций замыкания циклов

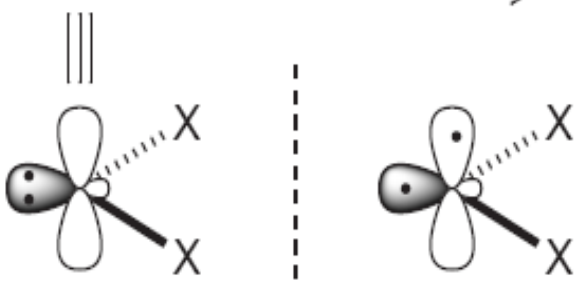
Размер цикла	Продукт	Относительная скорость[а]	Продукт реакции[б]	Относительная скорость[а]	Оценка реакции
3		0,07			С умеренной скоростью
4		0,001		0,58	Медленная
5		100		833	Очень быстрая
6		1		1	Быстрая
7		0,002		0,0087	Медленная
8				0,00015	Очень медленная

Parman, Schweizer *Org. React.* **1963**, *13*, 55.
Moss *Acc. Chem. Res.* **1989**, *22*, 15.
Acc. Chem. Res. **1980**, *13*, 58.
Kostikov, Molchanov, Khlebnikov *Russ. Chem. Rev.* **1989**, *58*, 654.

$2\pi^s + 2\omega^a$ cycloaddition

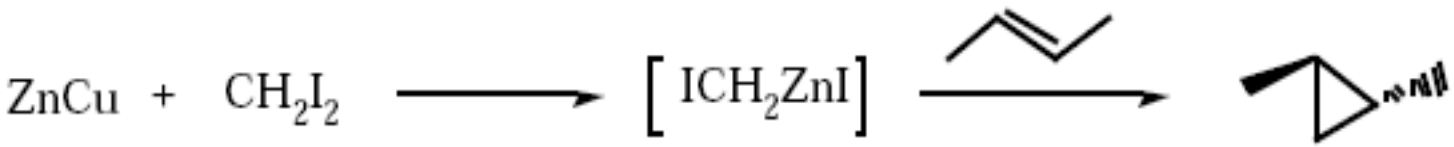


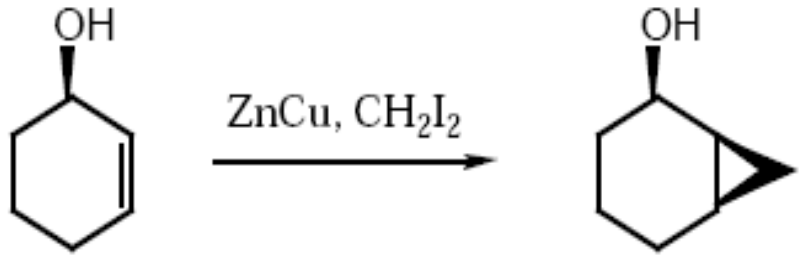
Addition of a singlet carbene proceeds by a concerted process in a *syn* fashion.



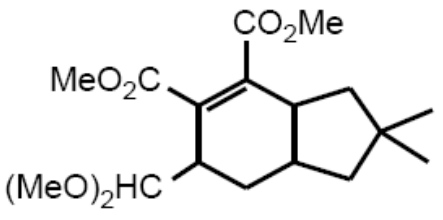
Triplet carbene behaves as a diradical.

- Реакция Симмонса-Смита

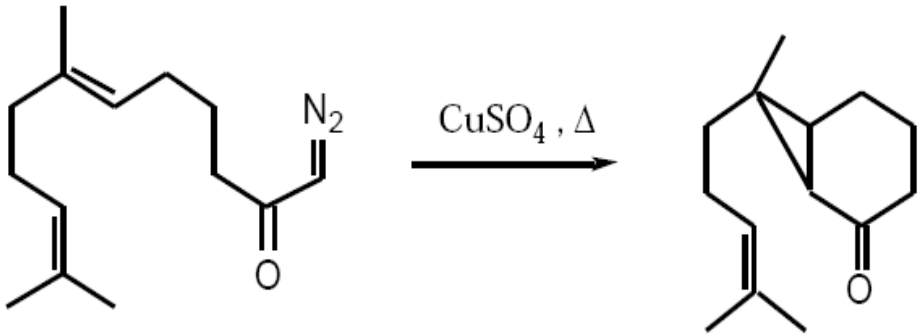




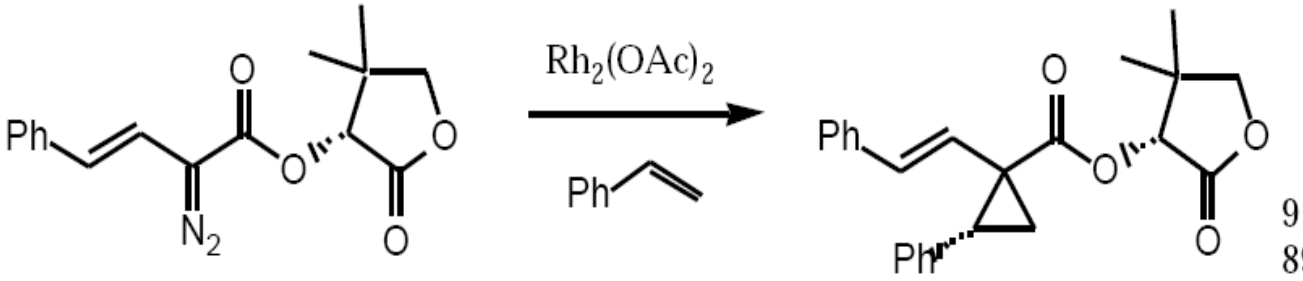
JACS **1979**, *101* , 2139



JACS **1975**, *97* , 6075



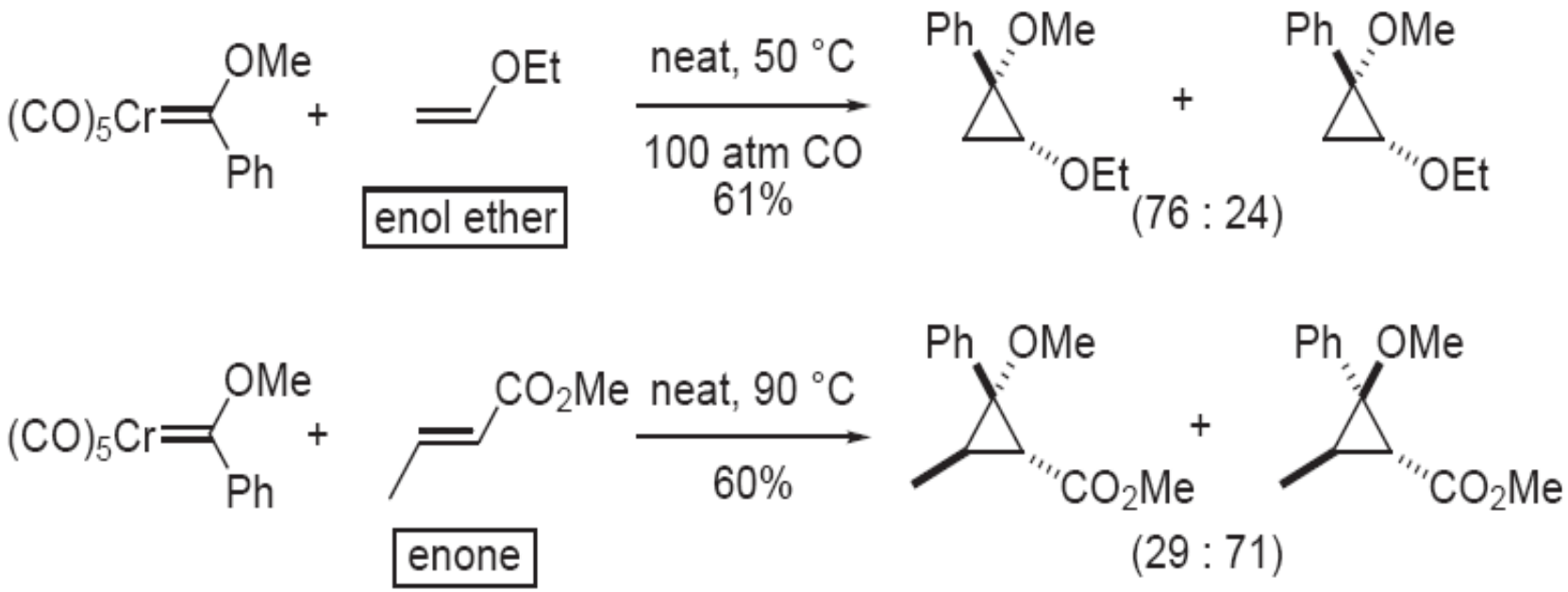
JACS **1970**, *92* , 3429
JACS **1969**, *91* , 4318



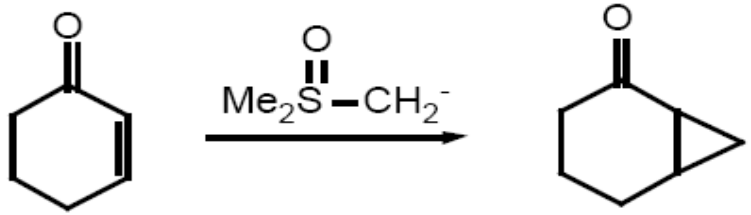
JACS **1993**, *115*, 9468

91 % yield
89 % de

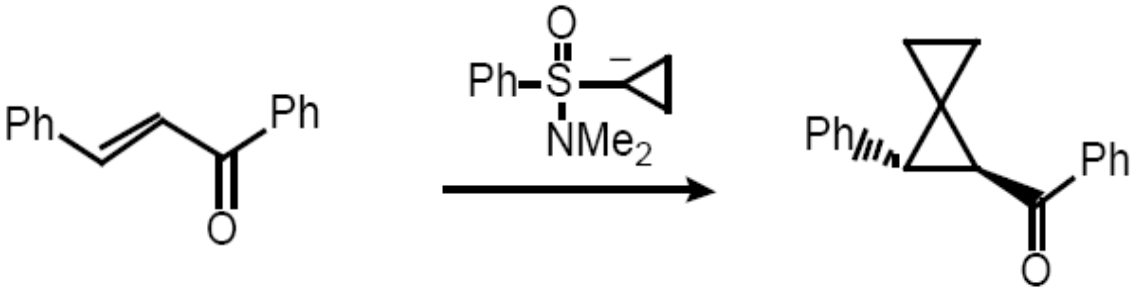
[2+1]



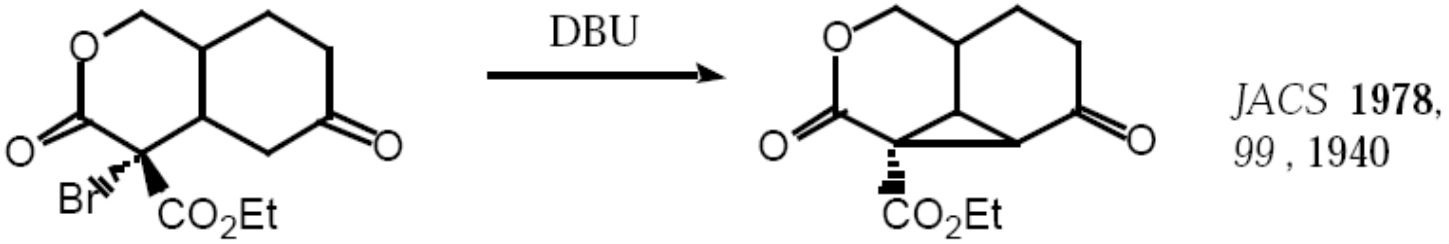
Fischer, Dötz *Chem. Ber.* **1972**, *105*, 3966.
Chem. Ber. **1972**, *105*, 1356.



Tetrahedron **1987**, *43* , 2609

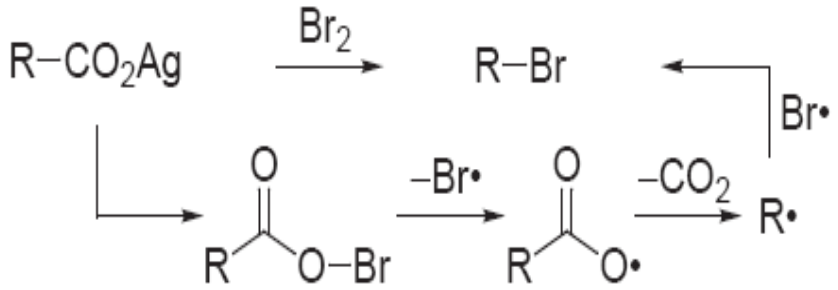


ACR **1973**, *6* , 341

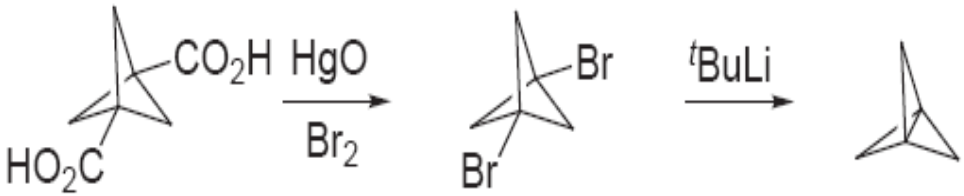


JACS **1978**, *99*, 1940

- Циклизации типа «радикал-радикал»

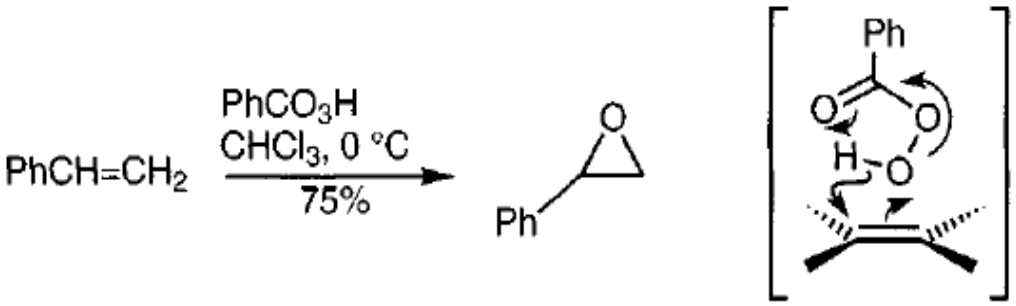


Hunsdiecker, H.; Hunsdiecker, C. *Ber.* **1942**, *75*, 291.

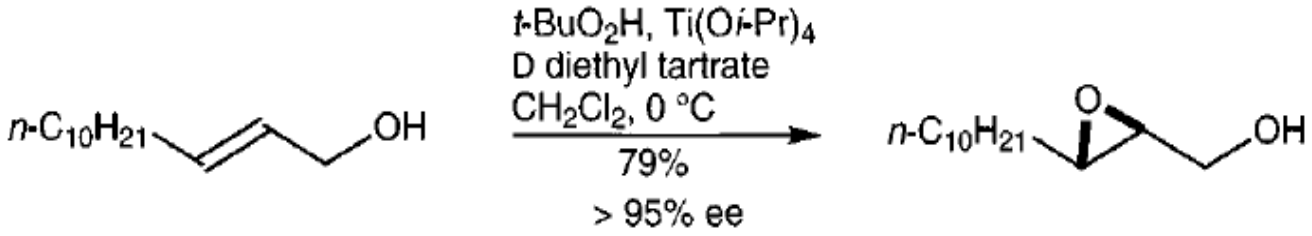


Wiberg *Acc. Chem. Res.* **1984**, *17*, 379.

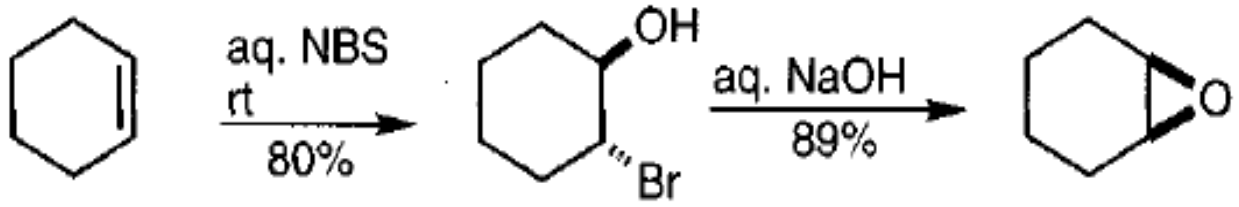
-надкислоты, гидропероксиды, диоксираны



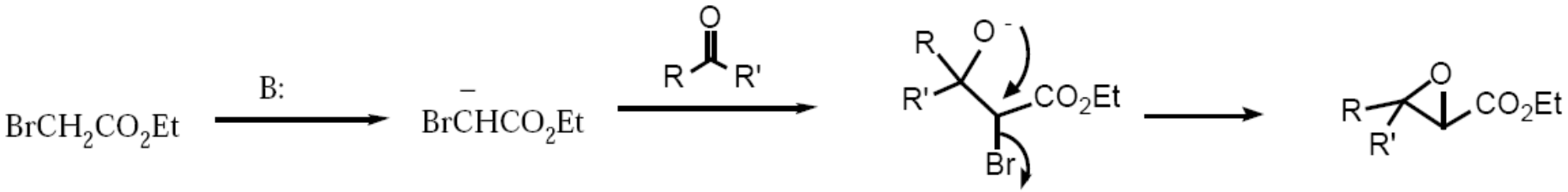
-эпоксидирование, катализируемое переходными металлами (Шарплесс, Якобсен)



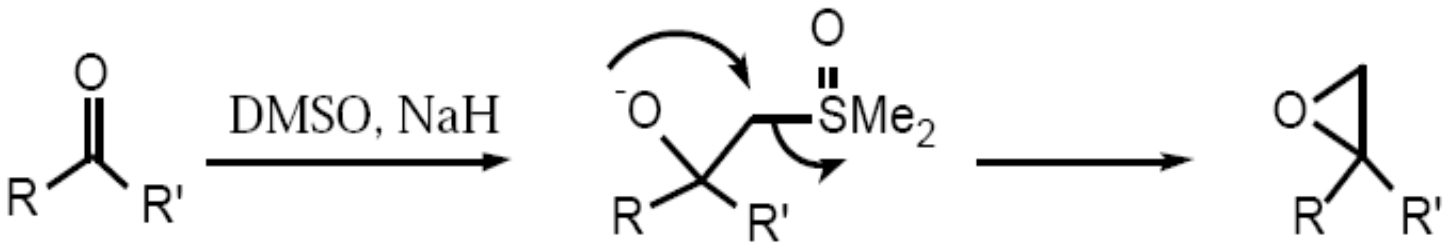
-галогенгидрины:



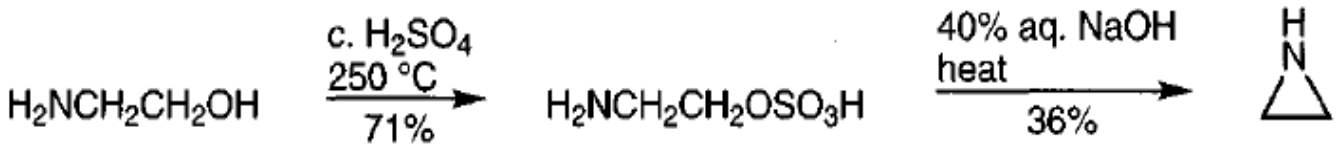
-конденсация Дарзана

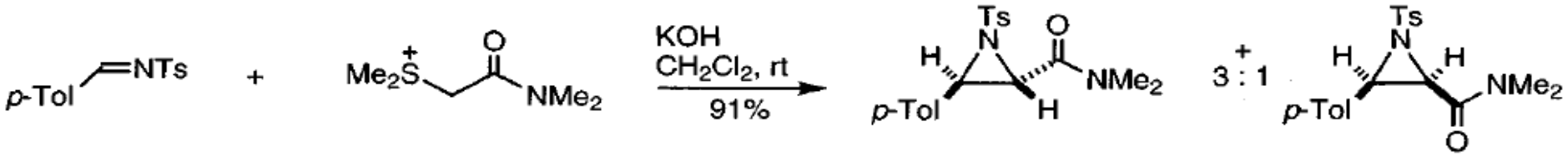


-илиды серы



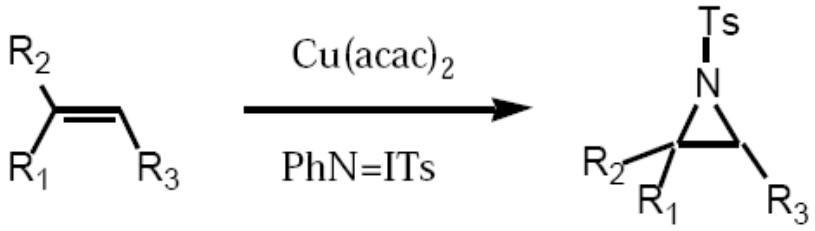
- S_N2-реакции



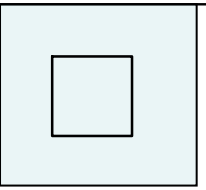


(не напоминает Кори-Чайковского?)

-нитрены:



J. Org. Chem. .**1991**, *56*, 6744



1. Циклобутаны и циклобутены:

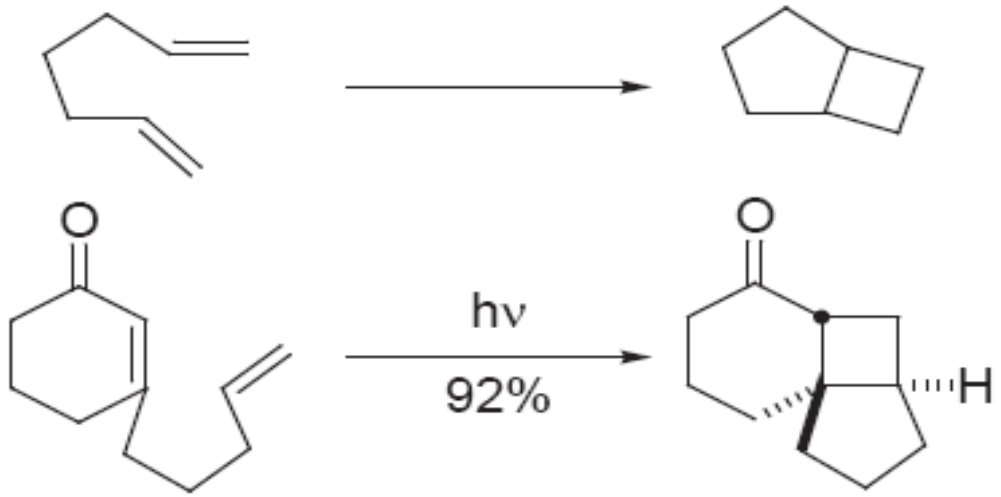
- **[2+2]-циклоприсоединение**
- **кетены + алкены**
- **S_N2-реакции**
- **ацилоиновая конденсация**

- илиды серы

2. Оксетаны:

- [2+2]-циклоприсоединение (реакция Патерно-Бухи)
- S_N2-реакции
- илиды серы
- β-лактоны

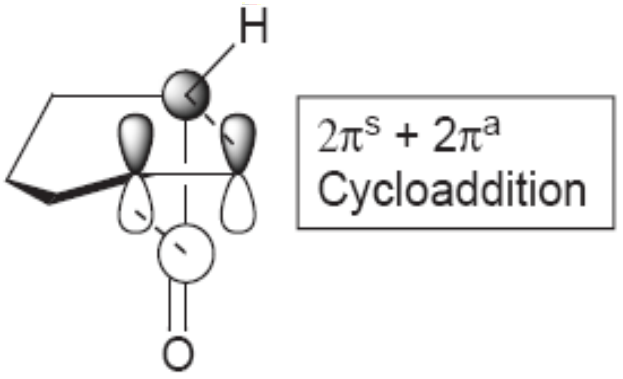
- [2+2]-циклоприсоединение

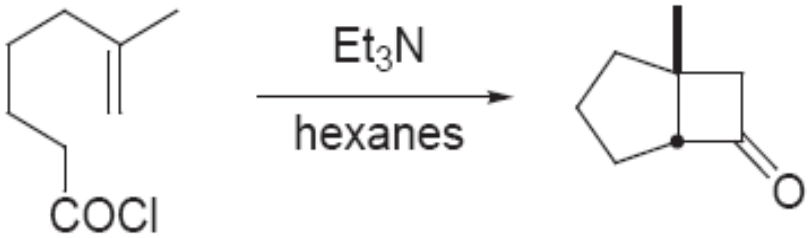


Cargill *Tetrahedron Lett.* **1978**, 4465.

- [2+2]: кетен+алкен

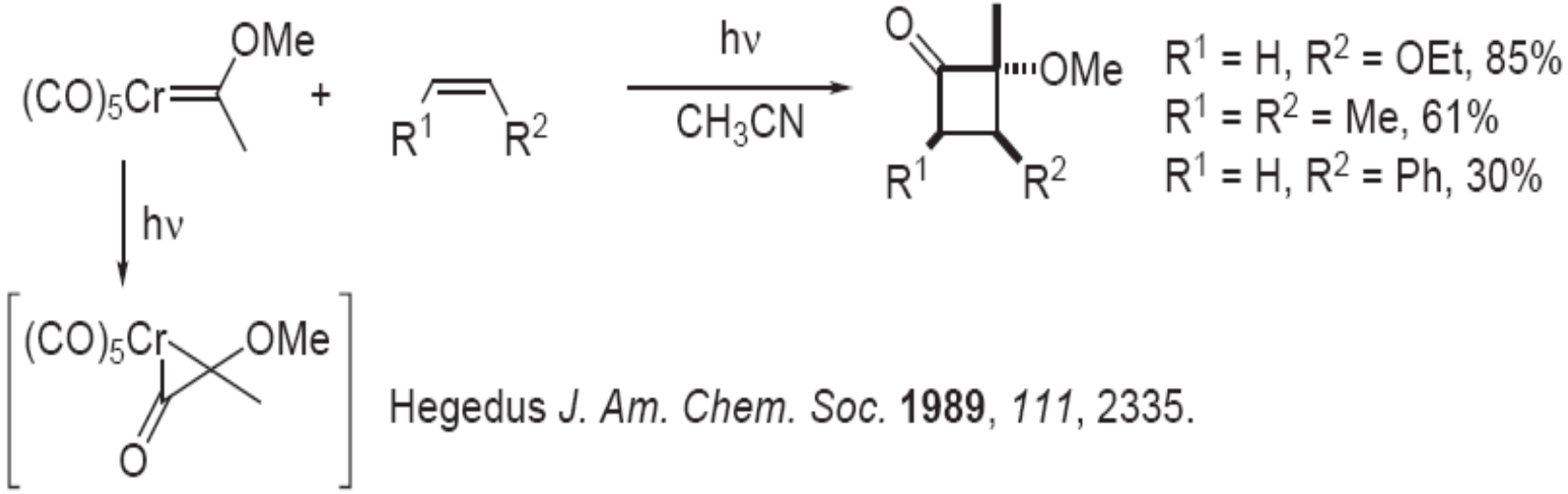
Org. React. **1995**, *45*, 159.



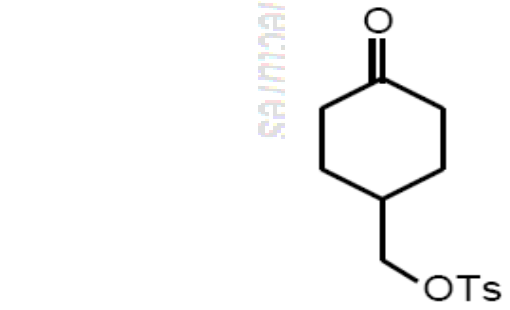


Baldwin *J. Chem. Soc., Chem. Commun.* **1972**, 1337.

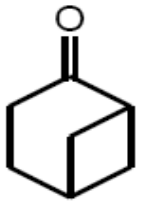
[2+1+1]



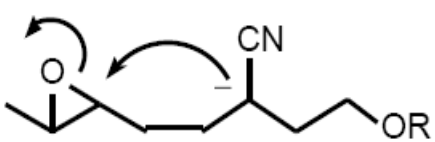
Hegedus *J. Am. Chem. Soc.* **1989**, *111*, 2335.

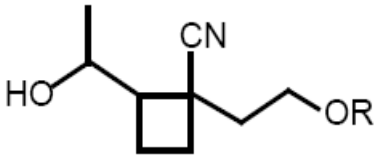


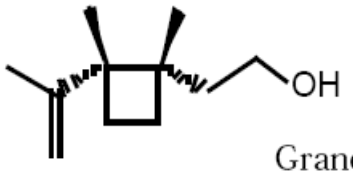
KH, DMSO



JACS **1980**, *102* , **1404**

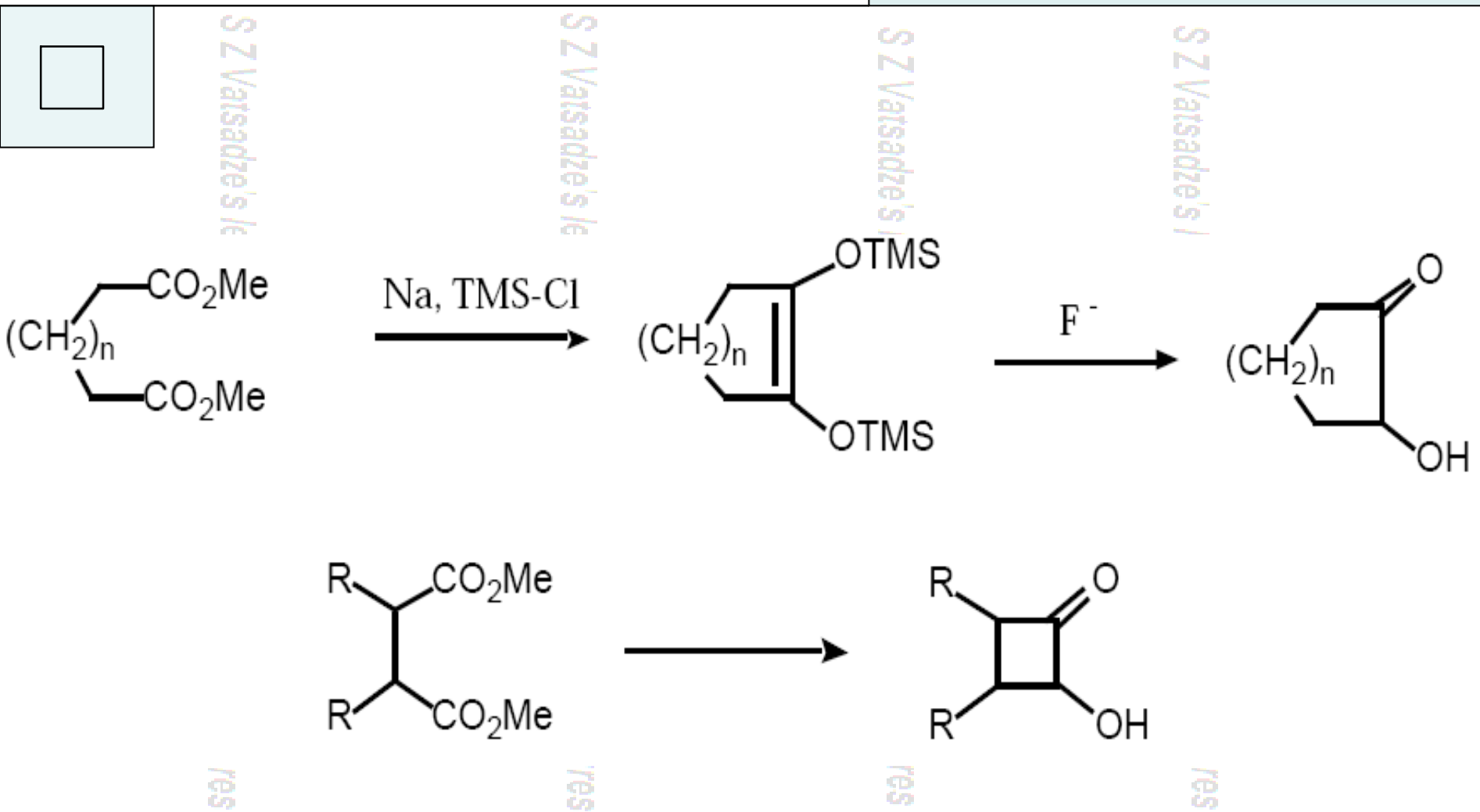






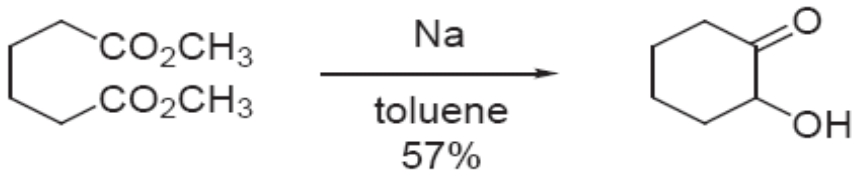
Grandisol

JACS **1974**, 96, 5268, 5272


CO2Me
(CH2)n
CO2Me
Na, TMS-Cl
OTMS
(CH2)n
OTMS
F -
O
(CH2)n
OH
R
CO2Me
R
CO2Me
R
O
R
OH

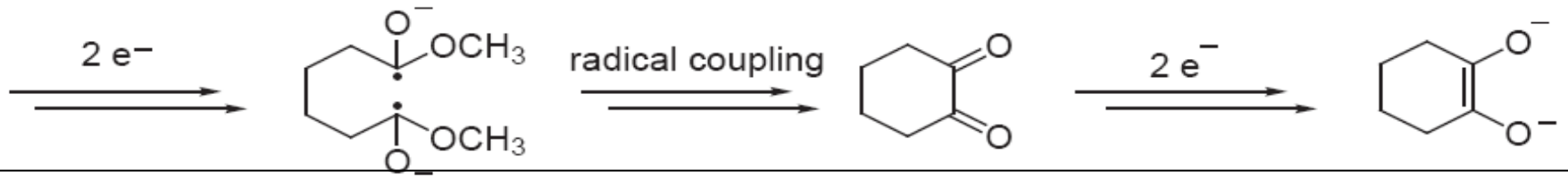
- Восстановительная димеризация карбонилов

a. Acyloin Condensation

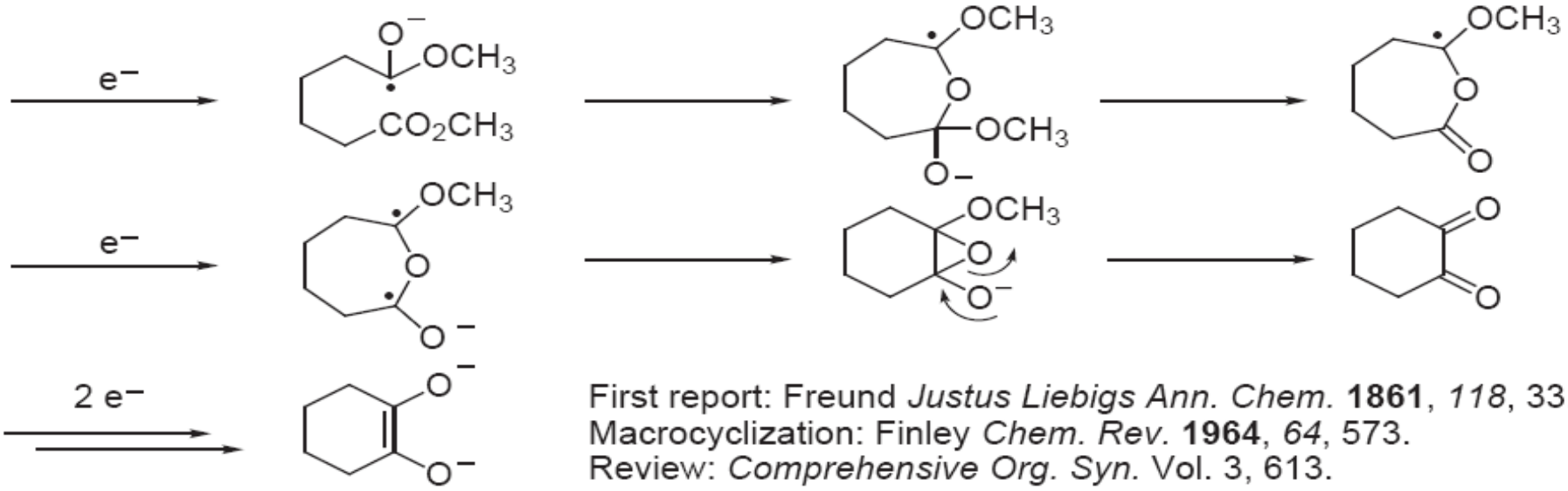


Sheehan *J. Am. Chem. Soc.* **1950**, *72*, 3376.

- Mechanism

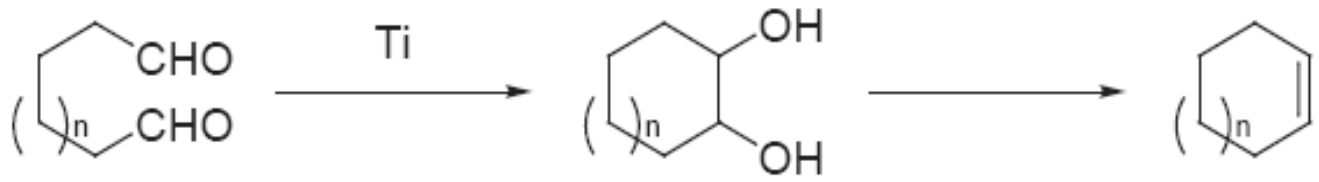


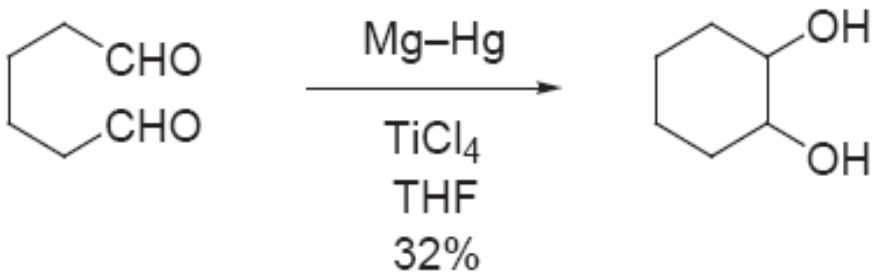
- Alternative



First report: Freund *Justus Liebigs Ann. Chem.* **1861**, *118*, 33.
Macrocyclization: Finley *Chem. Rev.* **1964**, *64*, 573.
Review: *Comprehensive Org. Syn.* Vol. 3, 613.

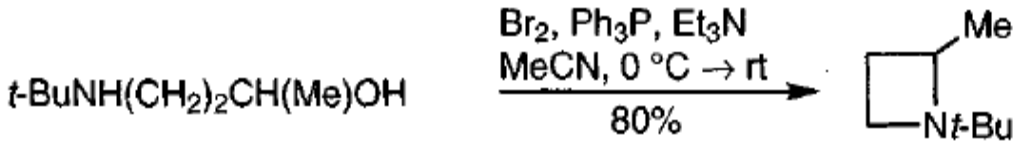
- Восстановительная димеризация карбонилов

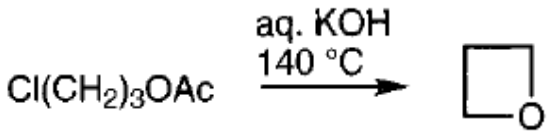


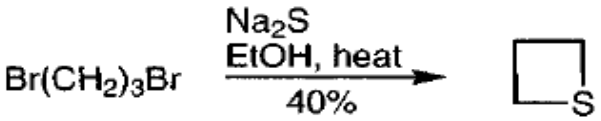


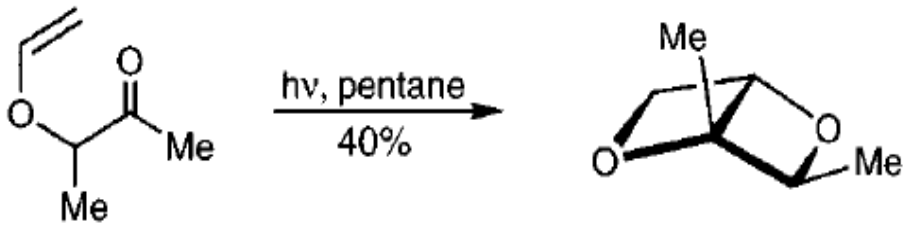
Corey, Danheiser *J. Org. Chem.* **1976**, *41*, 260.

Вспомните реакцию МакМурри!

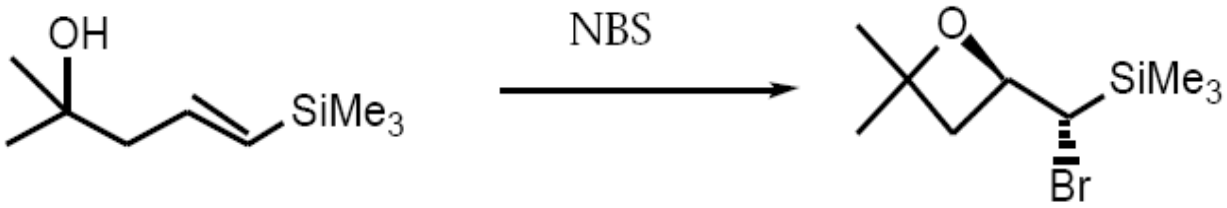

t-BuNH(CH2)2CH(Me)OH
Br2, Ph3P, Et3N
MeCN, 0 °C → rt
80%
Me
Nt-Bu


Cl(CH2)3OAc
aq. KOH
140 °C
O

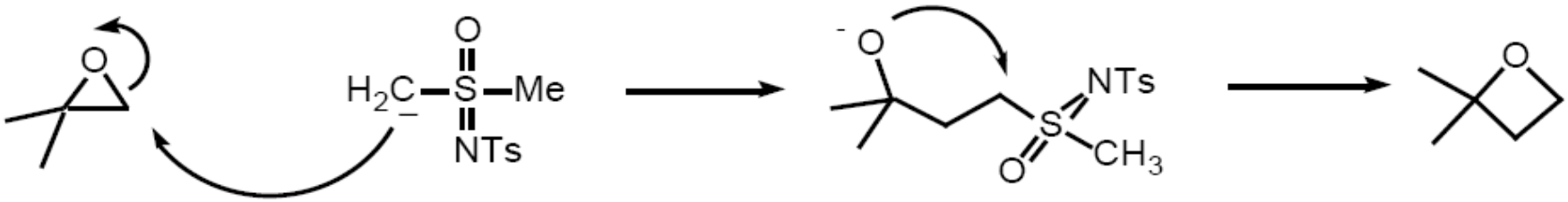

Br(CH2)3Br
Na2S
EtOH, heat
40%
S


O
O
Me
Me
hν, pentane
40%
Me
O
O
Me

-S_N2-реакции

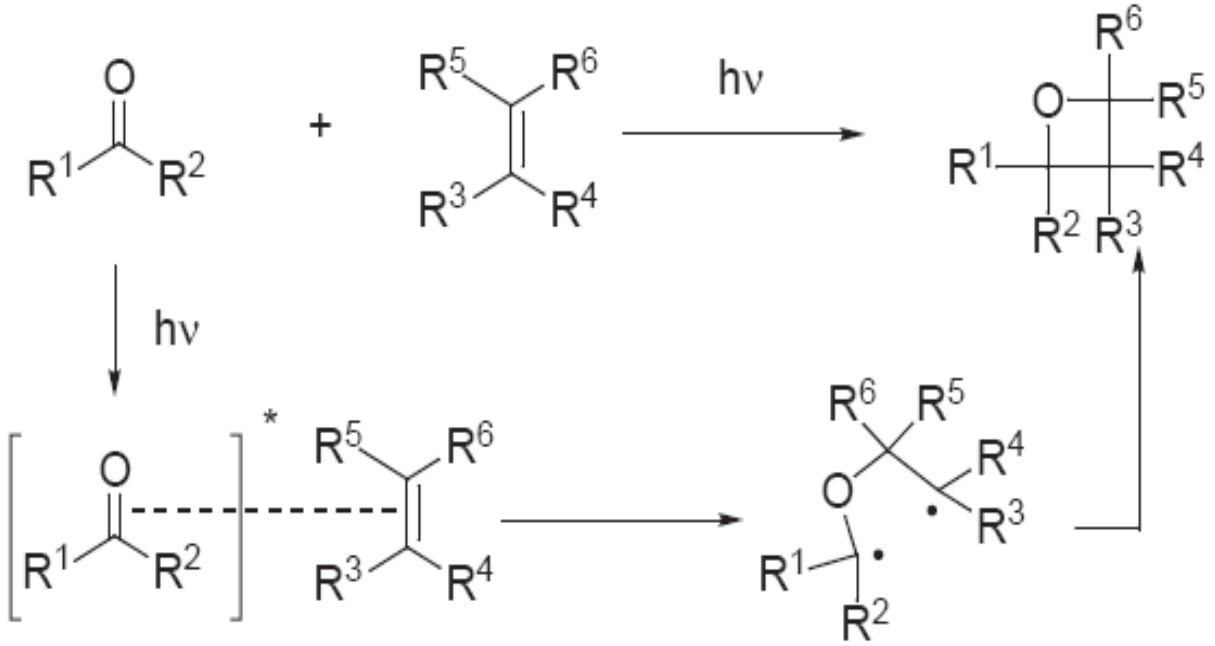


-илиды серы (вспомните Кори-Чайковский!)

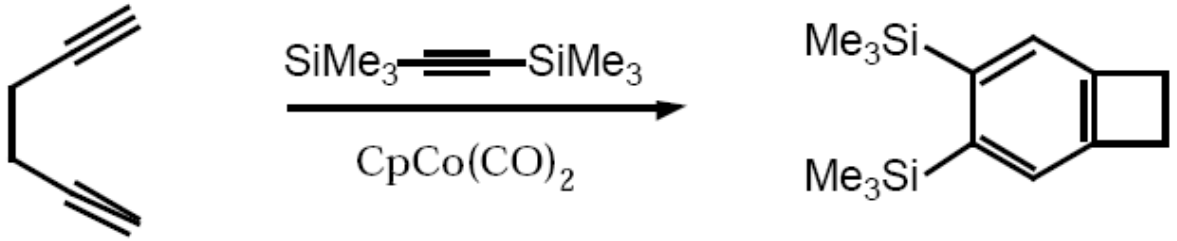


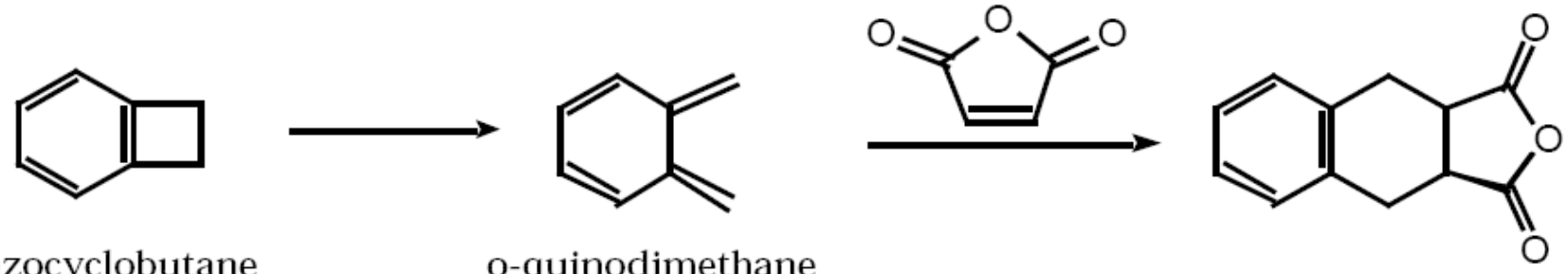
- Реакция Патерно-Бюхи

Comprehensive Org. Syn., Vol. 5, 151.
Dermuth *Synthesis* **1989**, 152.
First studied in detail by Buchi *J. Am. Chem. Soc.* **1954**, *76*, 4327.



1. Циклобутаны и циклобутены:
- разное

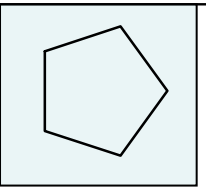




benzocyclobutane

o-quinodimethane

Образование циклов



- **S_N2-реакции**
- **ацилоиновая кондесация**
- **присоединение по Михаэлю**
- **альдольная конденсация**
- **внутримолекулярное олефинирование по Виттигу**
- **метатезис с замыканием цикла**
- **диазосоединения**
- **радикальные циклизации**
- **реакция Посона-Хэнда**

-1,3-диполярное присоединение ([3+2]-циклоприсоединение)

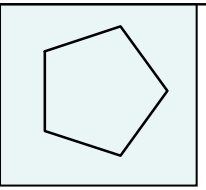
-реакции расширения и сужения циклов:

a. 3 ® 5
b. 4 ® 5
c. 6 ® 5

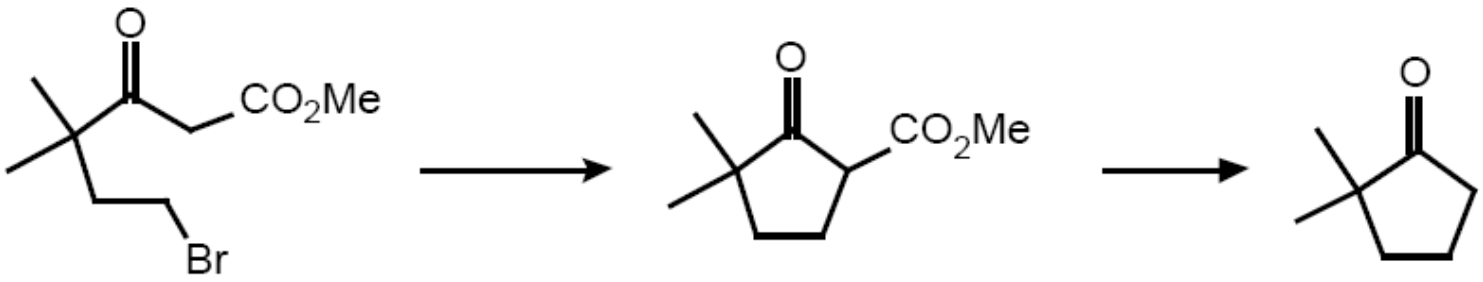
-циклизация по Назарову

-циклизация по Нойори

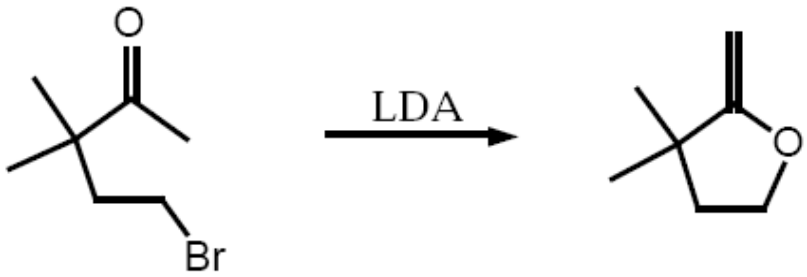
-фотоциклизации арен+алкен



5-ЭКЗО-ТЕТ

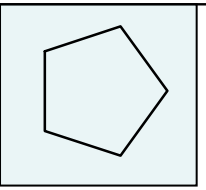


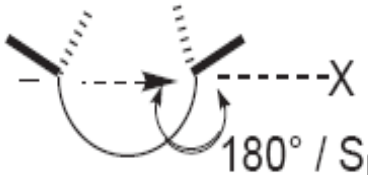
Но:



Почему:

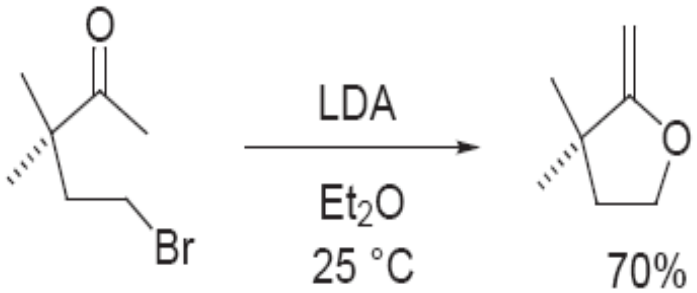
- Внутримолекулярное алкилирование енолятов

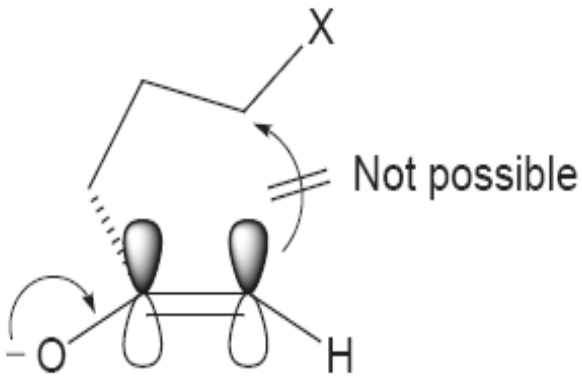


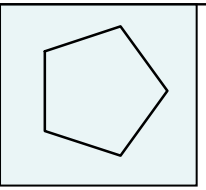


180° / S_N2 displacement

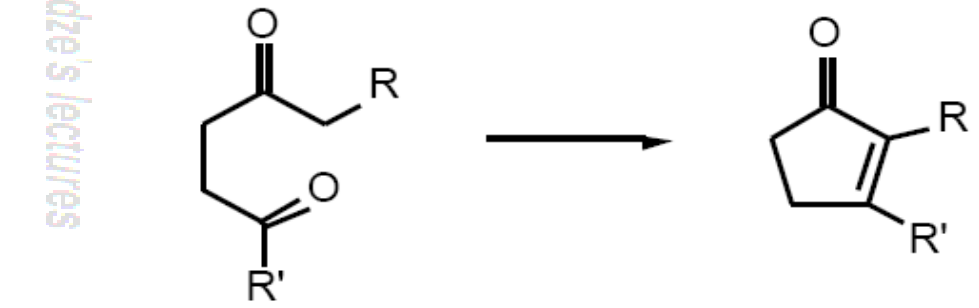
- Note Baldwins Rules
Preceded by Eschenmoser
Helv. Chim. Acta **1970**, *53*, 2059.

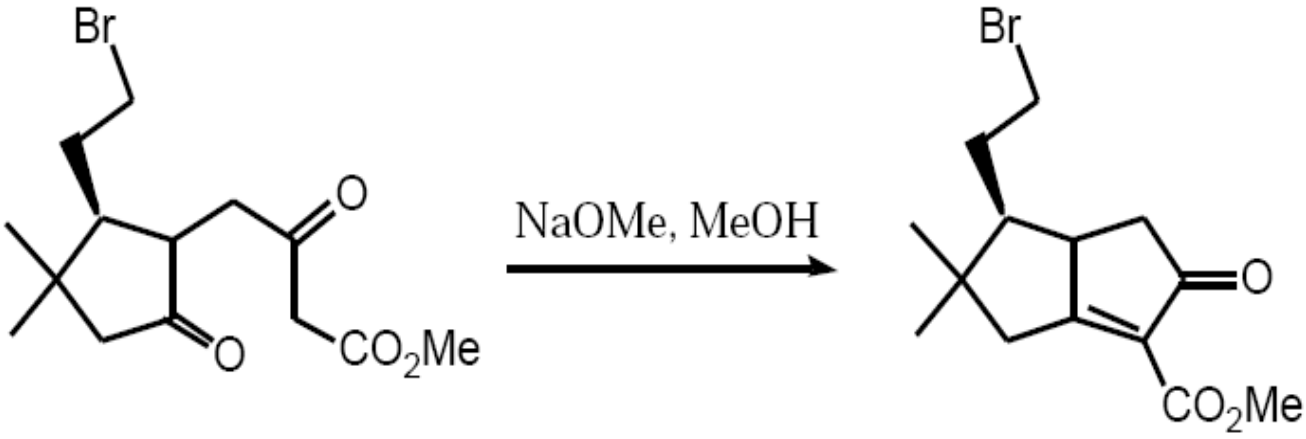


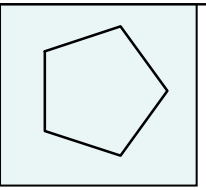




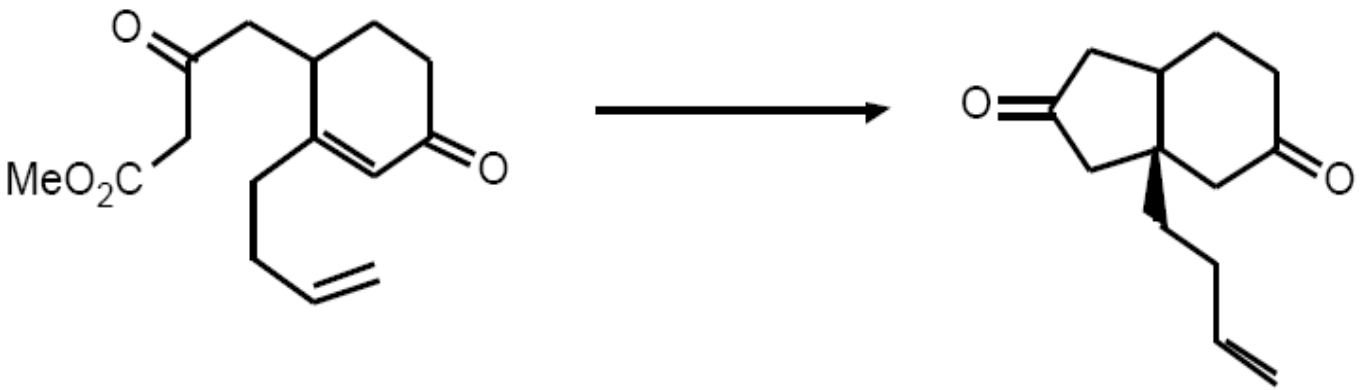
5-ЭКЗО-ТРИГ



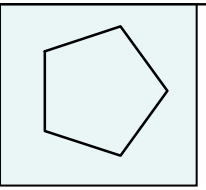




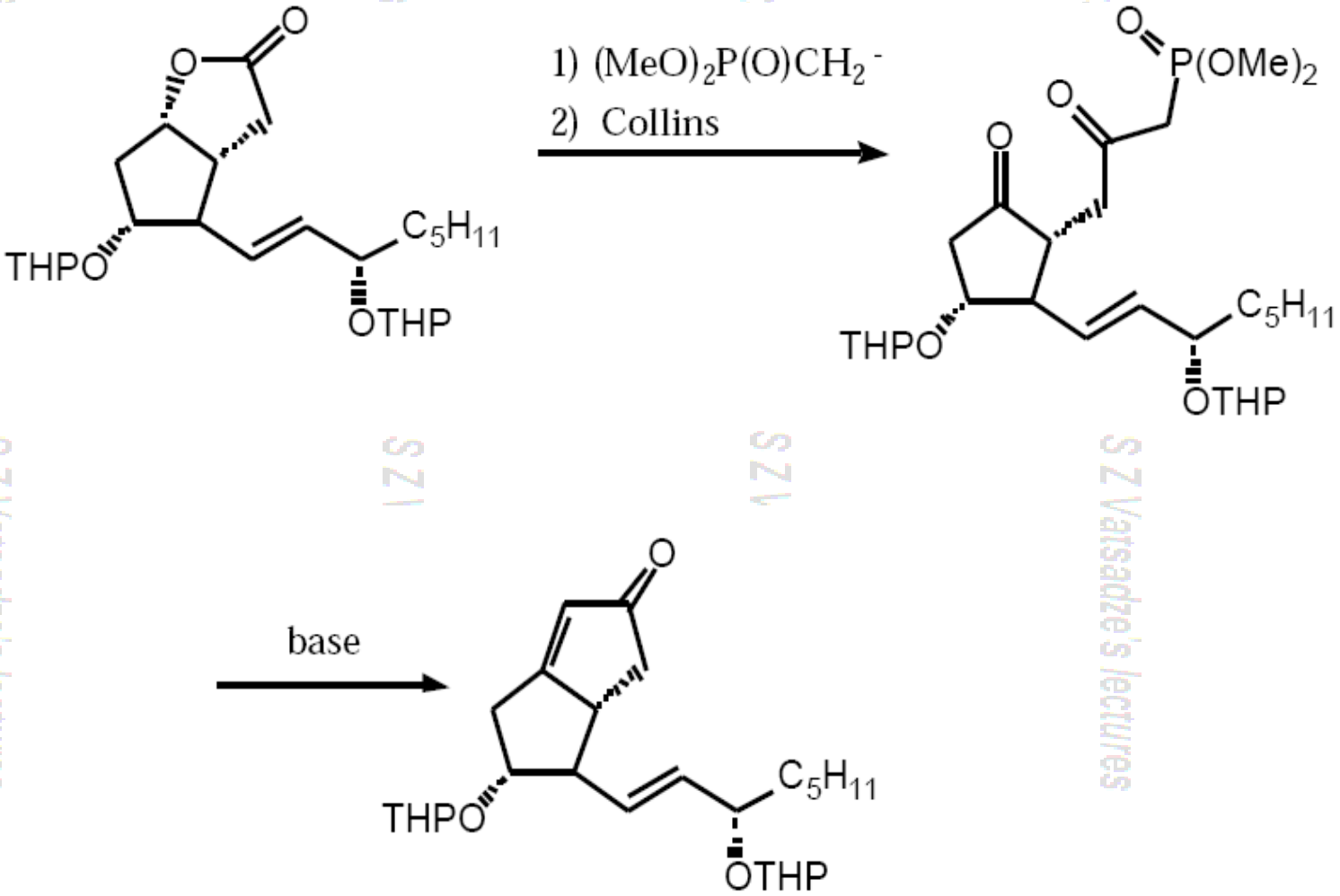
5-ЭКЗО-ТРИГ



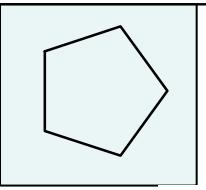
- Внутримолекулярное олефинирование

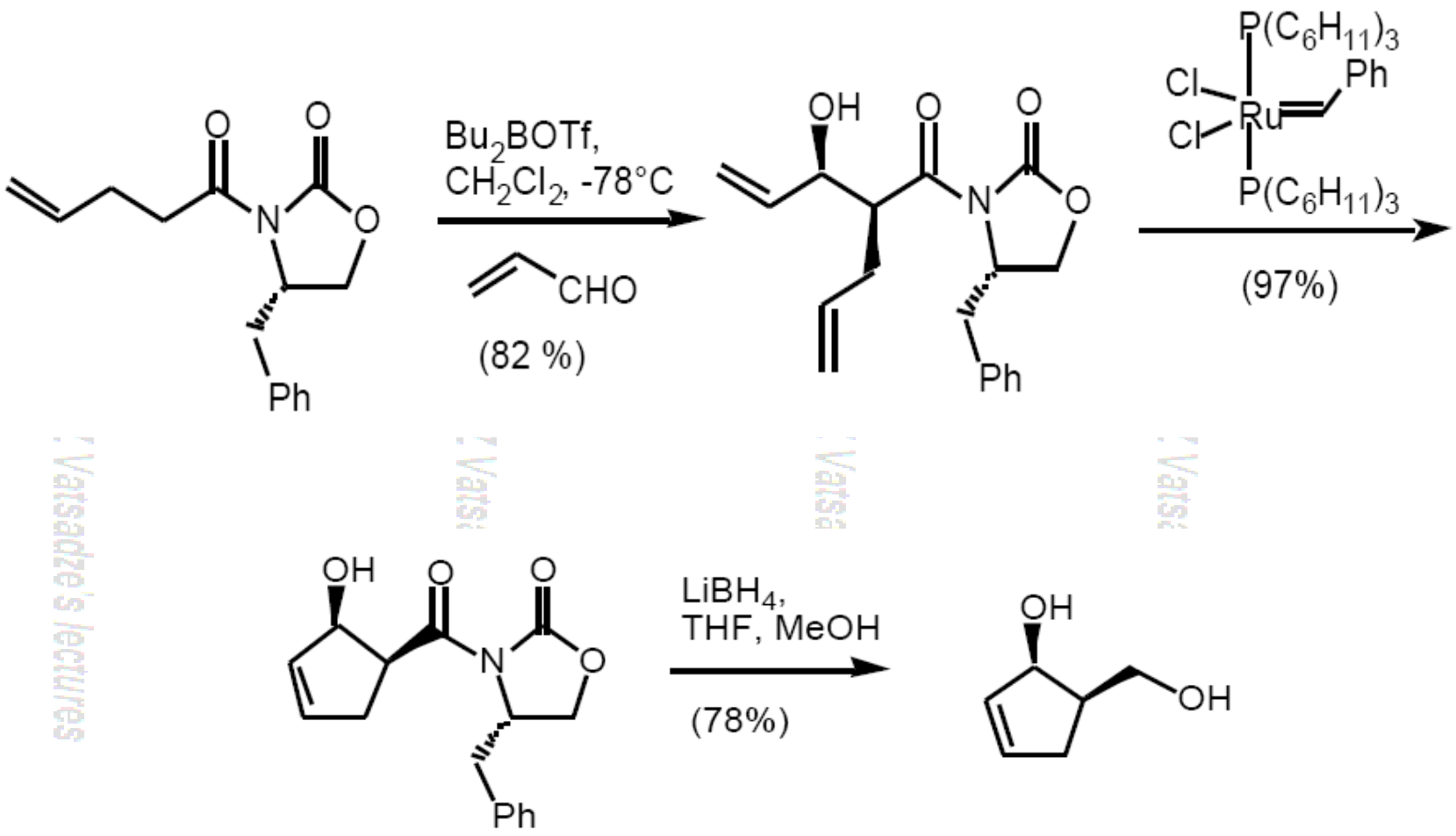


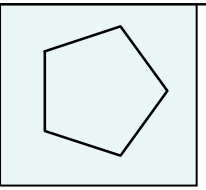
5-ЭКЗО-ТРИГ

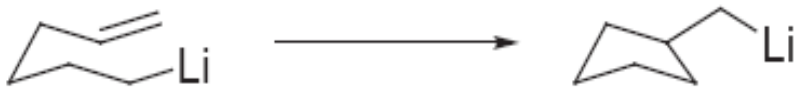


- Метатезис с замыканием цикла







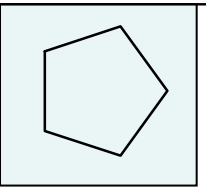


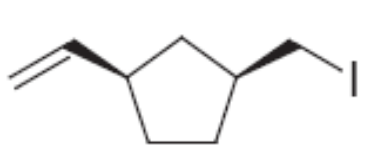
stable at –78 °C
$t_{1/2}$ = 5.5 min at 25 °C

Bailey *J. Am. Chem. Soc.* **1992**, *114*, 8053.
J. Am. Chem. Soc. **1991**, *113*, 5720.
J. Am. Chem. Soc. **1987**, *109*, 2442.

Intramolecular carbometalation, review:
Comprehensive Org. Syn., Vol. 4, 871.

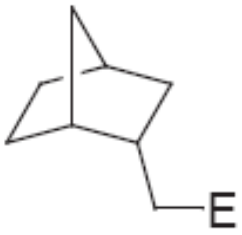
- Анионные циклизации: примеры



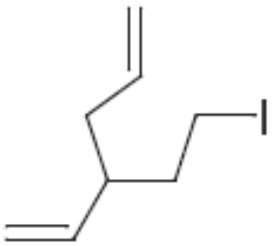


1. ^{t}BuLi

2. E^{+}

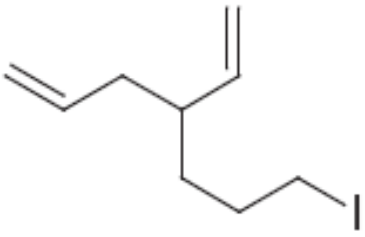


63–91%

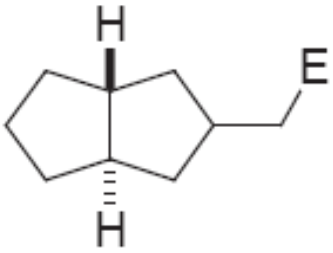


tandem cyclizations

65–90%

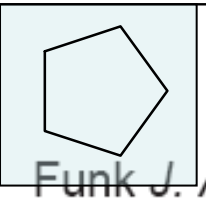


tandem cyclizations



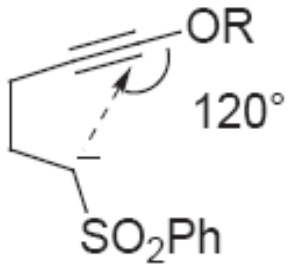
65–87%

- Анионные циклизации: примеры

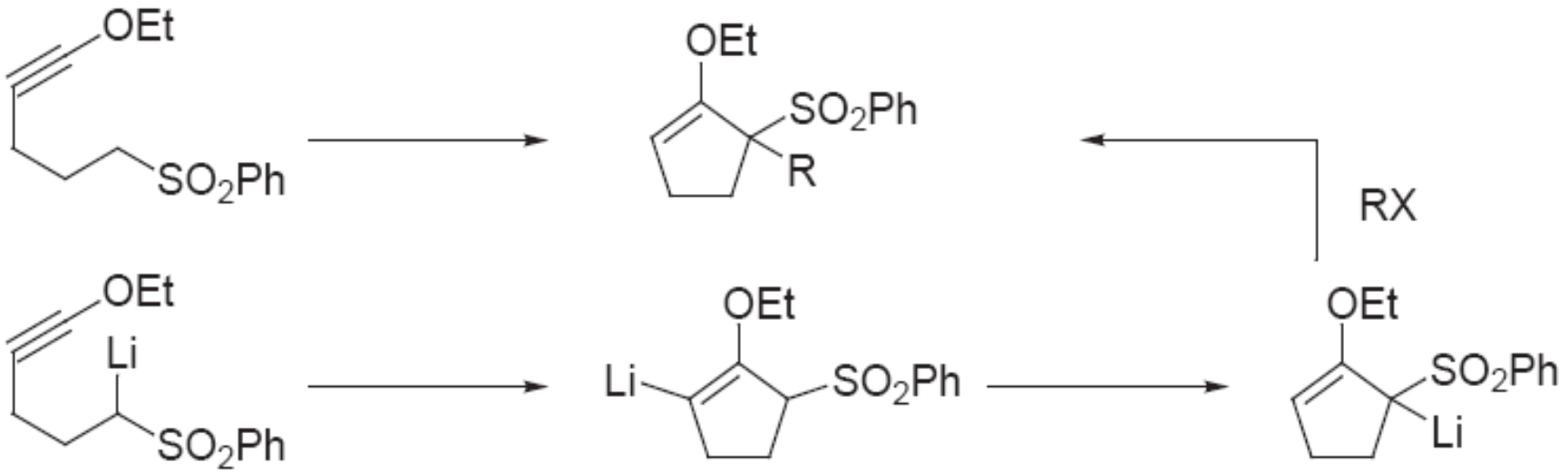


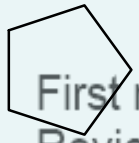
Funk *J. Am. Chem. Soc.* **1993**, *115*, 7023.

5-*endo-dig* cyclization

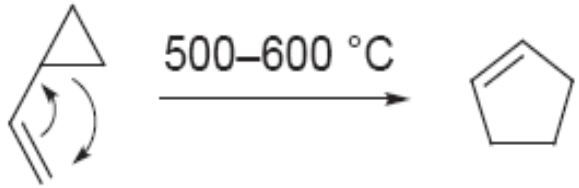


line of attack



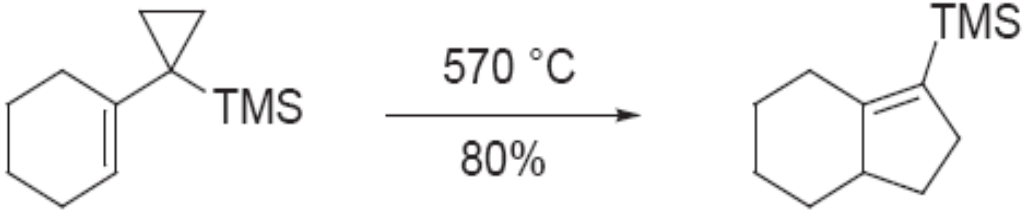


First report: Neureiter *J. Org. Chem.* **1959**, *24*, 2044.
Review: Hudlicky *Chem. Rev.* **1989**, *89*, 165.

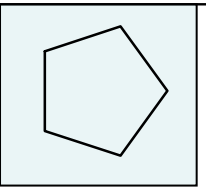


Org. React. **1985** *33*, 247.

Mechanism:



Paquette *Tetrahedron Lett.* **1982**, *23*, 263.



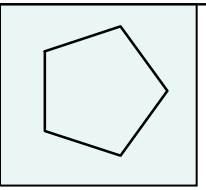
Что еще по циклопентанам:

•**радикальные циклизации**

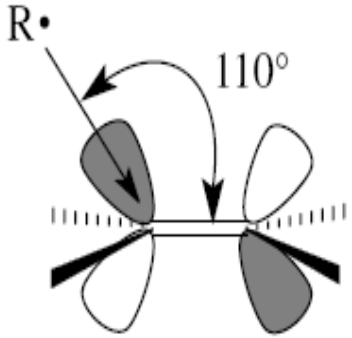
-реакции расширения и сужения циклов:

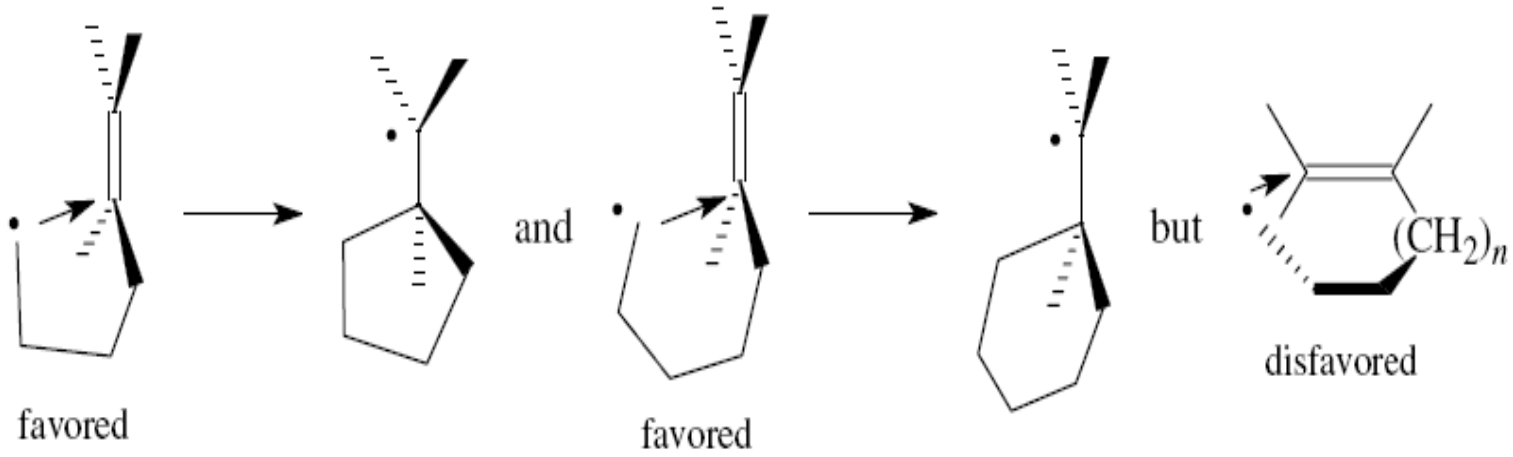
a. 3 ® 5
b. 4 ® 5
c. 6 ® 5

-ацилоиновая конденсация
-1,3-диполярное присоединение
-фотоциклизации арен+алкен

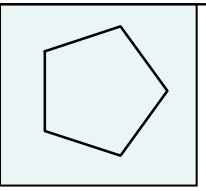


Вспоминаем правила Болдуина!!!





- Циклизации типа «радикал-олефин»



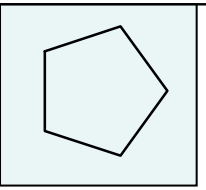
Радикалы бывают **электрофильные** и **нуклеофильные**.

Алкильные радикалы относятся к **нуклеофильным** радикалам:

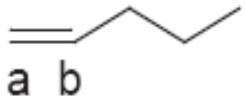
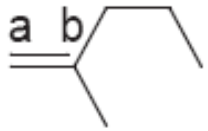
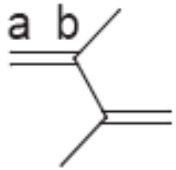
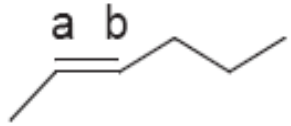
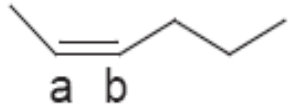
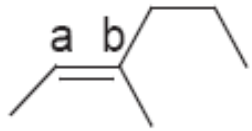
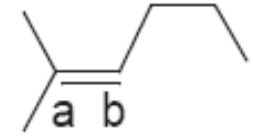
- Relative rates of addition to  $PO(OEt)_2$: typical electron-deficient olefin.

	$CH_3\bullet$	$CH_3CH_2\bullet$	$CH_3OCH_2\bullet$	$(CH_3)_2CH\bullet$	$(CH_3)_3C\bullet$
k_{rel} =	1	1	2.7	4.8	24

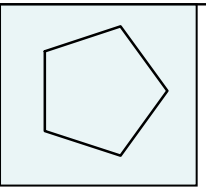
- Циклизации типа «радикал-олефин»

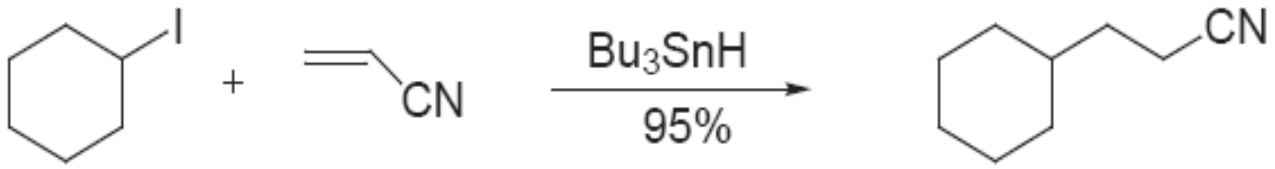


Стереоэлектронные требования

olefin	% addition to: Ca	Cb	k_{rel}
 a b	>95	<5	1.16
 a b	>95	<5	18.4
 a b	>95	<5	2 × 136
 a b	50	50	2 × 0.50
 a b	50	50	2 × 0.63
 a b	>95	5	15
 a b	<5	>95	13.9

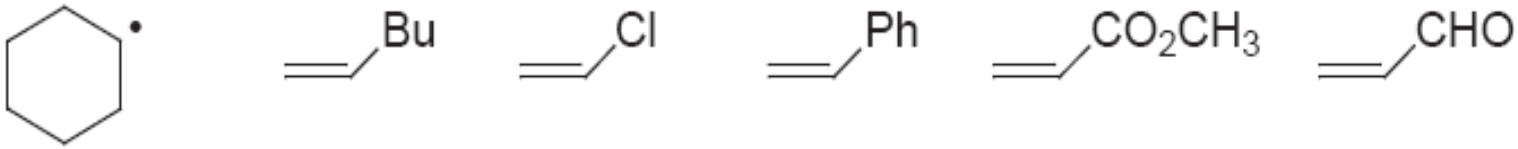
- Циклизации типа «радикал-олефин»





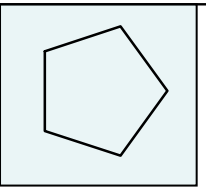
Nucleophilic radical

Electrophilic acceptor alkene

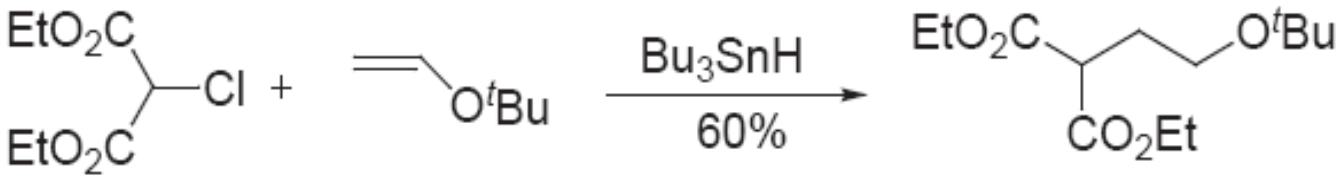


k_{rel}	1.0	8.4	84	3000	8500

- Циклизации типа «радикал-олефин»

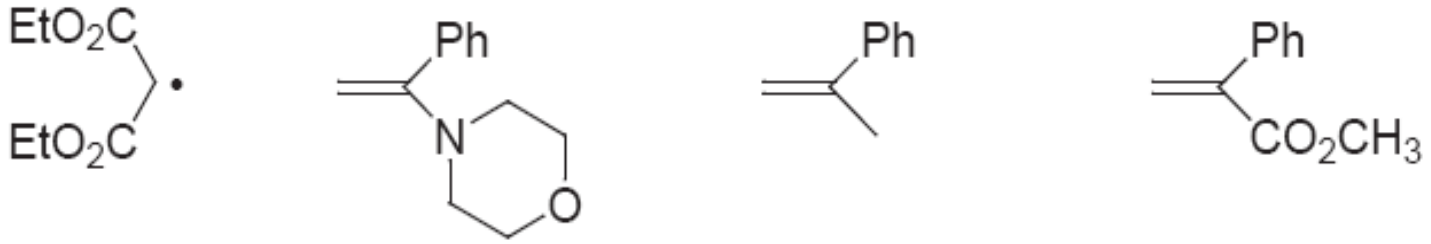


Электрофильные радикалы – стабилизированы электроноакцепторными группами:

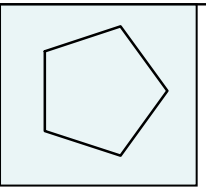


Electrophilic radical

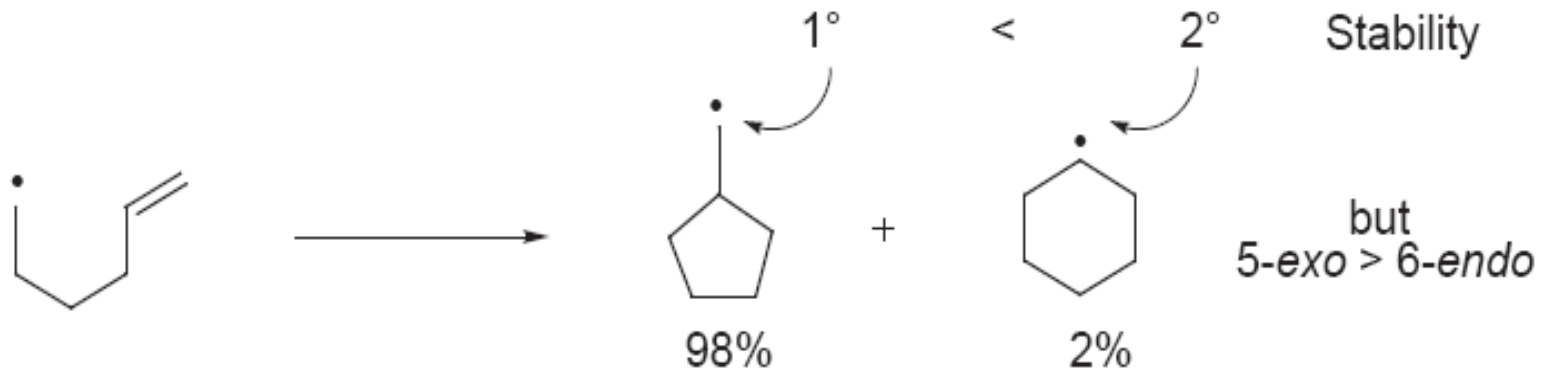
Nucleophilic acceptor alkene



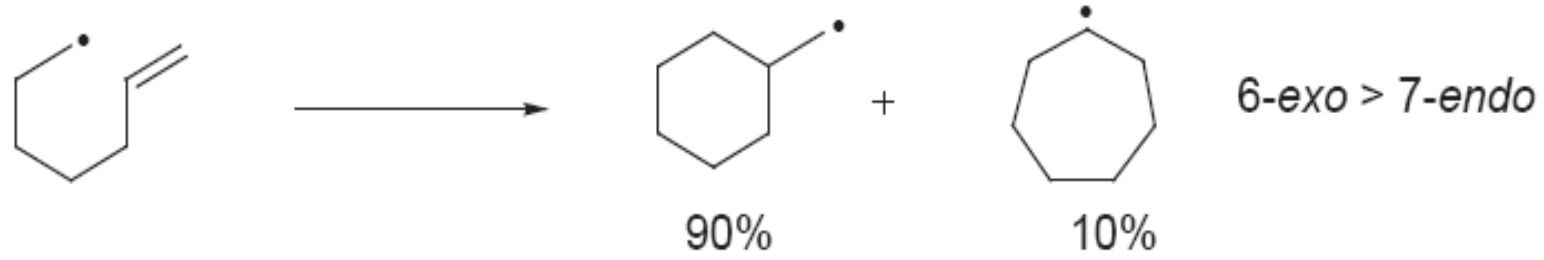
k_{rel}	23	3.5	1



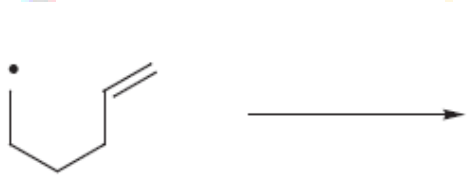
Скорости, регио- и диастереоселективность



Beckwith *J. Chem. Soc., Chem. Commun.* **1974**, 472.
Beckwith *J. Chem. Soc., Chem. Commun.* **1980**, 484.

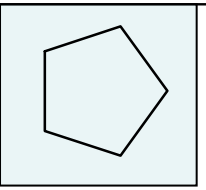


Скорости, регио- и диастереоселективность

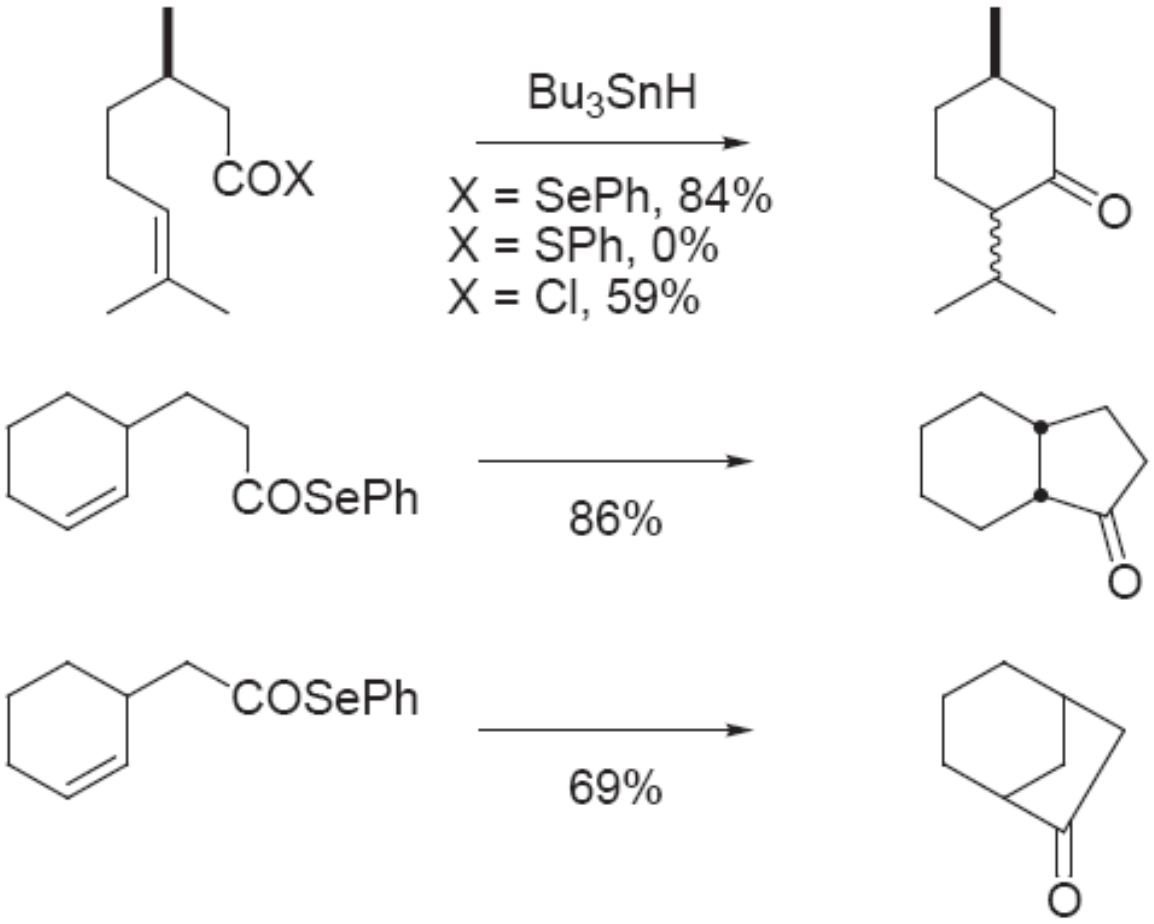


k_{rel} *exo*	k_{rel} *endo*	Product ratio
1.0	0.02	(98 : 2)
1.4	0.02	(99 : 1)
2.4	<0.01	(>200:1)
0.022	0.04	(36 : 64) *endo* predominates
0.16	<0.002	*exo* >> *endo* (>80:1)

- Циклизации типа «радикал-олефин»



Карбонилрадикалы

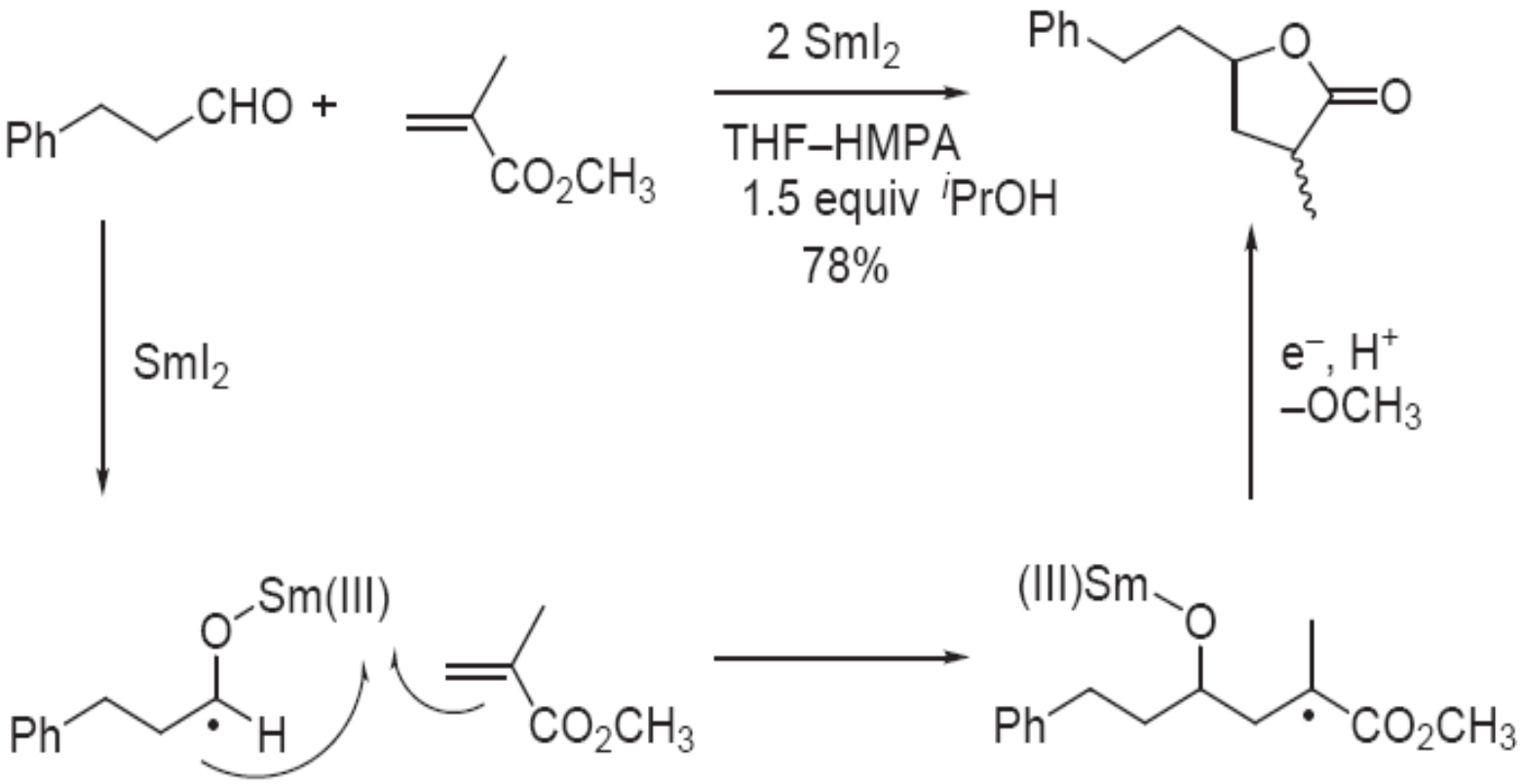


- Восстановительное сочетание с участием SmI_2

Molander *Chem. Rev.* **1992**, *92*, 29.

Molander in *Chemistry of the Carbon Metal Bond*, Hartley, F. R.; Patai, S., Eds.; Wiley: NY, 1989, Vol. 5

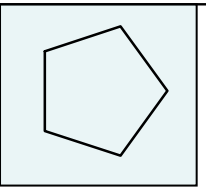
Molander in *Comprehensive Org. Syn.*, Vol. 1, 262.

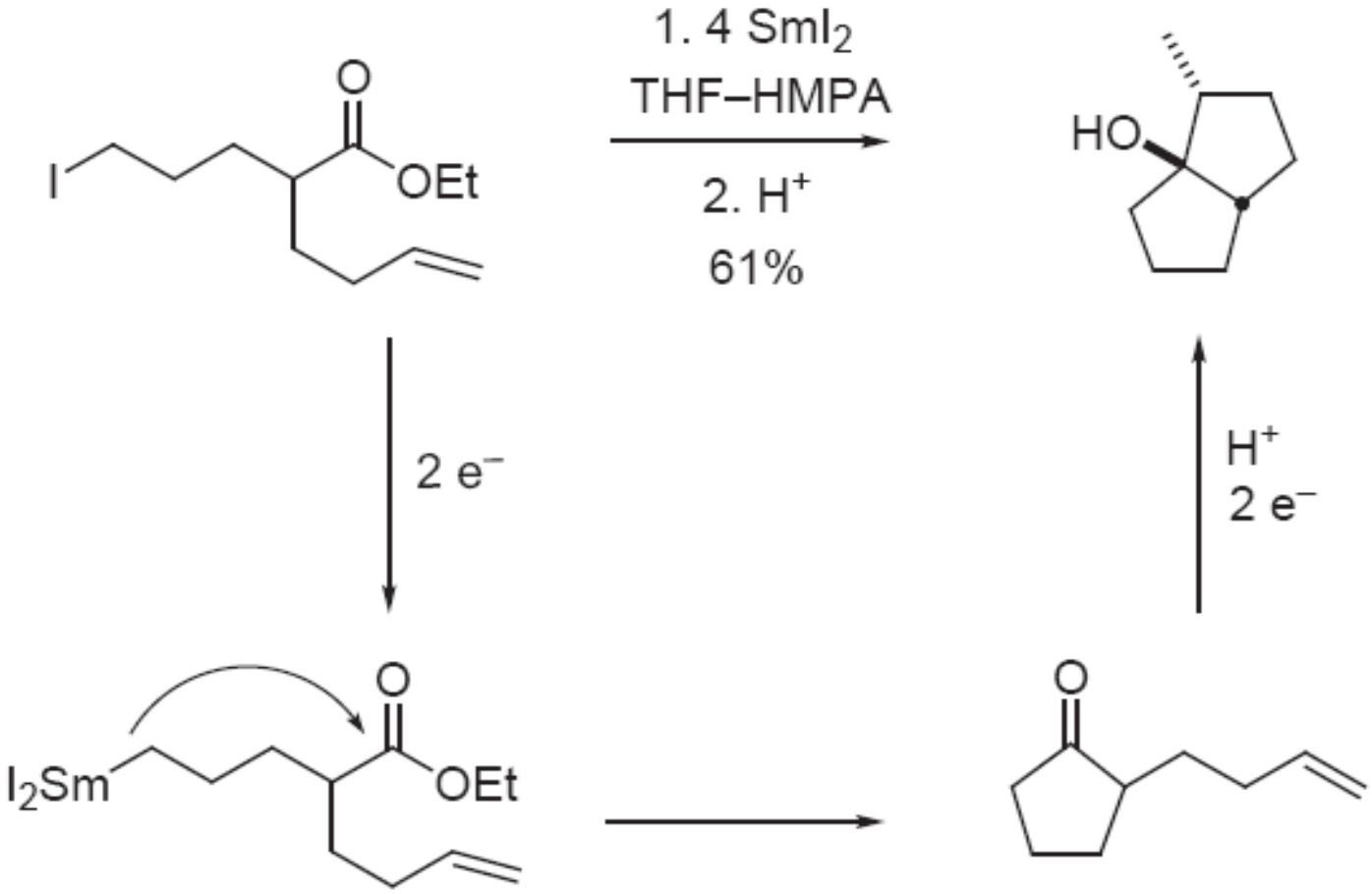


Inanaga *Tetrahedron Lett.* **1986**, *27*, 5763.

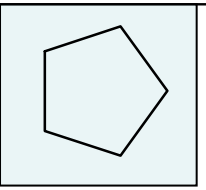
Tetrahedron Lett. **1989**, *30*, 2837.

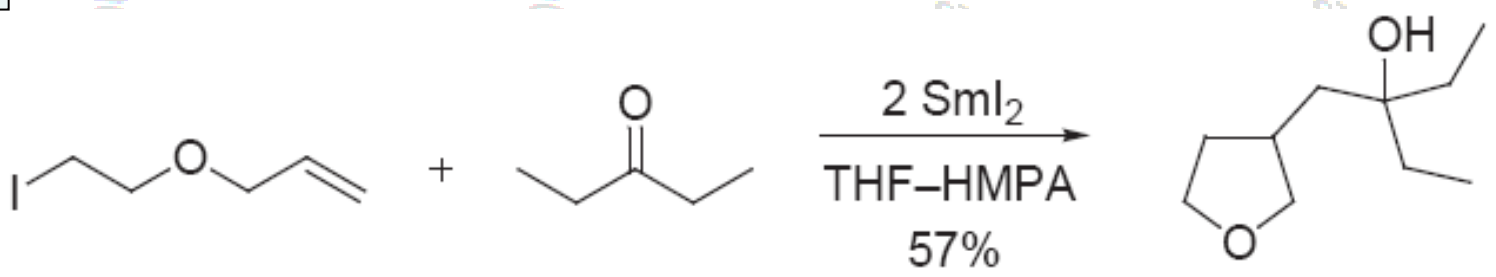
- Восстановительное сочетание с участием SmI_2



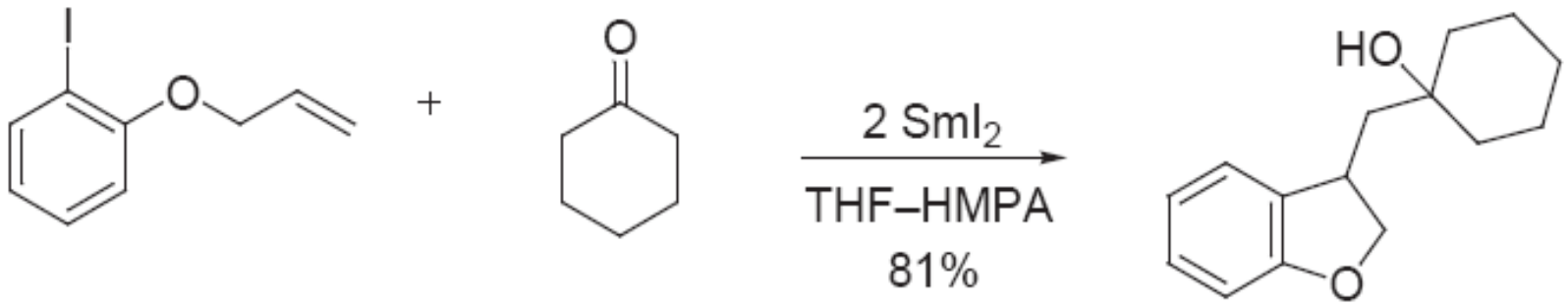


- Восстановительное сочетание с участием SmI_2

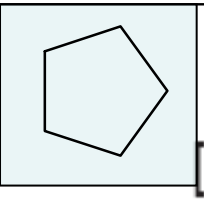




Molander *J. Org. Chem.* **1990**, *55*, 6171.



Curran *Synlett* **1990**, 773.



[2 + 2 + 1]

Comprehensive Org. Syn., Vol. 5, pp 1037–1064.

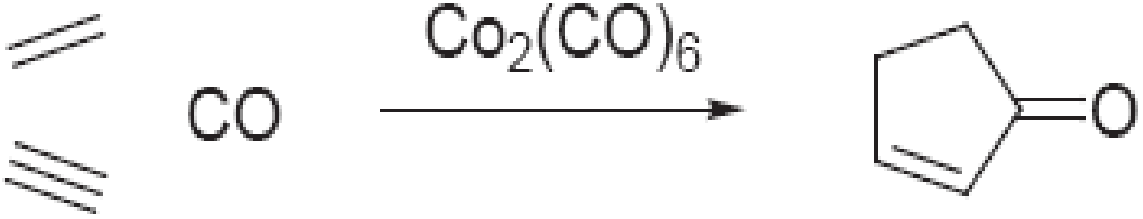
Org. React. **1991**, *40*, 1.

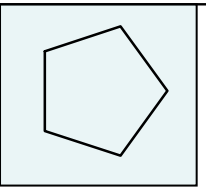
Pauson *Tetrahedron* **1978**, *41*, 5855.

Schore *Chem. Rev.* **1988**, *88*, 1081.

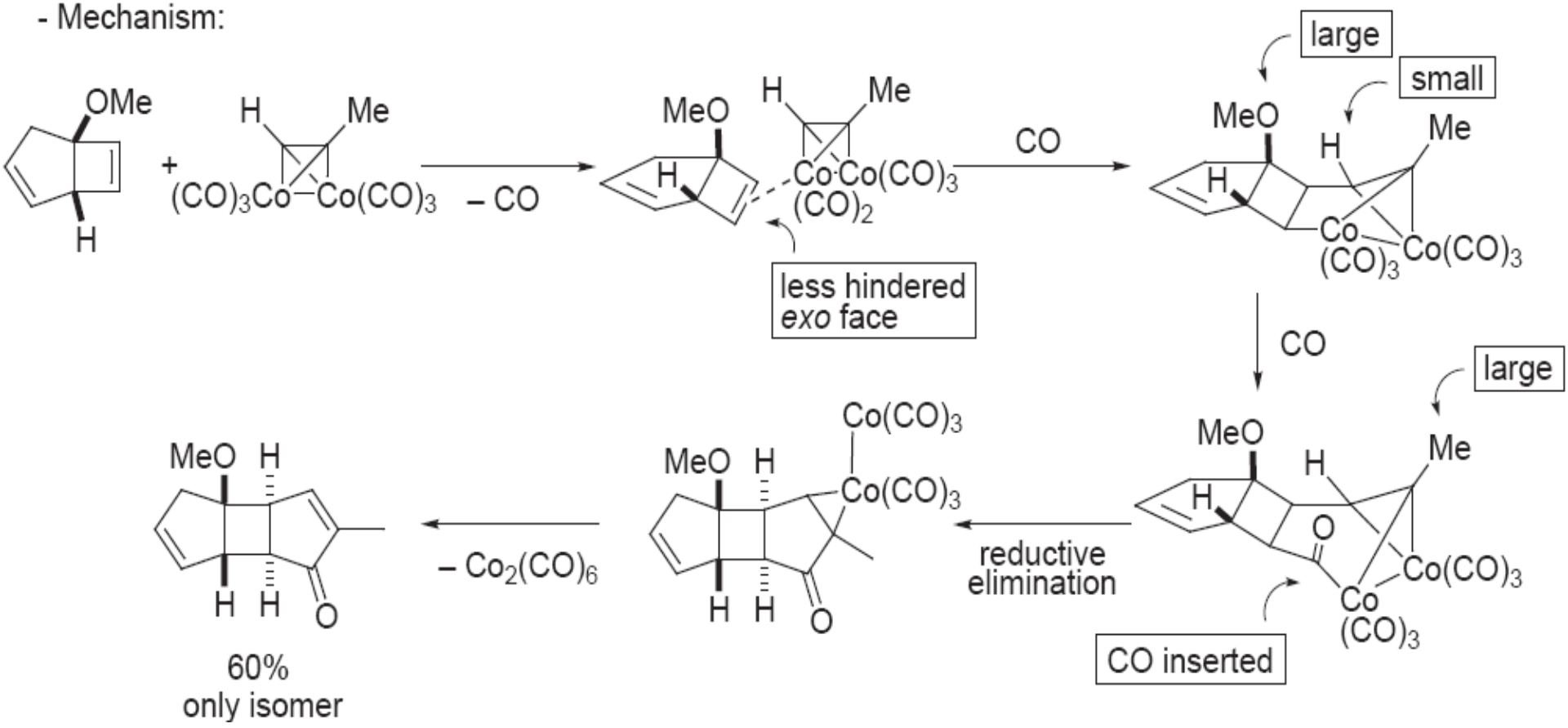
Brummond *Tetrahedron* **2000**, *56*, 3263.

First detailed study: Khand *J. Chem. Soc., Perkin Trans. 1* **1973**, 977.



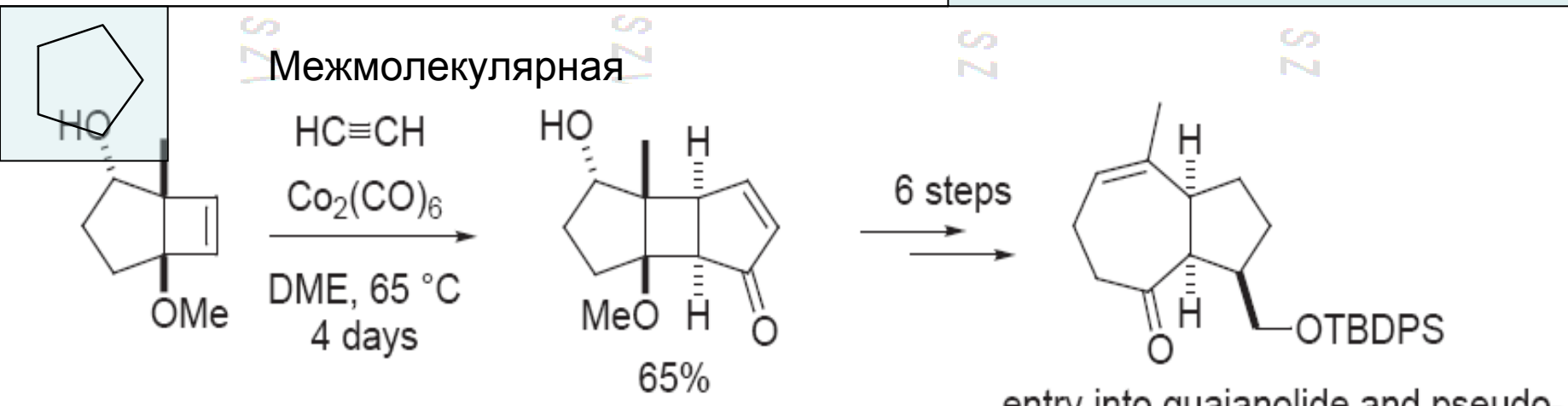


- Mechanism:



- Реакция Посона-Хэнда: примеры

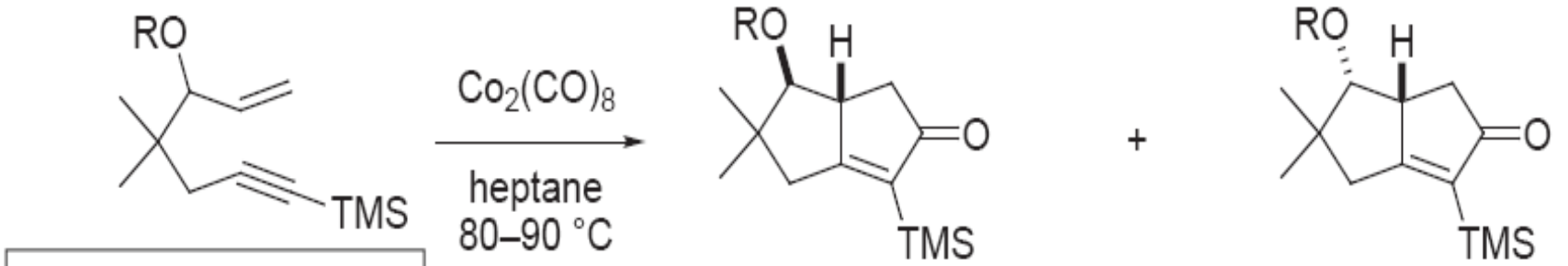
Межмолекулярная



Schore *J. Org. Chem.* **1987**, *52*, 3595.

entry into guaianolide and pseudo-guaianolide natural products

Внутримолекулярная



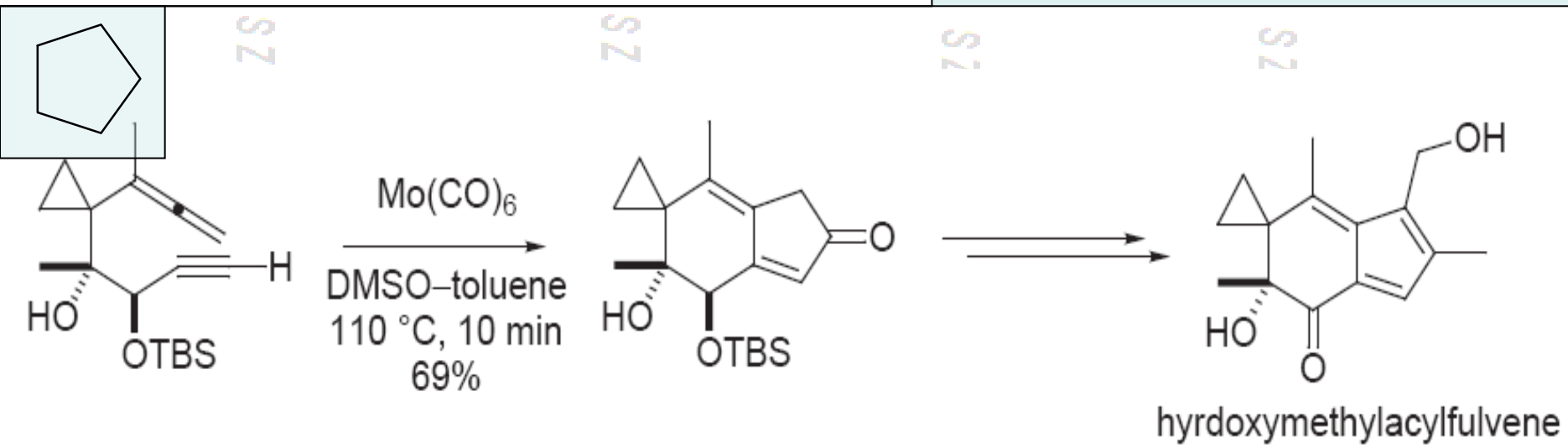
The dimethyl and alkyne substituents accelerate the reaction.

R = H, 18%
R = MOM, 69%

R = H, 7%
R = MOM, 0%

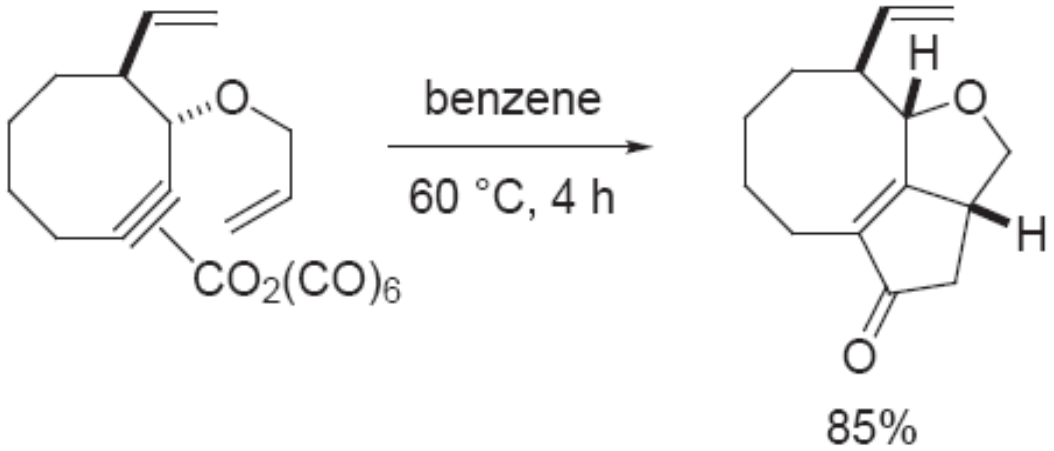
Magnus *J. Am. Chem. Soc.* **1983**, *105*, 2477.

- Реакция Посона-Хэнда: примеры



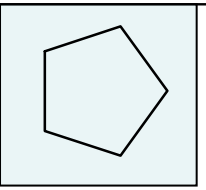
hyrdoxymethylacylfulvene

Brummond *J. Am. Chem. Soc.* **2000**, *122*, 4915.

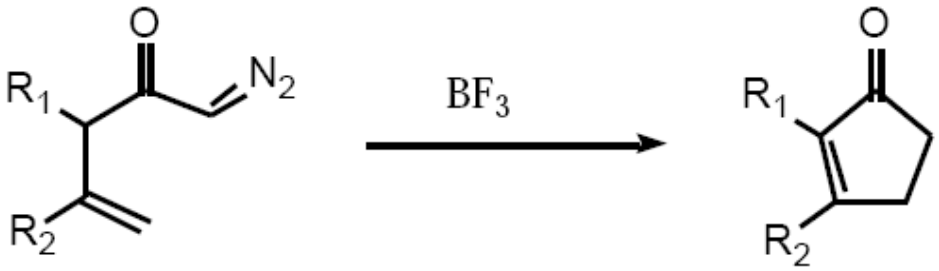


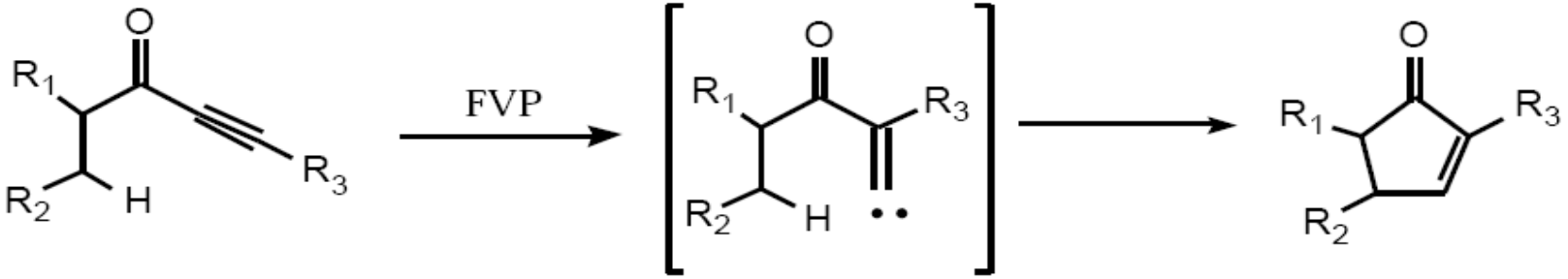
85%

Schreiber *J. Am. Chem. Soc.* **1986**, *108*, 3128.

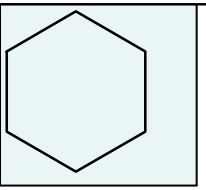


-диазосоединения





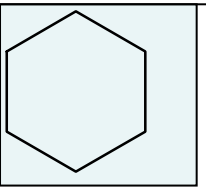
Образование циклов

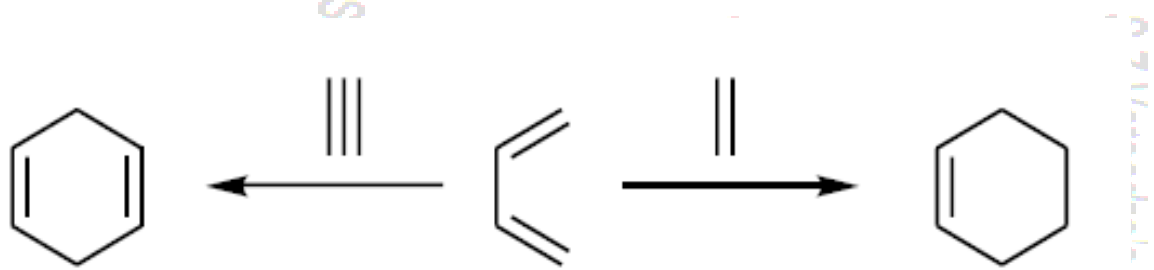


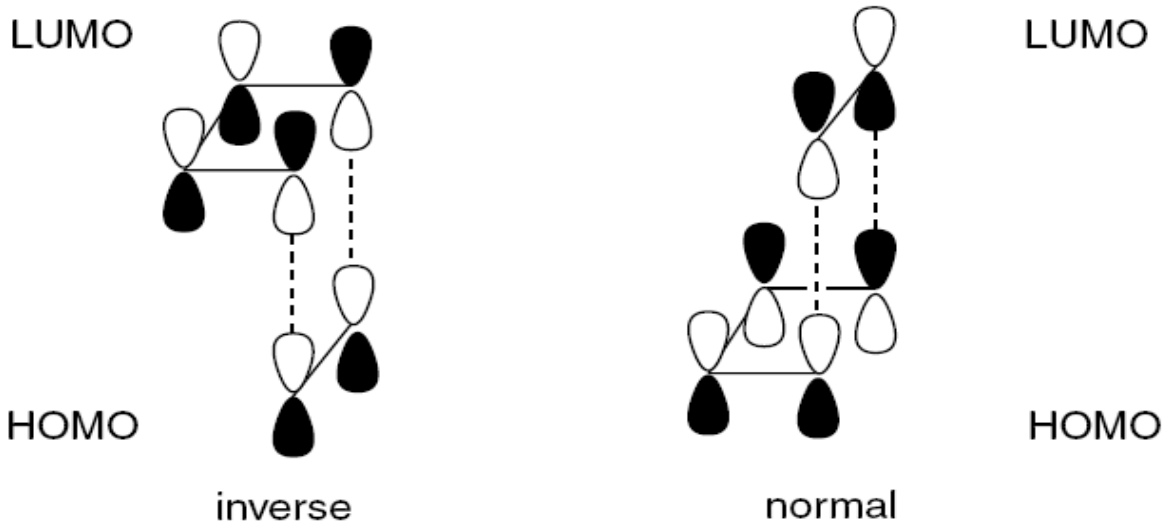
•сложноэфирная и альдольная конденсация
•присоединение по Михаэлю
•аннелирование по Робинсону
•метатезис с замыканием цикла
•циклизации катион+алкен
•Фишеровские карбены (р-я Дётса)
•тримеризация ацетиленов
•циклизация по Бергману и родственные процессы

-внутримолекулярное олефинирование по Виттигу
-S_N2-реакции
-ацилоиновая кондесация
-реакция Дильса-Альдера, *о*-хинодиметаны
-расширение и сужение циклов
-ароматическое замещение с послед. гидрирированием или восстановлением по Берчу
-радикальные циклизации
-сигматропные перегруппировки
--внутримолекулярная еновая реакция

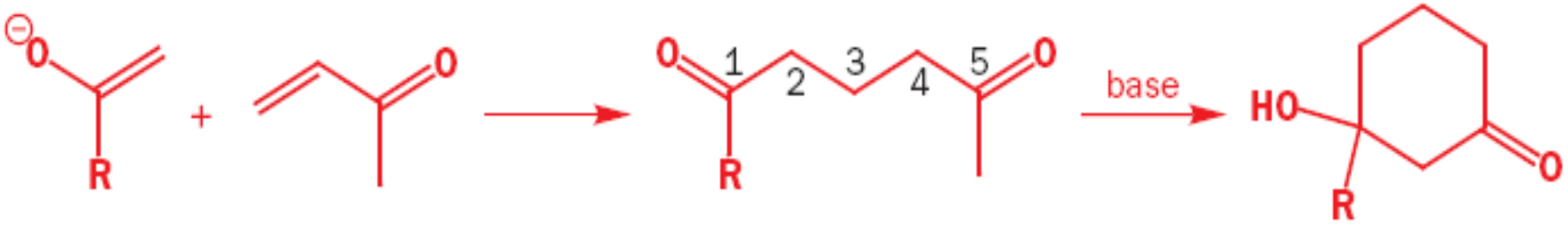
- [4+2]-циклоприсоединение





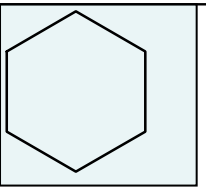


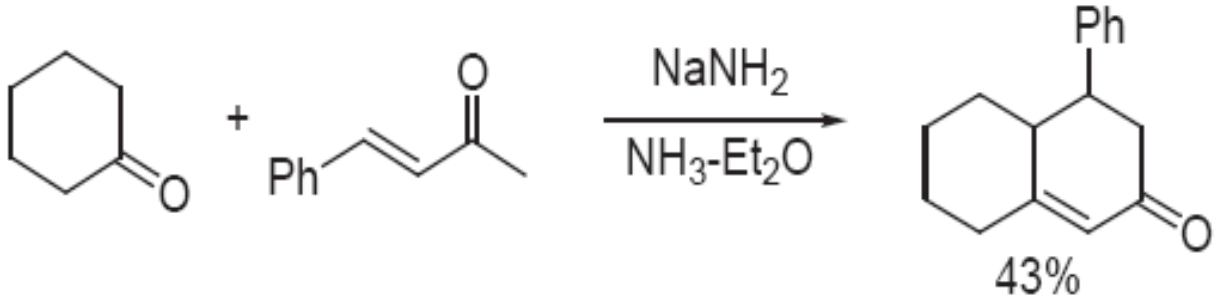
- Реакция Робинсона



1947
SIR ROBERT ROBINSON for his investigations on plant products of biological importance, especially the alkaloids.

1886-1975



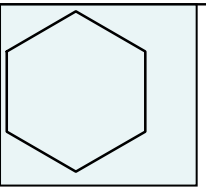


Robinson *J. Chem. Soc.* **1935**, 1285.

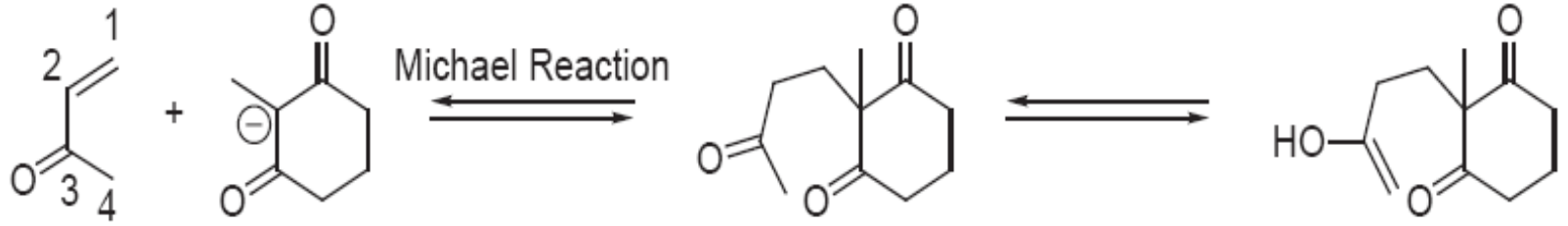
Reviews
M. Jung, *Tetrahedron* **1976**, *32*, 3.
Org. React. **1959**, *10*, 179.
Org. React. **1968**, *16*, 3.
Synthesis **1976**, 777.
Synthesis **1969**, 49.

Robinson *J. Chem. Soc.* **1917**, 762. (tropinone)

- Реакция Робинсона



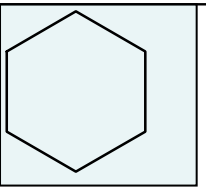
- Formally, a [4 + 2] condensation approach



H. Wieland received the 1927 Nobel Prize in Chemistry for his work in isolating and deducing the structures of bile acids/steroids including cholic acid. He concluded his Nobel Lecture with the statement that he had a "duty" to synthesize the bile acids even though the task was insurmountable at the time.

Wieland–Miescher ketone

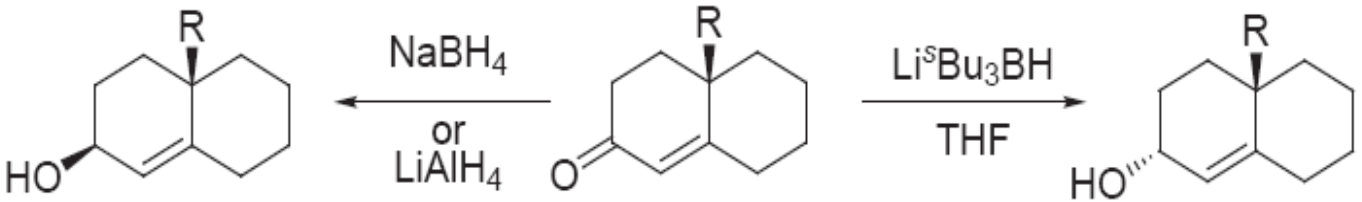
Wieland and Miescher *Helv. Chim. Acta* **1950**, *33*, 2215.



- Alternative "[3 + 3] Robinson Annulation"

Both the [4 + 2] and [3 + 3] approaches were first generalized by Robinson
J. Chem. Soc. **1937**, 53.

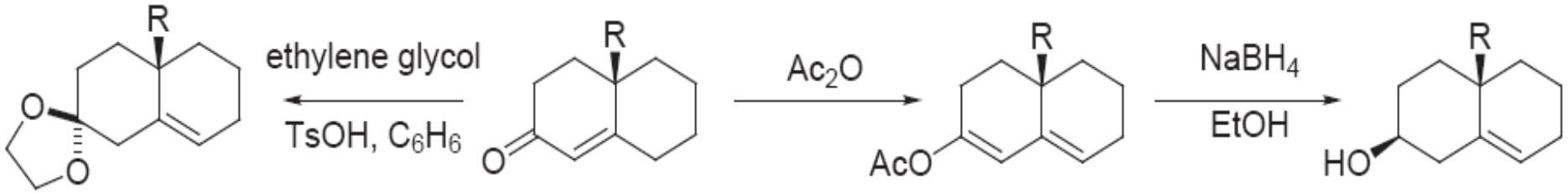
Некоторые синтетические превращения Робинсоновских продуктов



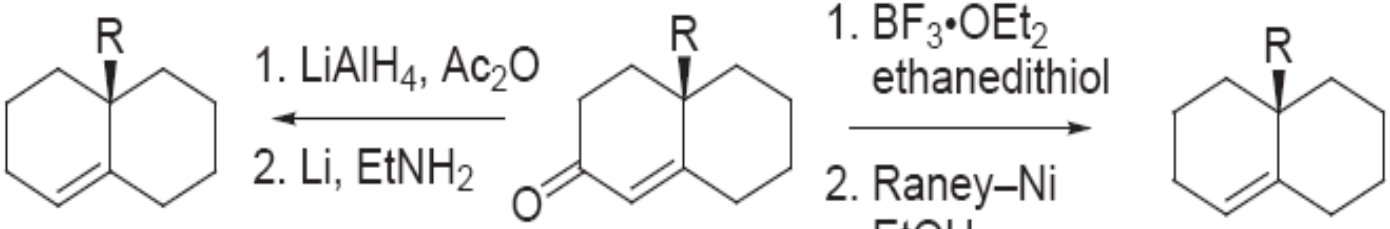
axial H^- delivery
equatorial –OH

equatorial H^- delivery
axial –OH

- Deconjugation with ketalization or reduction



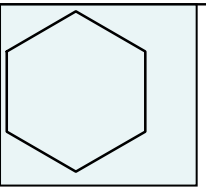
Marshall *J. Org. Chem.* **1972**, *37*, 982.



- Внутримолекулярное ацилирование енолятов

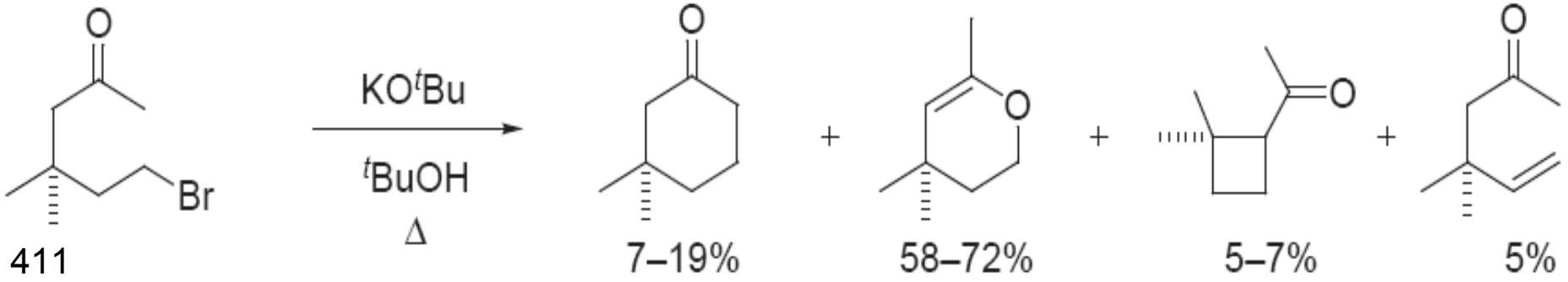
Конденсация Дикмана

- Внутримолекулярное алкилирование енолятов

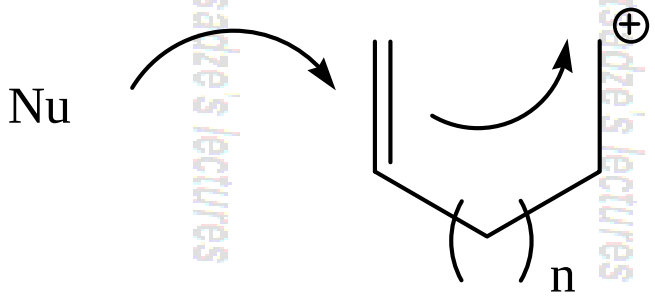


House *J. Org. Chem.* **1978**, *43*, 700.

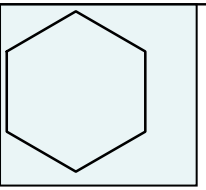
Сравните с т/д условиями:



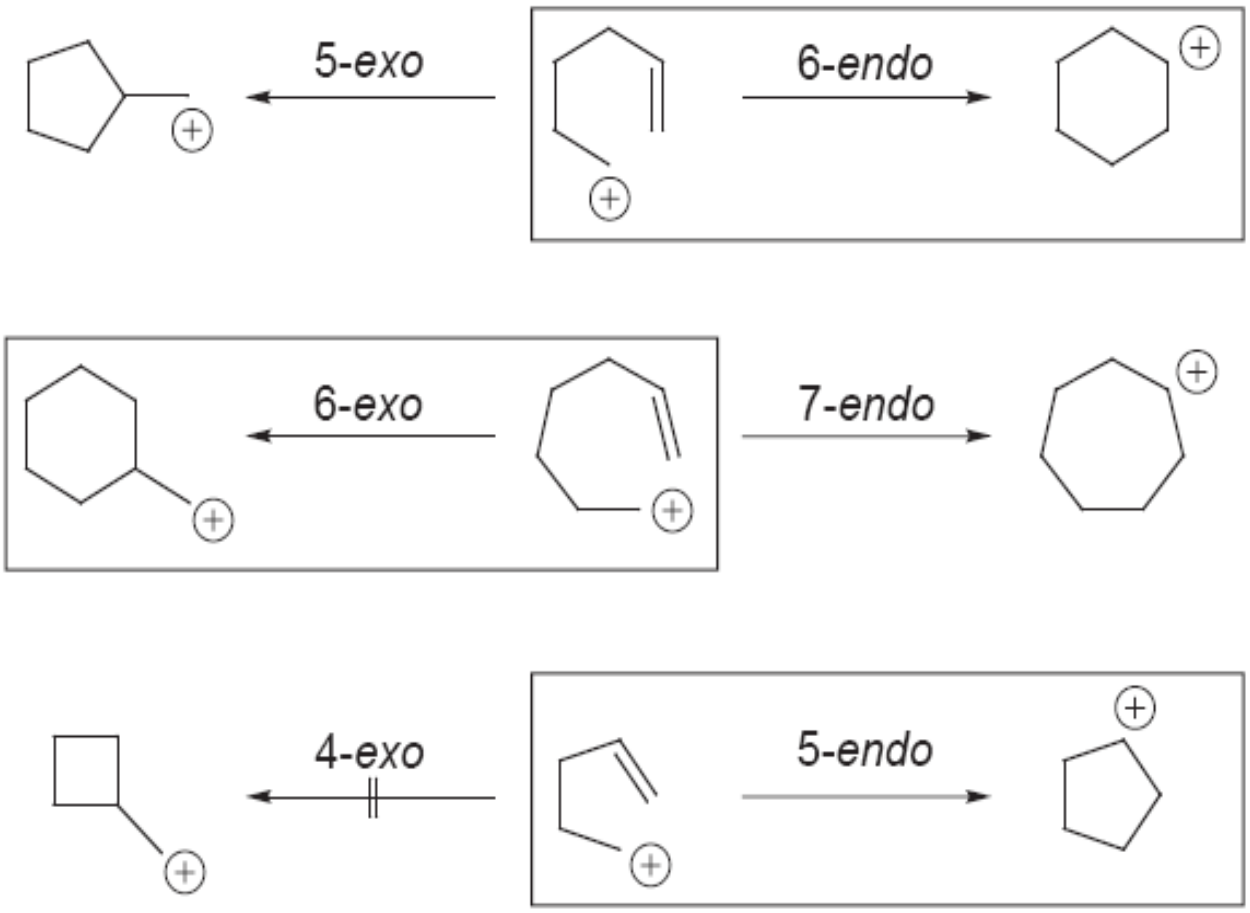
- Катион-алкен/алкин

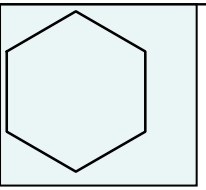


Johnson	*Acc. Chem. Res.* **1968**, *1*, 1.
	Angew. Chem., Int. Ed. Eng. **1976**, *15*, 9.
	Bioorg. Chem. **1976**, *5*, 51.
van Tamelen	*Acc. Chem. Res.* **1968**, *1*, 111.
Harding	*Bioorg. Chem.* **1973**, *2*, 248.
Goldsmith	*Fortschr. Chem. Org. Nat.* **1972**, *29*, 363.
Lansbury	*Acc. Chem. Res.* **1972**, *5*, 311.
Speckamp	*Recl. Trav. Chim. Pays-Bas.* **1981**, *100*, 345.
Sutherland	*Comprehensive Org. Syn.* Vol 3, pp 341–377.

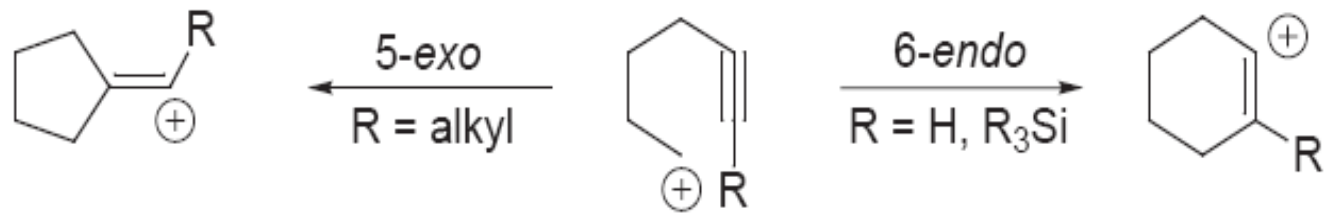


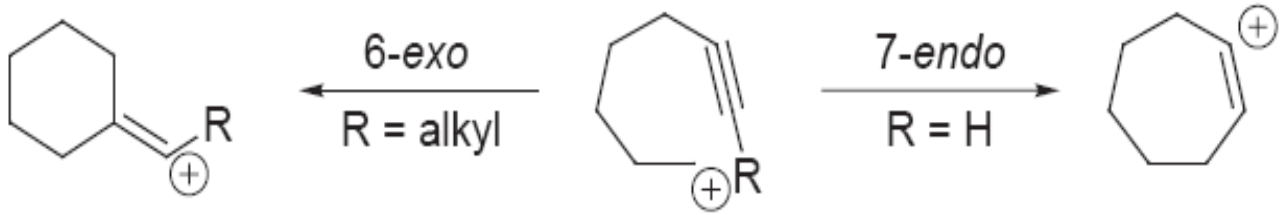
Алкены



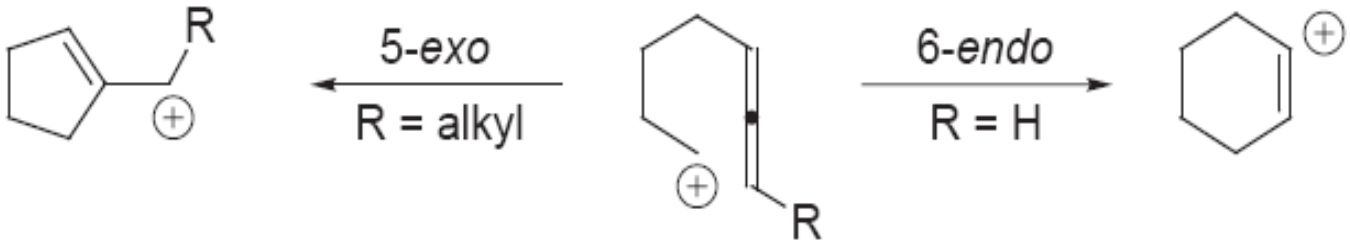


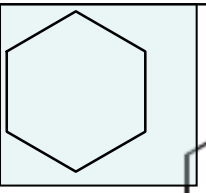
Алкины

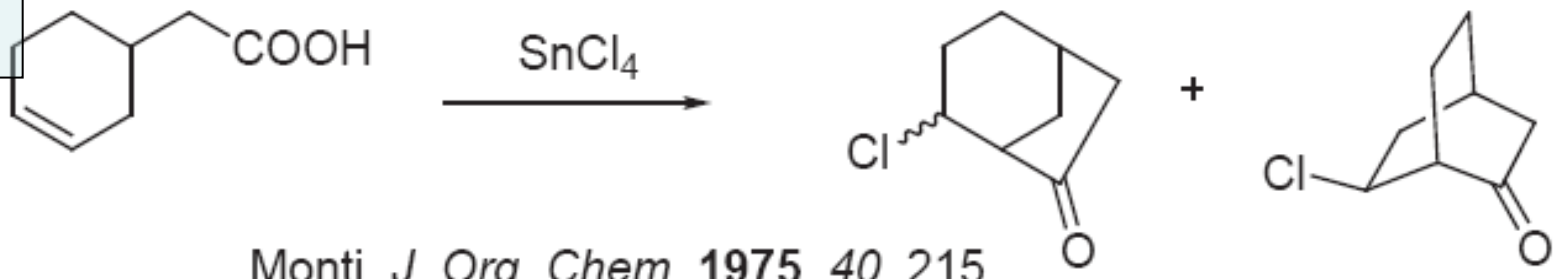




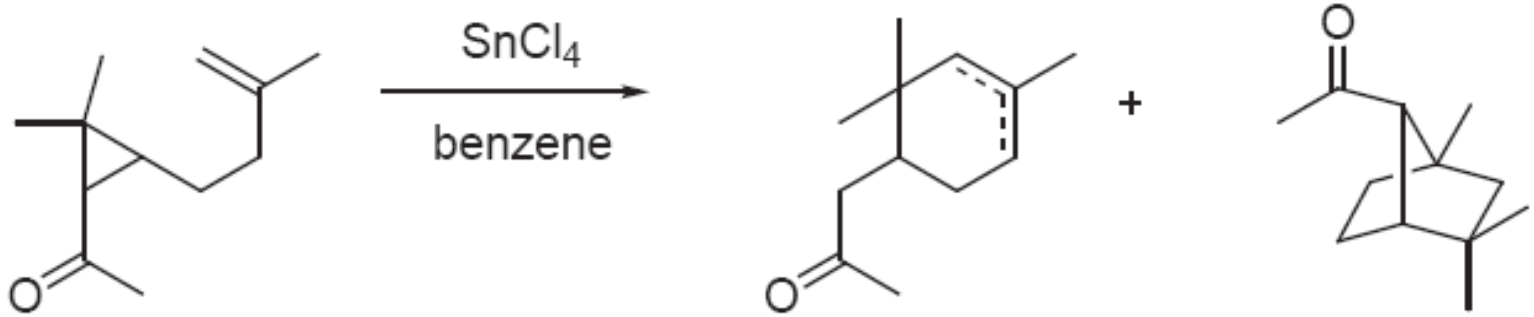
Аллены



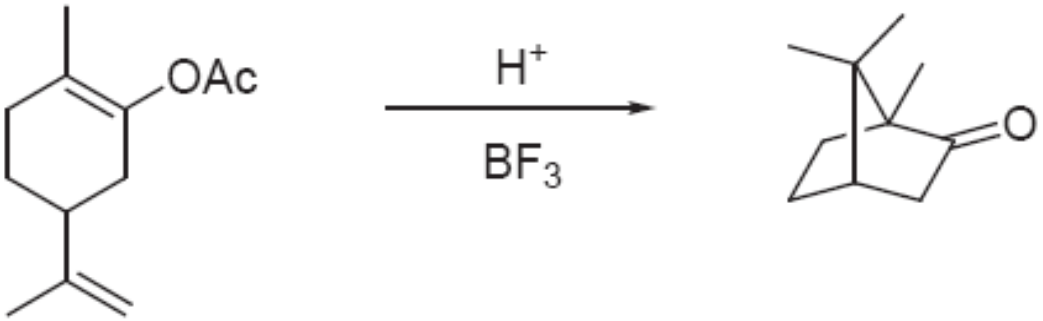




Monti *J. Org. Chem.* **1975**, *40*, 215.

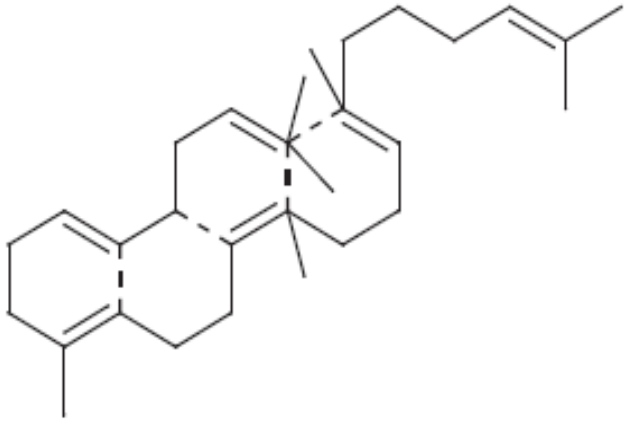


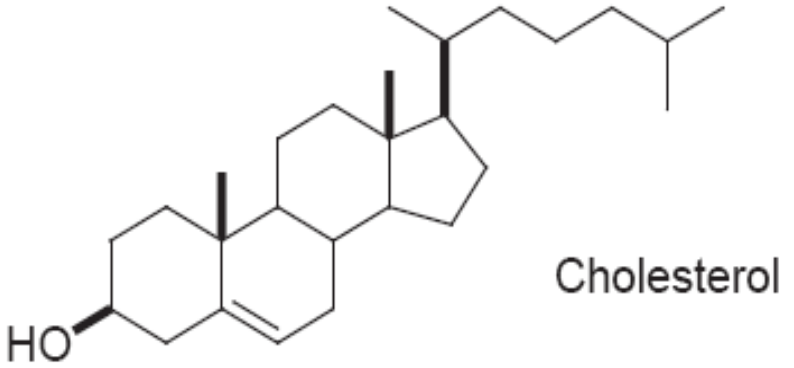
Grieco *Tetrahedron Lett.* **1974**, 527.



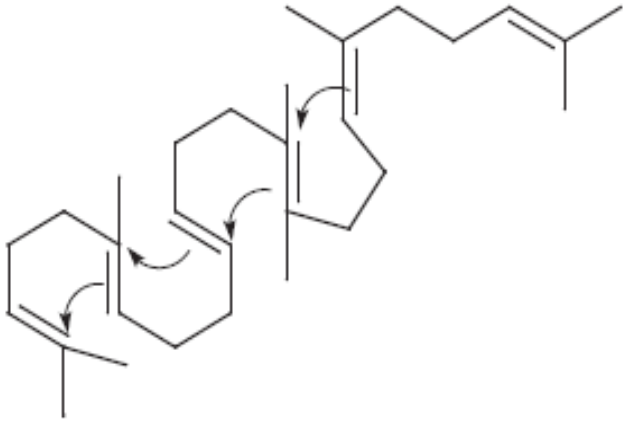
Money *J. Chem. Soc., Chem. Commun.* **1969**, 1196.
Goldsmith *J. Org. Chem.* **1970**, *35*, 3573.

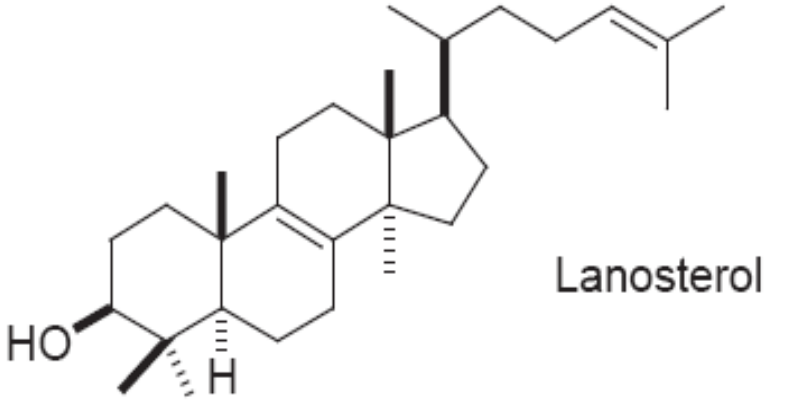
- Robinson's proposal





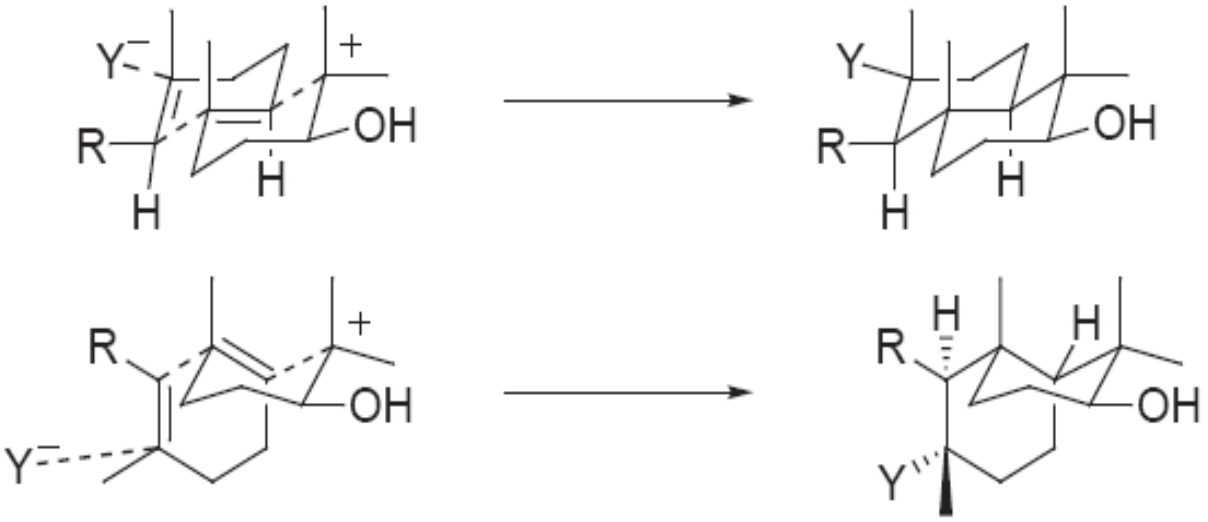
- Correct cyclization scheme





Lanosterol was proposed in 1953 by Woodward and Bloch.

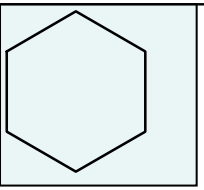
Гипотеза Сторка-Эшенмозера: транс-анти-транс-стереохимия является результатом согласованной циклизации полиенов

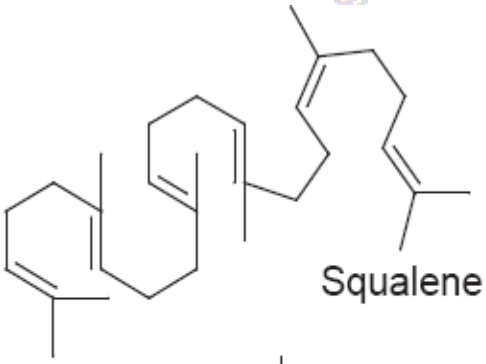


Сравните с AdE стереохимией!!!

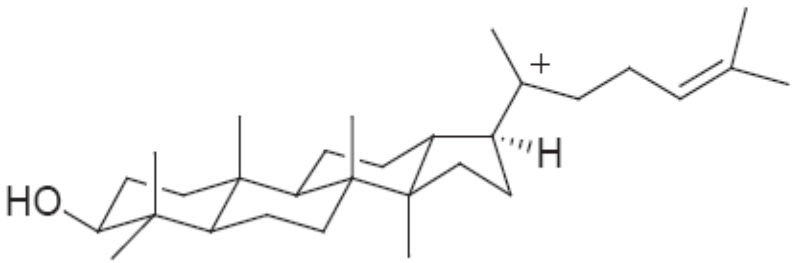
- Катион-алкен/алкин

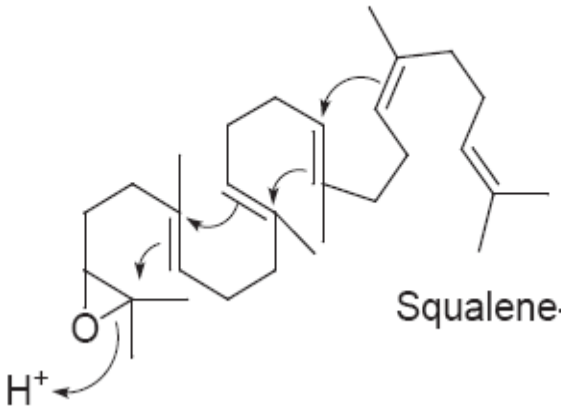
Образование циклов





Squalene
monooxygenase

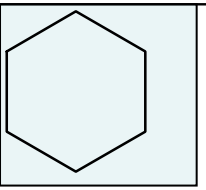




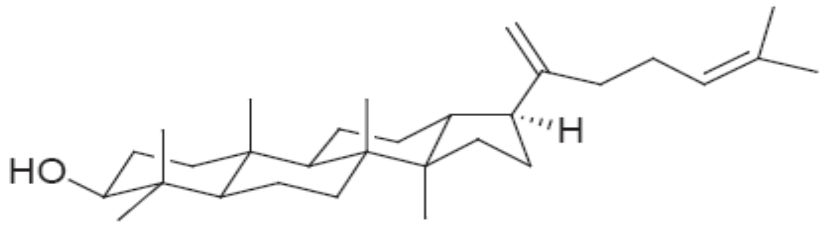
Squalene-2,3-oxide

- Катион-алкен/алкин

Образование циклов

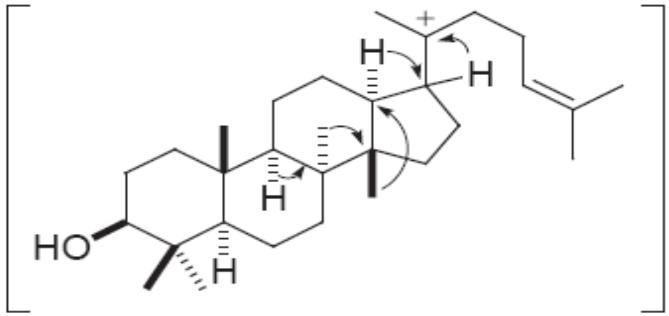


$-H^+$



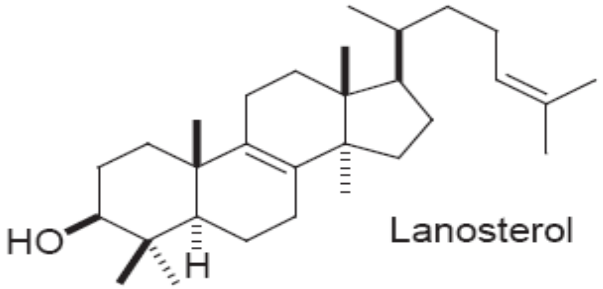
Dammaradienol
8 chiral centers with 256 possible stereoisomers

2,3-Oxidosqualene
lanosterol cyclase



- Two methyl migrations and two hydride transfers

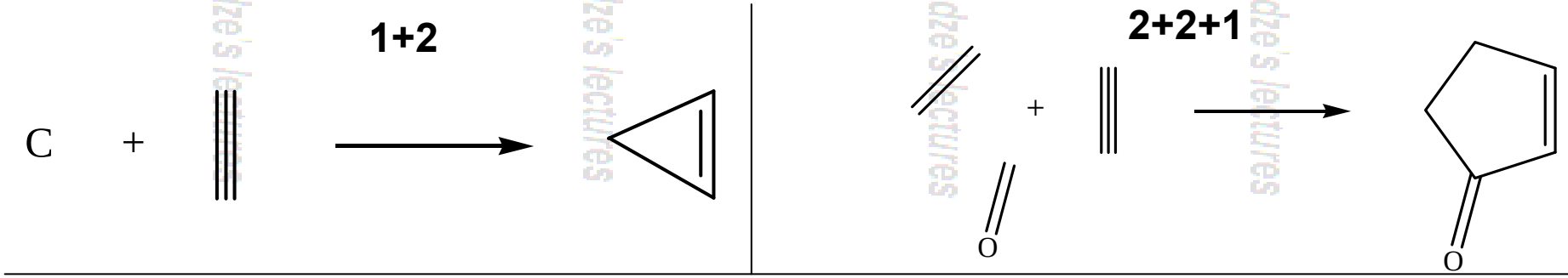
$-H^+$

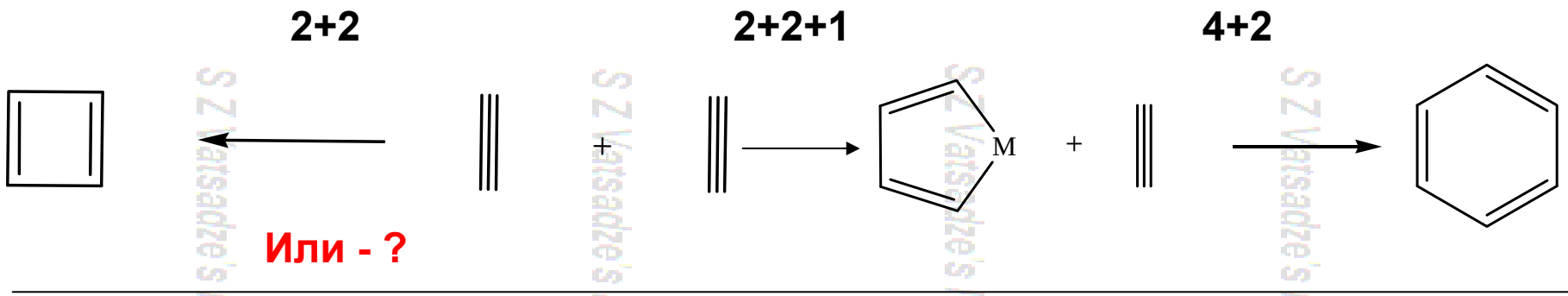


Lanosterol

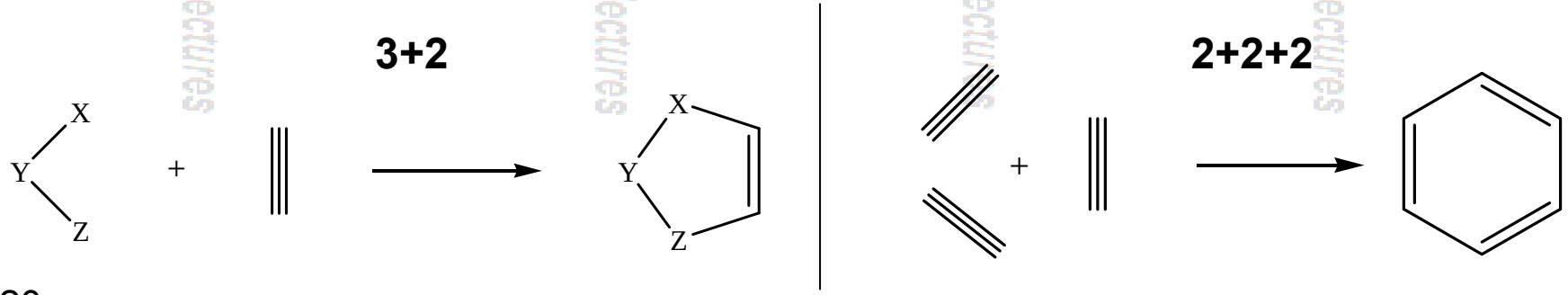
Алкины в синтезе циклов

Алкин – поставщик С2-фрагмента. Следовательно, можно предложить несколько схем реакций циклизации с участием алкинов





Или - ?

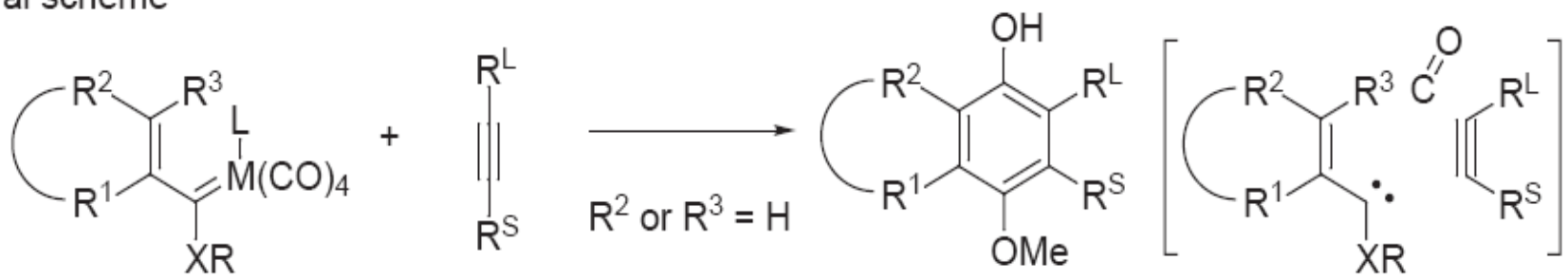


С алкинами обычно [3+2+1]

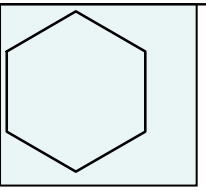
- Six-membered rings [3 + 2 + 1] (Fischer carbene addition to alkynes)

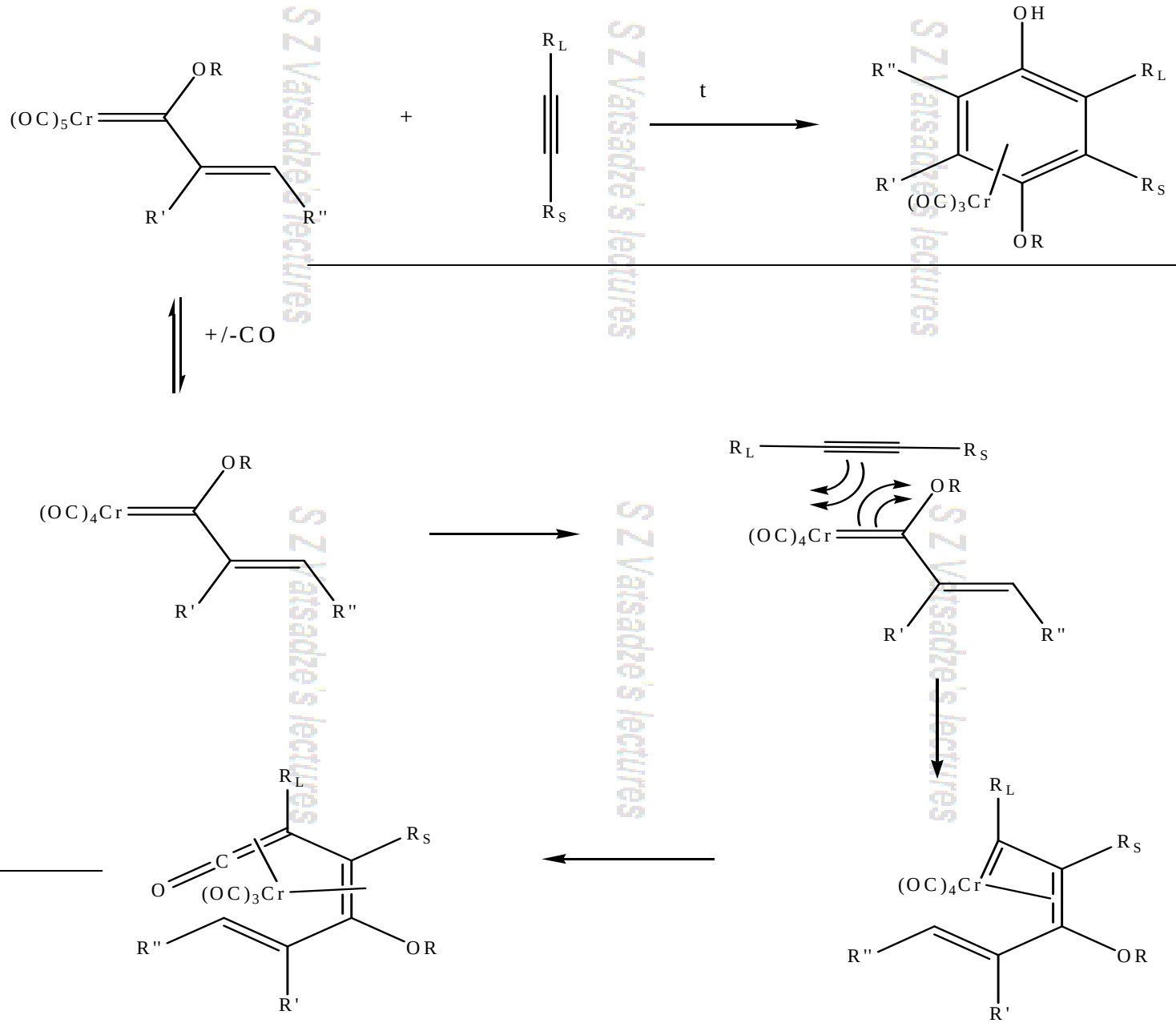
Dötz, Fischer *Transition Metal Carbene Complexes*, VCH: Deerfield Beach, FL, 1983.
Dötz *Angew. Chem., Int. Ed. Eng.* **1984**, *23*, 587.
Casey in *Transition Metal Organometallics in Organic Synthesis*, Academic Press: New York, 1976, Vol. 1.
Dötz *Pure Appl. Chem.* **1983**, *55*, 1689.
Casey in *Reactive Intermediates*, Wiley Interscience: New York, 1982, Vol. 2, and 1985, Vol. 3.
Hegedus *Principles and Applications of Organotransition Metal Chemistry*, University Science Books: Mill Valley, CA, 1987, 783.
Brown *Prog. Inorg. Chem.* **1980**, *27*, 1.
Wulff in *Advances in Metal-Organic Chemistry*, JAI Press: Greenwich, CT, 1989, Vol. 1.

- General scheme



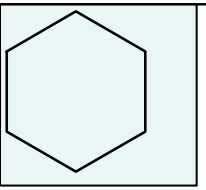
- 2+2: применение - реакция Дётса

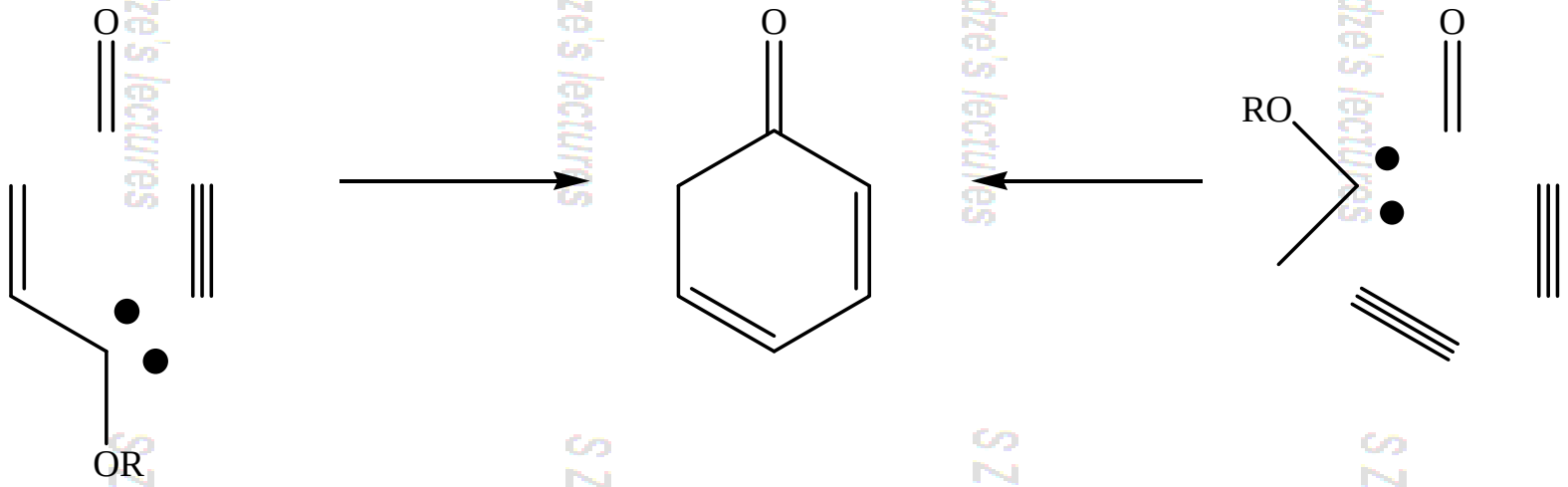




Закончить!

- 2+2: применение - реакция Дётса - обобщение

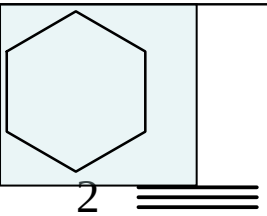




3+2+1

2+2+1+1

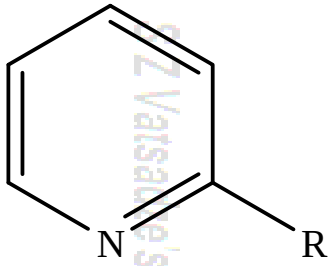
- Каскадные реакции с металлами$(2+2)^n$

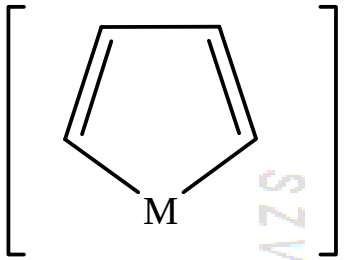


2

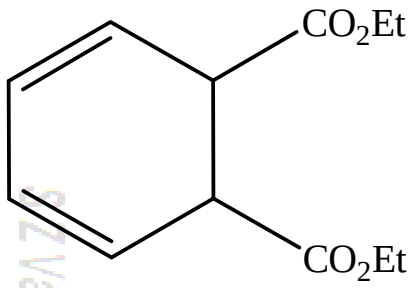
M

RCN

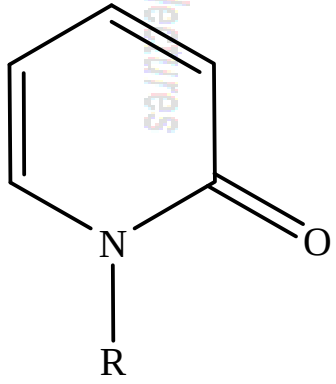




$EtO_2CCH=CHCO_2Et$



R-N=C=O



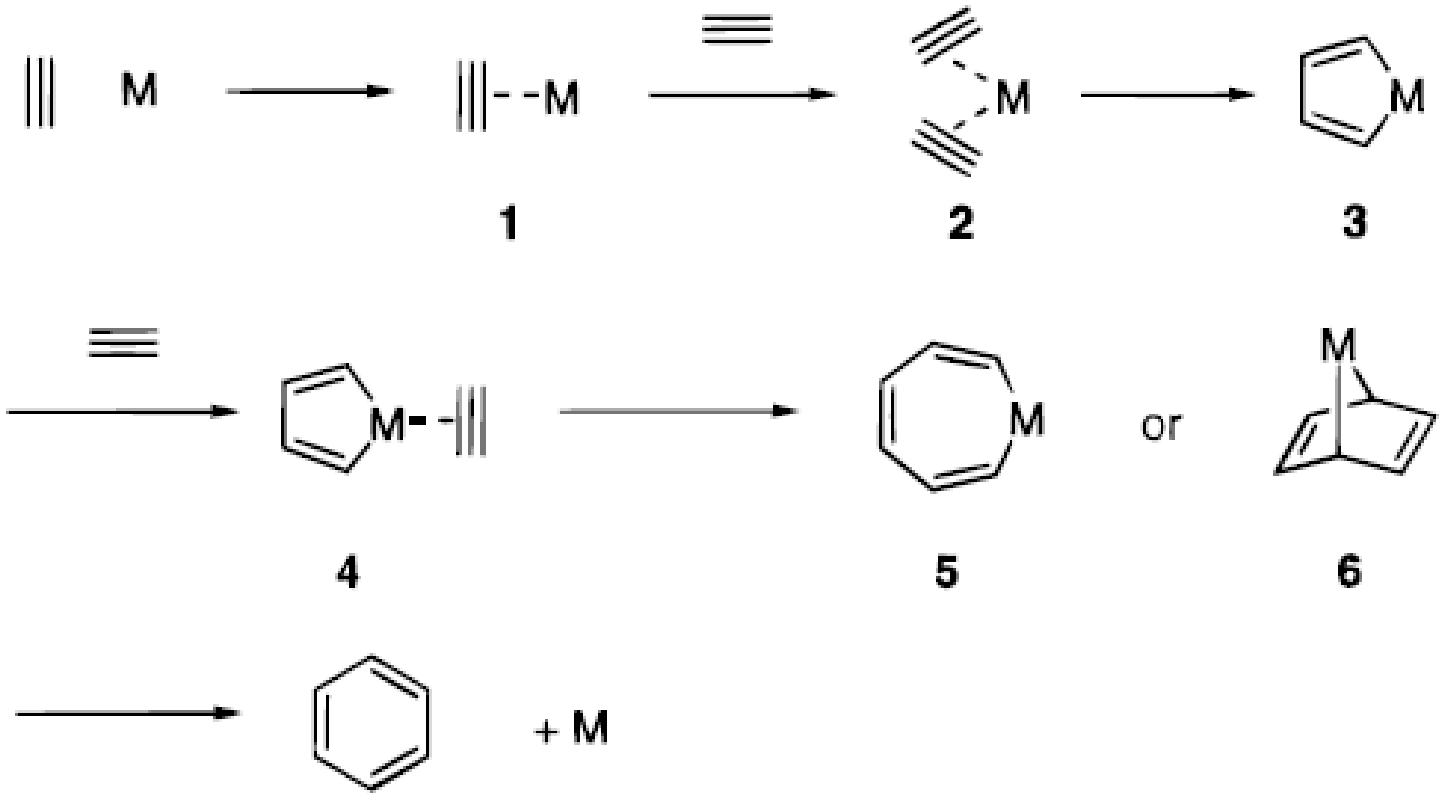
M = CoCp

2+2+2

Chem. Rev. 2000, 100, 2901–2915

Recent Advances in the Transition-Metal-Catalyzed Regioselective Approaches to Polysubstituted Benzene Derivatives

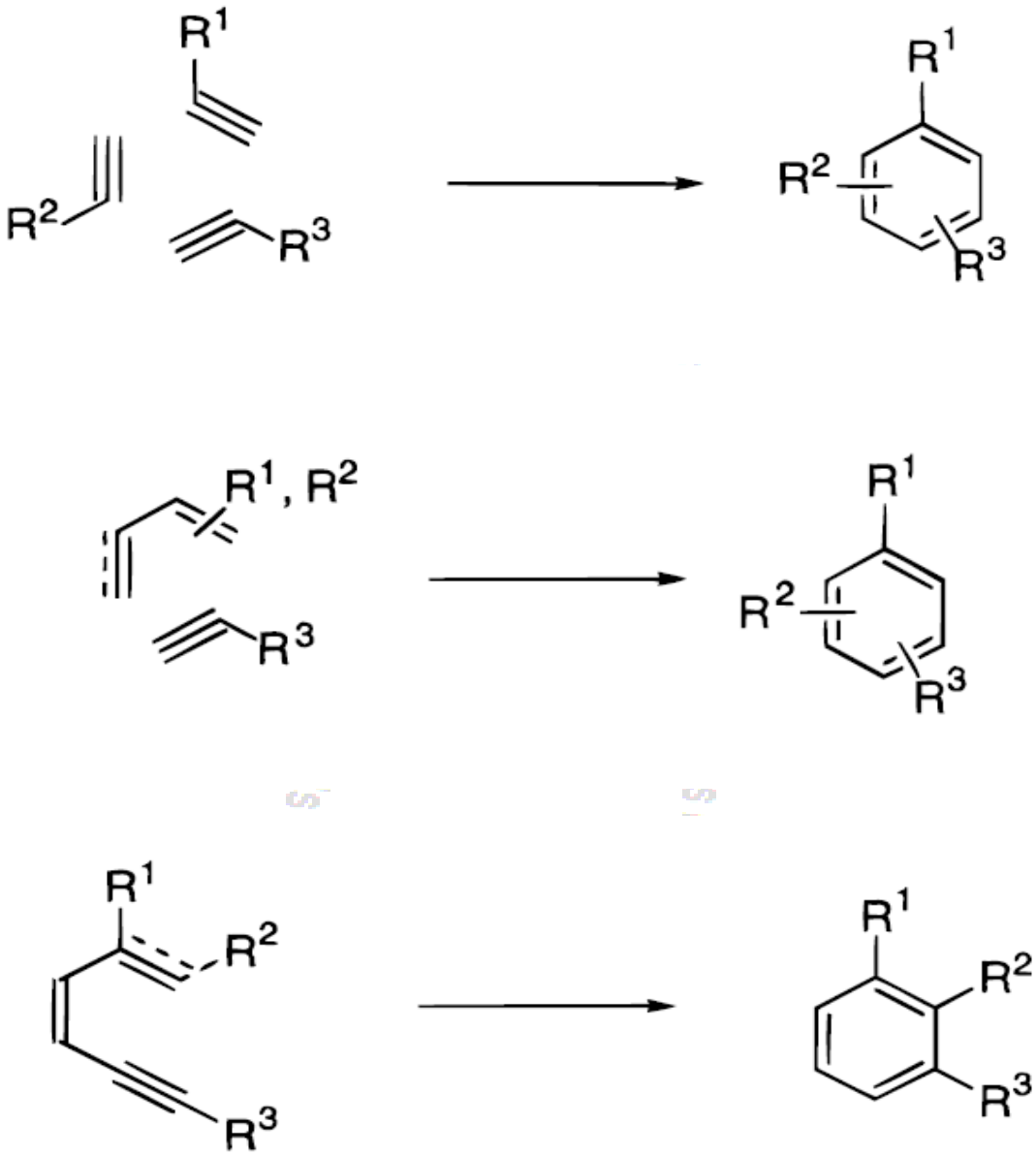
Shinichi Saito* and Yoshinori Yamamoto*



1 2 3 4 5 6 7

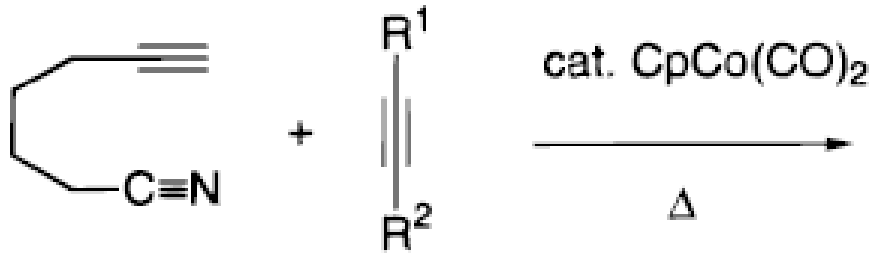
2+2+2

- 2+2+2: применение

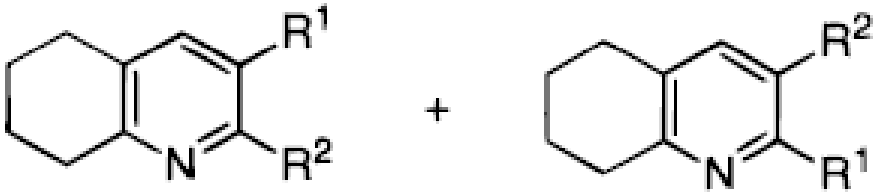


2+2+2

- 2+2+2: применение



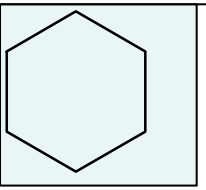
28 **29**

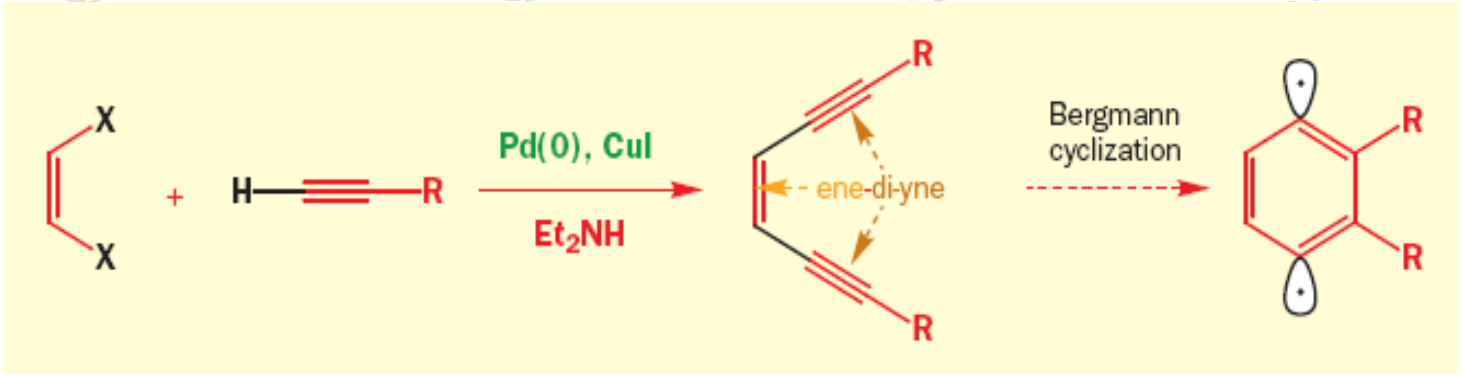


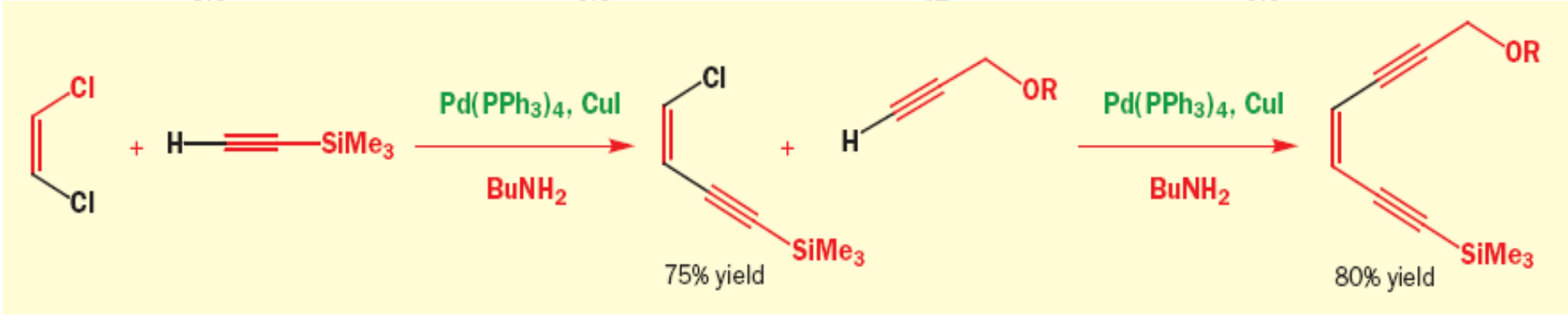
30 **31**

2+2+2

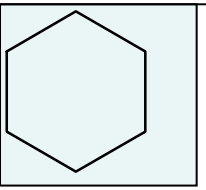
- Циклизация по Бергману

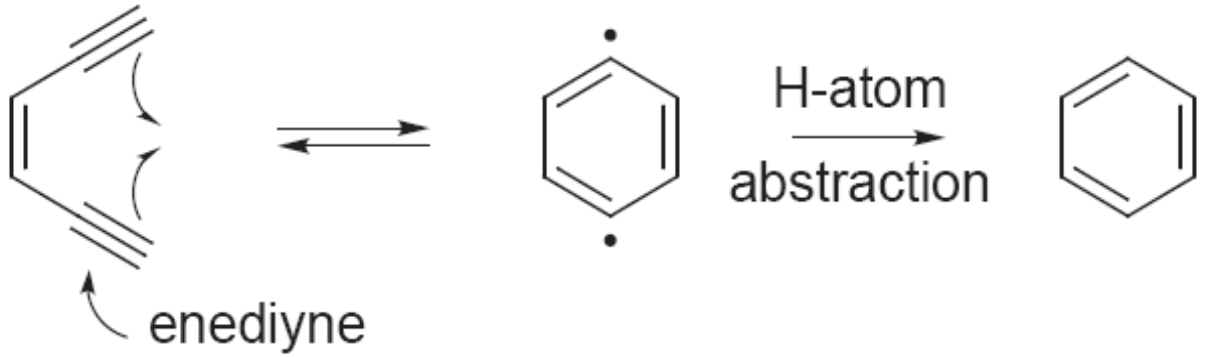




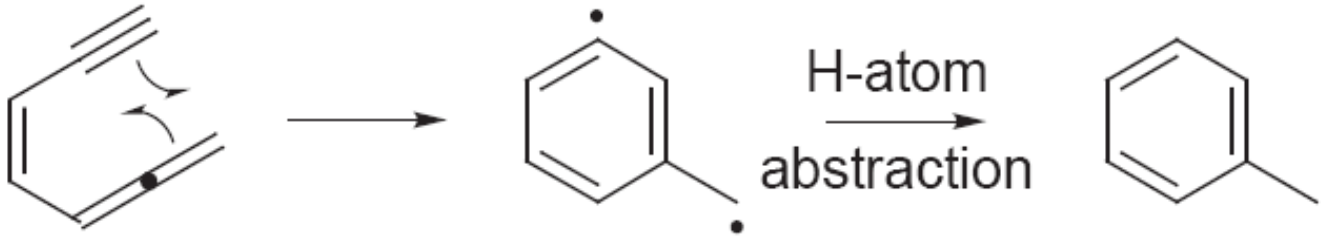


- Циклизация по Бергману и Майерсу-Сайто



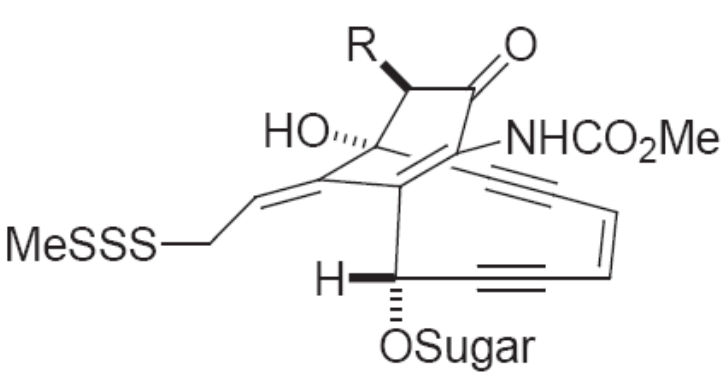


Bergman *J. Am. Chem. Soc.* **1972**, *94*, 660.
Acc. Chem. Res. **1973**, *6*, 25.

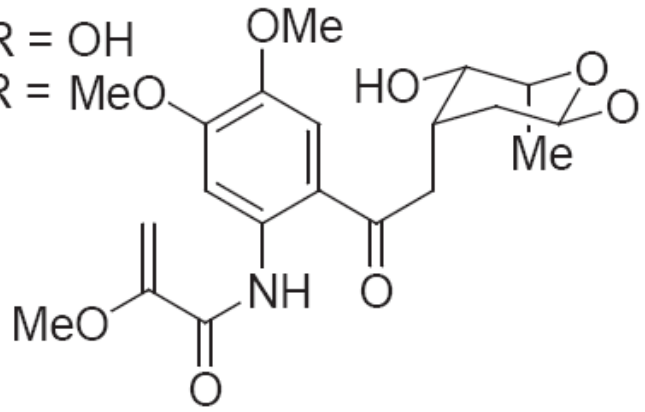


Myers *J. Am. Chem. Soc.* **1988**, *110*, 7212; **1992**, *114*, 9369.

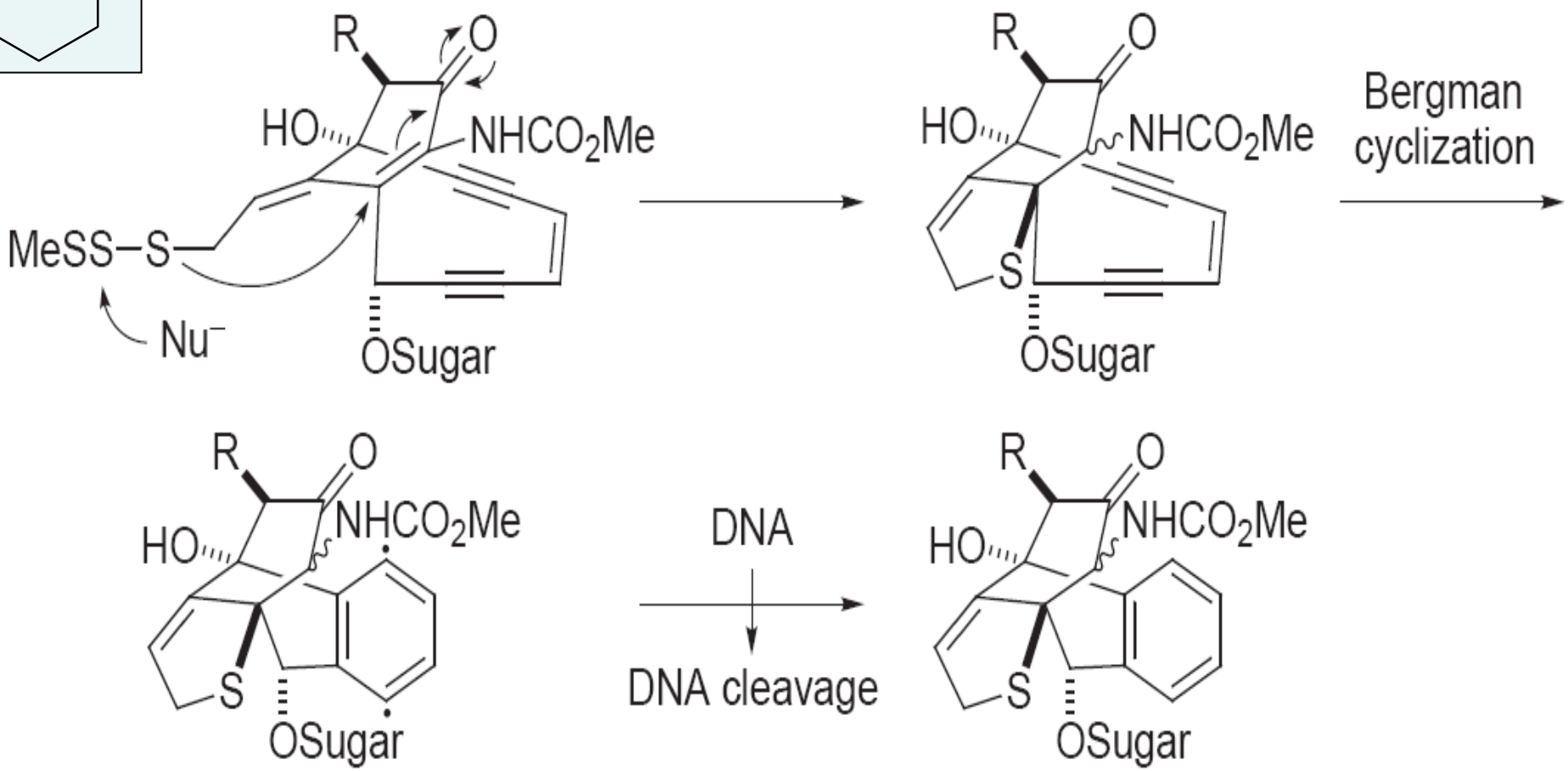
- Циклизация по Бергману: ендииновые антибиотики



calicheamicin R = OH
esperamicin R = MeO

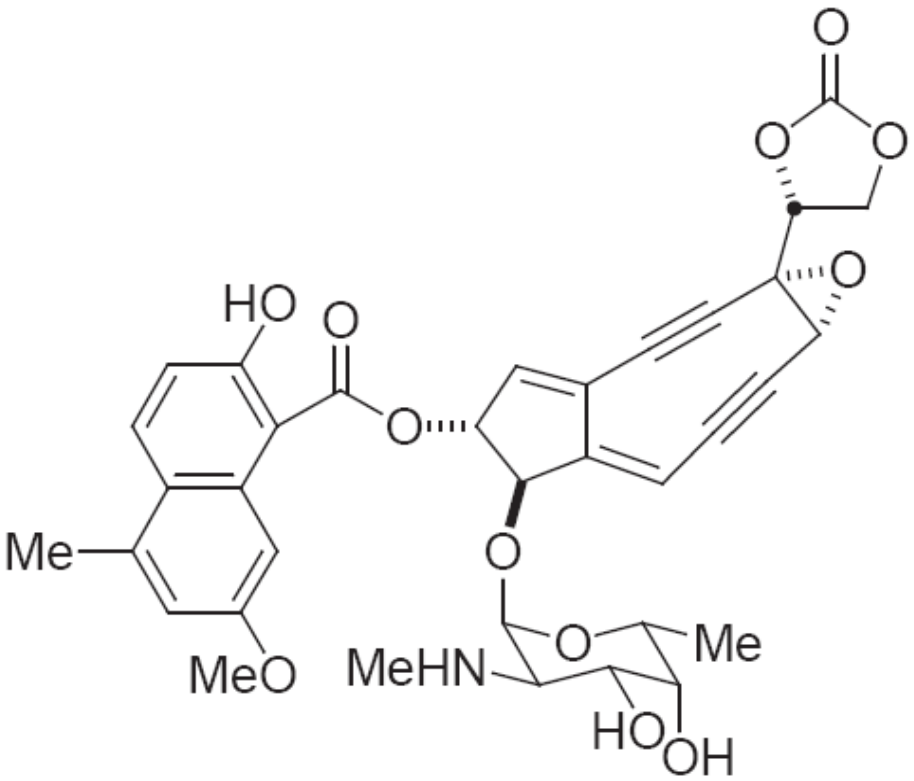


- Циклизация по Бергману: ендииновые антибиотики



***Full-story*: Бочков, Смит, Кейпл**

- Циклизация по Майерсу-Сайто: ендииновые антибиотики



neocarzinostatin chromophore

- Циклизация по Майерсу-Сайто: ендииновые антибиотики