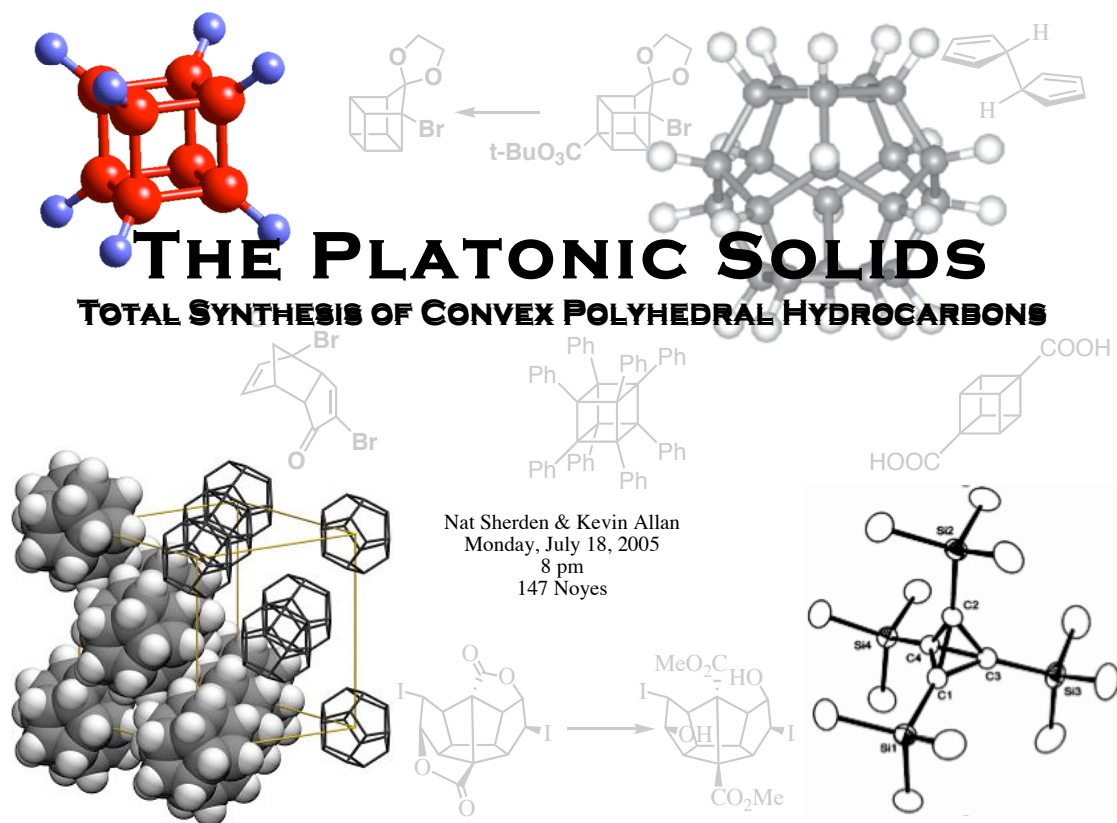




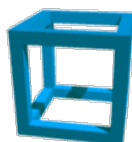
The Five Elements - Platonic Solids



Tetrahedron

Fire

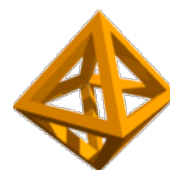
$$4 + 4 - 6 = 2$$



Hexahedron (Cube)

Earth

$$8 + 6 - 12 = 2$$



Octahedron

Air

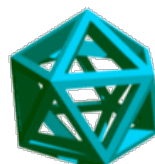
$$6 + 8 - 12 = 2$$



Dodecahedron

Heavenly Matter

$$20 + 12 - 30 = 2$$



Icosahedron

Water

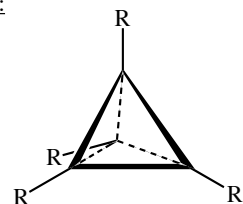
$$12 + 20 - 30 = 2$$

- **Polyhedron:** a closed surface made up of polygonal regions.
- **Regular polyhedron:** a polyhedron whose faces are congruent regular polygonal regions, and each vertex is the intersection of the same number of edges.
- There are exactly FIVE that can be made: the Platonic solids, first emphasized by Plato.
- Plato believed that each of the polyhedra represented an element, the combination of which resulted in the creation of all matter.
- Each polyhedron obeys Euler's Formula: # vertices + # faces - # edges = 2

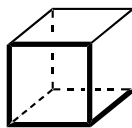
<http://www.3quarks.com/GIF-Animations/PlatonicSolids/>

The Platonic Solids as Hydrocarbons

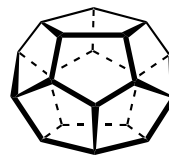
Reported:



Substituted Tetrahedrane
Maier (1978)

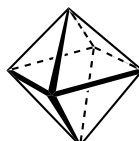


Cubane
Eaton (1964)



Dodecahedrane
Paquette (1983)

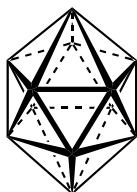
Not Yet Reported (Chemically Unlikely):



Octahedrane

- Chemical formula: C_6
- Carbon bonding orbitals are 60° away from each other.
- 8-sided octahedranes have been reported, though none with O_h symmetry.

Impossible Hydrocarbon:

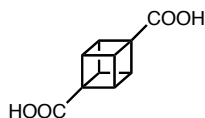
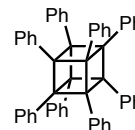


Icosahedrane

- 5 coordinate vertices make the use of carbon impossible.

In the Beginning there was Cubane. . .

- The first molecule containing the cubane carbon skeleton was reported in 1961 by H. H. Freedman et al. in their "serendipitous" syntheses of octaphenyl cubane.^{1,2} (not discussed)



- Philip E. Eaton and Thomas W. Cole, Jr. finish the first "Tactical" synthesis of the cubane skeleton in 1964 with the synthesis of cubane-1,4-dicarboxylic acid.³ (not discussed)

- Following a route elaborated from their cubane diacid synthesis, Eaton and Cole, publish the first synthesis of cubane later the same year (1964).⁴

- This synthesis was later streamlined by N.B. Chapman who combined a number of steps from the original Eaton and Cole synthesis creating the process used today to commercially manufacture cubane.



- A shorter cubane synthesis was reported by James C. Barborak, L. Watts, and R. Pettit in 1966. At four steps from commercial materials it is still the shortest synthesis of cubane known to date.⁵

1) Freedman, H. H. *J. Am. Chem. Soc.*, **1961**, *83*, 2195 - 2196.

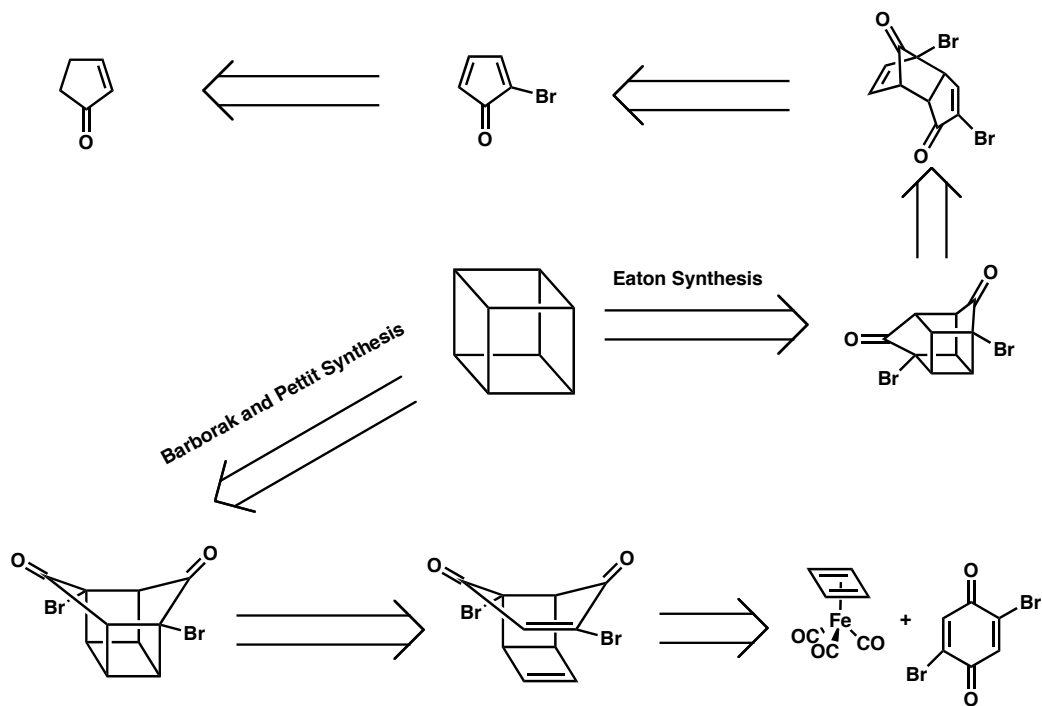
2) Freedman, H. H.; Persen, D. R. *J. Am. Chem. Soc.*, **1962**, *84*, 2837 - 2838.

3) Eaton, P. E.; Cole, T. W. *J. Am. Chem. Soc.*, **1964**, *86*, 962 - 964.

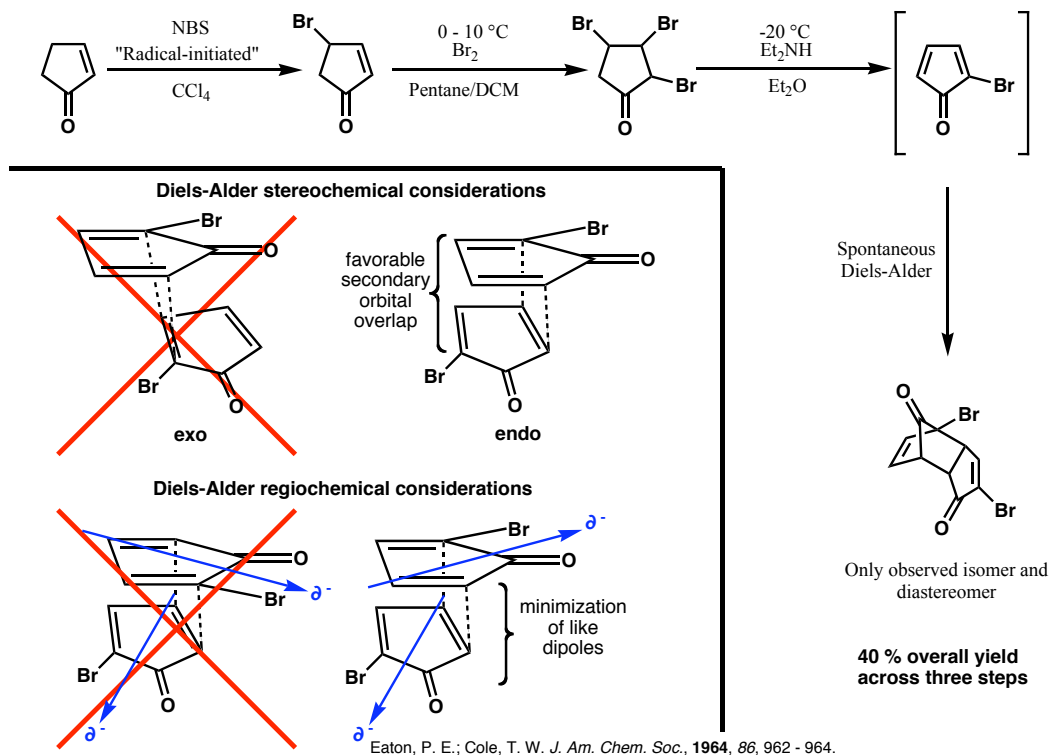
4) Eaton, P. E.; Cole, T. W. *J. Am. Chem. Soc.*, **1964**, *86*, 3157 - 3158.

5) Barborak, J. C.; Watts, L.; Pettit, R. *J. Am. Chem. Soc.*, **1966**, *88*, 1328 - 1329

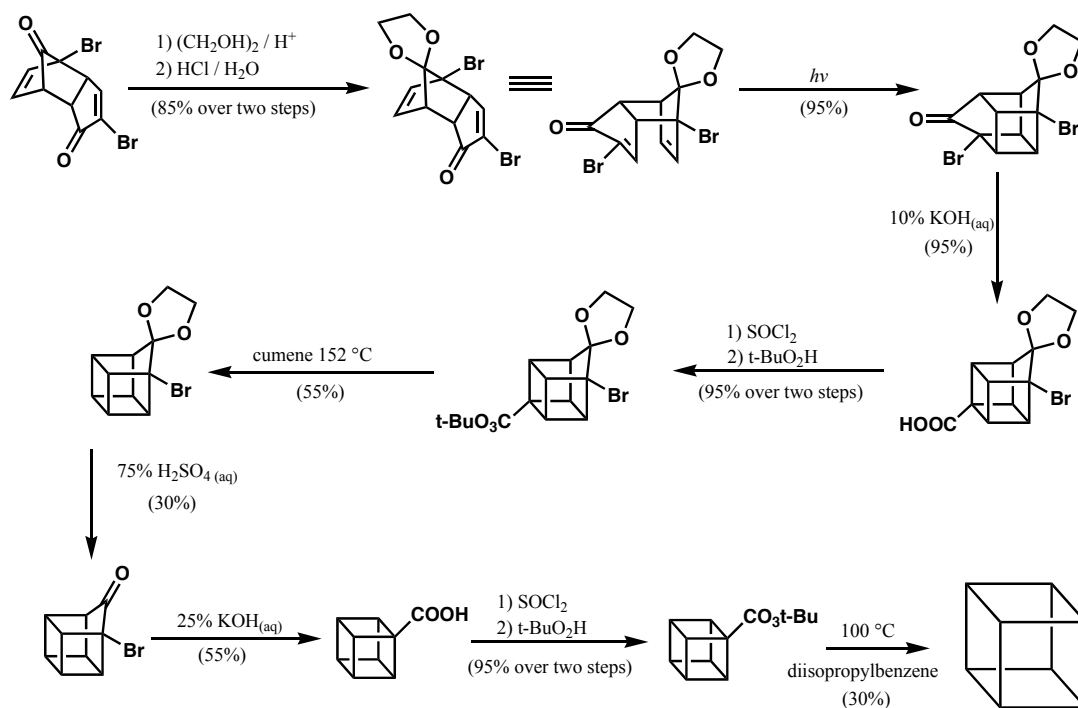
Cubane Retrosyntheses



Original Synthesis by Eaton and Cole

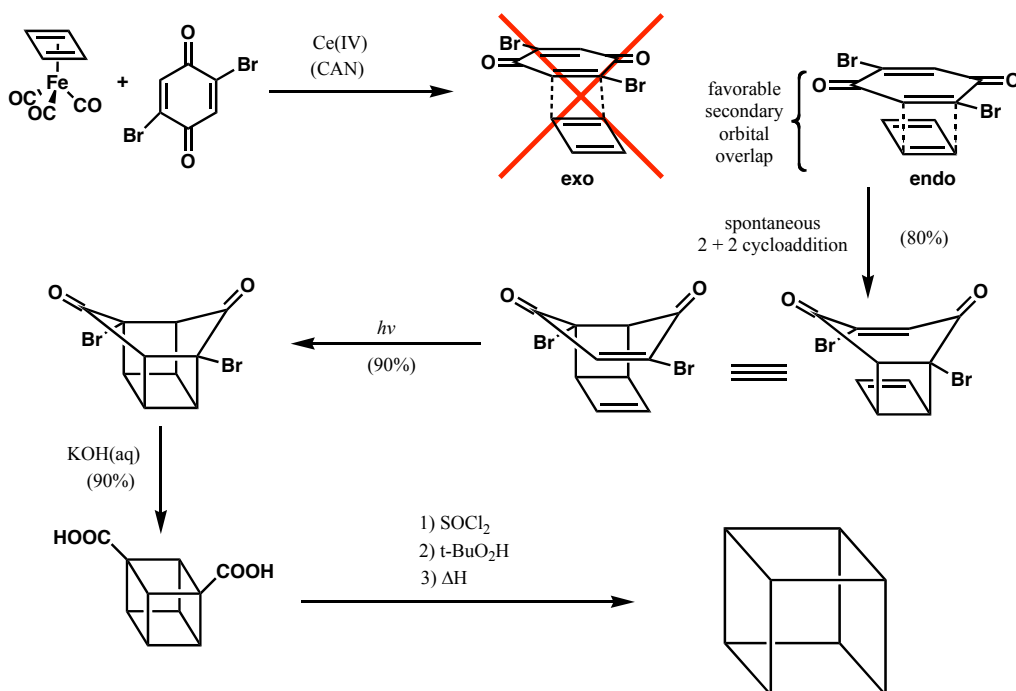


Original Synthesis by Eaton and Cole



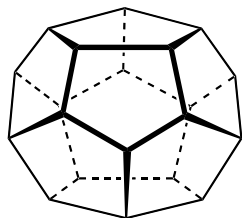
Eaton, P.E.; Cole, T.W. *J. Am. Chem. Soc.*, **1964**, *86*, 3157 - 3158.

Barborak, Watts, Pettit synthesis

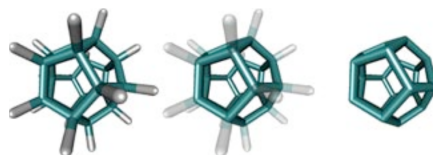
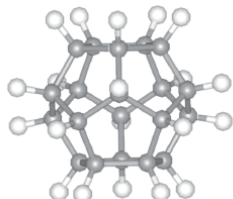


Barborak, J. C.; Watts, L.; Pettit, R. *J. Am. Chem. Soc.*, **1966**, *88*, 1328 - 1329

Dodecahedrane

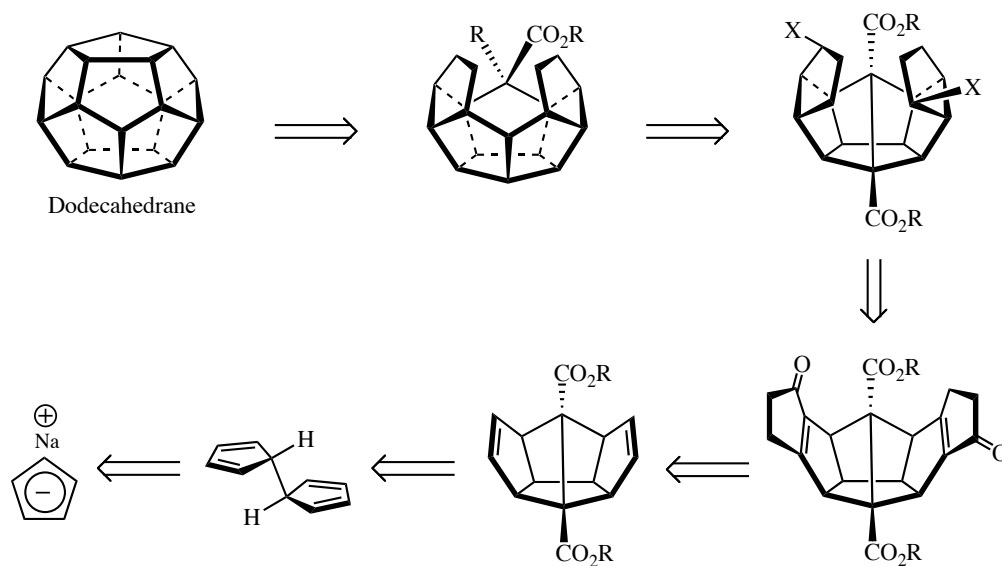


- $C_{20}H_{20}$ stabilomer
- I_h symmetry
 - 12 pentagonal faces
 - 30 edges
 - 20 vertices
- First synthesis reported by Paquette and co-workers in 1983
 - 23 steps from sodium cyclopentadienide
 - followed synthesis of 1,16-dimethyldodecahedrane in 1982 by same
 - most intermediates contain C_2 rotational axis or mirror plane, thus simplifying characterization

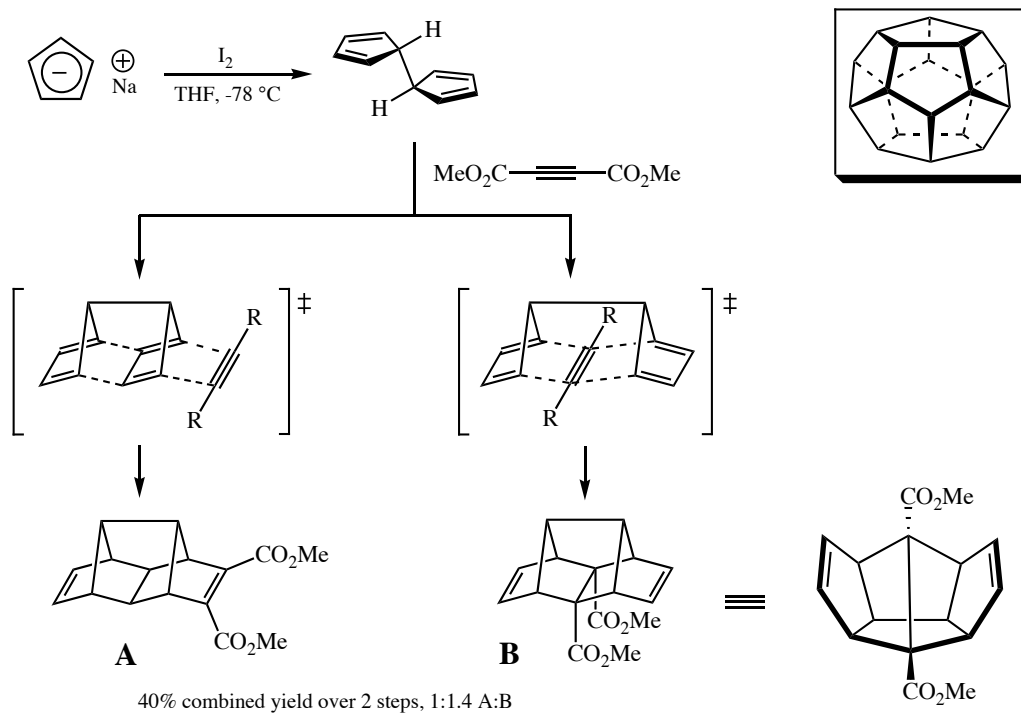


For a review of dodecahedrane and related spherical molecules: Paquette, L. A. *Chem. Rev.* **1989**, 89, 1051-1065.
 Paquette, L. A.; Wyvratt, M. J.; *J. Am. Chem. Soc.* **1974**, 96, 4673.
 Paquette, L. A.; Wyvratt, M. J.; Schallner, O.; Schneider, D. F.; Begley, W. J.; Blankenship, R. M. *J. Am. Chem. Soc.* **1976**, 98, 6744-6745.
 Paquette, L. A.; Wyvratt, M. J.; Schallner, O.; Muthard, J. L.; Begley, W. J.; Blankenship, R. M.; Balogh, D. *J. Org. Chem.* **1979**, 44, 3616-3630.
 Paquette, L. A.; Balogh, D. *J. Am. Chem. Soc.* **1982**, 104, 774-783.
 Paquette, L. A.; Ternansky, R. J.; Balogh, D. W. *J. Am. Chem. Soc.* **1982**, 104, 4502-4503.
 Paquette, L. A. *Proc. Natl. Acad. Sci. USA* **1982**, 79, 4495-4500.
 Paquette, L. A.; Ternansky, R. J.; Balogh, D. W.; Kentgen, G. *J. Am. Chem. Soc.* **1983**, 105, 5446-5450.

Retrosynthetic Analysis

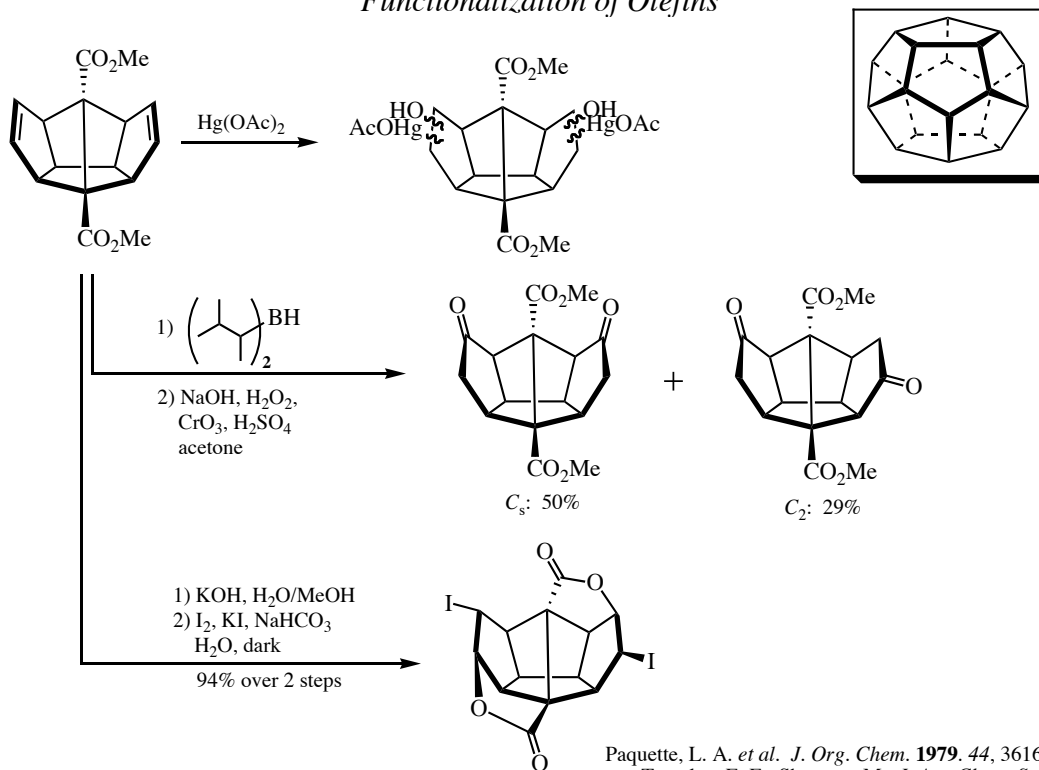


Formation of the Tetracyclic Core via 'Domino Diels-Alder'

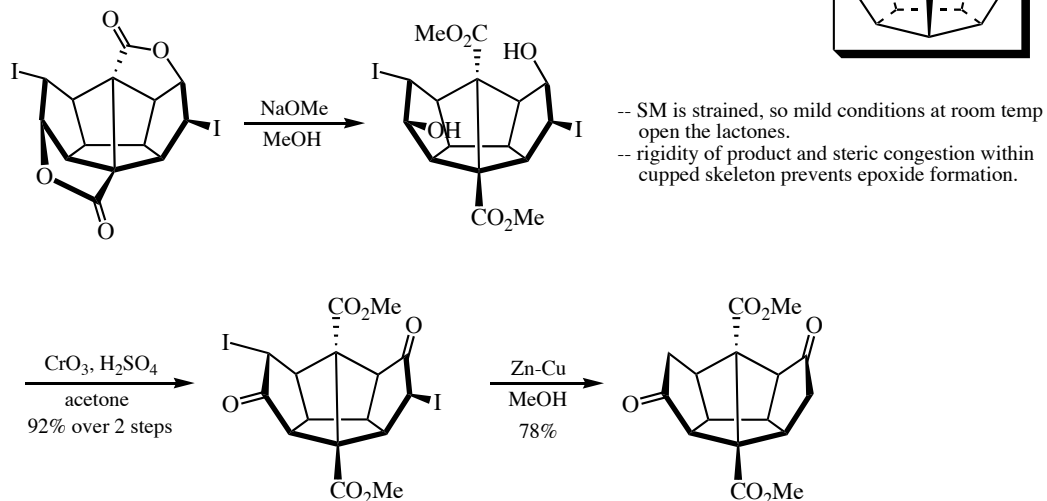
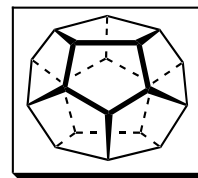


Paquette, L. A.; Wyratt, M. J.; *J. Am. Chem. Soc.* **1974**, 96, 4673.

Functionalization of Olefins

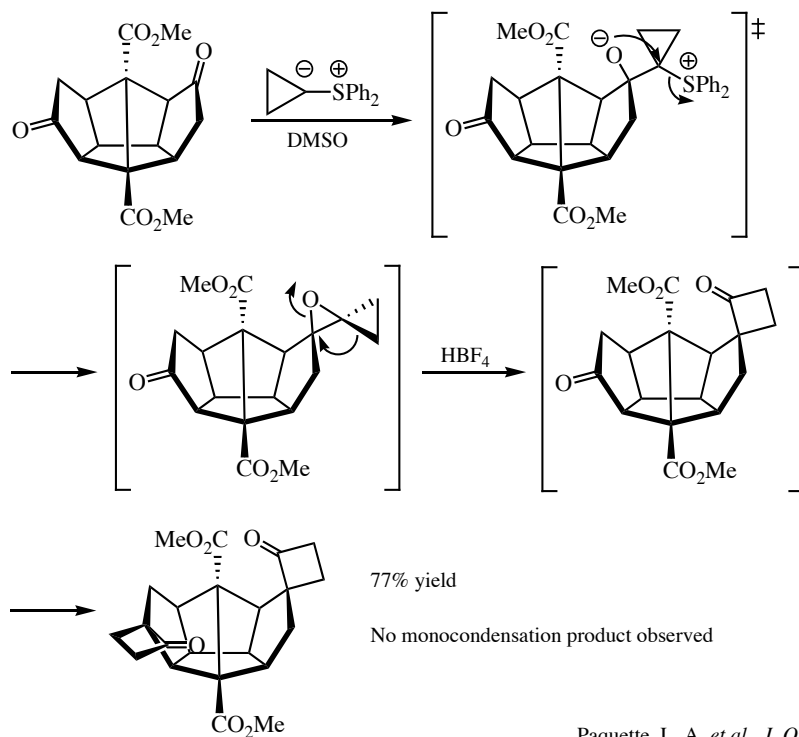
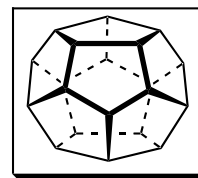


Diketone Formation



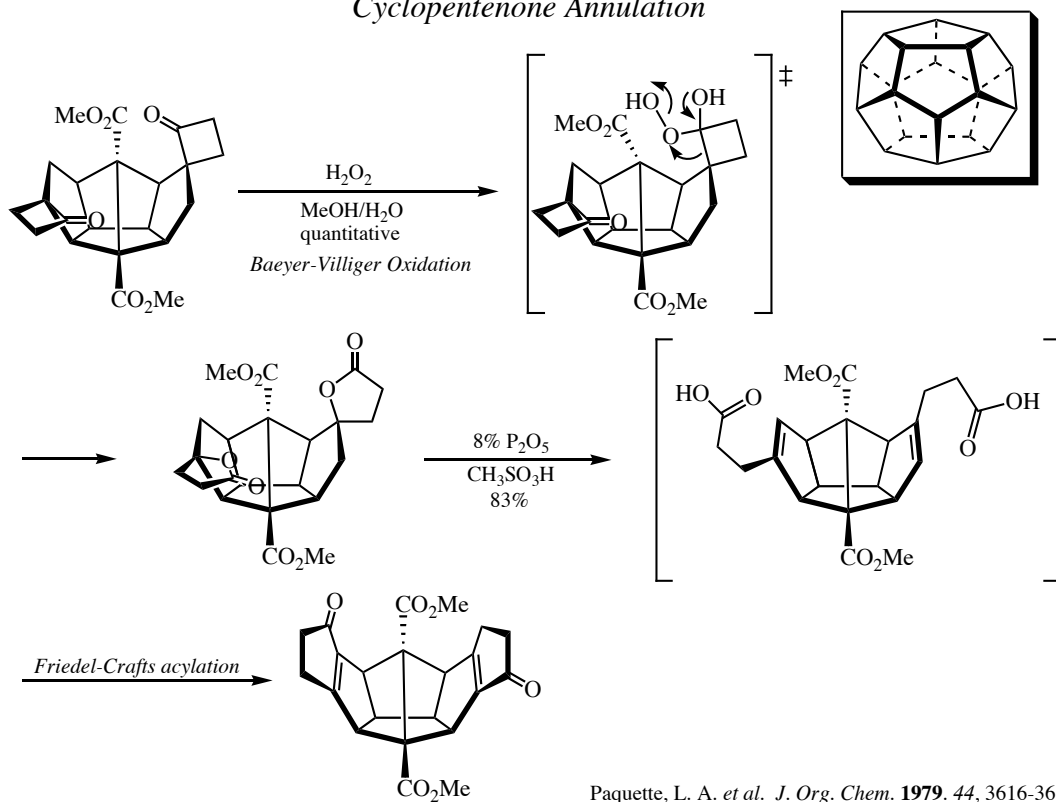
Paquette, L. A. *et al.* *J. Org. Chem.* **1979**, 44, 3616-3630.
 Paquette, L. A. *et al.* *J. Am. Chem. Soc.* **1976**, 98, 6744-6745.

Spirocyclobutanone Condensation

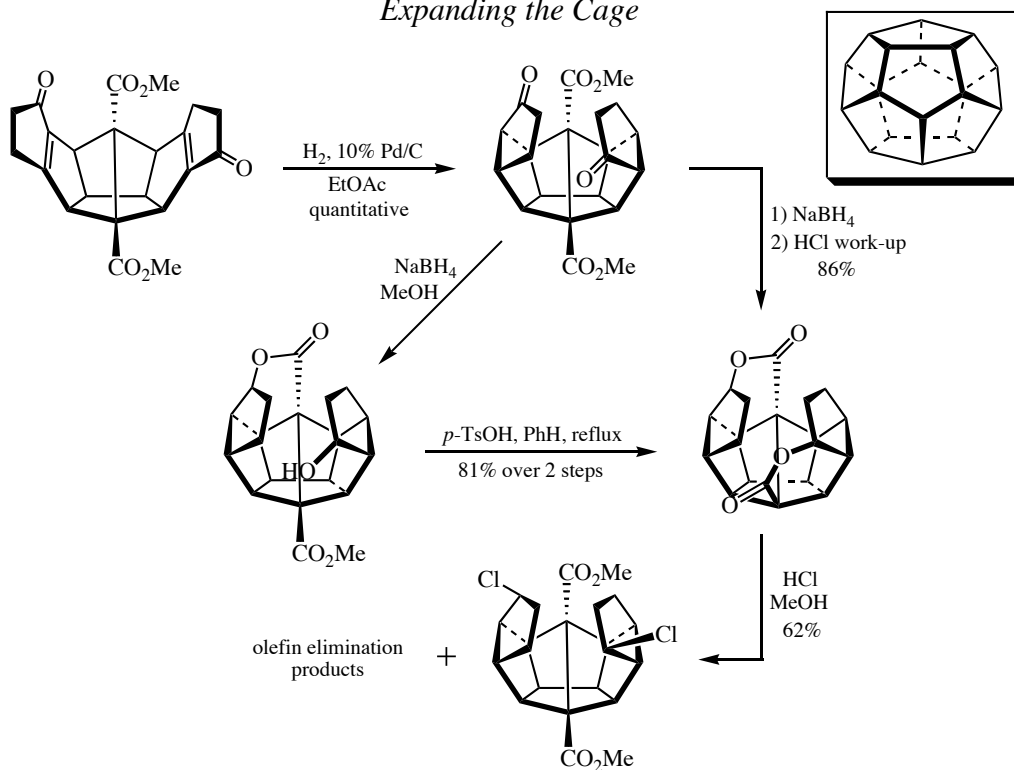


Paquette, L. A. *et al.* *J. Org. Chem.* **1979**, 44, 3616-3630.

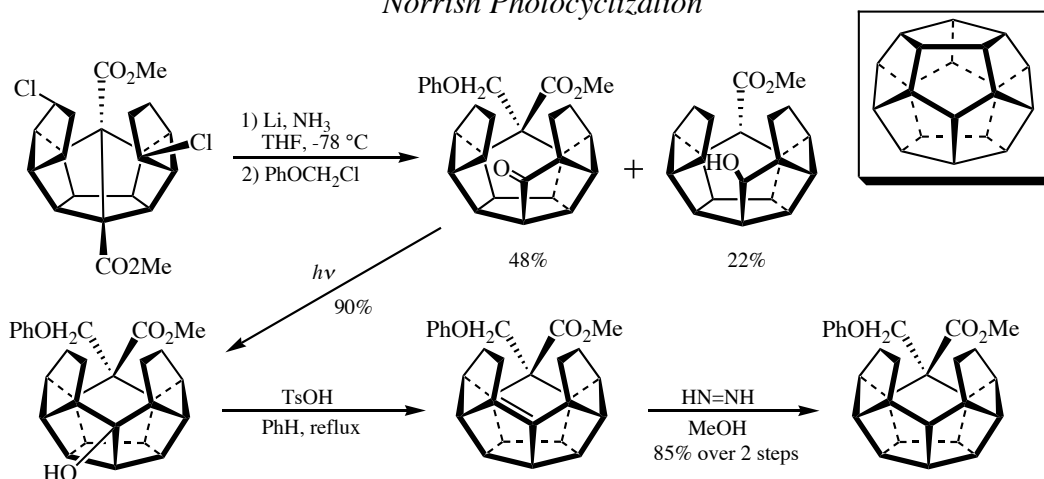
Cyclopentenone Annulation



Expanding the Cage

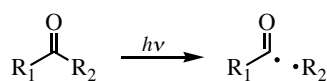


Norrish Photocyclization

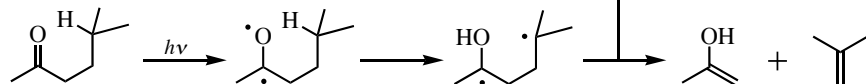


Norrish Radical Cleavage of Aldehydes and Ketones

Norrish Type I:



Norrish Type II:

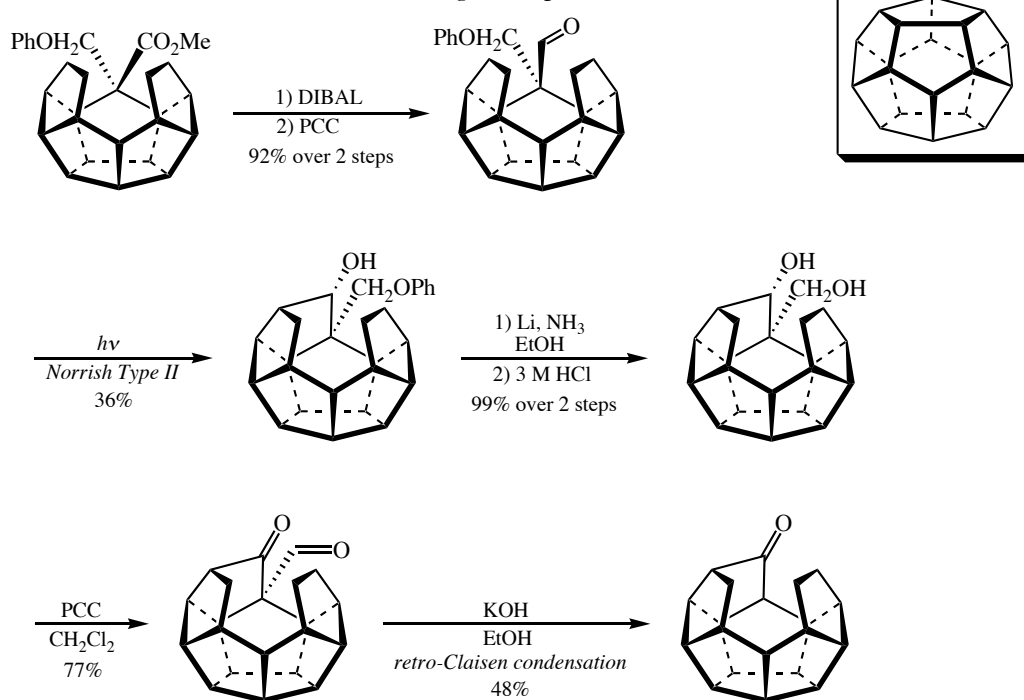


Paquette, L. A. *et al.* *J. Am. Chem. Soc.* **1983**, 105, 5446-5450.

Norrish, R. G. W.; Bamford, C. H. *Nature* **1936**, 138, 1016.

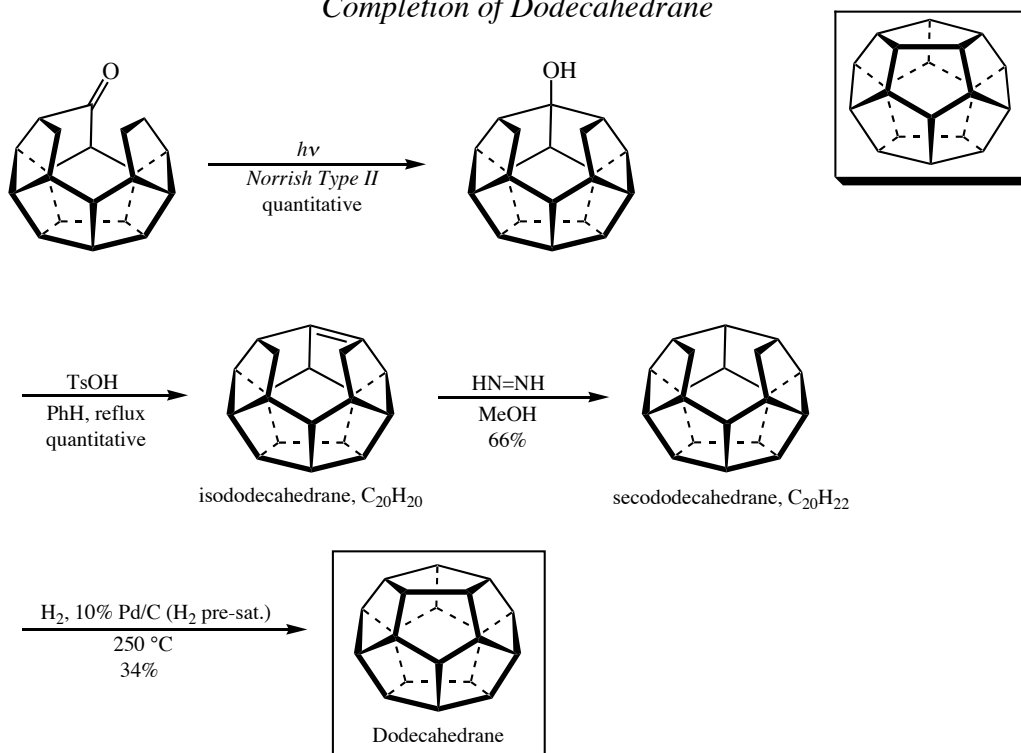
Norrish, R. G. W.; Bamford, C. H. *Nature* **1937**, 140, 195.

Blocking Group Removal



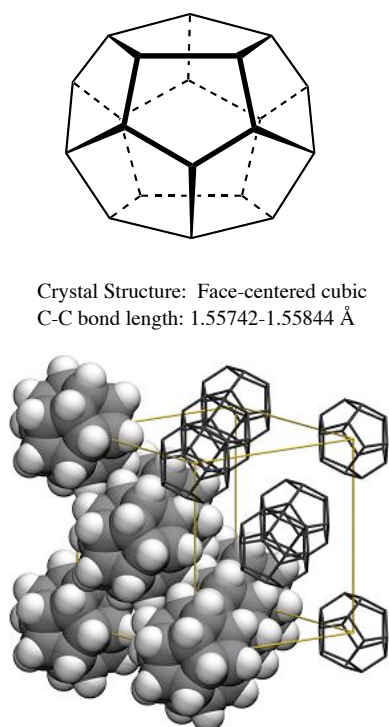
Paquette, L. A. *et al.* *J. Am. Chem. Soc.* **1983**, 105, 5446-5450.

Completion of Dodecahedrane

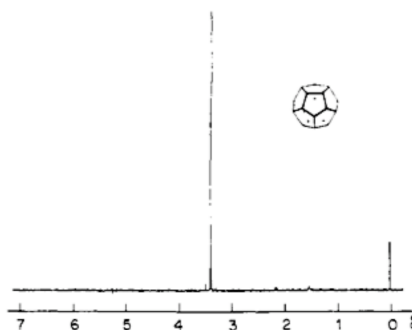


Paquette, L. A. *et al.* *J. Am. Chem. Soc.* **1983**, *105*, 5446-5450.

Characterization of Dodecahedrane



$^1\text{H NMR}$ (CDCl_3): 3.38 ppm



$^{13}\text{C NMR}$ (CDCl_3): 66.93 ppm

^{13}C - ^1H coupling constant: 134.9 Hz

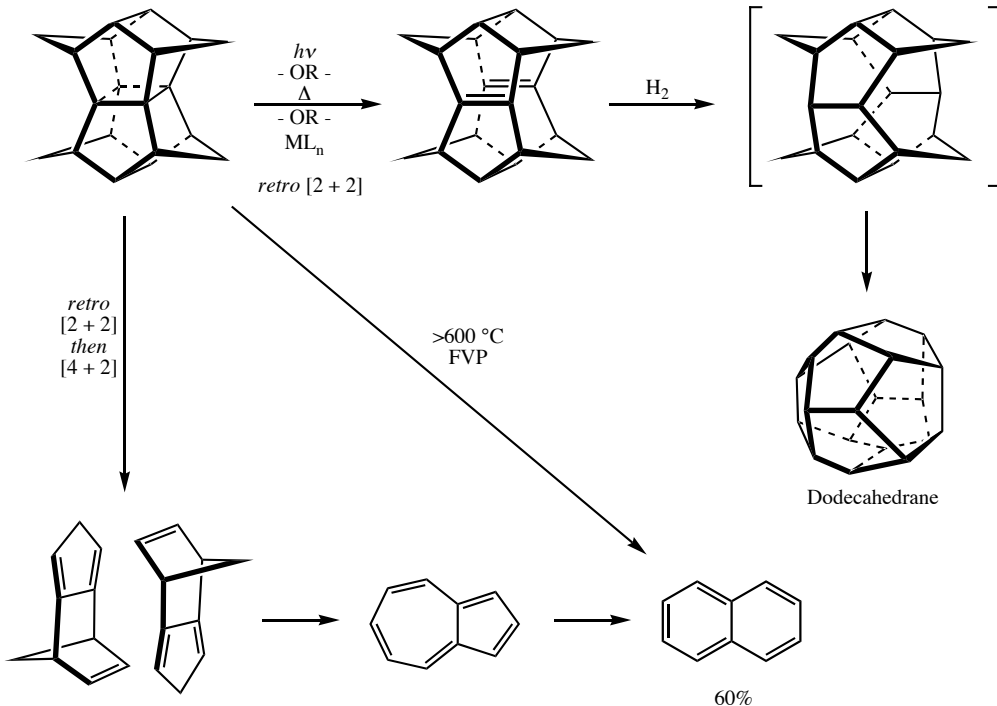
IR (3T_{10}): 2945, 1298, 728 cm^{-1}

m/e (M^+): calcd 260.1565, obsd 260.1571

MP: $430 \pm 10\text{ }^\circ\text{C}$

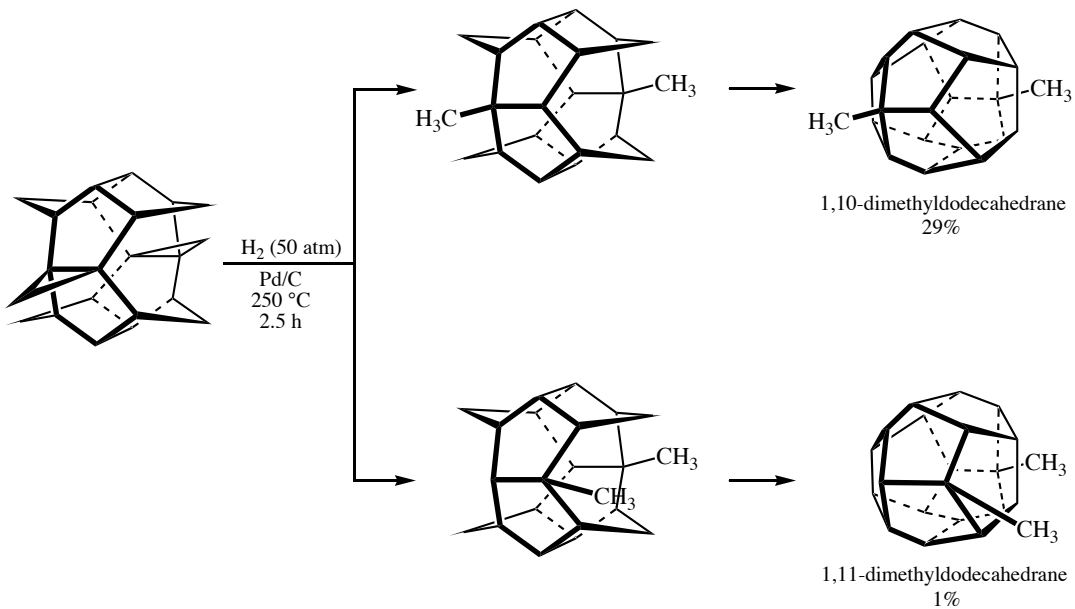
Paquette, L. A. *et al.* *J. Am. Chem. Soc.* **1983**, *105*, 5446-5450.
Hudson, B. S. *J. Phys. Chem. A.* **2005**, *109*, 3418-3424.

Alternate Route to Dodecahedrane via Pagodane



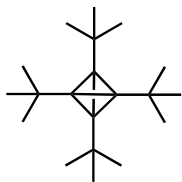
Fessner, W.-D.; Murty, B. A. R. C.; Prinzbach, H. *Angew. Chem. I. E.* **1987**, 26, 451-452.

Alternate Route to Dodecahedrane via Pagodane



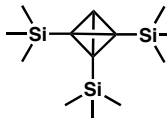
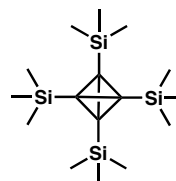
Prinzbach, H.; Schleyer, P. v.-R.; Maier, W. F. *Angew. Chem. I. E.* **1987**, 26, 452-454.

The On-going Saga of Tetrahedrane



- Günther Maier, Stephan Pfriem, Ulrich Schäfer and Rudolf Matusch complete tetra-tert-butyltetrahedrane in 1978. Tetra-tert-butyltetrahedrane is the first isolated molecule that contains the tetrahedrane carbon skeleton deep within its core. Synthesis is 12 steps and low yielding.¹

- Gunther Maier creates a fast synthesis for tetra-tert-butyltetrahedrane in 1991,² that he later uses to make Tetrakis(trimethylsilyl)tetrahedrane in 2002. Tetrakis(trimethylsilyl)tetrahedrane reveals an unpredicted method of stabilization via the trimethylsilyl groups that allow the molecule to be stable up to 300 °C.³



- The Sekiguchi group notes that one of the silyl groups can be removed and replaced with a number of other groups including a lone hydrogen. This represents a small step farther towards the desired parent hydrocarbon, tetrahedrane.⁴ (Not discussed)

- The base platonic solid hydrocarbon, tetrahedrane, has yet to be synthesized. Unstabilized ring strain makes for an exceedingly difficult synthesis. Theoreticians do not believe it is necessarily impossible, but it is unanimously thought to be highly unstable and likely to decompose at or below room temperature.⁵ (Not discussed)



1) Maier, G.; Pfriem, S., *Angew. Chem.*, **1978**, 17, 520 - 521.

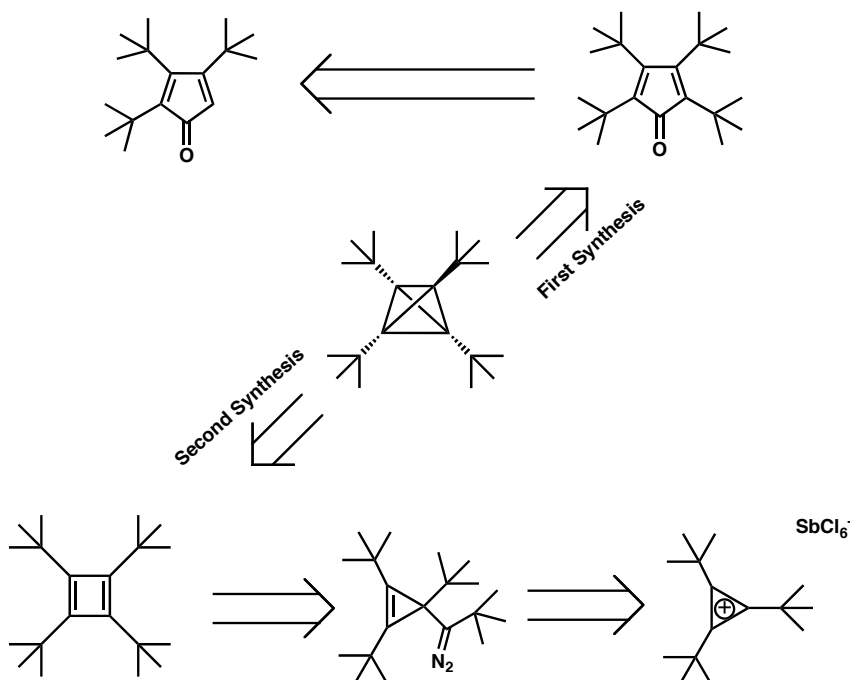
2) Maier, G., *Pure & Appl. Chem.*, **1991**, 63, 275 - 282.

3) Maier, G.; Neudert, J.; Wolf, O.; Pappusch, D.; Sekiguchi, A.; Tanaka, M.; Matsuo, T., *J. Am. Chem. Soc.*, **2002**, 124, 13819 - 13826.

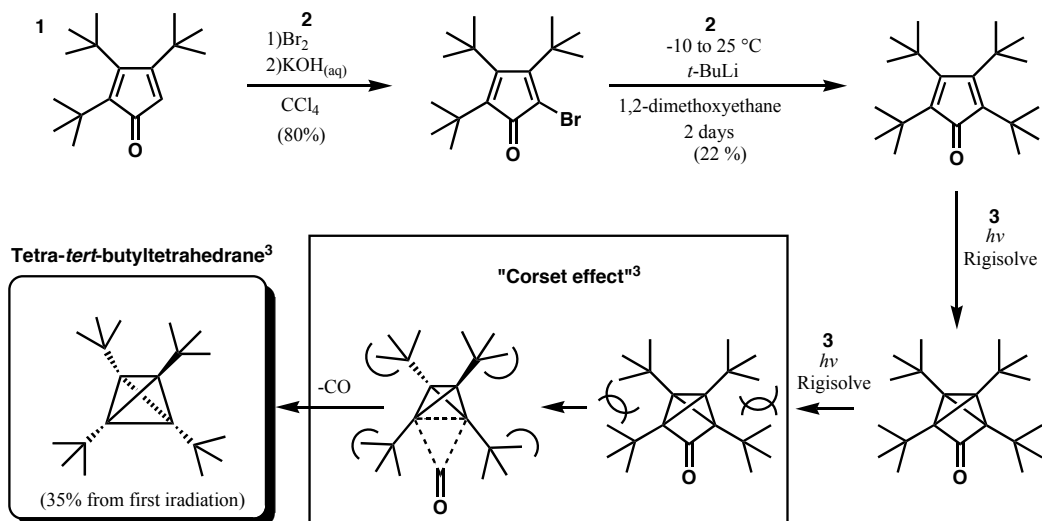
4) Sekiguchi, A.; Tanaka, M., *J. Am. Chem. Soc.*, **2003**, 125, 12684 - 12685.

5) Zhou, G.; Zhang, J.; Wong, N.; Tian, A., *Theo. Chem.*, **2004**, 668, 189 - 195.

Tetrahedrane Retrosyntheses



First Synthesis of Tetra-tert-butyltetrahedrane



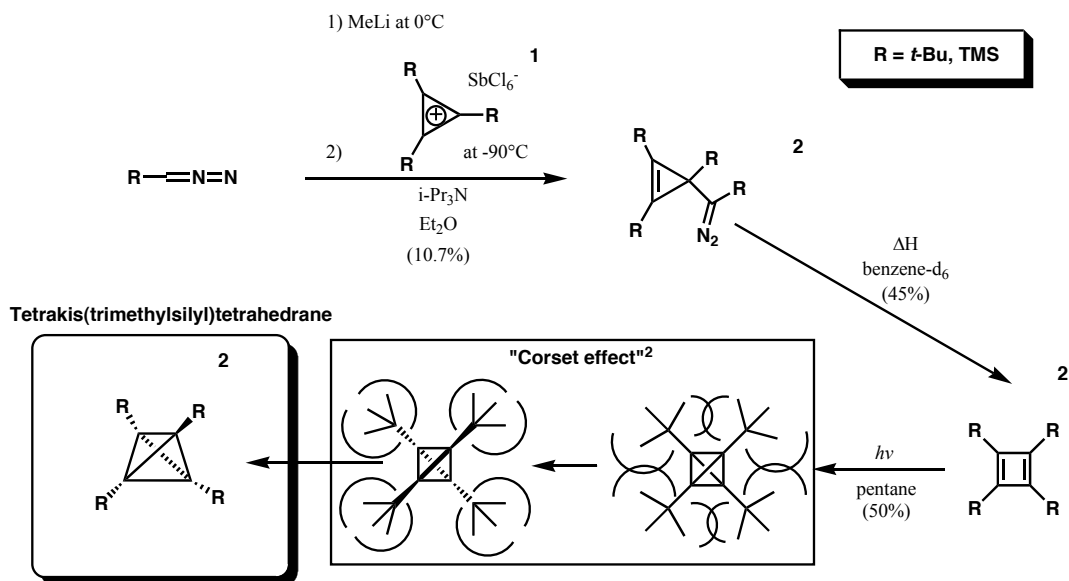
At 130°C tetra-tert-butyltetrahedrane isomerizes to Tetra-tert-butylcyclobutadiene, which is a stable cyclobutadiene derivative because the tert-butyl groups prevent the cyclobutadiene from getting close enough to any other molecule to do a 2 + 2 cycloaddition, the usual decomposition pathway for cyclobutadienes. Upon irradiation tetra-tert-butylcyclobutadiene spontaneously rearranges back into tetra-tert-butyltetrahedrane.³

1) Known from Maier, G.; Bosslet, F. *Tetrahedron Lett.*, **1972**, 1025.

2) Part of the partial synthesis from Maier, G. Pfriem, S. *Angew. Chem.*, **1978**, 17, 519 - 520

3) Final stage of synthesis from Maier, G.; Pfriem, S., *Angew. Chem.*, **1978**, 17, 520 - 521.

Second Synthesis of Tetra-tert-butyltetrahedrane and Synthesis of Tetrakis(trimethylsilyl)tetrahedrane

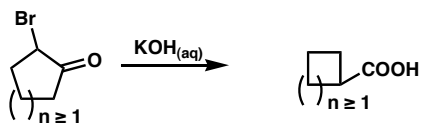


1) Maier, G.; Volz, D.; Neudert, J. *Synthesis* **1992**, 561 - 564.

2) Maier, G.; Neudert, J.; Wolf, O.; Pappusch, D.; Sekiguchi, A.; Tanaka, M.; Matsuo, T., *J. Am. Chem. Soc.*, **2002**, 124, 13819 - 13826.

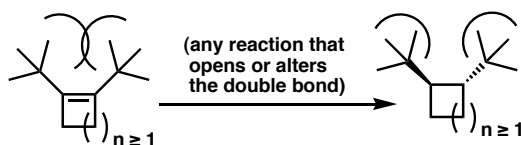
Important Techniques for Construction of 3-Dimensional Carbon Scaffolds

Favorskii Rearrangement.



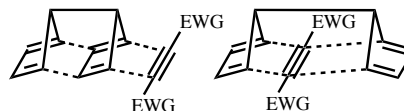
Allows for contraction of already strained rings into even smaller and more constrained rings. Works with or without target ring being fused within extremely strained systems.

Corset Effect



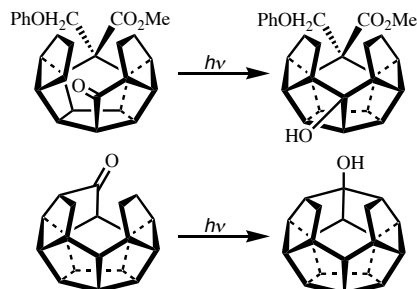
Can be used to lower the energy of products that are otherwise unattainable relative to starting materials via elevation of massive plane enforced steric clashing. Also forces a *trans* product over a potential *cis*. Often the thermodynamics of the product can be favored as well as the relevant kinetics via this process.

Domino Diels-Alder



Forms 4+ rings in a single reaction. Variation of the EWG affects reaction rate and ratio of product isomers.

Norrish Photocyclization



Used in conjunction with a rigid superstructure, this reaction has the ability to form carbon-carbon bonds in nearly quantitative yield and with preservation of convex architecture.