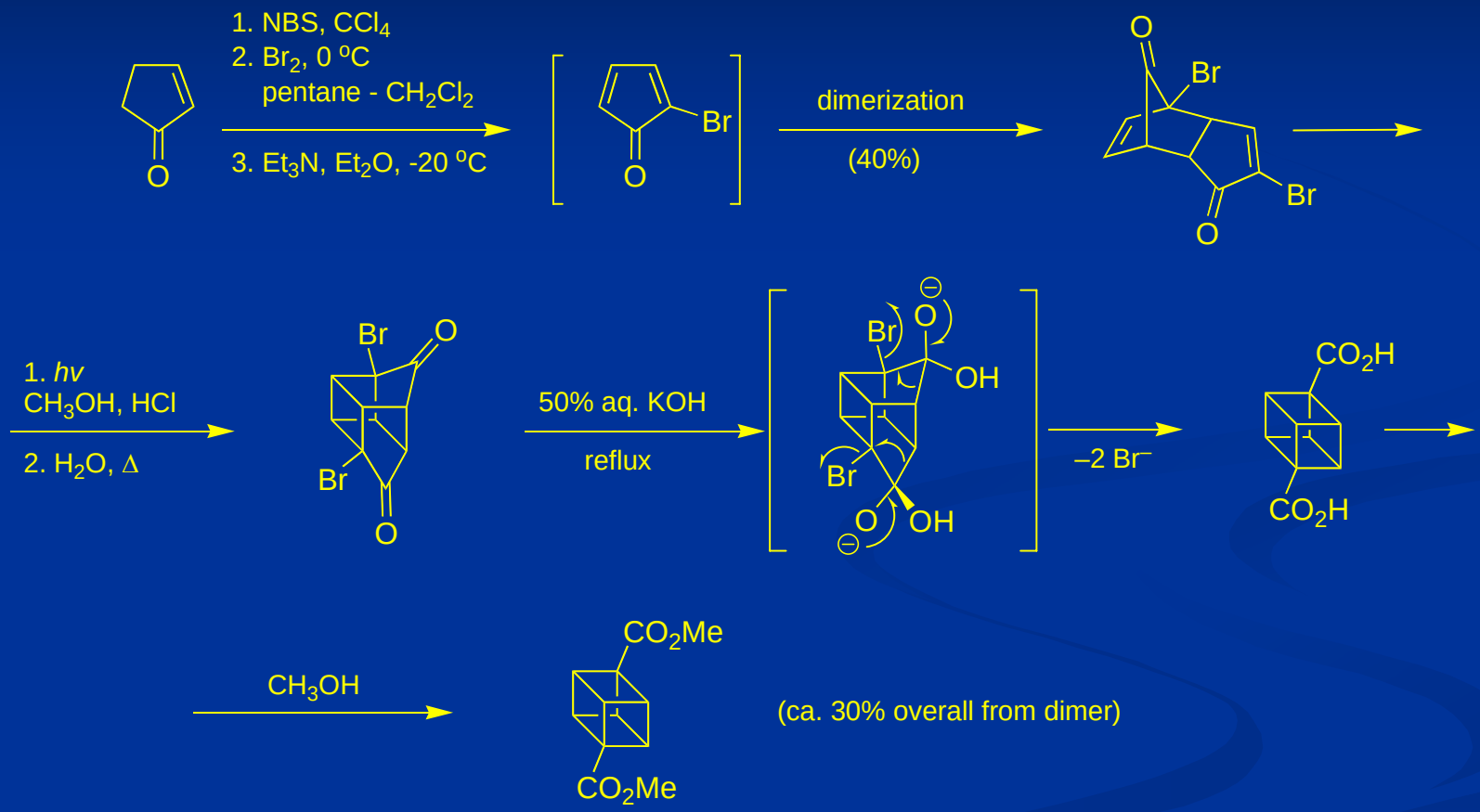
Cubanes and Olygohomocubanes: Synthesis and Functionalizations

Rodionova Tetyana

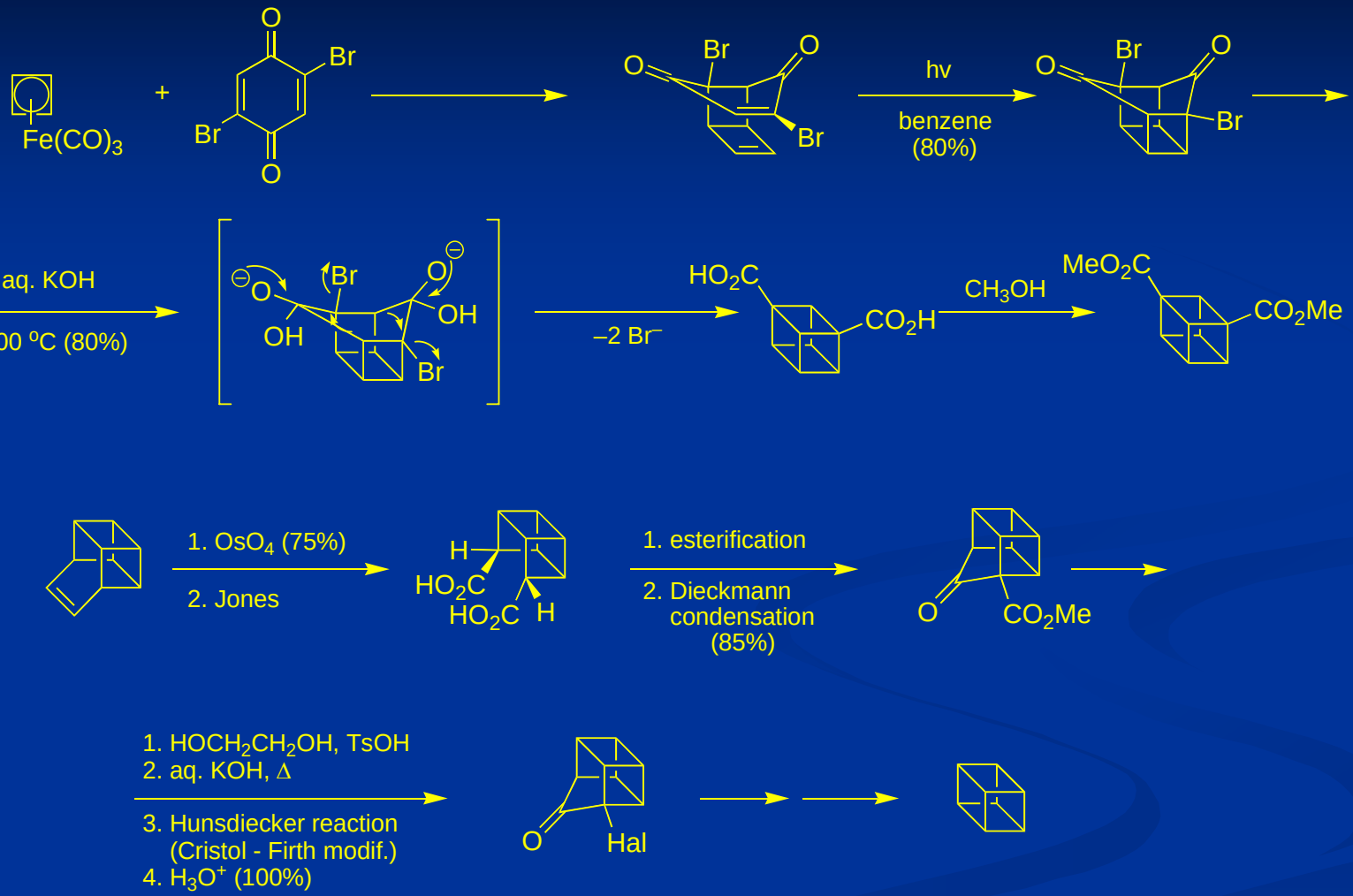
Giessen, 25-11-2005

First synthesis of the cubane skeleton



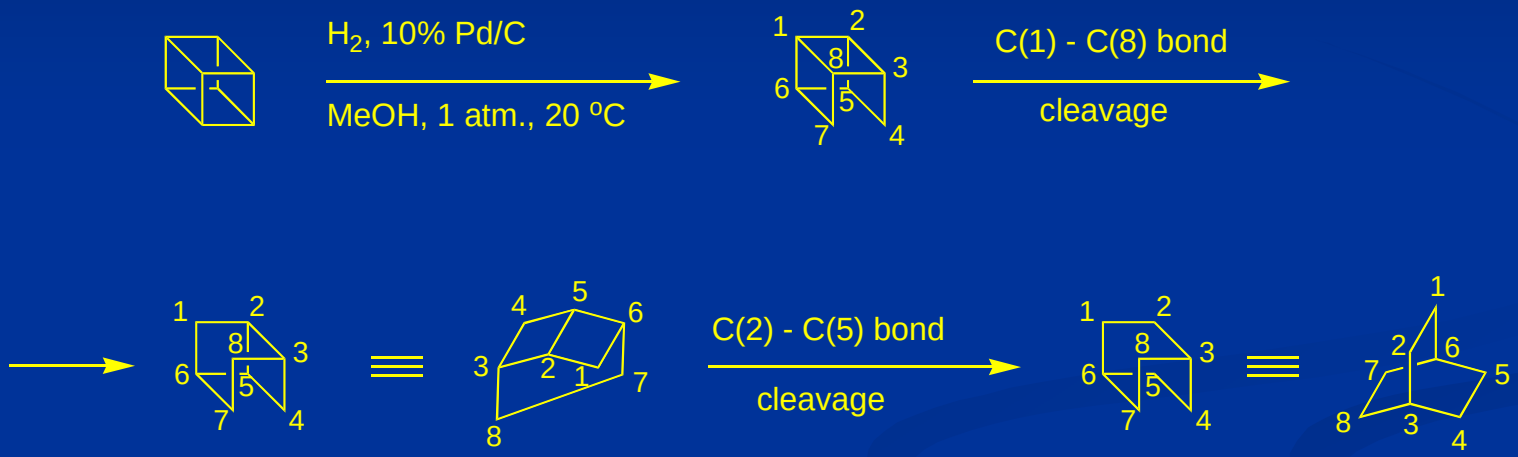
Eaton, P.E.; Cole, T.W., Jr. *J. Am. Chem. Soc.* **1964**, *86*, 962.

Other ways to cubane



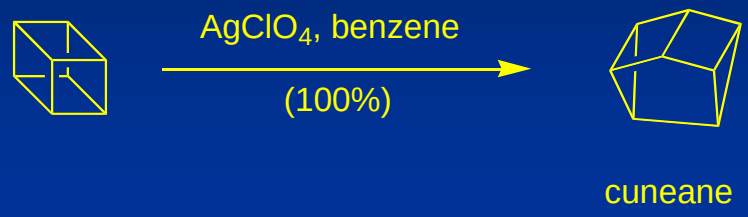
1. Barborak, J.C.; Watts, L.; Pettit, R. *J. Am. Chem. Soc.* **1966**, *88*, 1328.
2. Chin, C.G.; Cuts, H.W.; Masamune, S. *J. Chem. Soc., Chem. Commun.* **1966**, 880.

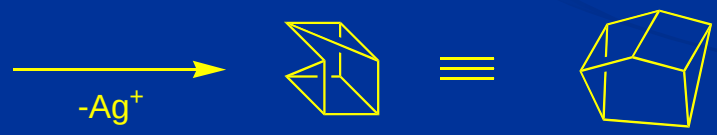
Fragmentations of cubane skeleton



Stober, R.; Musso, H; Osawa, E. *Tetrahedron* **1986**, *42*, 1757.

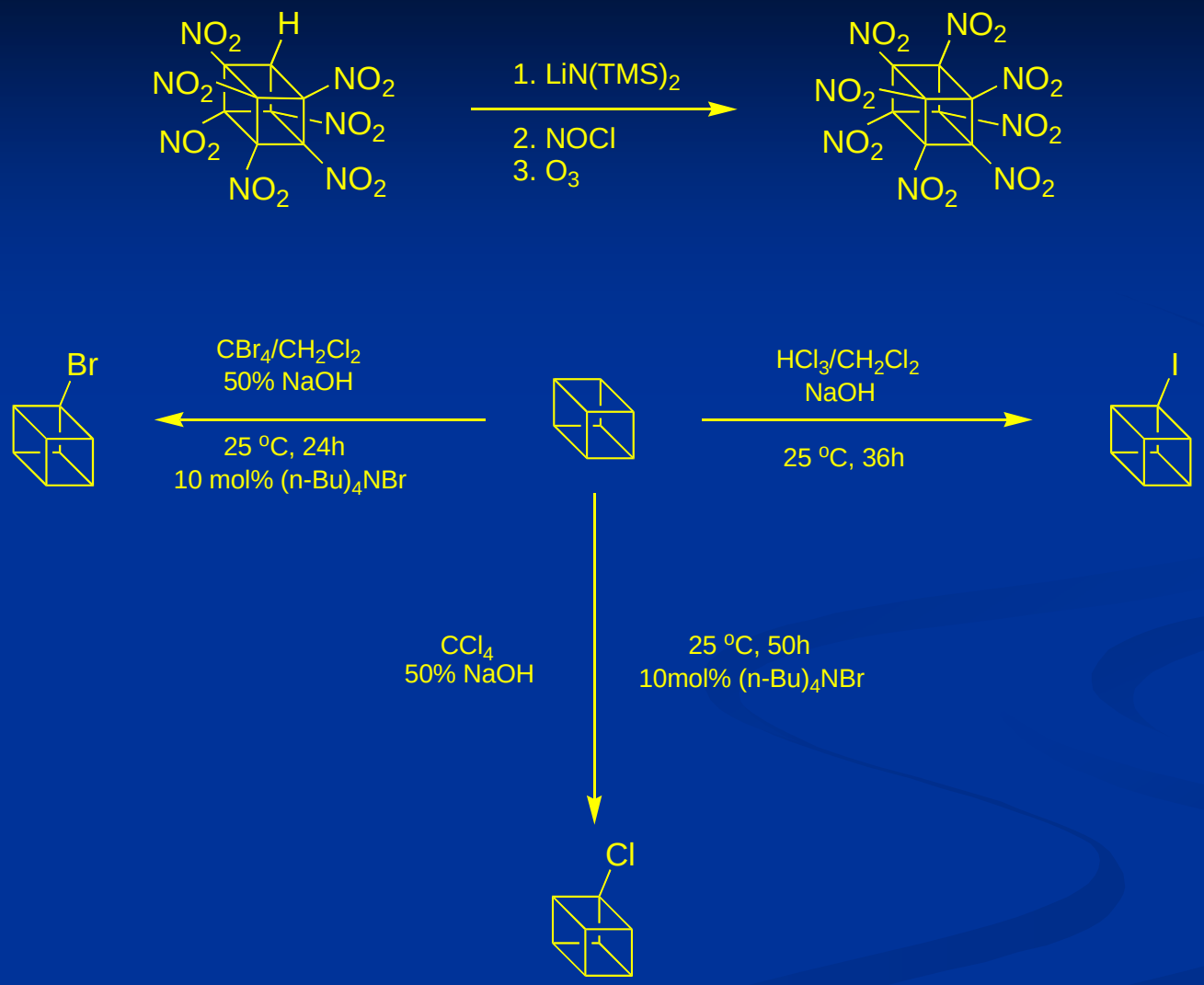
Rearrangements of cubane skeleton





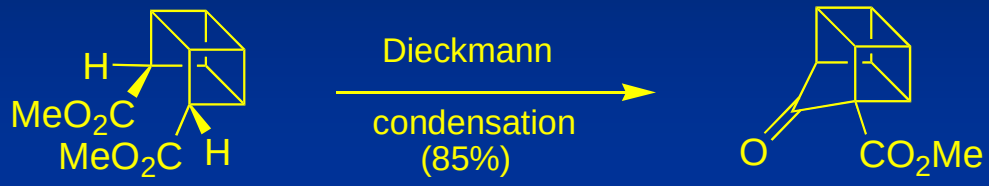
1. Cassar, L.; Eaton, P.E.; Halpern, J. *J. Am. Chem. Soc*. **1970**, *92*, 6366.
2. Byrd, J.E.; Cassar, L.; Eaton, P.E.; Halpern, J. *J. Chem. Soc., Chem. Commun*. **1971**, 40.

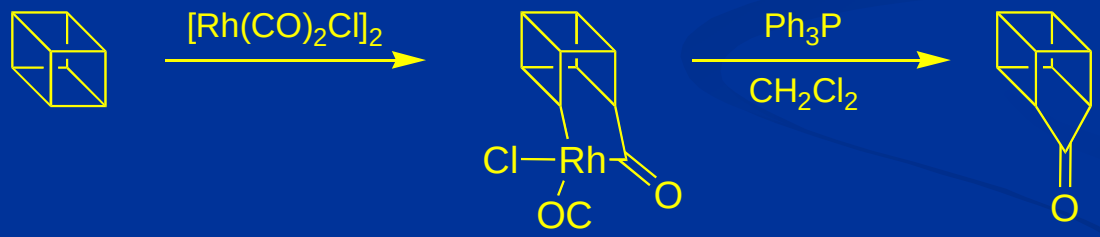
Recent reactions of cubane and it's derivatives



1. Eaton P.E.; Mao-Xi Zhang; Gilardi R. *Angew. Chem. Int. Ed.* **2000**, *39*, 401.
2. Fokin A.A.; Lauenstein, O.; Gunchenko, P.A.; Schreiner, P.R. *J. Am. Chem. Soc.*, **2001,** *123*, 1842.

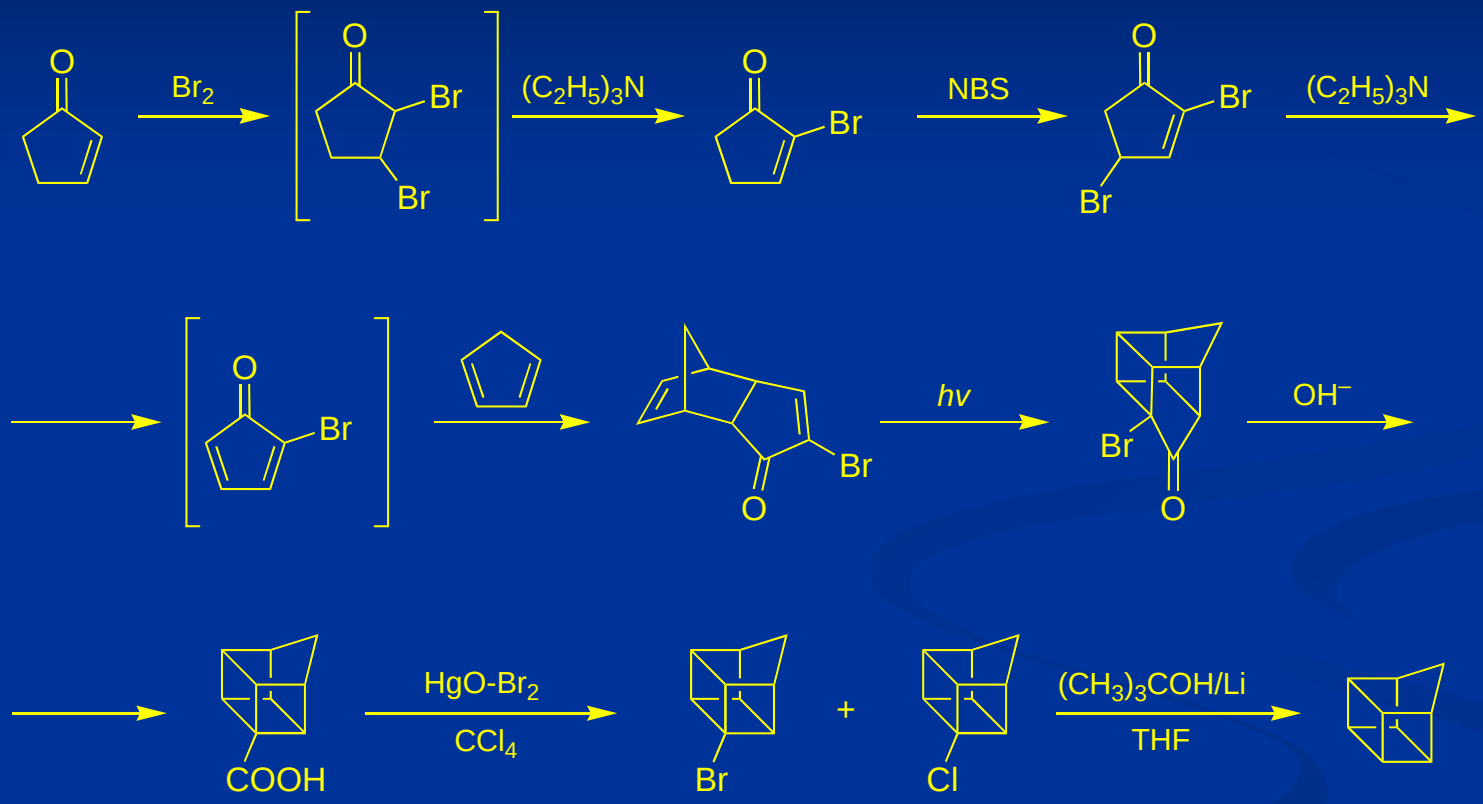
Synthesis of the substituted homocubanes





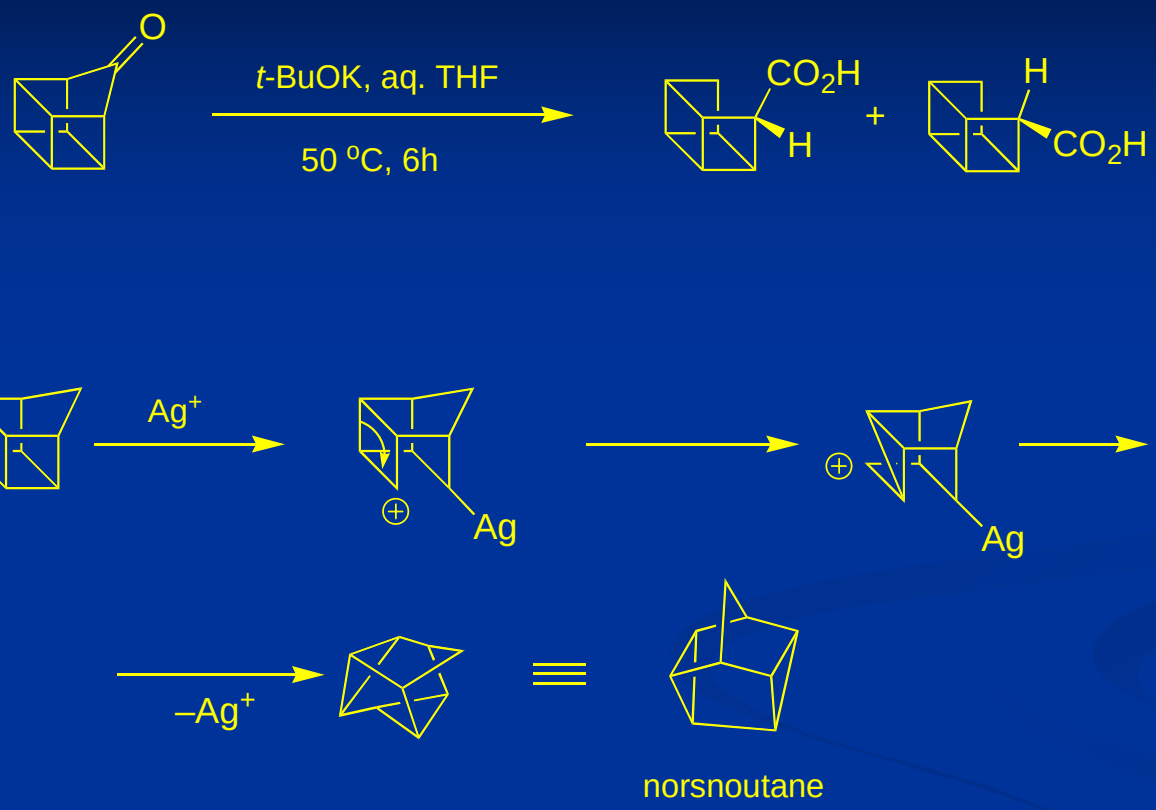
1. Chin, C.G.; Cuts, H.W., Masamune, S. *Chem. Commun*. **1966**, 880.
2. Cassar, L.; Eaton, P.E.; Halpern, J. *J. Am. Chem. Soc*. **1970**, *92*, 3515.

Synthesis of the homocubane



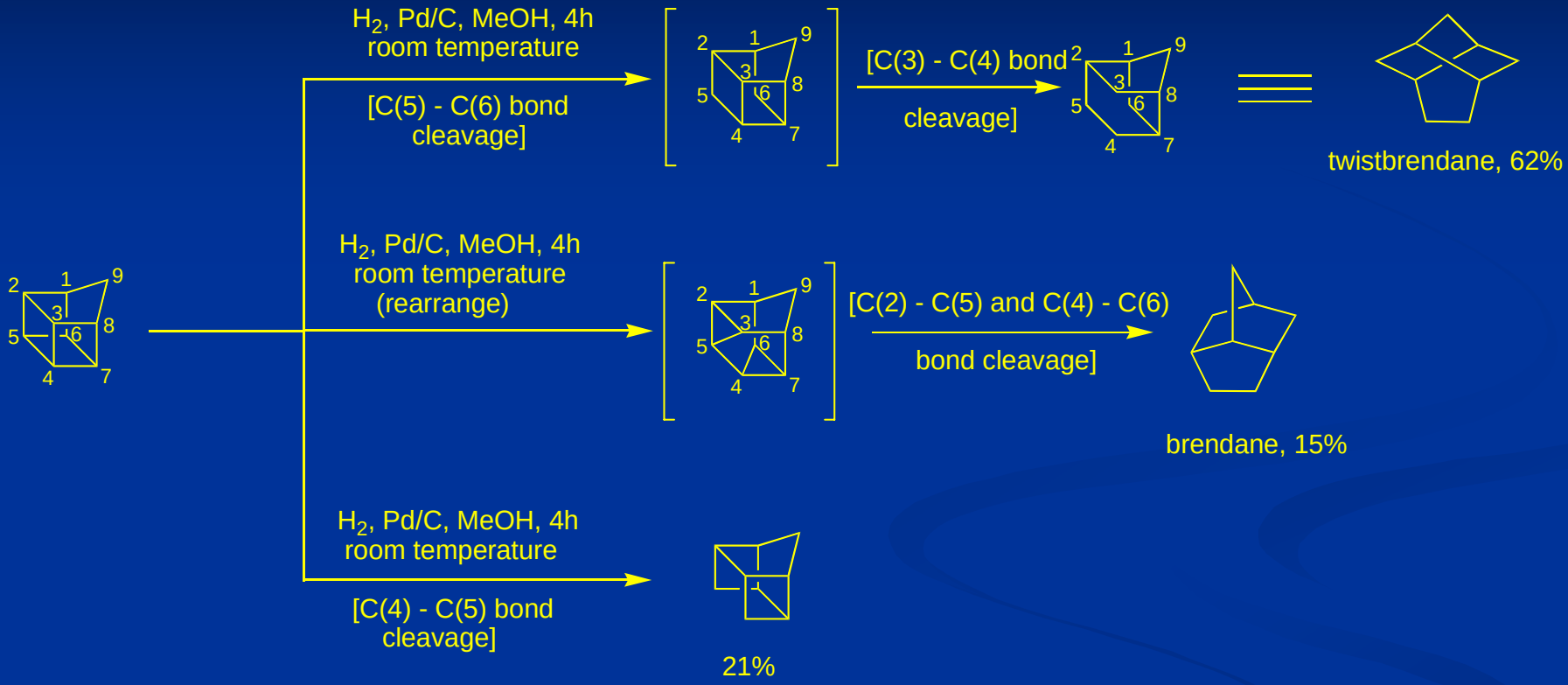
Dunn, G.L.; DiPasquo, V.J.; Hoover J.R.E. *J. Org. Chem*. **1968**, *33*, 1454.

Some reactions of homocubanes



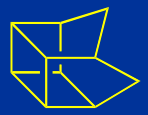
1. Gassman, P.G.; Lumb, J.T.; Zalar, F.V. *J. Am. Chem. Soc.* **1967**, *89*, 946.
2. (a) Paquette, L.A. *Acc. Chem. Res.* **1971**, *4*, 280.
   (b) Osawa, E.; Shleyer, P. von R.; Chang, L.W.K.; Kane, V.V. *Tetrahedron Lett.* **1974**, 4189.
   (c) Paquette, L.A.; Ward, J.S.; Boggs, R.A.; Farnham, W.B. *J. Am. Chem. Soc.* **1975**, *97*, 1101.
   (d) Paquette, L.A., Boggs, R.A., Ward, J.S. *J. Am. Chem. Soc.* **1975**, *97*, 1118.

Rearrangements of the homocubane skeleton

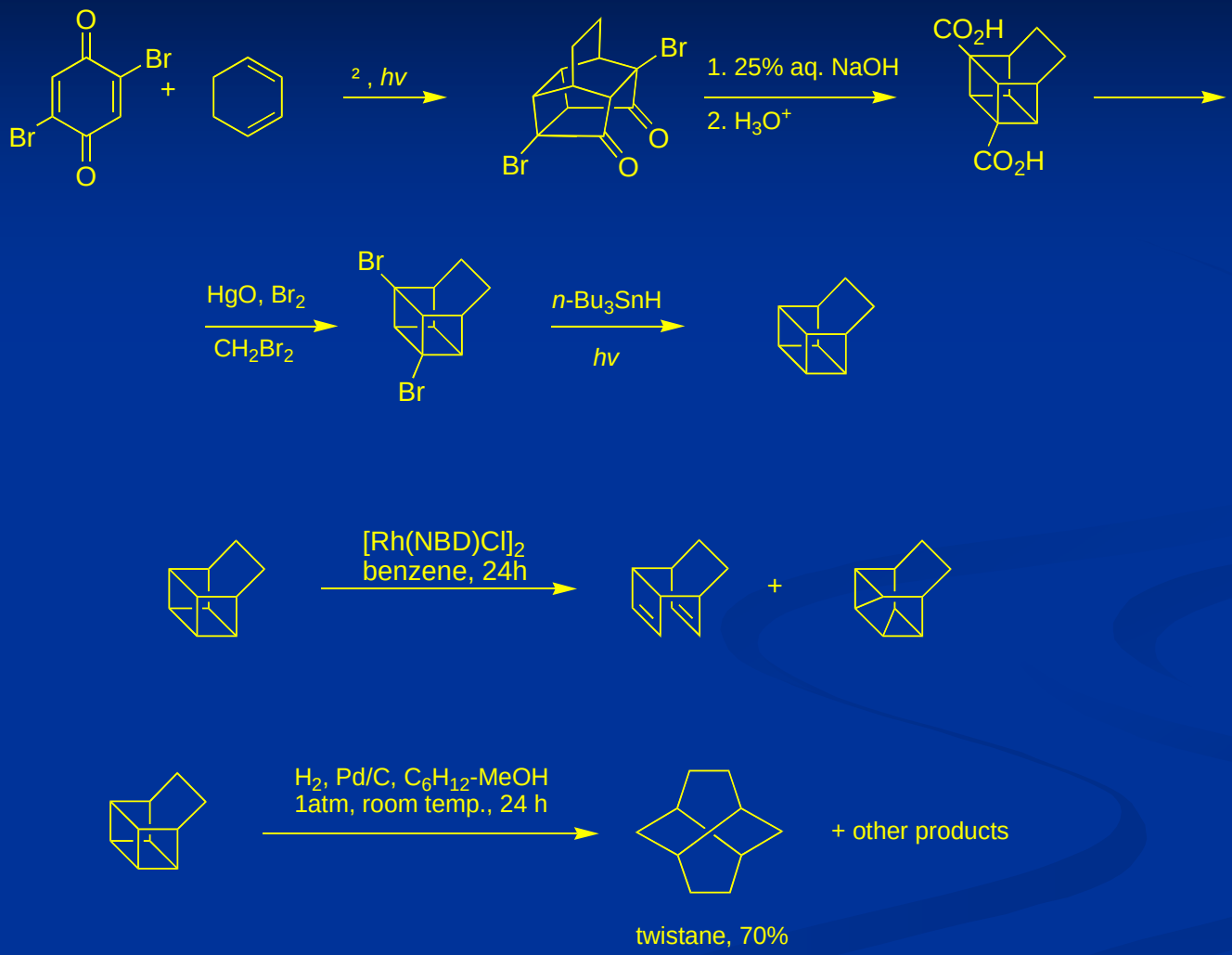


1. Osawa, E.; Schneider, I.; Toyne, K.J.; Musso, H. *Chem. Ber*. **1986**, *119*, 2350.
2. Stober, R.; Musso, H.; Osawa, E. *Tetrahedron* **1986**, *41*, 1757.
3. Toyne, K.J. *J.Chem Soc., Perkin Trans. 1* **1976**, 1346.

Bishomocubanes

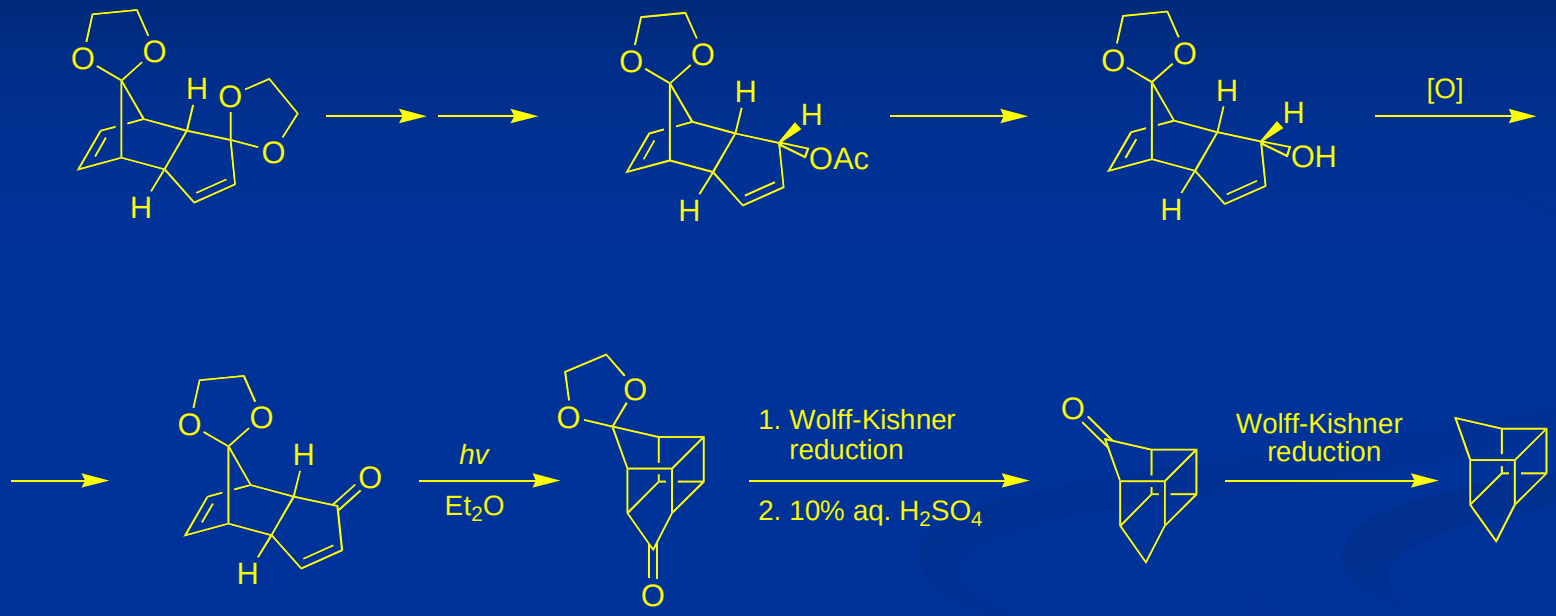
#	Structure	Name
1		pentacyclo[4.4.0.$0^{2,5}$.$0^{3,8}$.$0^{4,7}$]decane; 1,1'-bishomocubane; l,8-bishomocubane; basketane
2		pentacyclo[4.4.0.$0^{2,5}$.$0^{3,9}$.$0^{4,7}$]decane; 1,2-bishomocubane; C_s-bishomocubane
3		pentacyclo[5.3.0.$0^{2,6}$.$0^{3,9}$.$0^{4,8}$]decane; octahydro-1,2,4-metheno-l*H*-cyclobuta-[*cd*]pentalene; C_2-bishomocubane; 1,3-bishomocubane
4		pentacyclo[4.4.0.$0^{2,5}$.$0^{3,9}$.$0^{4,8}$]decane; C_{2v}-bishomocubane; secopentaprismane
5		pentacyclo[5.3.0.$0^{2,6}$.$0^{3,9}$.$0^{4,8}$]decane; octahydro-1,3,4-metheno-1*H*-cyclobuta-[*cd*]pentalene; D_{2h}-bishomocubane

Synthesis and rearrangements of basketane



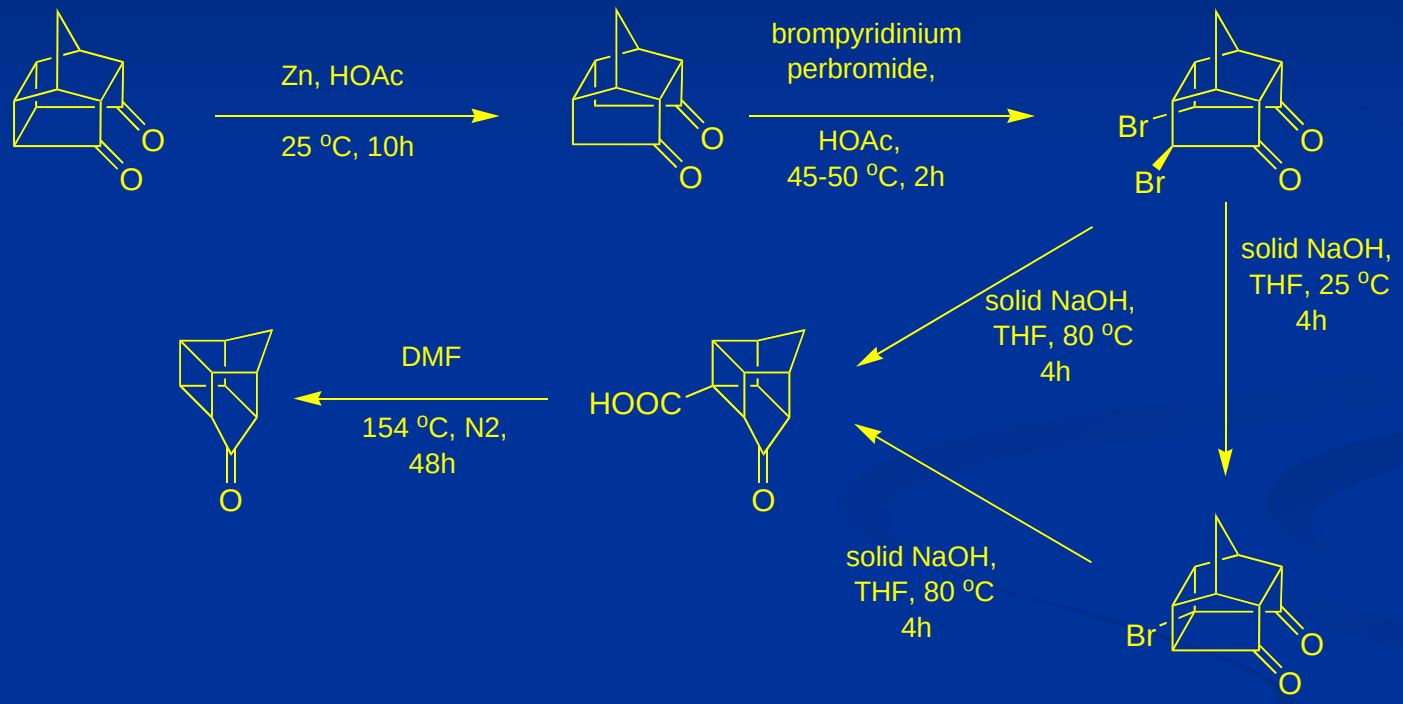
1. Gassman, P.G.; Yamaguchi, R. *J. Org. Chem*. **1978**, *43*, 4654.
2. Takaya, H.; Yamakawa, M.; Noyori, R. *Chem Lett*. **1973**, 781.
3. Osawa, E.; Schleyer, P. von R.; Chang, L.W.K.; Kane, V.V. *Tetrahedron Lett*. **1974**, 4189.

Synthesis of C_2-bishomocubane



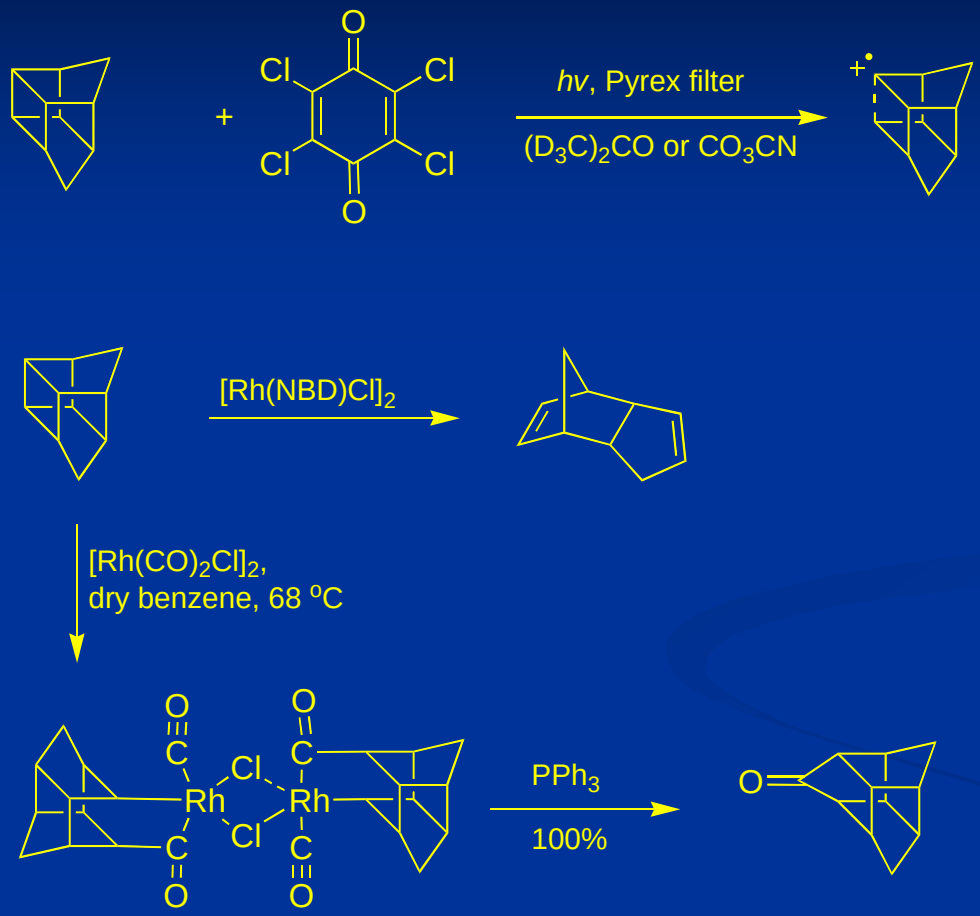
1. Nakazaki, M.; Naemura, K. *J. Org. Chem.* 1977, *42*, 2985.
2. Nakazaki, M.; Naemura, K.; Nakahara, S. *J. Org. Chem.* **1978**, *43*, 4745.
3. Klunder, A.J.H.; Huizinga, W.B.; Hulshof, A.J.M.; Zwanenburg, B. *Tetrahedron. Lett.* **1986**, *27*, 2543.

Synthesis of C_2-bishomocubane skeleton



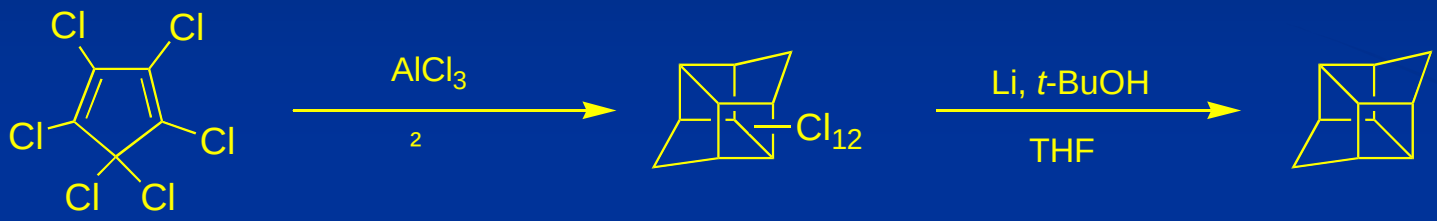
Marchand, A.P.; Reddy, D.S. *J. Org. Chem.* **1985**, *50*, 724.

Reactions of C_2-bishomocubane



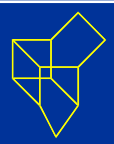
1. Andrews, L.; Dunkin, I.R.; Kelsall, B.J.; Lurito, J.T. *J. Phys. Chem.* **1985**, *89*, 821.
2. Shida, T.; Momose, T.; Ono, N. *J. Phys. Chem.* **1985**, *89*, 815.
3. Roth, H.D.; Shilling, M.L.M.; Abelt, C.J. *Tetrahedron* **1986**, *42*, 6157.
4. Zlotogorski, C.; Blum, J.; Osawa, E.; Schwarz, H.; Höhne, G. *J. Org. Chem.* **1984**, *49*, 971.

Synthesis of D_{2h}-bishomocubane

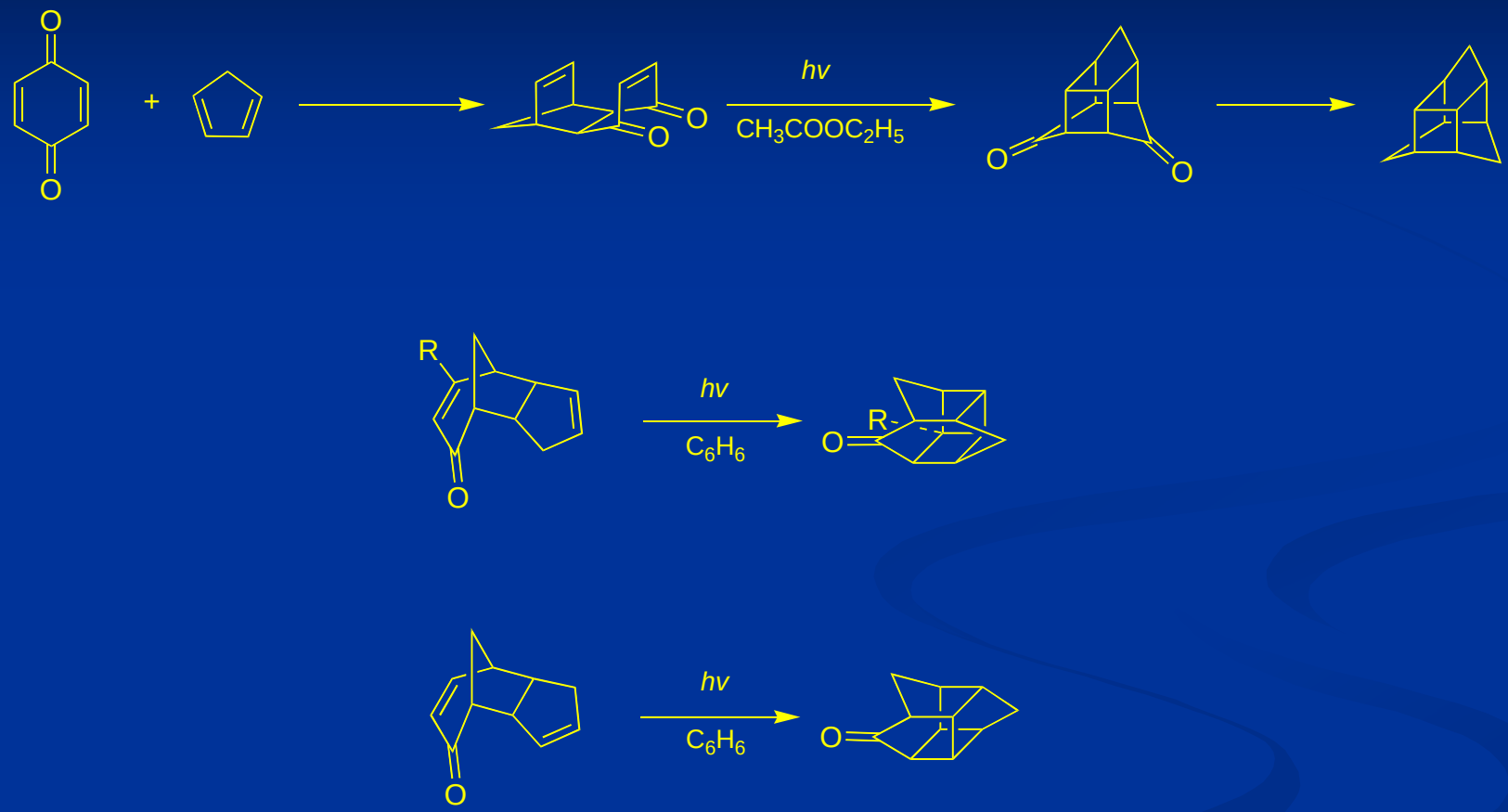


1. McBee, E.T.; Dilling, W.L.; Braendlin, H.P. *J.Org.Chem*. **1962**, *27*, 2704.
2. Dilling, W.L.; Braendlin, H.P.; McBee, E.T. *Tetrahedron* **1967**, *23*,1211.
3. Alley, E.G., Dollar, D.A.; Layton, B.R.; Minyard, J.P., Jr. *J.Agric.Food Chem*. **1973**, *21*, 138.

Trishomocubanes

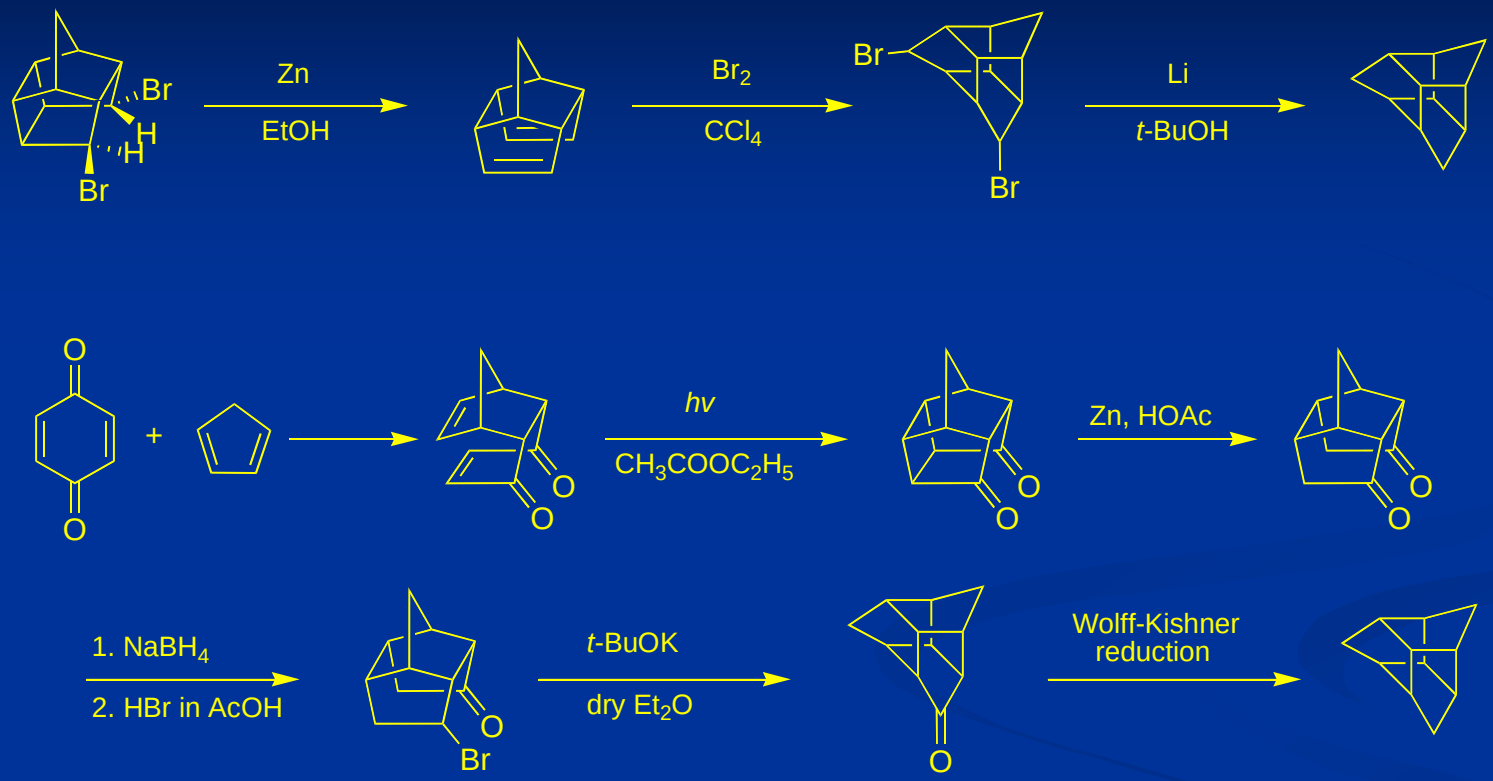
#	Structure	Name	#	Structure	Name
1		C_s-trishomocubane, pentacyclo[5.4.0.0^{2,6}.0^{3,10}.0^{5,9}]undecane	8		pentacyclo[5.4.0.0^{2,6}.0^{3,11}.0^{4,10}]undecane
2		D_3-trishomocubane, pentacyclo[6.3.0.0^{2,6}.0^{3,10}.0^{5,9}]undecane	9		pentacyclo[5.4.0.0^{2,10}.0^{5,9}.0^{8,11}]undecane
3		pentacyclo[5.4.0.0^{2,6}.0^{3,10}.0^{4,8}]undecane	10		pentacyclo[5.4.0.0^{3,10}.0^{5,9}.0^{8,11}]undecane
4		pentacyclo[5.4.0.0^{2,6}.0^{3,10}.0^{5,8}]undecane	11		pentacyclo[5.4.0.0^{2,6}.0^{3,10}.0^{4,9}] undecane
5		pentacyclo[5.4.0.0^{2,5}.0^{3,11}.0^{4,8}]undecane	12		pentacyclo[5.4.0.0^{2,6}.0^{3,11}.0^{4,9}]undecane
6		pentacyclo[5.4.0.0^{2,6}.0^{3,9}.0^{4,8}]undecane	13		pentacyclo[5.4.0.0^{2,10}.0^{3,9}.0^{8,11}]undecane
7		pentacyclo[5.4.0.0^{2,5}.0^{3,10}.0^{4,8}]undecane	14		pentacyclo[5.3.1.0^{2,5}.0^{3,10}.0^{4,9}]undecane

Synthesis of selected trishomocubanes



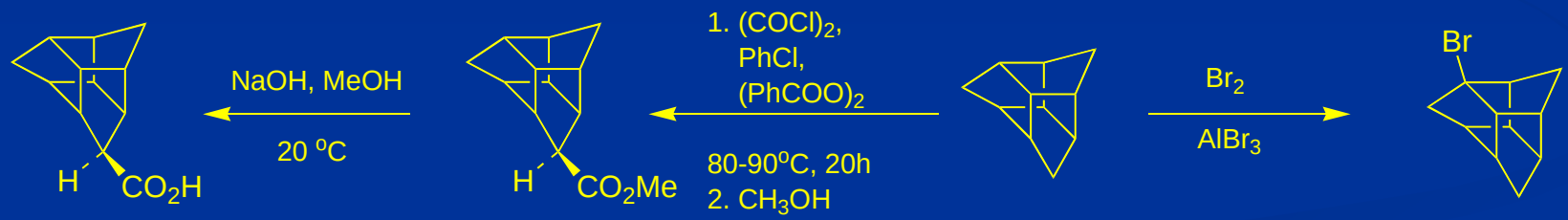
1. Marchand, A.P.; Allen, R.W. *J. Org. Chem.* **1974**, *39*, 11, 1596.
2. Ogino, T.; Awano, K. *Chem. Lett.* **1982**, 891.
3. Ogino, T.; Awano, K. *Bull. Chem. Soc. Jpn.* **1986**, *59*, 2811.

Synthesis of D_3- trishomocubane



1. Underwood, G.R.; Ramamoorthy, B. *Tetrahedron Lett.* **1970**, 4125.
2. Godleski, S.A.; Schleyer, P. von R.; Osava, E.; Wipke. W.T. *Prog. Phys. Org. Chem*. **1981**, *13*, 63.
3. Kent G.J.; Godleski, S.A.; Osava, E.; Schleyer, P. von R. *J. Org. Chem.* **1977**, *42*, 3852.
4. Godleski, S.A.; Schleyer, P. von R.; Osava, E.; Kent, G.J. *J. Chem. Soc., Chem. Commun.* **1974**, 976.
5. Eaton, P.E.; Hudson, R.A.; Giordano, C. *J. Chem. Soc., Chem. Commun.* **1974**, 978.

Functionalizations of D_3- trishomocubane



1. Sorochinskii, A.E.; Aleksandrov, A.M.; Petrenko, A.E.; Kukhar', V.P. *J.Org.Chem. USSR (Engl. Transl.)* **1988**, *23*, 1987.
2. Petrenko, A.E.; Aleksandrov, A.M.; Sorochinskii, A.E.; Kukhar', V.P. *J.Org.Chem. USSR (Engl. Transl.)* **1988**, *23*, 1988.

Goals of the work

1. To develop convenient preparative methods for the synthesis of olygohomocubanes.

2. To evaluate possible ways for their functionalizations with computational methods.

3. To study the functionalization reactions of olygohomocubanes experimentally.

Objects of computational modeling

O_h

C_s

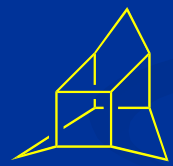
C_{2v}

D_{2h}

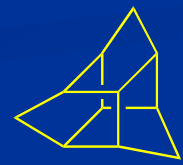
D_3

C_{2v}

C_2

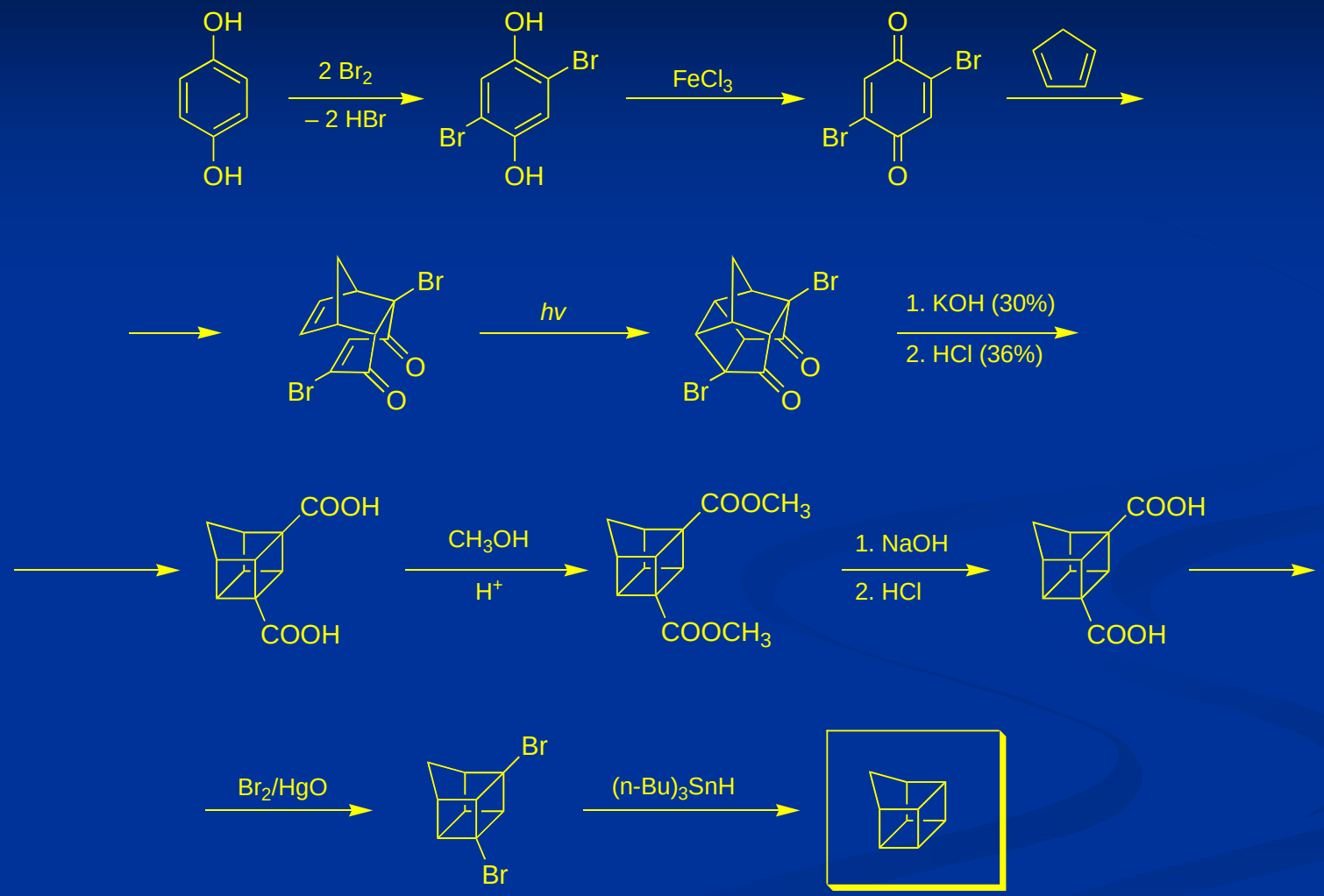


C_s

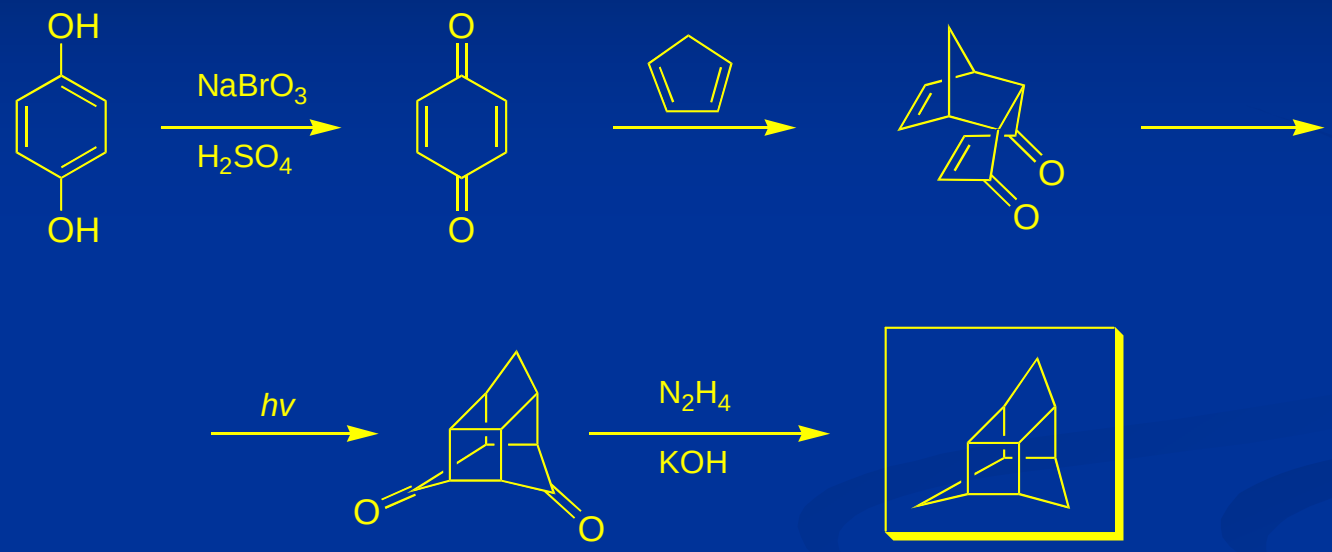


D_3

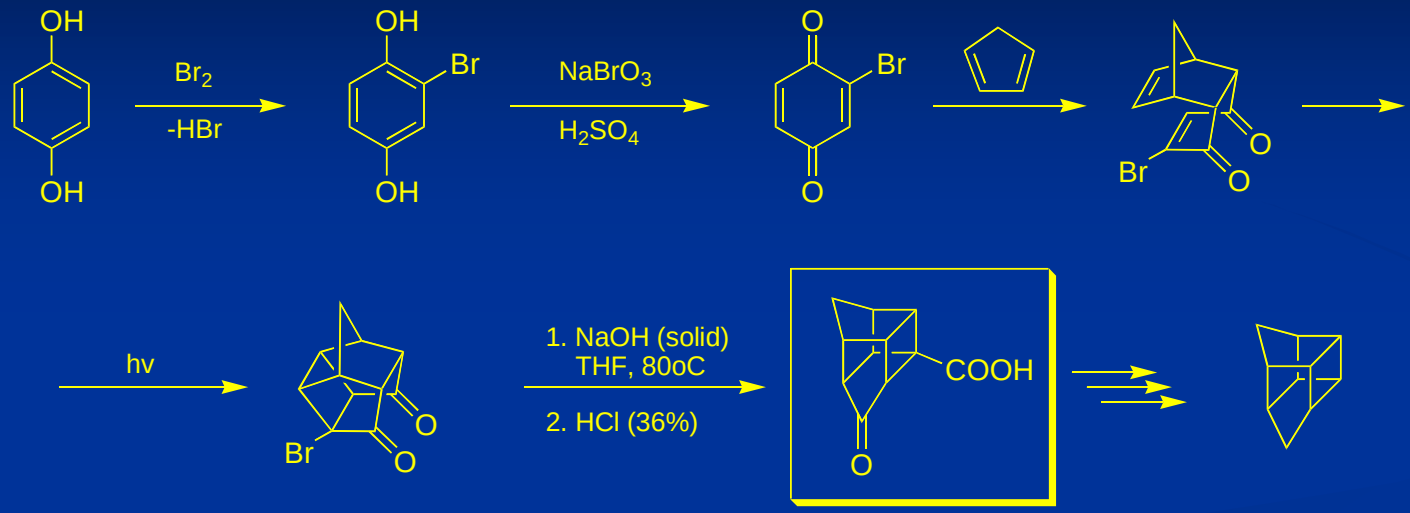
Synthesis of monohomocubane



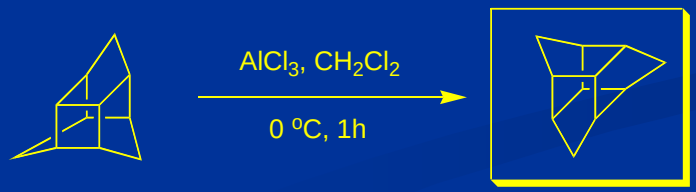
Synthesis of C_s-trishomocubane



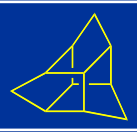
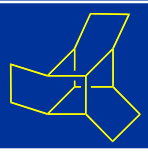
Synthesis of C_2-bishomocubane



Synthesis of D_3-trishomocubane

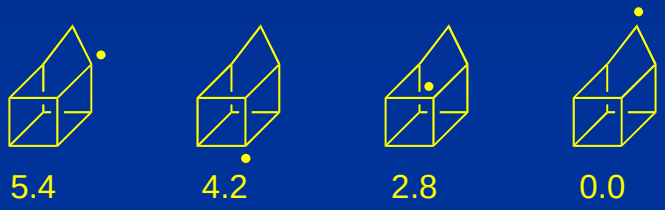


Strain energies of cubanes computed via homodesmotic equations (B3LYP/6-31G*)

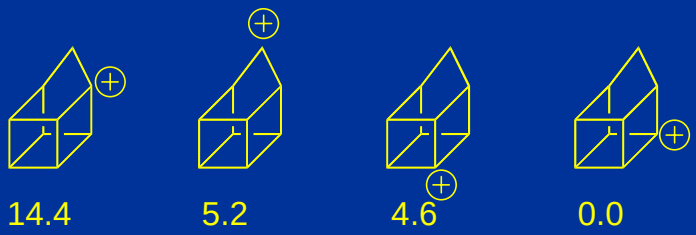
Structure	E_{str} , kcal/mol	$E_{str/C}$, kcal/mol
	153.8	19.2
	108.8	12.1
	86.5	8.6
	82.2	8.2
	70.0	7.0
	68.5	6.8
	41.9	3.8
	40.2	3.7
	32.4	2.3

Relative stability of radical and cationic intermediates: homocubane and C_2-bishomocubane

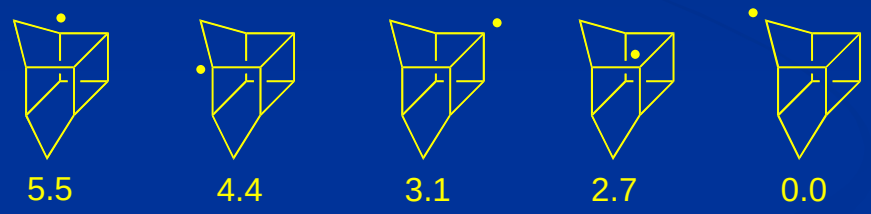
Radicals



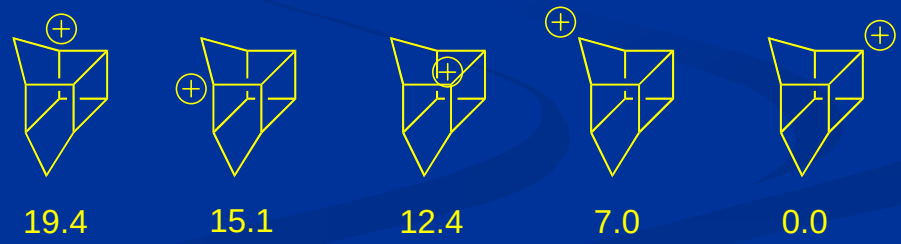
Cations



Radicals

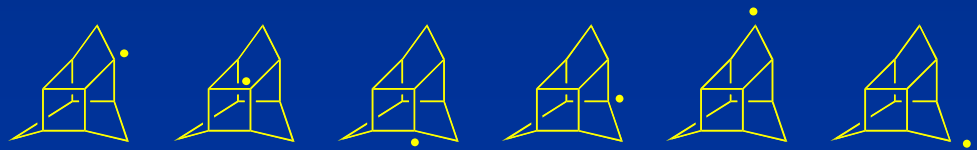


Cations

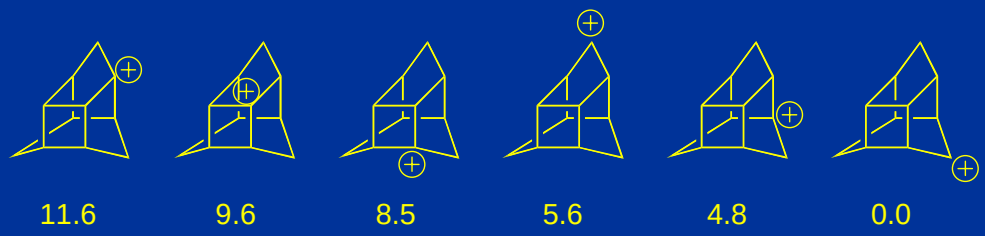


Relative stability of possible intermediates: C_S-trishomocubane and D_3-trishomocubane

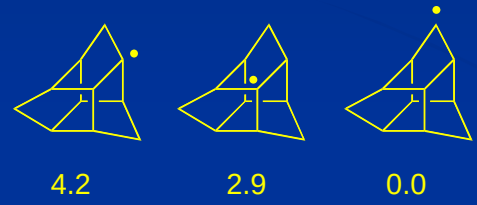
Radicals



Cations

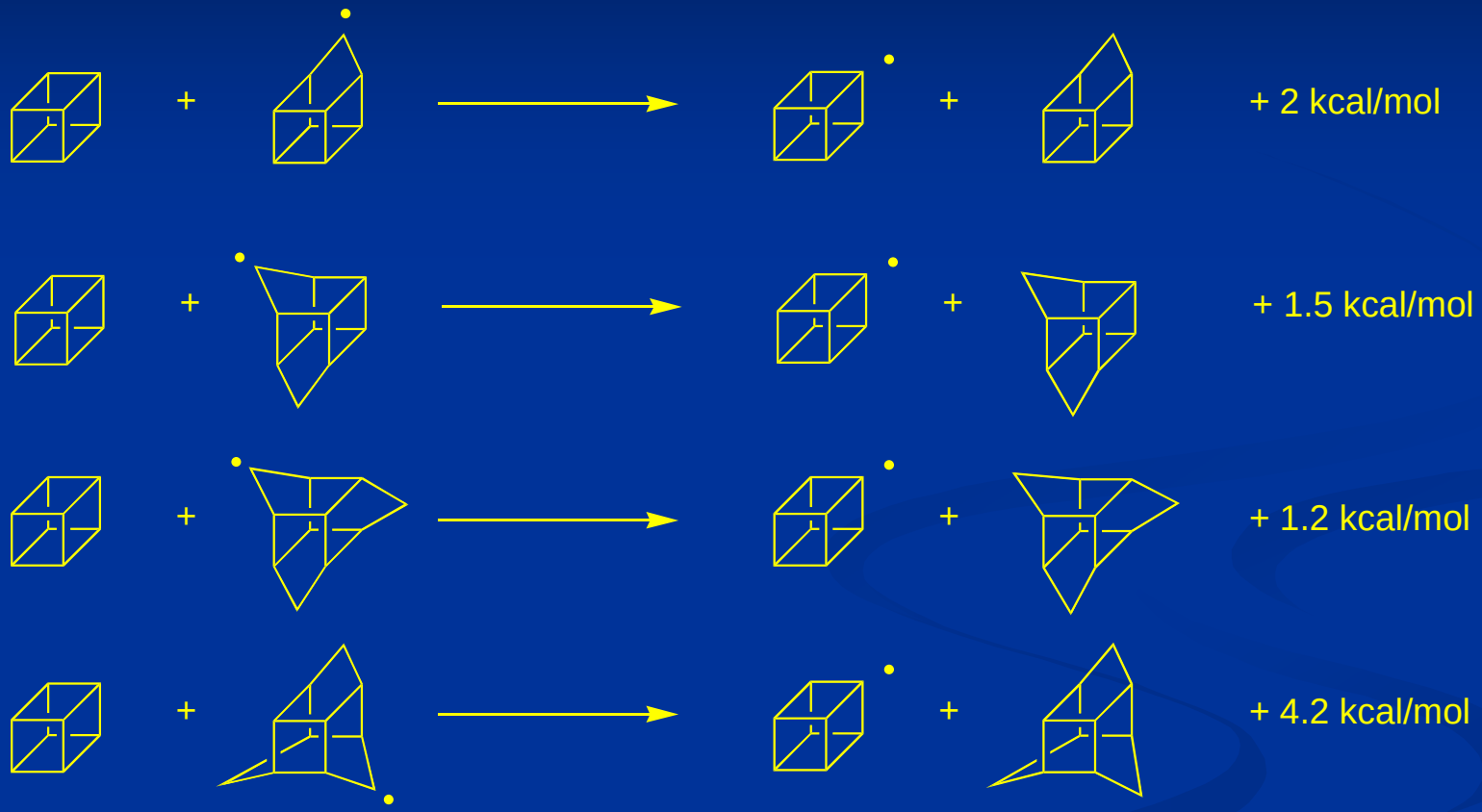


Radicals

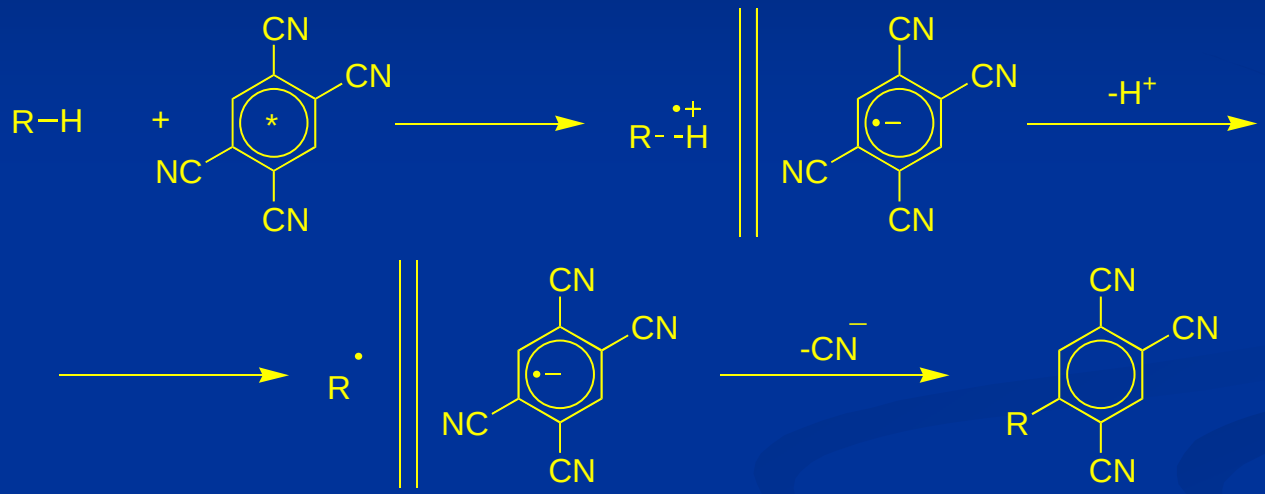


Cations

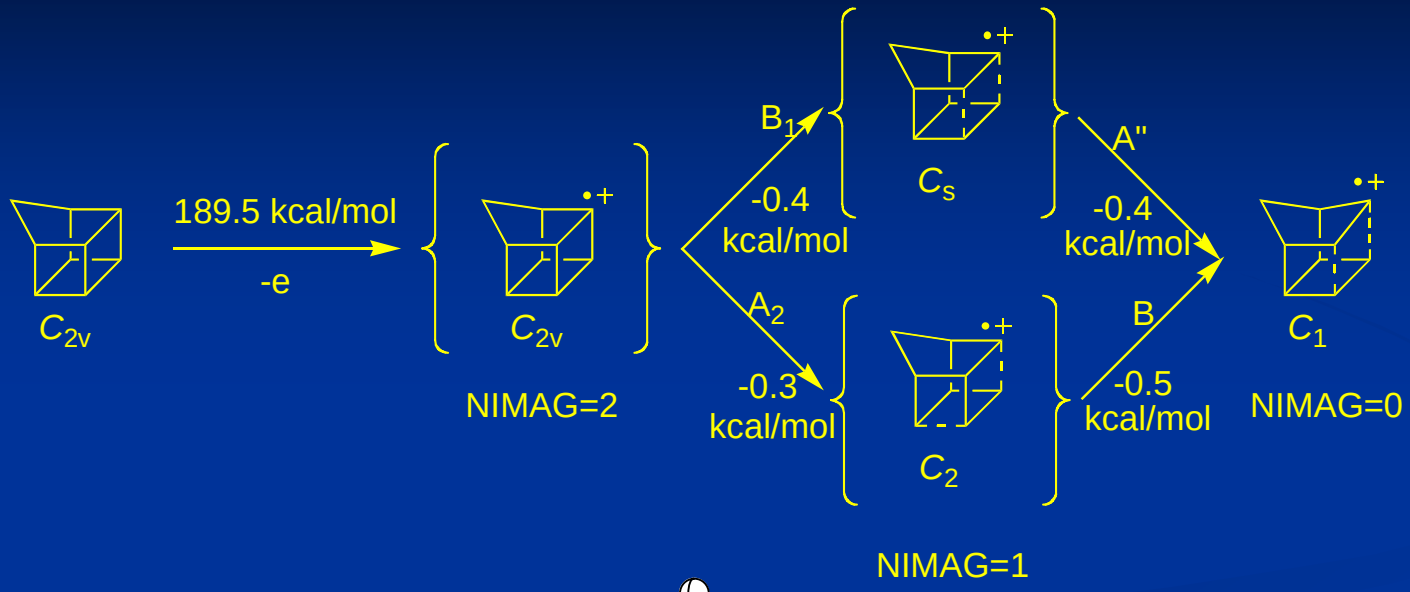
Energies of oligohomocubyl radicals relatively to cubyl radical

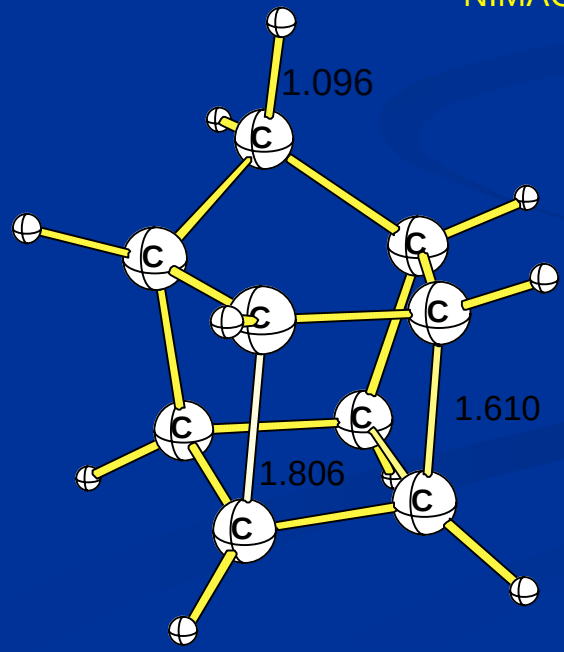


General scheme for hydrocarbon oxidations with TCB



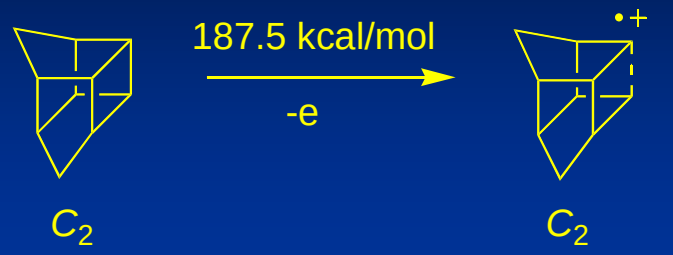
Radical cation of homocubane



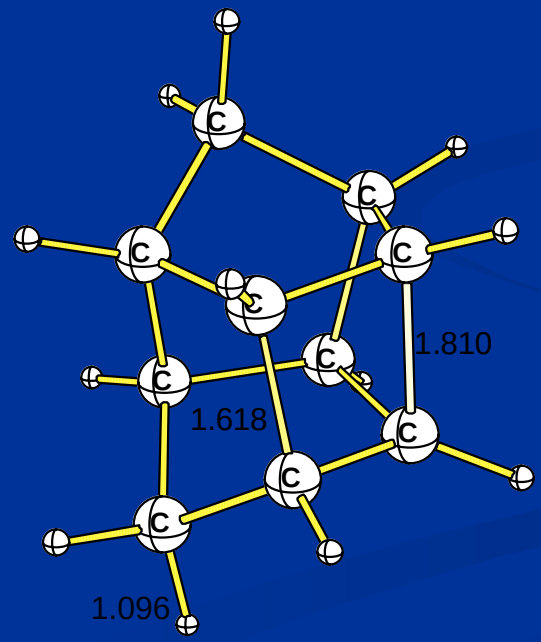


B3LYP/6-31G*

Radical cation of C_2-bishomocubane

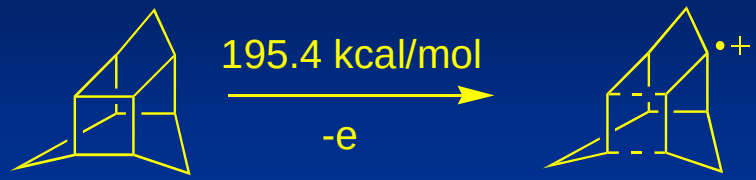


NIMAG=0



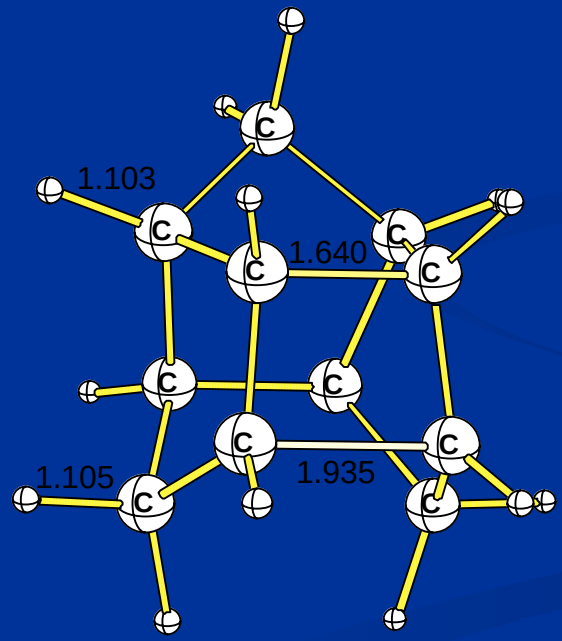
B3LYP/6-31G*

Radical cation of C_s-trishomocubane



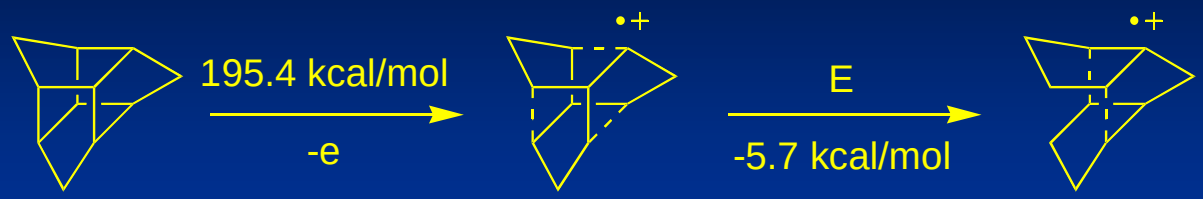
C_s C_s

NIMAG=0



B3LYP/6-31G*

Radical cation of D_3-trishomocubane



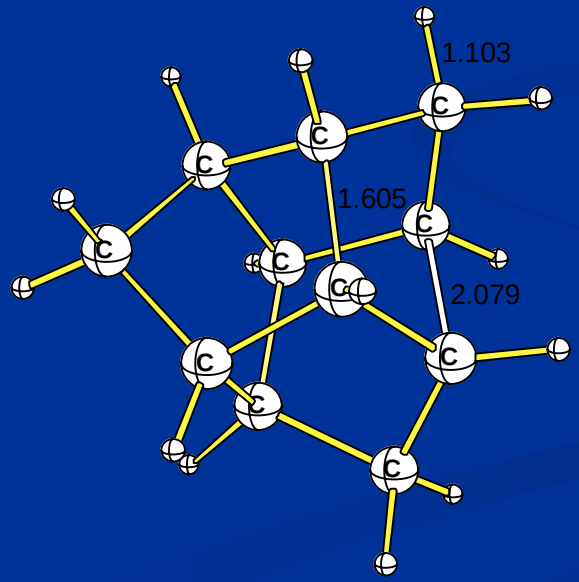
D_3

D_3

NIMAG=2

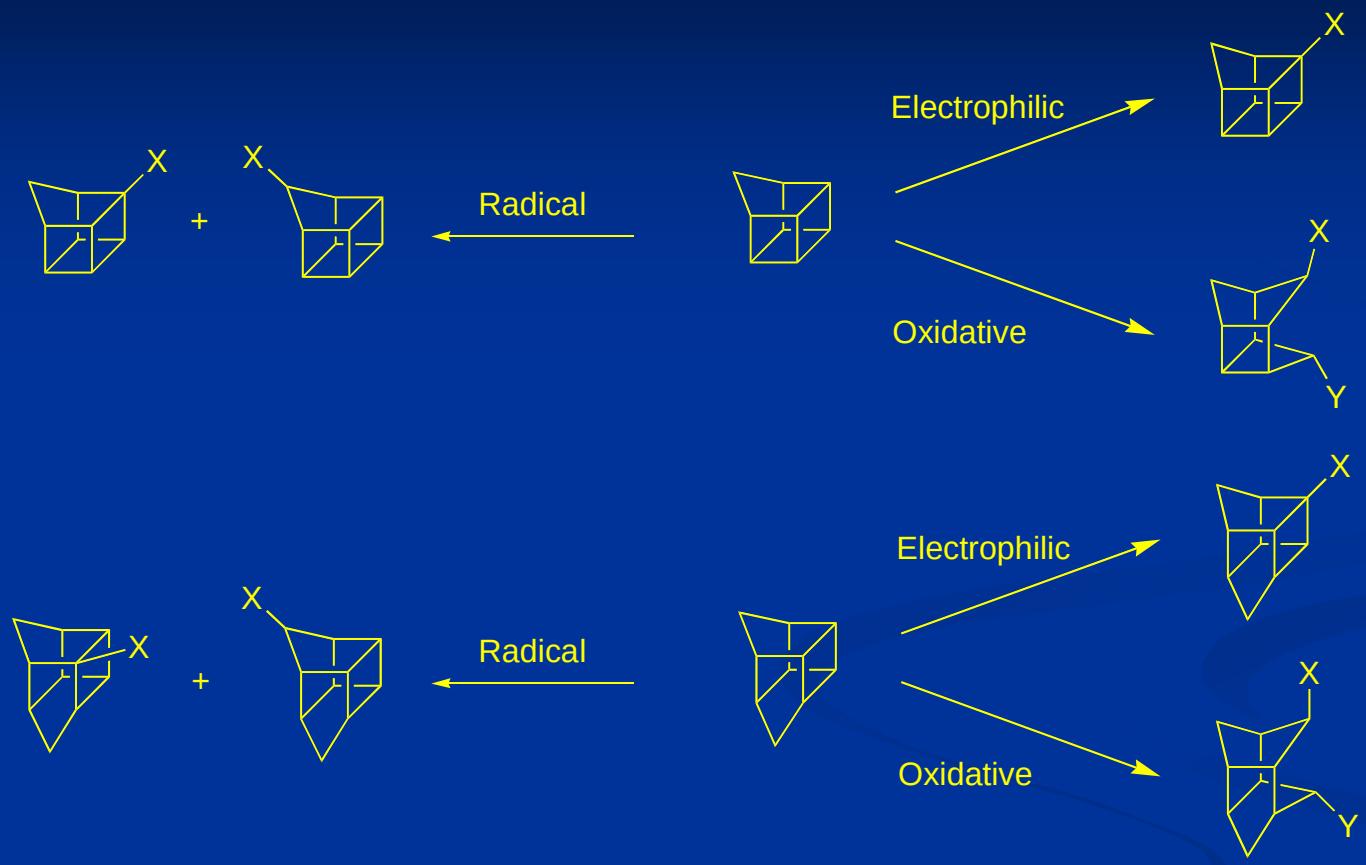
C_2

NIMAG=0

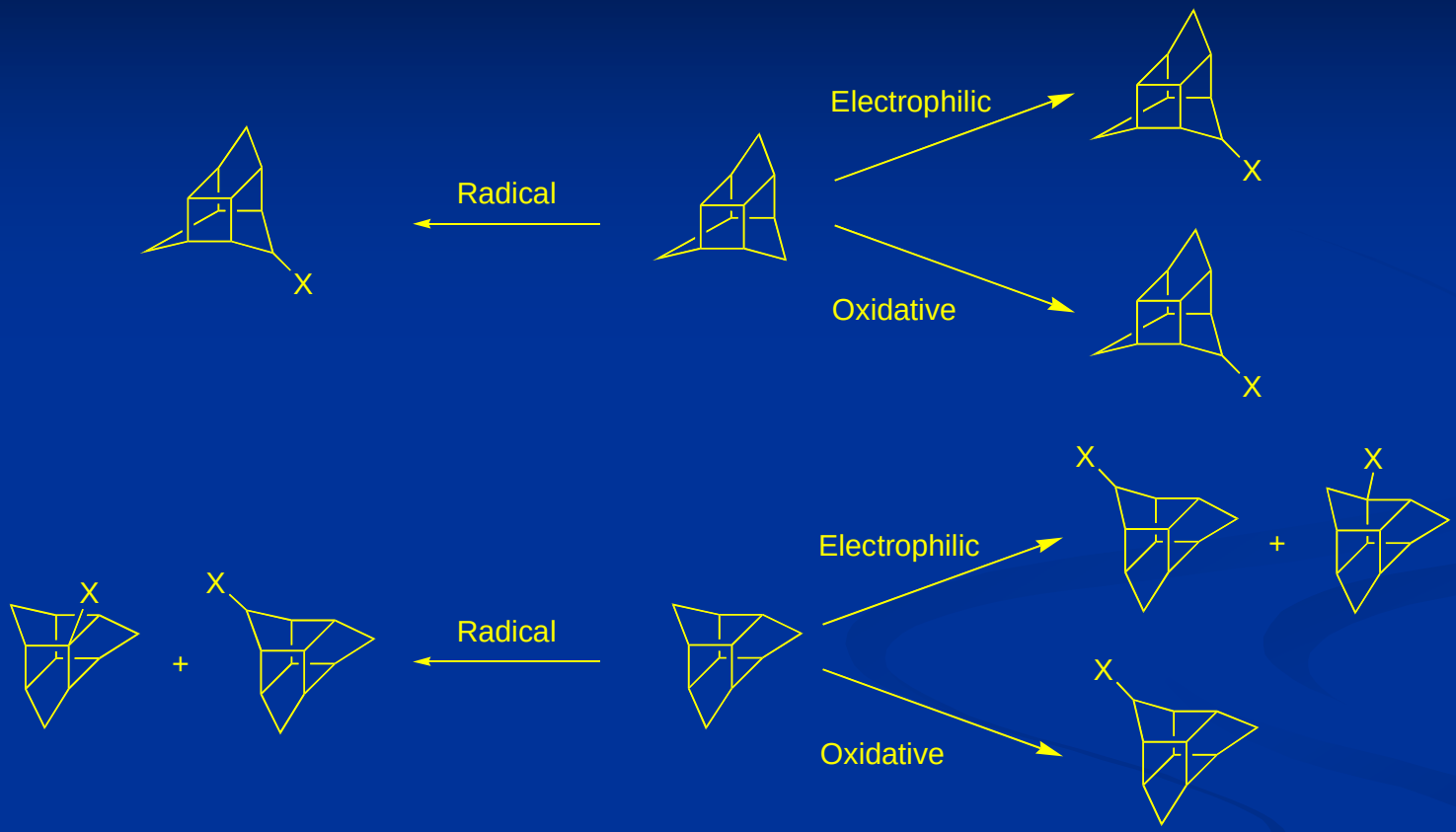


B3LYP/6-31G*

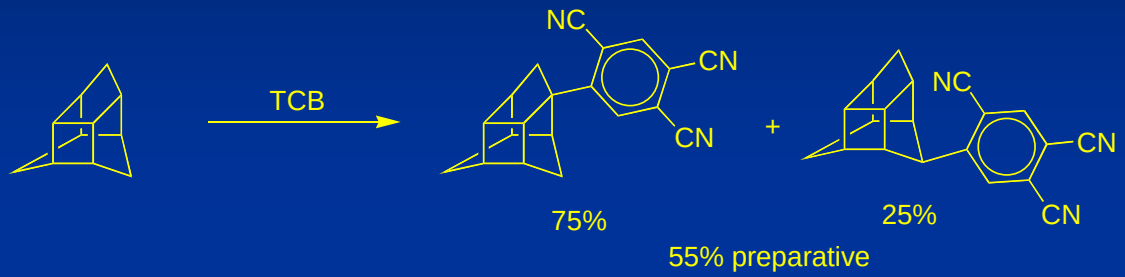
Possible ways of C–H substitution in homocubane and C_2-bishomocubane



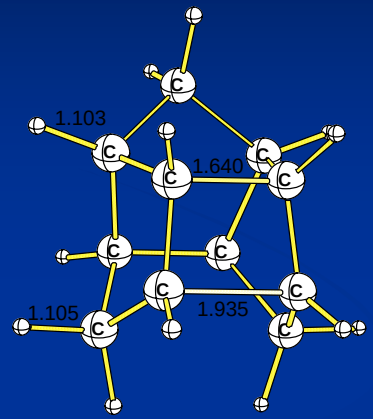
Possible ways of C–H substitution in trishomocubanes

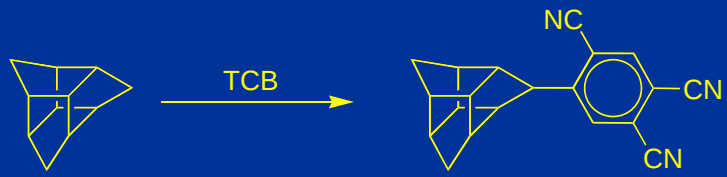


Oxidation of trishomocubanes by 1,2,4,5-tetracyanobenzene

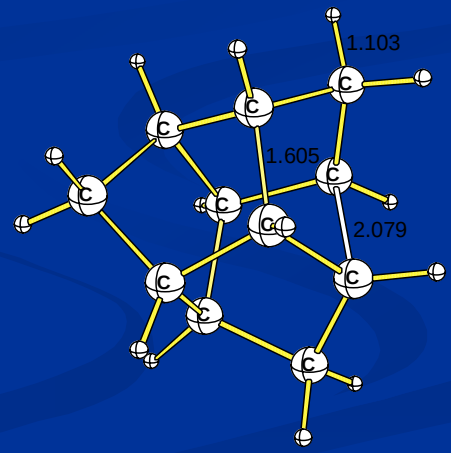


55% preparative





100% (75% preparative)



Conclusions

1. Preparative methods of synthesis of homocubane, C_s- and D_3-trishomocubanes have been developed from hydroquinone with overall yields 30%, 60% and 39%, respectively.
2. The scheme for the preparation of C_2-bishomocubane from hydroquinone have been proposed and the key intermediate have been prepared.
3. The strain energies of the set of olygohomocubanes have been computed at B3LYP/6-31G*. The most significant lowering of the strain was found for monohomologization of cubane (ca 45 kcal/mol). The strain energy of bishomocubanes depends on the relative positions of the bridges.
4. Structure and relative stability of cations, radicals and radical cations derived from olygohomocubanes have been evaluated. This makes possible to predict the ways of functionalization of these cage compounds under electrophilic, radical and oxidative conditions.
5. The SET oxidations of trishomocubanes was studied, and the observed selectivities for C–H substitutions are in full agreement with the computed structures of the trishomocubanes radical cations.