Generation of organometal species

1. Organo halide + Metal

- $R\text{-}X + 2M = RM + MX$ M = 1 electron donor (Li, Na, K, Cu, SmI_2 ...) Wurtz coupling occurred easily with reactive substrates
- $R\text{-}X + M = RMX$ M = 2 electron donor (Mg, Ca, Ba, Zn ...)

Reactivity of R-X

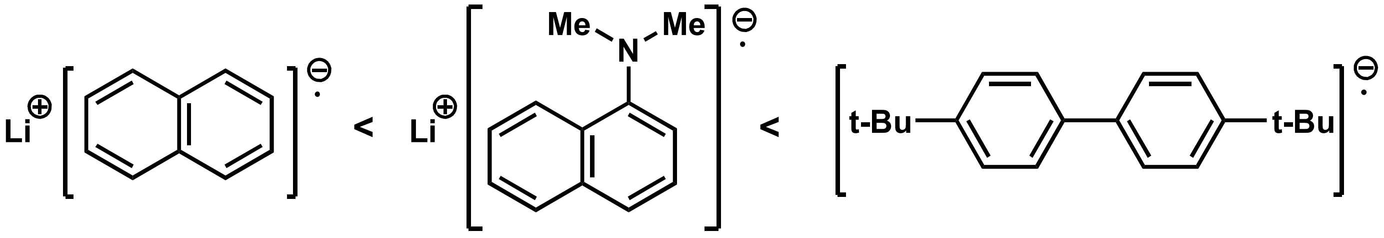
$F << Cl < Br < I$

Stereochemistry

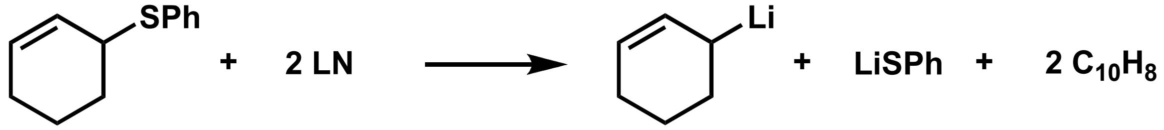
Depend on substrates and reactivty of metals

Activation of metals to facilitate halogen-metal exchange.

- alkali metal arenide



LN (lithium naphtalenide) LDMAN (lithium 1-dimethylamino-naphtalenide) LDBB (lithium 4,4'-di-*tert*-butyl-biphenylide)



- Rieke metals (Mg, Zn, Ba, Cu etc...)

$$MX_n + nK \text{ (or } nNa) \xrightarrow{\text{naphtalene cat.}} M^* + nKX \text{ (or } nNaX)$$

Highly active metal(0) is generated.

R. D. Rieke *Acc. Chem. Res.* 1977, *10*, 301.
A. Furstner *Angew. Chem. Int. Ed.* 1993, *32*, 164.

$$nC_8H_{17}F + Mg^* \longrightarrow nC_8H_{17}MgF$$

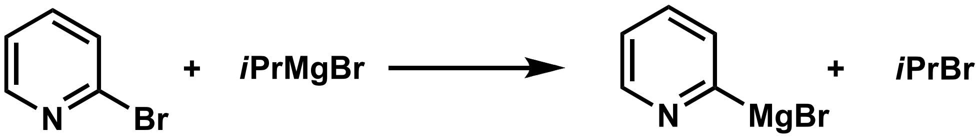
2. Halogen-Metal exchange

● $RX + R'M \longrightarrow [R{-}X{-}R']^{\ominus}\ M^{\oplus} \longrightarrow RM + R'X$

via ate complex

X = halogen, Se, Te...

Anion of RM should be more stable than R'M.



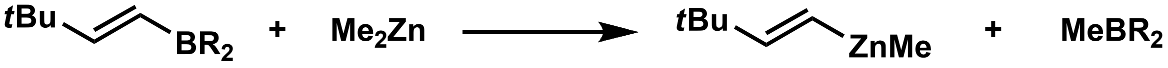
3. Metal-Metal exchange

● $RM' + R'M \longrightarrow [R{-}M'{-}R']^{\ominus}\ M^{\oplus} \longrightarrow RM + R'M'$

via ate complex

Anion shold be
thermodynamicaly more stable.

M' = Sn, B etc... (easily form ate complex)
R'M ··· High polarity



retention of configuration

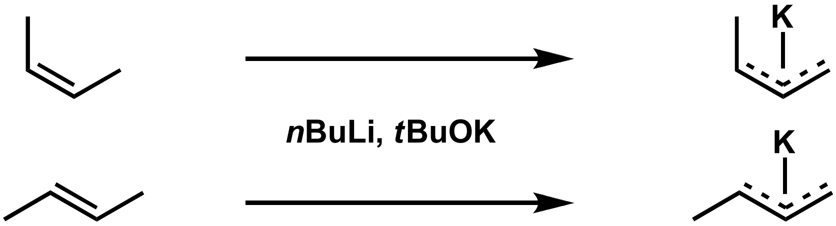
4. Hydrogen-Metal exchange (Metalation)

● $RH + R'M \longrightarrow RM + R'H$ difference in pKa >2 ~3

basicity of R'M

Cs > Rb > K > Ba > Na > Ca > Li > Mg

mixture of *n*BuLi and *t*BuOK···super base (Schlosser base)



retention

ortho metalation

effect of directing group

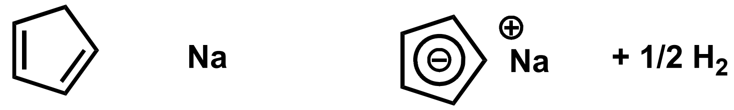
$SO_2NR_2 > SO_2Ar > CONR_2 > CONHR > CH_2NMe_2 > OR > NHAr > SR > NR_2 > CR_2O^-$

5. Others

- $RM' + M \longrightarrow RM + M'$ electronegativity M < M'

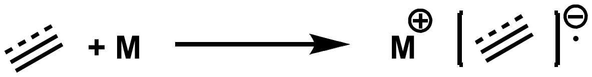
$Et_2Zn + 2Cs \longrightarrow 2\,EtCs + Zn$

- $RH + M \longrightarrow RM + 1/2\,H_2$ salt free organic metals

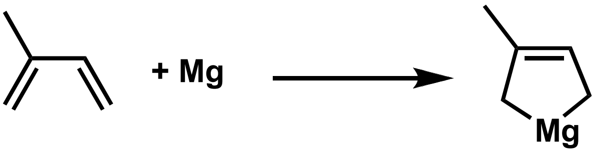


- $RM' + X'M \longrightarrow RM + M'X'$ M'X' ... driving force

$RLi + CeCl_3 \longrightarrow RCeCl_2 + LiCl$

- 

π* accepts one electron
radical anion ... potent 1 electron donor (metal arenide)



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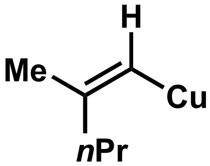
hydrometalation
carbometalation

$Me-C\equiv C-H + nPrCu(MgBr_2)(SMe_2) \longrightarrow$



Feature of organo metalic species

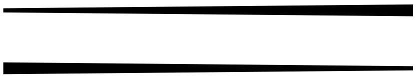
1) How ionic?
2) Stability of carbanion
3) η^1, η^3, η^5
4) Lewis acidity of the metal
5) Ligand effect
6) Aggregation
7) Steric factor

	Li	Na	K	Be	Mg	Ca	Ba	B	Al	Tl	Cu	Zn	lantanoid
electron negativity (χ_M)	1.0	0.9	0.8	1.5	1.2	1.0	0.9	2.0	1.5	1.8	1.9	1.6	1.1~1.2
ionic nature (%)	43	47	51	22	34	43	47	6	22	12	9	18	38~34

	C(sp)	C(sp^2)	C(sp^3)
electron negativity (χ_M)	3.29	2.75	2.5

basicity

nucleophilicity



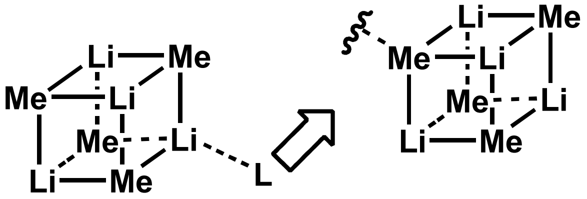
(steric factor)

π-conjugated system (allyl, benzyl etc...) showed exceptional reactivity.

Li, Na, K, Rb, Cs, Fr (mainly Li)

aggregation state

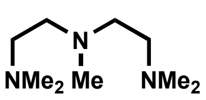
large R
high *s* character
highly coordinating solvent
} lower aggregation state



or THF etc...

multiple coordination

TMEDA ··· dimer or trimer



··· monomer

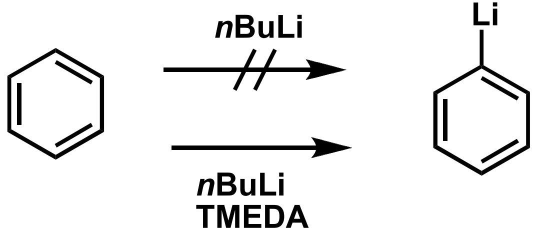
(PMDTA)

4-center-2-electron

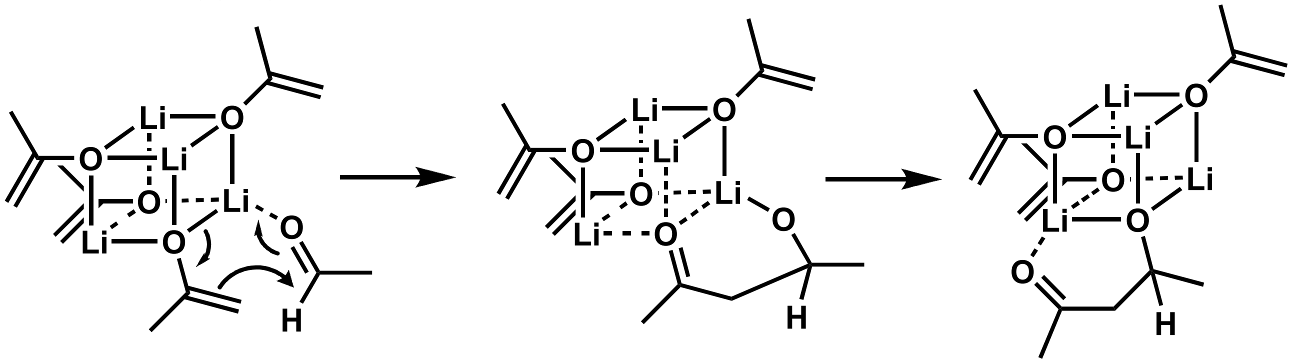
π-conjugated system (allyl, benzyl etc...) ··· lower aggregation state
lithium amide ··· dimer
lithium enolate ··· tetramer

reaction path

● dissotiation path



● maintain aggregation



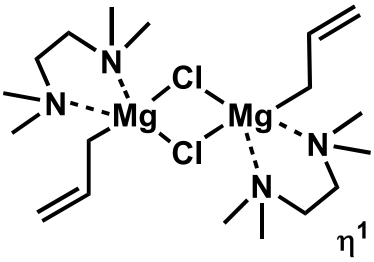
Half-life of organo lithium

solvent	temp.	MeLI	EtLi	*n*BuLi	*s*BuLi	*t*BuLi	vinyl-Li	PhLi
Et_2O	rt	months	54 hr	6 days		decomp.	> 7 days	
	35 °C			31 hr				12 hr
THF	rt			2 hr			> 7 days	
	0 °C			1 day	30 min.	decomp.		
	-30 °C			5 days				short time
DME	25 °C			10 min.				

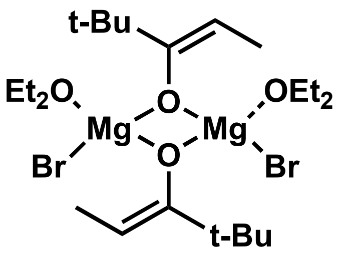
Be, Mg, Ca, Sr, Ba, Ra

aggregation state

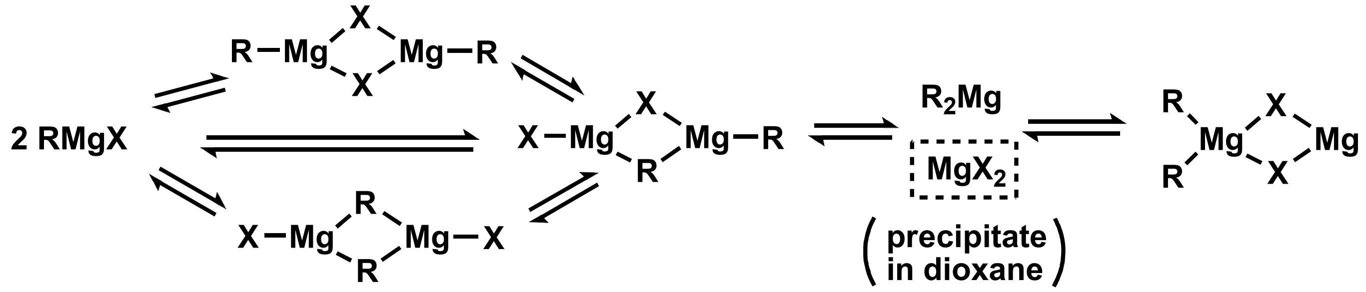
variable ex. monomer in variable conc. in THF
low conc. in Et_2O



η¹ structure

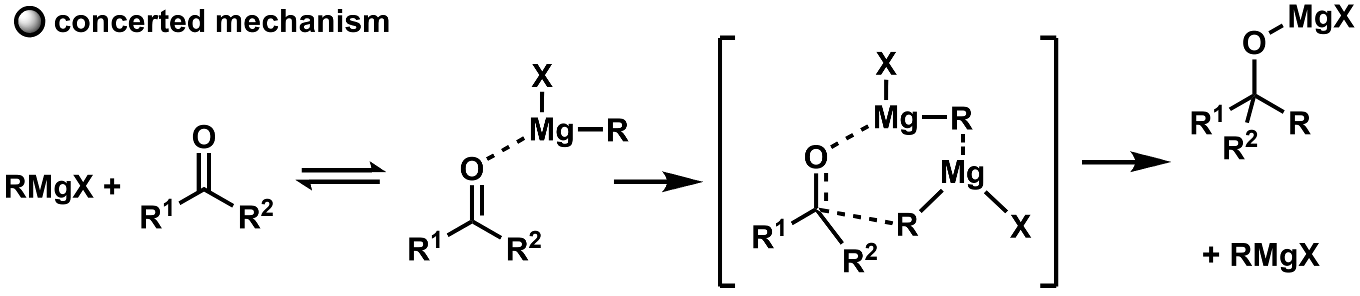


Schlenk equilibrium

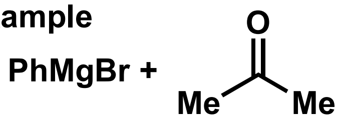


reaction mechenism of Grignard reagent

- concerted mechanism

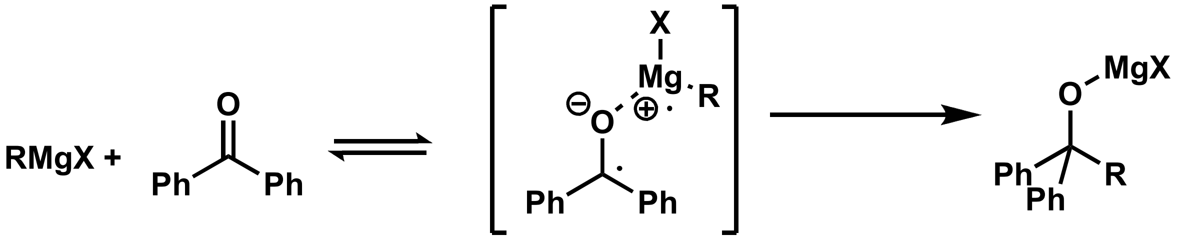


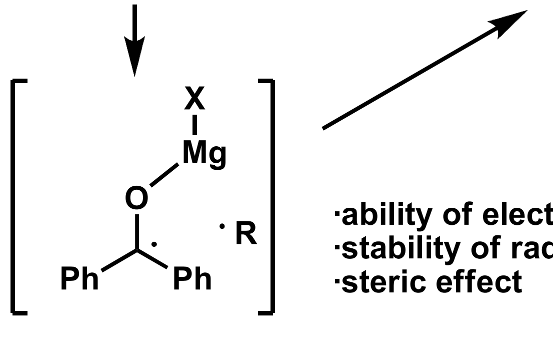
typical example



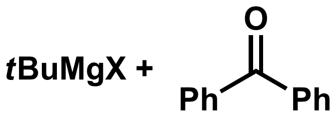
steric effect is major factor

- electron transfer mechanism





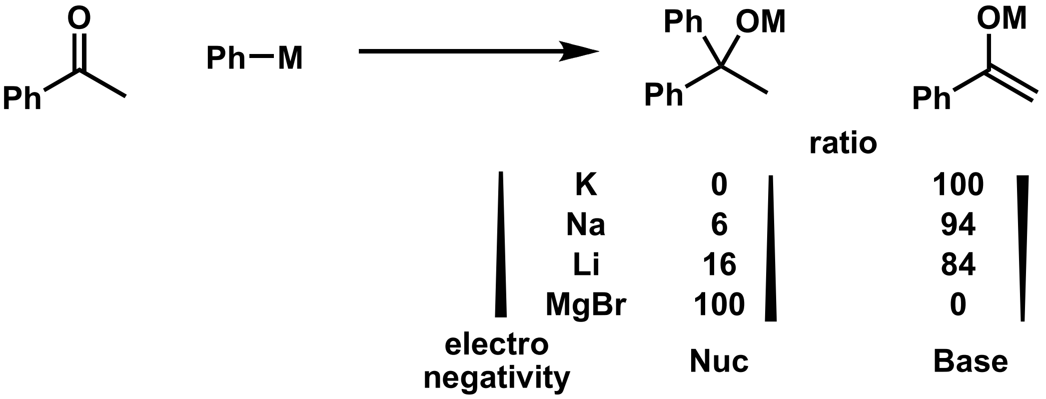
typical example



·ability of electron donor
·stability of radical species
·steric effect

alkali and alkaliearth metals

basicity vs nucleophilicity

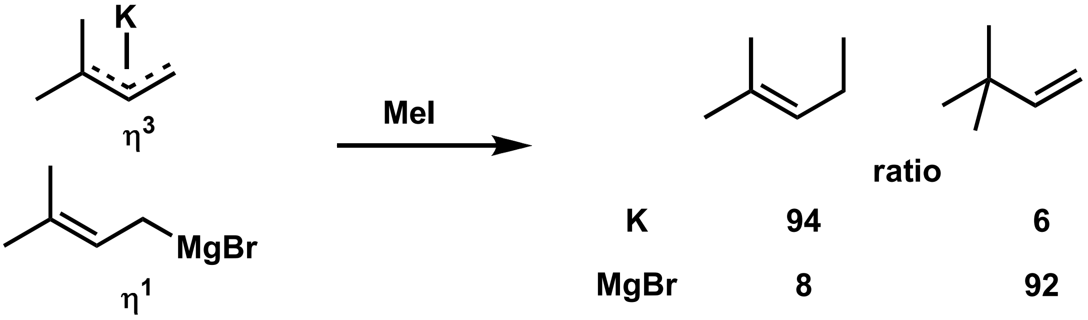


ratio

	Nuc	Base
K	0	100
Na	6	94
Li	16	84
MgBr	100	0

electro negativity

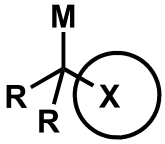
regioselectivity



ratio

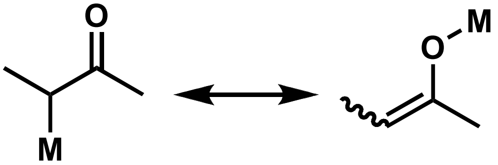
K	94	6
MgBr	8	92

effect of α-substituent



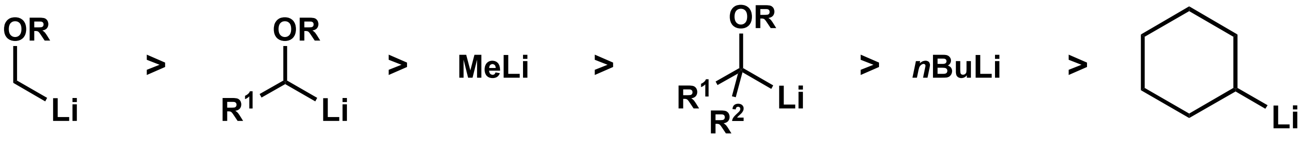
- electron withdrawing group
  - stabilize the anion via conjugation effect

X = COR, CN, NC, NO_2, SOR, $P(O)(OR)_2$ etc...



- stabilize the anion via inductive effect

X = OR, NR_2



OR ... 20~25 $kJmol^{-1}$ stabilize
R ... 15 $kJmol^{-1}$ destabilize

G. J. McGarvey *et al. J. Am. Chem. Soc.* 1988, *110*, 842.

- negative hyperconjugation

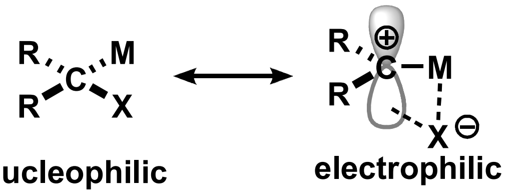
X = SiR_3, SR, SeR

$\sigma(C\text{-}M)–\sigma^*(X\text{-}R)$

● carbenoid

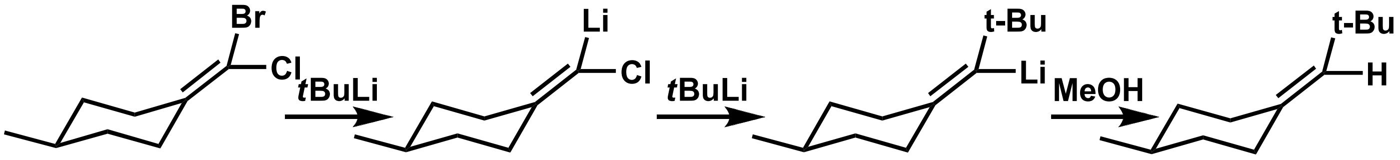
X = F, Cl, Br, I, OR

both nucleophilicity and electrophilicity at C center



C-X bond is longer than neutral compound.

H. Ahlbrecht *et al. Chem. Ber.* 1993, *126*, 1887.
A. Maercker *et al. Angew. Chem. Int. Ed.* 1993, *32*, 1023.



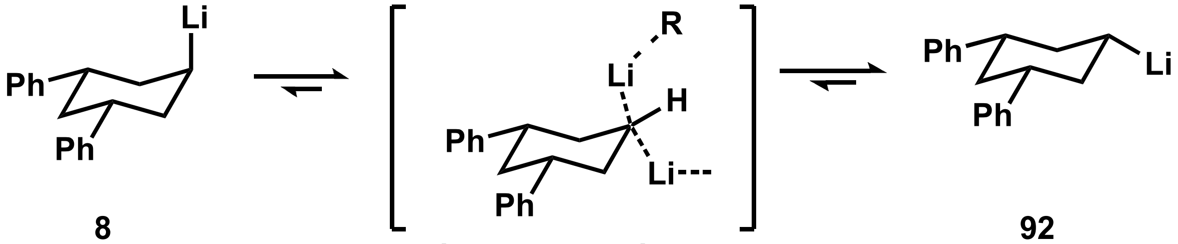
100% ee

39% ee

partially via carbene

cf. *gem*-bimetalic species (R_2CM_2) ... lower nucleophilicity than R_2CHM
ref. J. -F. Normant *et al.* Chem. Rev. 1996, *96*, 3241.

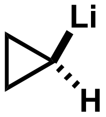
inversion of stereochemistry



8

via aggregated state

92

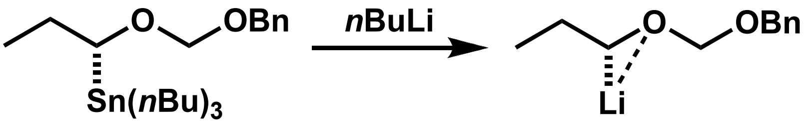


stable
(hard to form planar TS)

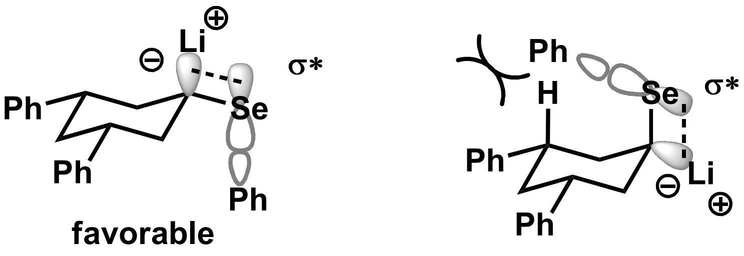
Grignard reagent

slower stereo inversion

α-alcoxy or amino organometals resist to stereo inversion at low temp.



α-SiR_3, SR, SeR etc organometals resist to stereo inversion at low temp.



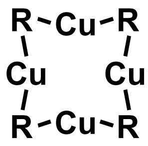
R. W. Hoffmann *et al. Angew. Chem. Int. Ed.* 1993, *32*, 1467.
R. R. Dykstra *et al. Angew. Chem. Int. Ed.* 1993, *32*, 1469.

Cu

- $CuX + RM \longrightarrow CuR + MX$

Lewis acid (MgX_2, TMSCl etc.)
Lewis base (R_3P, R_2S etc.)
coordinative solvent
} improves the reactivity

R = $TMSCH_2$



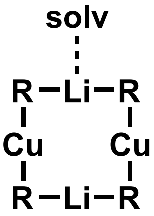
3-center-2-electron

cuprate

- $CuX + 2RM \longrightarrow MCuR_2 + MX$

Gillman reagent

higher stability
higher reactivity
higher solubility
} than CuR

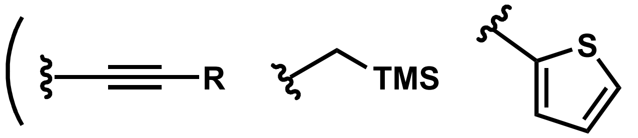


heterocuprate

- $CuZ + RM \longrightarrow MCuRZ$

Z = CN, SPh, NR'_2, OR'
less transferable group than R

higher stability
lower reactivity
} than $MCuR_2$

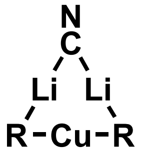


are also
less transferable gloup

higher order cuprate

- $CuCN + 2RM \longrightarrow M_2CuR_2(CN)$

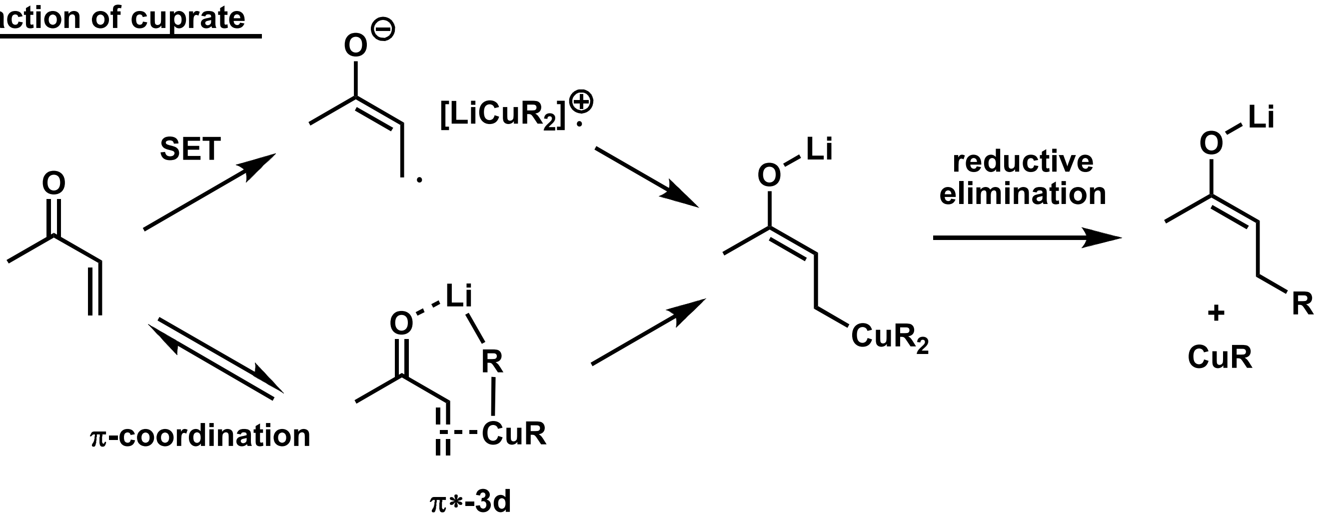
higher reactivity
higher stability
} than $MCuR_2$



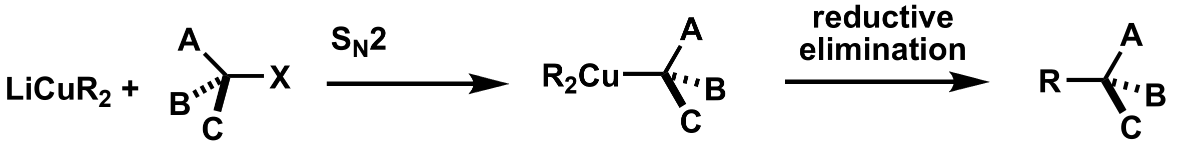
(proposed structure)

N. Krause *et al. J. Am. Chem. Soc.* 1996, *118*, 4149.

reaction of cuprate



S_N2 type substitution



SET process is also plausible in some cases.

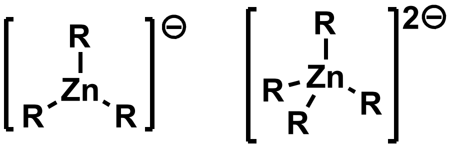
Zn

R-Zn-R ··· monomer, linear structure, low reactivity

Zn-C has lower polarization.
Not reactive in the absence of ligand.

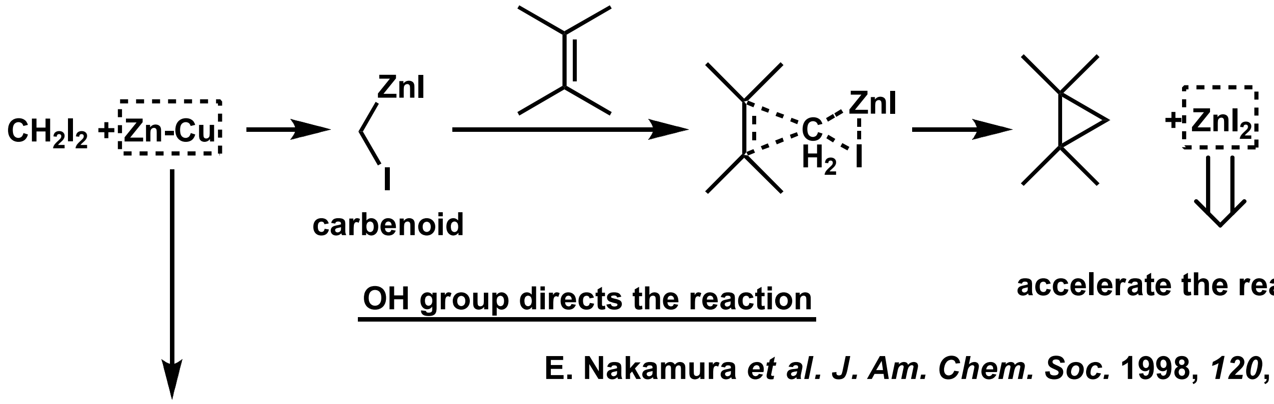
ligand { distorted the linear structure
improves the reactivity

ate complexes show higher reactivity



(R = alkynyl, O, N, X, carbonyl compound ··· various aggregation state)

Simmons-Smith reaction



accelerate the reaction

OH group directs the reaction

E. Nakamura *et al. J. Am. Chem. Soc.* 1998, *120*, 5844.

R_2Zn or R_3Al can also promote the reaction.

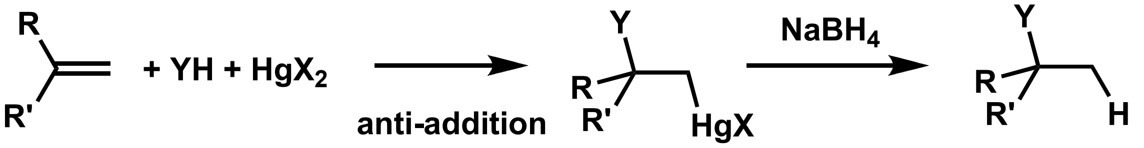
R_2Cd ··· monomer, linear structure, lower reactivity than R_2Zn

R_4Cd^{2-} ... unstable due to low Lewis acidity

R_2Hg, RHgX ··· monomer, linear structure, stable in water and O_2 atmosphere

Hg-C bond ... almost covalent bond

solvomercuration



B, Al, Ga, In, Tl

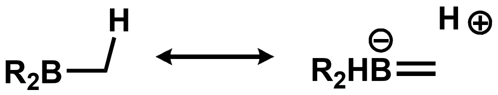
R_3M ··· planar structure

Lewis acidity

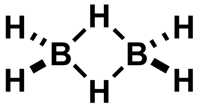
MCl_3	B > Al > Ga > In > Tl
MMe_3	Al > B > Ga > In > Tl

B

hyperconjugation stabilizes monomer species

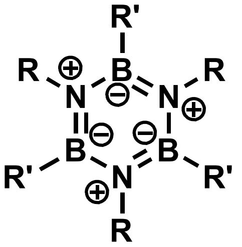


conjugation effect of hetero atoms Cl < S < O < F < N

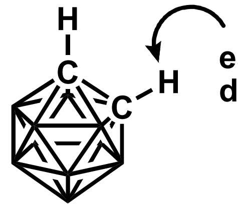


diborane

3-center-2-electron



borazine



carbaborane

easily deprotonated

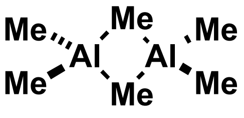
electron acceptor

R_3B ··· stable in water

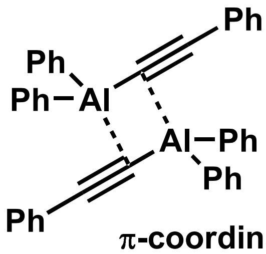
R· is generated under mild O_2 oxidation

Al

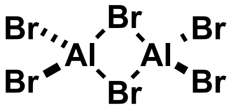
less effective stabilization by hyperconjugation



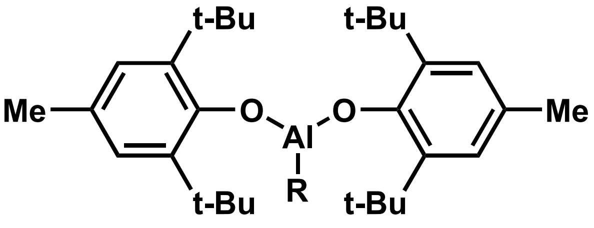
3-center-2-electron



π-coordination



2-center-2-electron



bulky substituents prefer monomeric species

rapid equibrium

$$R^1{}_3Al + R^2{}_3Al \rightleftharpoons R^1{}_2R^2Al + R^1R^2{}_2Al \rightleftharpoons ..... \rightleftharpoons .....\ \text{mixture}$$

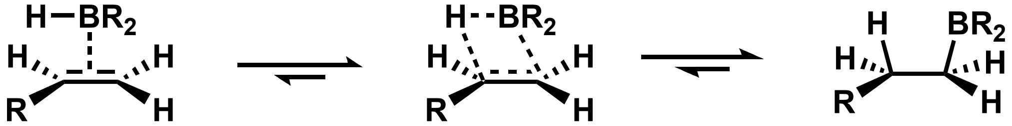
ate complex

$$AlEt_3 + LiEt \longrightarrow LiAlEt_4$$

coordination profile

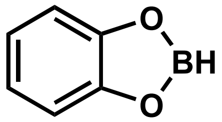
$Me_3N > Me_3P > Me_3As > Et_2O > Me_2S > Me_2Se > Me_2Te$

hydroboration

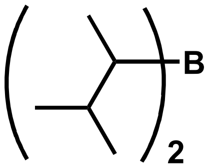


anti-
Markovnikov

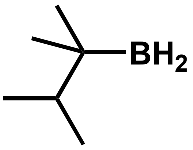
(Coordination of solvent promotes dissociation of dimer.)



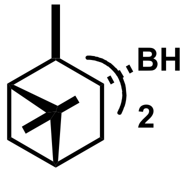
less reactive



$(Sia)_2BH$



texylborane



enantioselective

sensitive to steric effect

hydroalumination

Similar mechanism as hydroboration is proposed.

electronic effect > steric effect   t-Bu—≡—t-Bu > n-Bu—≡—n-Bu

20-fold faster

Ph—≡—Z + DIBAL

Z = $Me_2N(1900) > Me_3Si(431) > t\text{Bu}(28) > EtS(25) > H(12) > Me(1.2) > Ph(1)$

Lanthanoid

Sc, Y, Lanthanide

normally M^{3+} (M^{3+}/M reduction voltage E^o = -2.25~-2.52V)

other than M^{3+} ion

Ce^{4+} (f^0)
Eu^{2+} (f^7) f^0, f^7, f^{14} ions are rather stable
Yb^{2+} (f^{14})

lanthanide contraction

ionic radius

less efficient shield effect of 4*f* orbital

large ionic radius ⇨ higher coordination number (6 ~ 10)

small interaction between CO, alkene (π-backdonation type ligand)

shift reagent ... through pseudocontact shift