«Main Group» Organometallics

Nucleophilic Organometallics: Li, Mg, Zn, (Cu)

LiR **RMX** **MR_2** **$ZnR_n^{(n-2)-}$ (n= 3,4)**

Li-C very polarized covalent bond, sometimes almost ionic, depending on the nature of R and on solvent/additives

Mg-C polarized covalent bond; polarization degree dependent on R but lower than in the case of Li

Zn-C bond less polarized than Mg-C bond (85% covalent)

Mg and Zn compounds are worse bases than Li compounds, Zn compounds are worse nucleophiles than Li and Mg compounds

Nucleophilic Organometallics: Li, Mg, Zn, (Cu) Why only these metals?

Li is the only element of group 1 exhibiting covalent bonding to C.

Mg displays an organometallic chemistry very similar to Be; the latter provides expensive, poorly soluble, highly toxic compounds which are less reactive as nucleophiles. Other group 2 metals display M-C interactions that are predominantly ionic.

Zn displays an organometallic chemistry very similar to Cd; the latter provides highly toxic compounds which are less reactive as nucleophiles (which may be useful, e.g. acyl halides → ketones). Hg displays instead an entirely different organometallic chemistry, which will be discussed to some extent later in the course. Organometallic Hg compounds are however extremely toxic!

Synthetic methods (from metals)

1) Direct synthesis:

$2M_{(s)} + nRX \rightarrow R_nM + MX_n$ (or R_nMX_n) (**Li**, **Mg**, **Zn**, Al, *Si*, Sn)

$MX'_n + RX \rightarrow R\text{-}MX'_n\text{-}X$ (Sn, **transition metals**)

- Thermodynamically controlled by the formation of the inorganic salt.

- Facile with electropositive metals (Li>Mg>Zn), although it can be promoted by the use of alloys:

$$2Na + Hg + 2CH_3Br \rightarrow Hg(CH_3)_2 + 2NaBr$$

- Kinetically inhibited with X= F.

Direct synthesis

$$Li_{(s)} + R\text{-}X \rightarrow Li\text{-}R + LiX$$
$$M_{(s)} + R\text{-}X \rightarrow R\text{-}M\text{-}X \quad (R= Mg, Zn)$$

- The reaction efficiency depends on the free metal surface; it is necessary to maximize it and to clean it from oxides (e.g. with X_2 or XCH_2CH_2X for Mg).

- Extremely reactive, “active forms” of Mg or Zn exist:

$MCl_2 + K \rightarrow M^*$ (Rieke) Mg in THF reacts with $C_8H_{17}F$ at RT.

$MgI_2 + C_8K \rightarrow C_nMg$ forms the Grignard at –78°C

- The reactivity of the organic halide follows the order I > Br > Cl >> F. With halogens that are too reactive, though, the **Wurtz reaction** gains importance with Li and, more rarely, with Mg:

$Li\text{-}R + R\text{-}X \rightarrow R\text{-}R + LiX$ homogeneous homocoupling

Direct synthesis – The Wurtz reaction

$$\text{Li-R} + \text{R-X} \rightarrow \text{R-R} + \text{LiX}$$

- Iodides are therefore unsuited for direct synthesis with Li (<u>but are required for Zn</u>). Bromides are generally used with aromatic Rs, chlorides with aliphatic Rs. Only exception: Li and CH_3I

$$\text{Li}_{(s)} + \text{CH}_3\text{-I} \rightarrow \text{Li-CH}_3\downarrow + \text{LiI}$$

LiMe precipitates before undergoing the Wurtz reaction. Use of CH_3Br would be unpractical, since it is gaseous.

- Aliphatic Rs that stabilize a negative charge on C (benzyl, allyl) are also prone to undergo the Wurtz reaction.

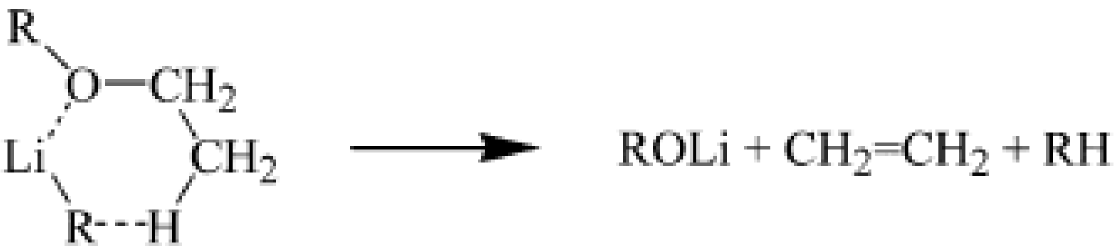
- Controlled addition of the halide is generally recommended with Li and Mg.

Direct synthesis

$$Li_{(s)} + R\text{-}X \rightarrow Li\text{-}R + LiX$$

$$M_{(s)} + R\text{-}X \rightarrow R\text{-}M\text{-}X \quad (R= Mg, Zn)$$

- The reaction solvent has a crucial importance: with **Li**, **hydrocarbons** (anhydrous and under an inert atmosphere) are invariably employed. Coordinating solvents (e.g. ethers) interact with Li enhancing the carbanionic (basic, nucleophilic) character of R and consequently favouring the Wurtz reaction! Furthermore, such solvents undergo (slow) acid-base reactions with Li-R;



Direct synthesis

$$Li_{(s)} + R\text{-}X \rightarrow Li\text{-}R + LiX$$

$$M_{(s)} + R\text{-}X \rightarrow R\text{-}M\text{-}X \quad (R= Mg, Zn)$$

- The reaction solvent has a crucial importance: with **Mg**, **ethers** (anhydrous and under an inert atmosphere) are invariably employed. Ethers are necessary to stabilize the organometallic products and do not cause ionization of the Mg-C bond since it is more covalent (less polarised) than in the Li case; the solvent binds to the free coordination sites on Mg, which assumes the tetracoordination that it requires <u>in all its organometallic compounds</u>.

- The choice of solvent is less crucial in the case of **Zn**.

Direct synthesis - reaction mechanism

The mechanism of such direct reactions is radicalic:

$Li_{(s)}$ + R-X → Li^+ + $[R\text{-}X]^{\bullet -}$ RDS. Ion formation! Consider E^{LUMO}
$[R\text{-}X]^{\bullet -}$ → R• + X^-
R• + $Li_{(s)}$ → Li-R

Other possible products:
2R• → R-R
2R• → R-H + alkene   abstraction of H from R•
R• + HS → R-H + S•   abstraction of H from solvent

The problem arises of determining the yield of the reaction (concentration of Li-R in the final solution) keeping also in mind that traces of O_2 and H_2O react with Li-R generating basic impurities (LiOH, LiOR).

Titration of LiR solutions

1) LiR + H_2O → RH + LiOH (+ basic impurities)

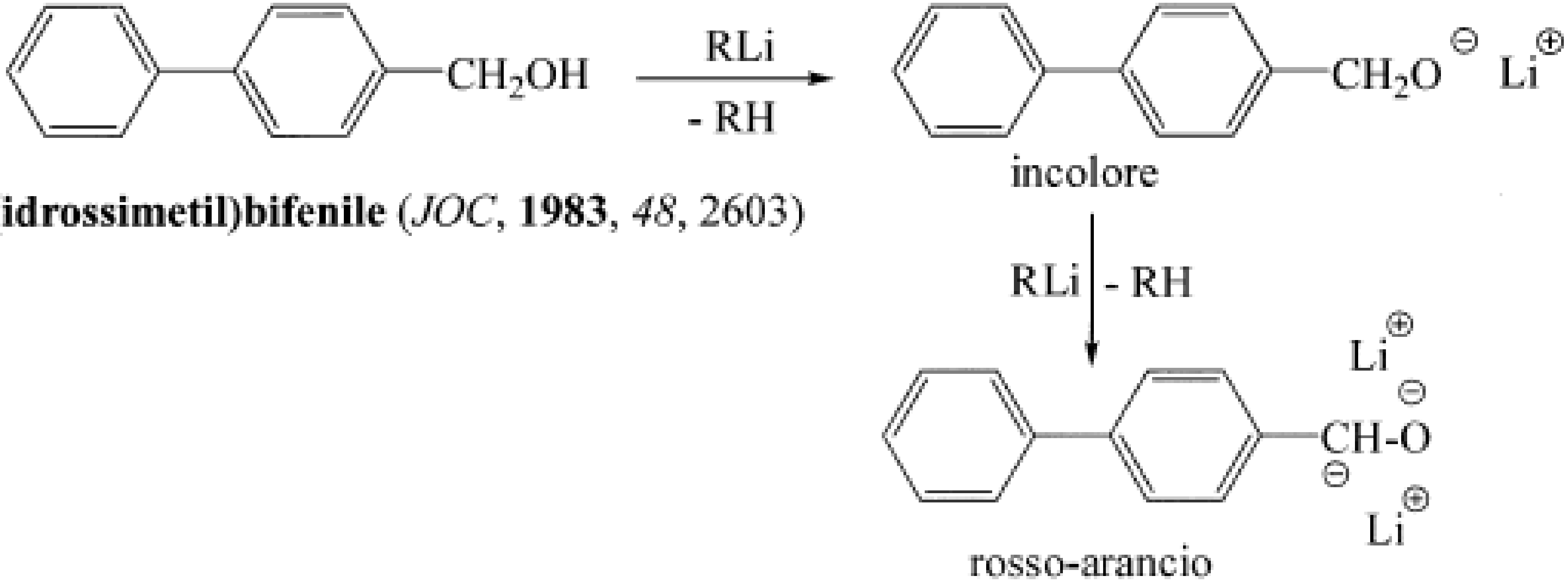
2) LiR + $PhCH_2Cl$ (excess) → $PhCH_2R$ + $PhCH_2CH_2Ph$ (+ basic impurities)

Titrating the solutions and subtracting the result of 2) from that of 1) the title of the solution is obtained.

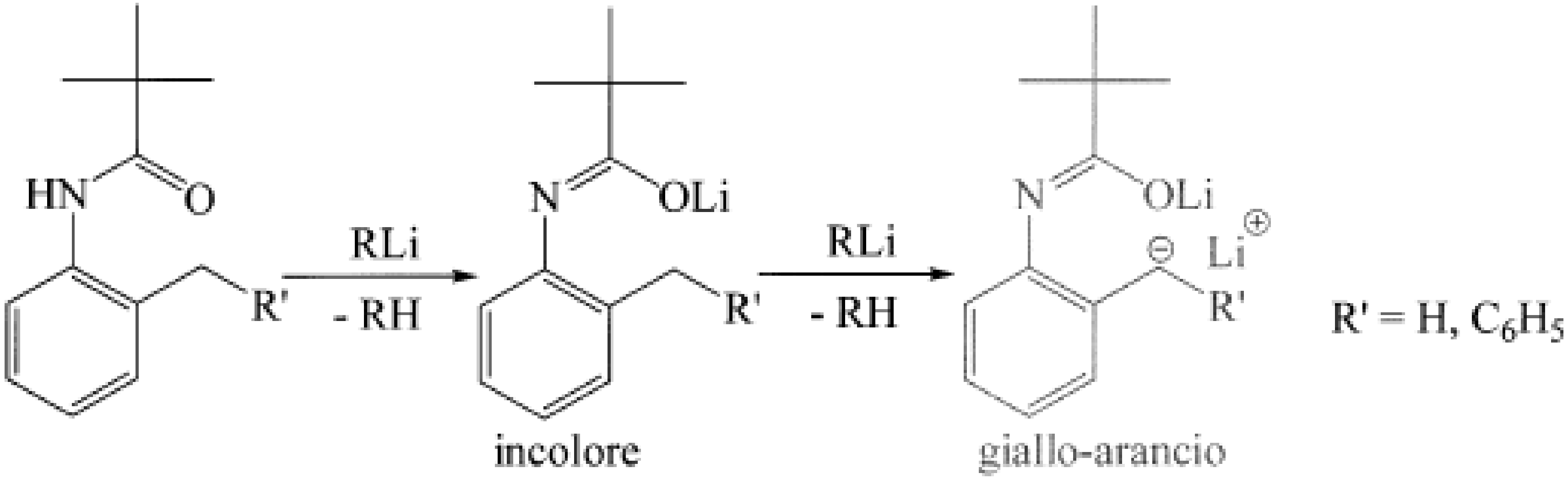
Alternatively, autoindicator reagents can be employed, which are able to react only with LiR.

Titration of LiR solutions

reagenti *auto-indicanti* che permettono una titolazione diretta:



4-(idrossimetil)bifenile (*JOC*, **1983**, *48*, 2603)



***N*-pivaloyl-*o*-toluidina (R' = H)** (*JOC*, **1989**, *54*, 509)

Synthetic methods (from metals)

2) (Transmetallation):

$$M_{(s)} + RM' \rightarrow RM + M'_{(s)}$$
$$2Li_{(s)} + HgR_2 \rightarrow 2LiR + Hg_{(l)}$$

- Cannot be rationalized taking into account redox potentials, since organometallic compounds are not salts and in general these reactions are not carried out in water;

- Facile with organometallic reagents with weaker M-C bonds than the product; consequently, compounds like HgR_2 are generally employed as reagent, which are also stable towards air and moisture (but very toxic!!!);

- Very clean reaction (Hg separates as liquid), convenient on a laboratory scale.

Synthetic methods (from metal salts)

3) Metathesis (transmetallation):

$$MX_n + RM' \leftrightarrows RMX_{n-1} + M'X$$

- The equilibrium is shifted towards the product if M' is more electropositive than M (the reaction spontanesously yields the more covalent organometallic). Consequently, **Li and Mg compounds are generally used as RM' reagents**! The method can be conveniently employed for the preparation of Zn compounds:

$$ZnX_2 + RLi(\text{or } RMgX) \leftrightarrows RZnX + LiX(\text{or } MgX_2)$$
$$RZnX + RLi(\text{or } RMgX) \leftrightarrows R_2Zn + LiX(\text{or } MgX_2)$$
$$R_2Zn + RLi(\text{or } RMgX) \leftrightarrows ZnR_n^{(n-2)-} \ (n= 3,4) + Li^+(\text{or } MgX^+)$$

With excess MR, though, «ate» complexes are formed!

Synthetic methods (from metal salts)

4) Metallation:

$$MY + RH \leftrightarrows YH + RM$$

- The position of the equilibrium depends on the relative acidity of RH and YH; MY reagents are more reactive if M is a **heavier alkaline metal**; furthermore, the base should be non-nucleophilic and soluble in apolar solvents;

- With acid organic substrates (terminal alkynes, ciclopentadienes) and reducing metals the reaction can be also performed starting directly from the metal:

$$RH + M \rightarrow MR + 1/2H_2$$

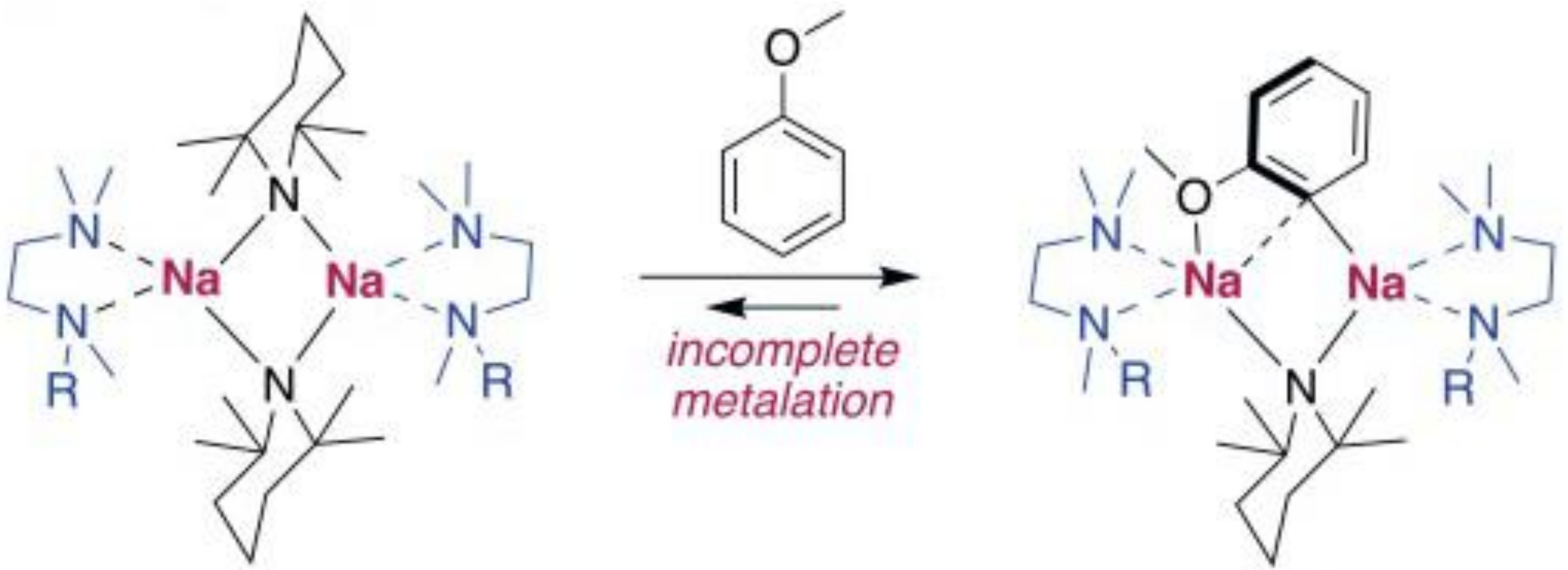
However, the resulting MR is actually an ionic compound!

Synthetic methods (from metal salts)

4) Metallation:

$$MY + R'H \leftrightarrows YH + R'M$$

Use of suitable **ligands** allows to prepare basic reagents and metallated products that are **soluble in hydrocarbons**!



Synthetic methods (from organometallic compounds)

5) Metal exchange:

$$RM + R'M' \leftrightarrows R'M + RM'$$
$$4Ph\text{-}Li + (CH_2{=}CH)_4Sn \leftrightarrows 4Li(CH{=}CH_2) + SnPh_4\downarrow$$

- Equilibrium reactions, which in order to go to completion need some special arrangement (e.g. removal of one of the reaction products by precipitation/distillation).

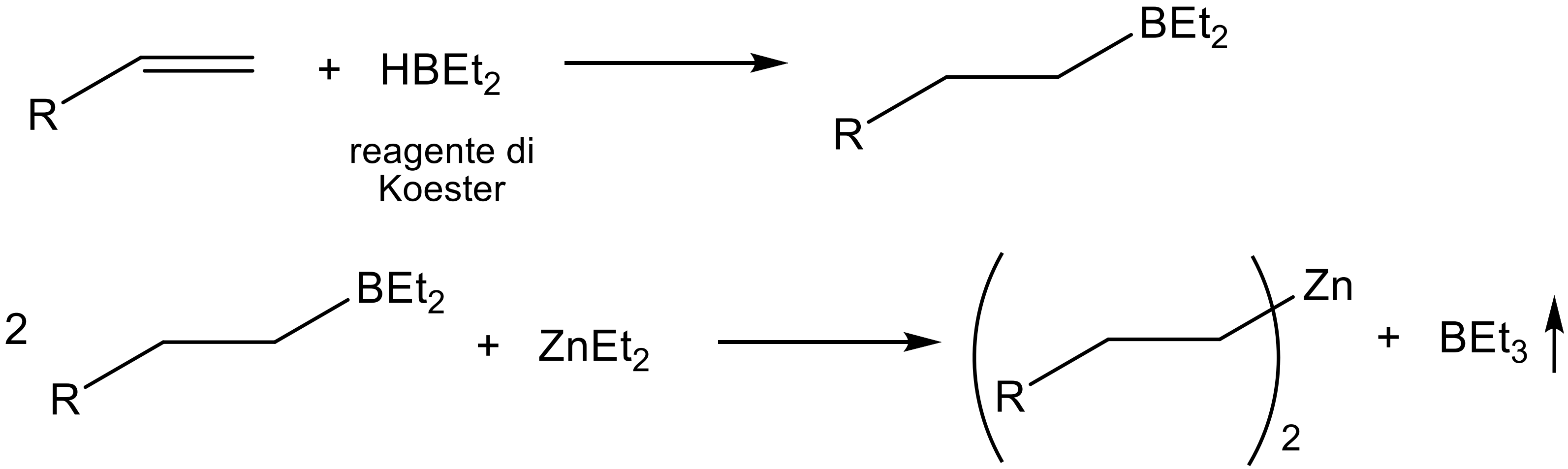
- More complex product mixtures may arise with metals having greater than 1 valency (Mg, Zn):

$$RMgX + R'M' \leftrightarrows R'MgX + RM' \quad (RMgR' + MX)$$
$$2RMgR' \leftrightarrows RMgR + R'MgR' \quad \text{(symmetrization)}$$

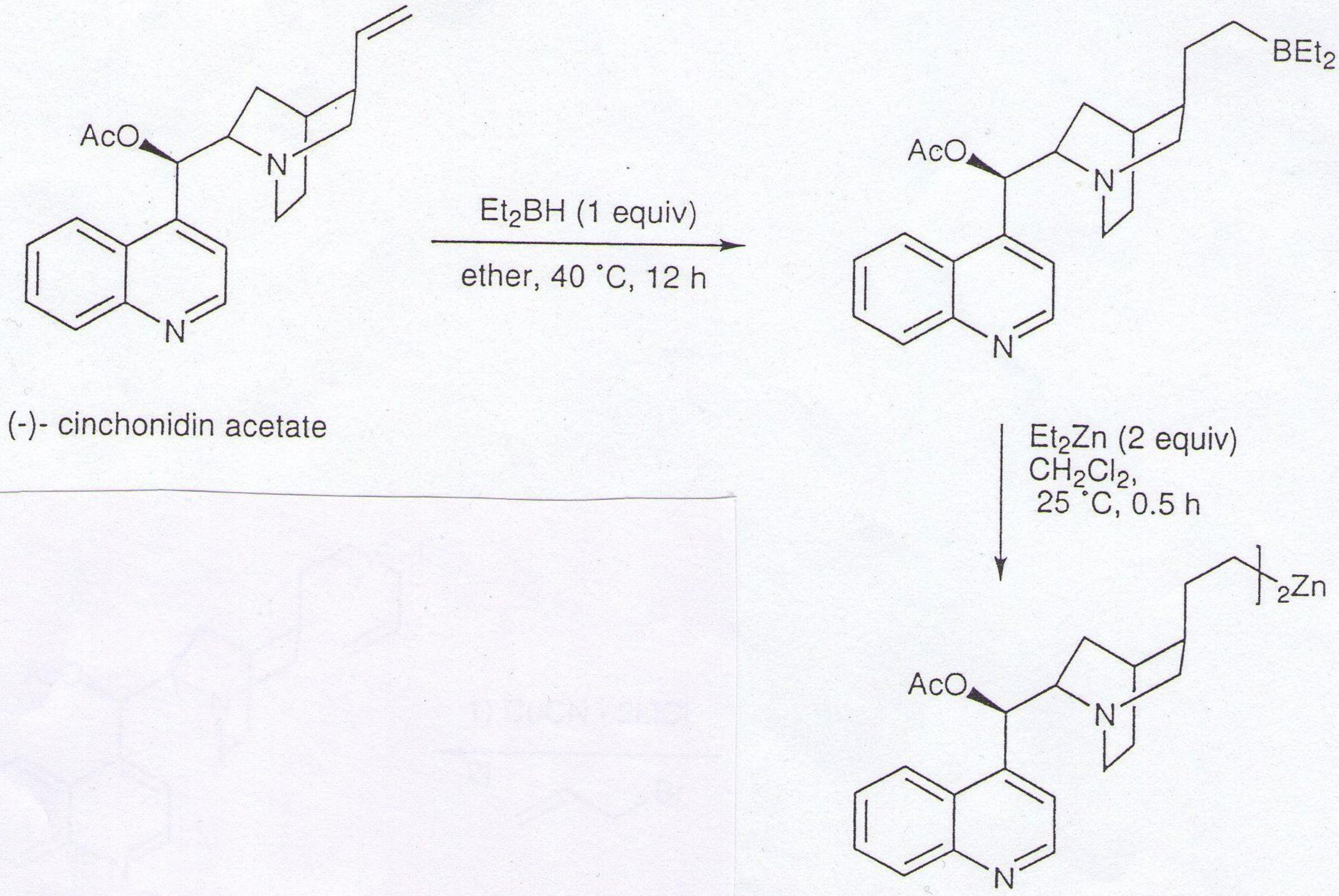
Synthetic methods (from organometallic compounds)

5) «Metal» exchange with Zn:

Zn compounds are particularly efficient at undergoing metathesis/»metal» exchange reactions. This can be exploited, for example, in a hydroboration/element exchange sequence:



Hydroboration / element exchange with Zn



(-)- cinchonidin acetate

J. Org. Chem. **1996**, *61*, 8229-8243

Synthetic methods (from organometallic compounds)

6) Metal-halogen exchange:

$RM + R'X \leftrightarrows RX + R'M$ M= **Li**, **Mg**, Zn

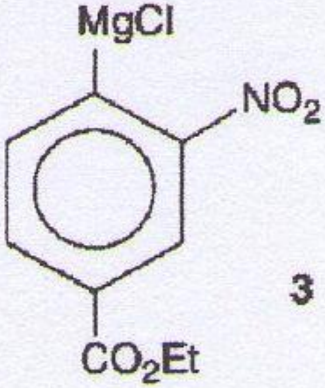
$RMX + R'X' \leftrightarrows R'MX + RX'$

- The equilibrium is shifted towards the product if R' stabilizes better than R a negative charge (R= alkyl, R'= aryl);

- Very fast reaction with Li and **Mg**, much slower with Zn (catalyst needed): proceeds cleanly and efficiently even at low temperatures, at which other reactions are suppressed;

- Mechanism involving the intermediate formation of radicals or of anionic complexes of the halogen $[R'XR]^{-}M^{+}$

RMgX by halogen exchange



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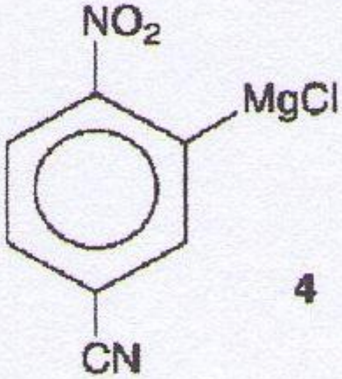

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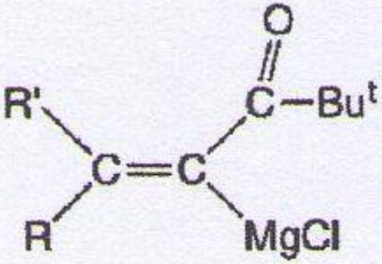

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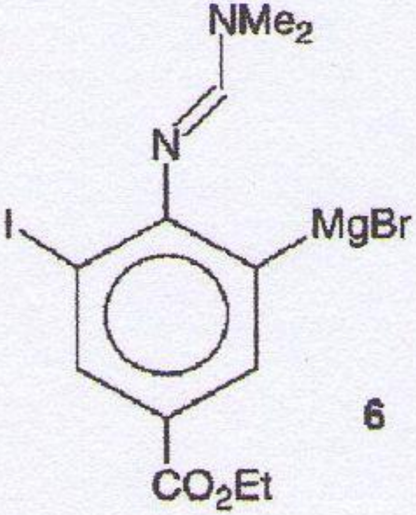

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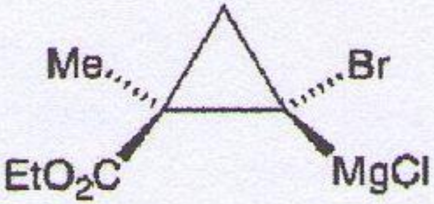

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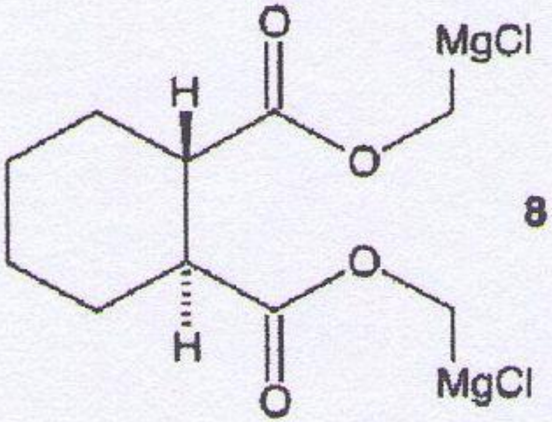

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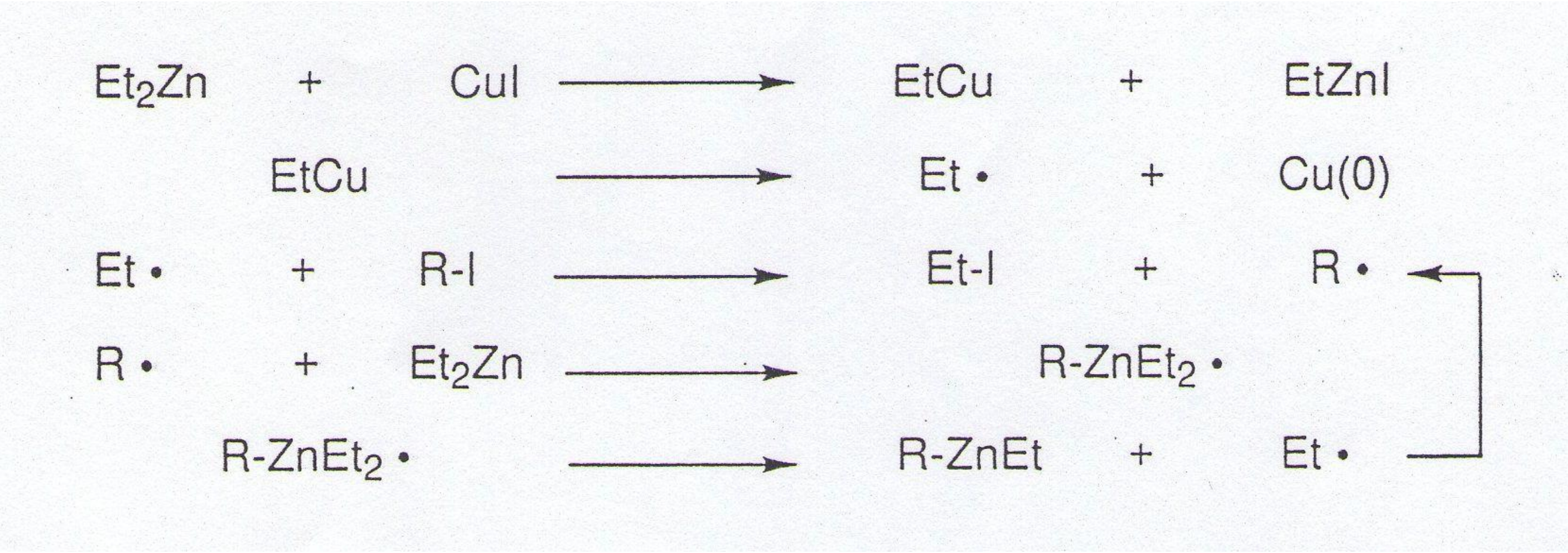
P. Knochel et al., *Angew. Chem. Int. Ed.* **2003**, *42*, 4302.

ZnR_2 by halogen exchange



$$Et_2Zn + CuI \longrightarrow EtCu + EtZnI$$

$$EtCu \longrightarrow Et\bullet + Cu(0)$$

$$Et\bullet + R\text{-}I \longrightarrow Et\text{-}I + R\bullet$$

$$R\bullet + Et_2Zn \longrightarrow R\text{-}ZnEt_2\bullet$$

$$R\text{-}ZnEt_2\bullet \longrightarrow R\text{-}ZnEt + Et\bullet$$

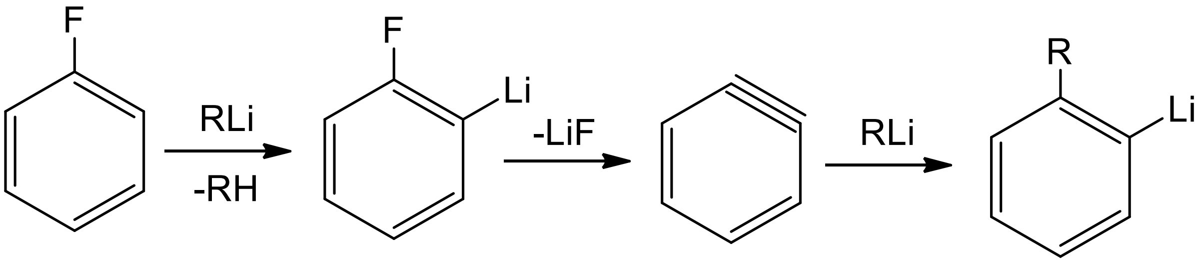
Organometallic reaction mechanism involving transition metal catalysis are also possible

Synthetic methods (from organometallic compounds)

6) Metal-halogen exchange:

- As organic halide iodides or bromides, more rarely chlorides, are employed.

- Fluorides undergo other reactions with Li, involving *o*-metallation and formation of aryne intermediates):



- With geminal dihalides and Li metallation takes place instead, with formation of carbenoid species or of free carbenes:

$$\mathrm{LiR} + \mathrm{RCHCl_2} \rightarrow \mathrm{RH} + \mathrm{LiCRCl_2} \rightarrow \mathrm{:CRCl} + \mathrm{LiCl}$$

Synthetic methods (from organometallic compounds)

7) Metallation (Li exclusively):

$$RLi + R'H \leftrightarrows RH + R'Li$$

- The position of the equilibrium depends on the relative acidity of RH and R'H; R'H with **pK_a up to 35** (with RMgX up to 25) can be metallated; the reaction rate is however extremely variabile; in the absence of additives, $LiCH_2Ph$ reacts 10^4 faster than $LiCH_3$, even if the benzyl anion has a pK_b 9 orders of magnitude lower than methyl…

Synthetic methods (from organometallic compounds)

7) Metallation (Li exclusively):

$$LiR + R'H \leftrightarrows RH + R'Li$$

In the absence of additives, $LiCH_2Ph$ reacts 10^4 faster than $LiCH_3$, even if the benzyl anion has a pK_b 9 orders of magnitude lower than methyl… kinetic problem due to the covalent nature of the bond and to the association of LiR in solution (depending on the nature of R).

It is important to maximize the reactivity of LiR: coordinating solvents (THF, dimethoxyethane) or ligands for Li^+ (es. tetramethylethylenediamine, TMEDA) are employed in order to render the Li compound monomeric and more ionic in nature. Possibility to trigger the activation by ligand addition!

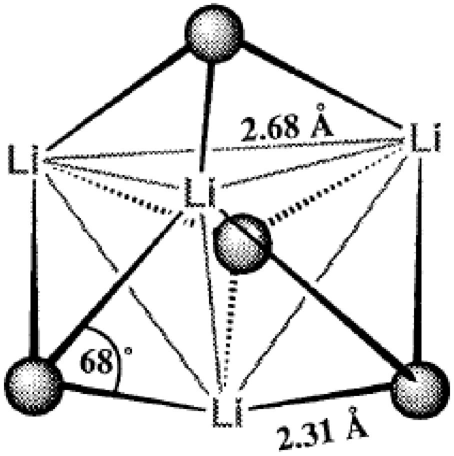
Nucleophilic Organometallics: Li, Mg, Zn, (Cu) Properties

Compounds sensitive to dioxygen (often pyrophoric).

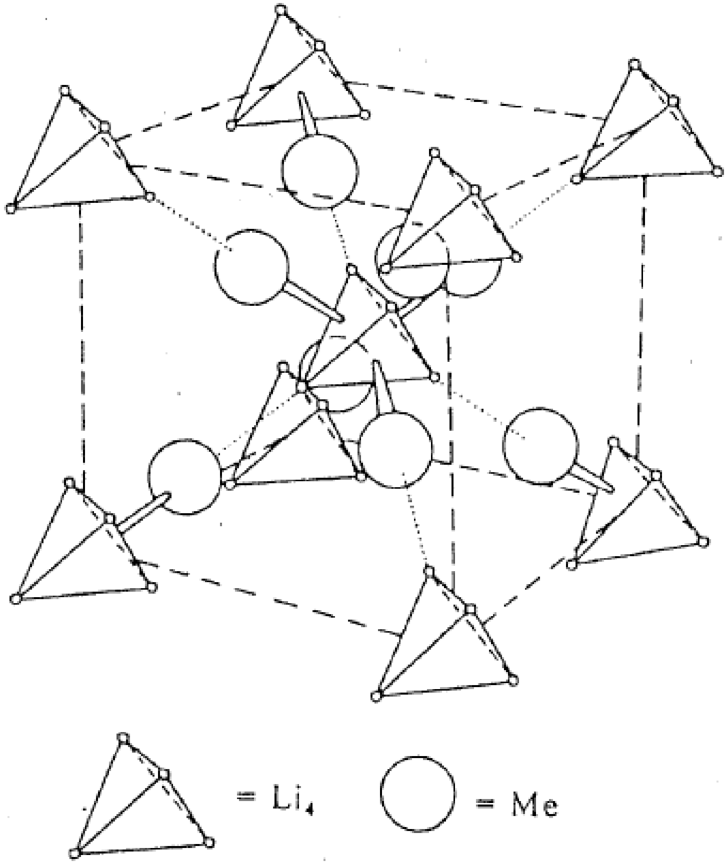
Compounds sensitive to water (readily hydrolized).

Compounds featuring small, strongly polarizing metal centres (Li, Mg) or a rather large but electronegative metal centre (Zn). All metal centres are electron-deficient. Tendency to aggregate and/or to coordinate solvent molecules or other compounds present in solution.

Association of $LiCH_3$



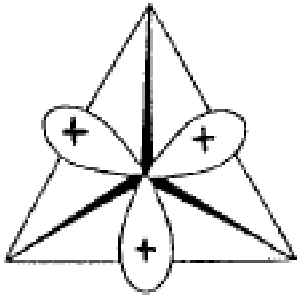
Molecola $Li_4(CH_3)_4$



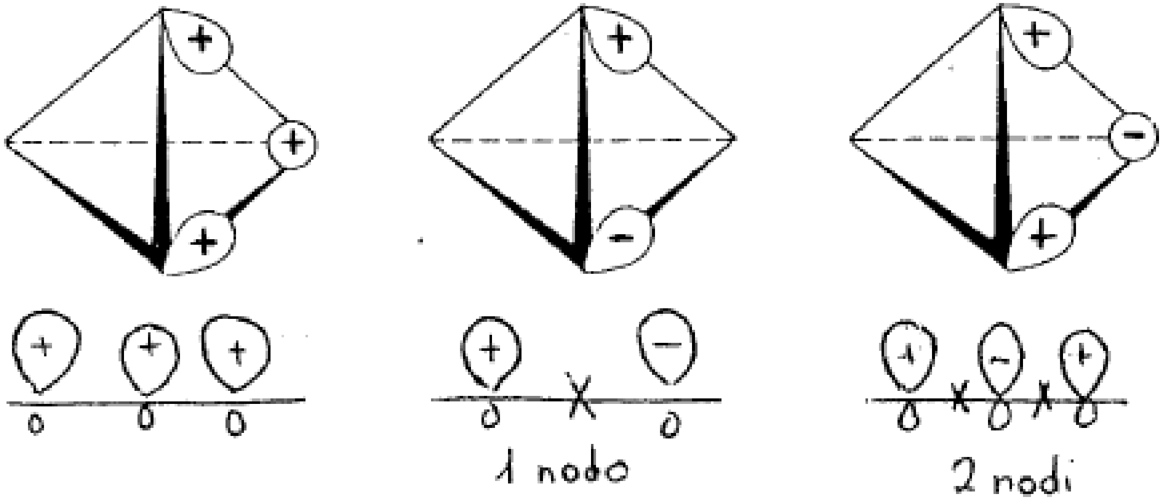
Struttura del metillitio

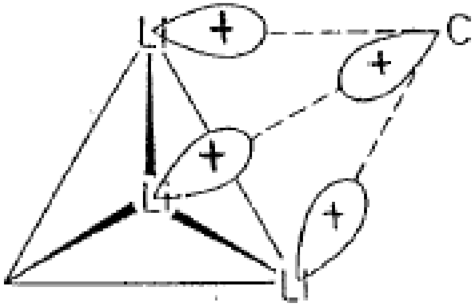
Association of $LiCH_3$

Ibridi sp^3 del Li



Precombinazione degli o.a. sp^3 del Li





Sovrapposizione fra gli orbitali sp^3
del C e del Li

Association of $LiCH_3$

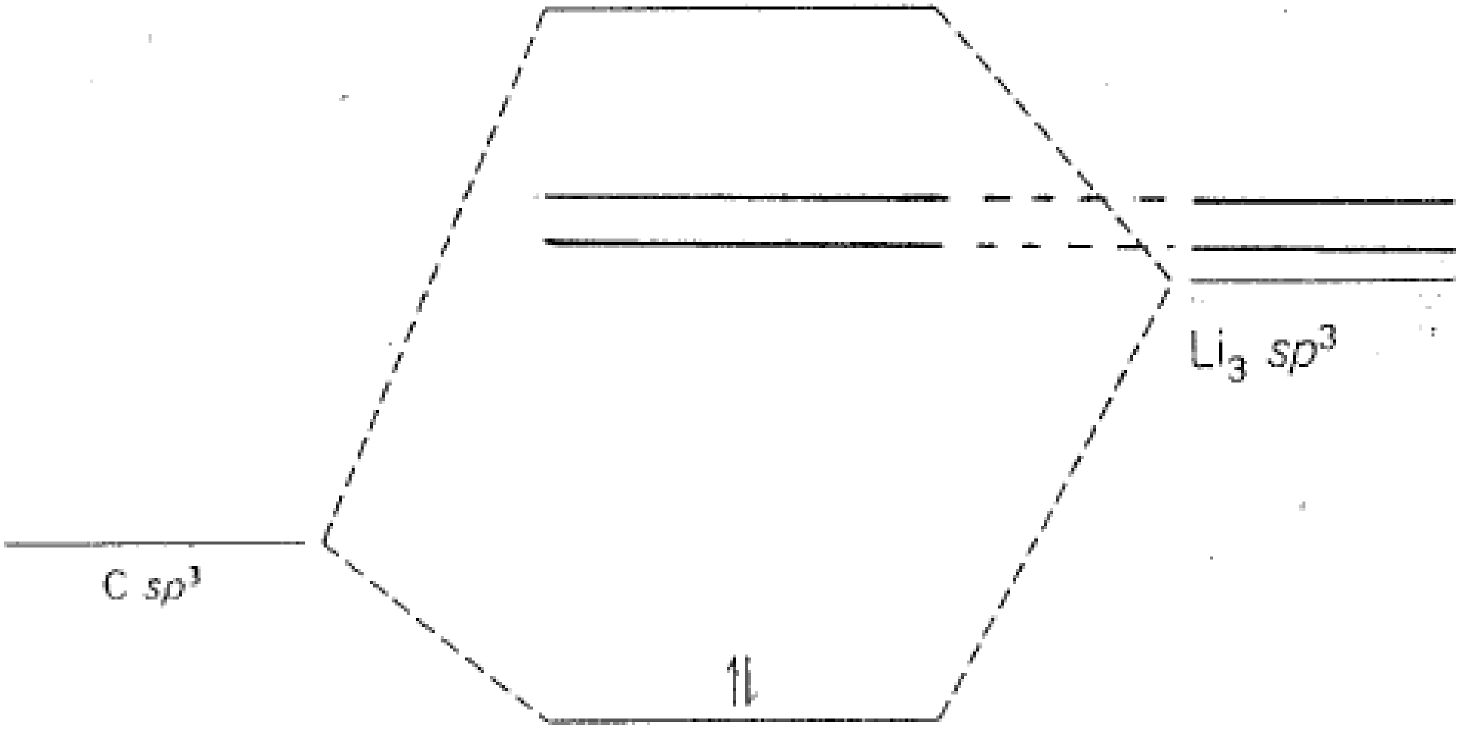
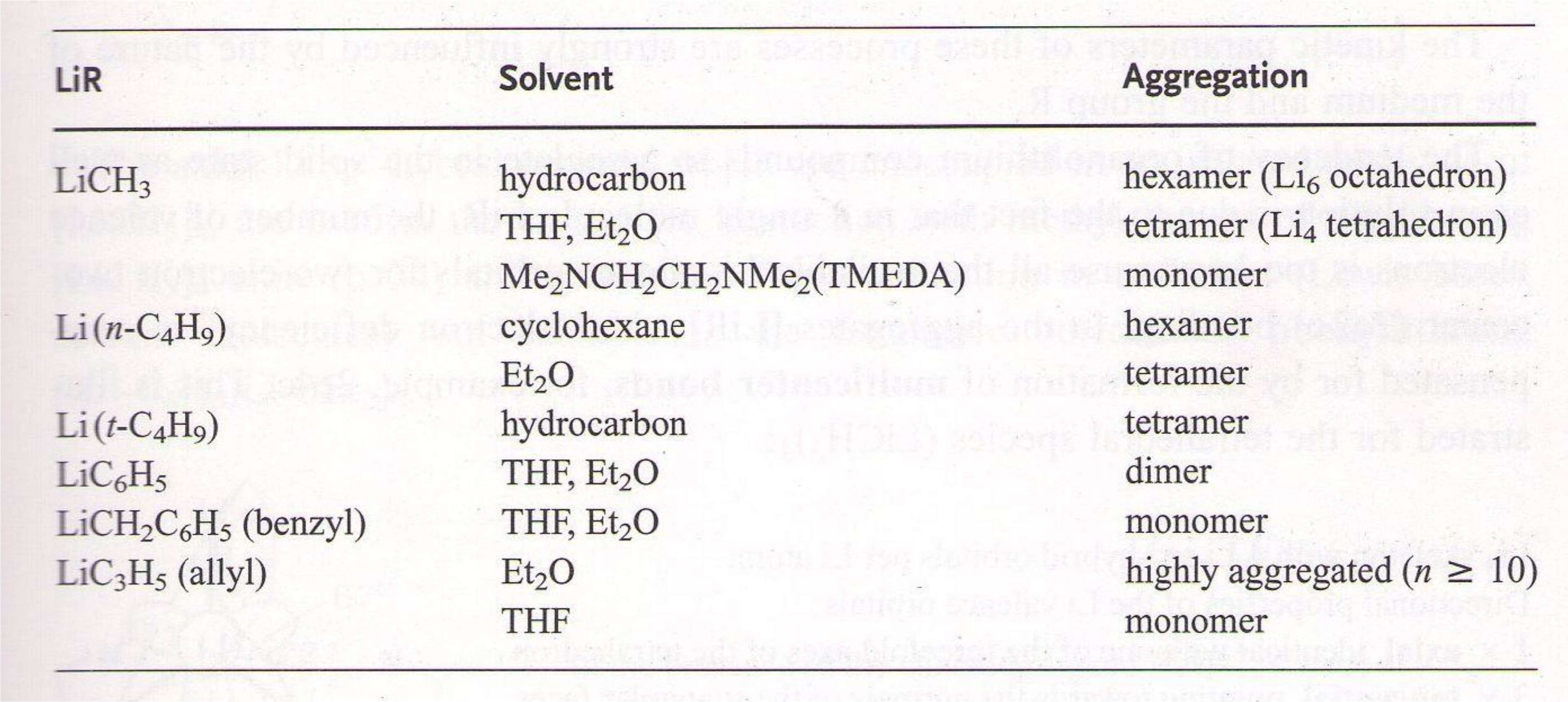


Diagramma qualitativo dei livelli di energia degli o.m. per una faccia

Association of Li-R



LiR	Solvent	Aggregation
$LiCH_3$	hydrocarbon	hexamer (Li_6 octahedron)
	THF, Et_2O	tetramer (Li_4 tetrahedron)
	$Me_2NCH_2CH_2NMe_2$(TMEDA)	monomer
Li(*n*-C_4H_9)	cyclohexane	hexamer
	Et_2O	tetramer
Li(*t*-C_4H_9)	hydrocarbon	tetramer
LiC_6H_5	THF, Et_2O	dimer
$LiCH_2C_6H_5$ (benzyl)	THF, Et_2O	monomer
LiC_3H_5 (allyl)	Et_2O	highly aggregated ($n \geq 10$)
	THF	monomer

The tendency towards association increases with decreasing size of R and with decreasing capability of R to stabilize a negative charge. Coordinating solvents also limit association.

Solution equilibria of RMgX

In solution, Grignard reagents RMgX undergo several equilibria (multiple species detected by e.g. ^{1}H or ^{25}Mg-NMR), which influence their reactivity (which is the most active species?):

Schlenk equilibrium:

$$MgX_2 + MgR_2 \leftrightarrows 2RMgX$$

Evidence 1: adding a solvent in which MgX_2 is insoluble (e.g. 1,4-dioxane), the equilibrium shifts towards the left leaving MgR_2 in solution;
Evidence 2: equimolar solutions of MgX_2 and MgR_2 behave as a Grignard reagent solution.

The position of the equilibrium depends in a decisive way on the nature of the solvent, in particular on its basicity.

Schlenk equilibrium- solvent dependence

$$MgX_2 + MgR_2 \leftrightarrows 2RMgX$$

K_{eq} at 25°C in Et_2O: ~ 50 –1000;

in THF: ~ 1 –10;

The position of the equilibrium depends on the strength of the Mg-solvent interaction and on the number of solvent molecules coordinated to MgX_2.

$MgX_2S_2 + MgR_2S_2 \leftrightarrows 2RMgXS_2$ S= Et_2O

$MgX_2S_4 + MgR_2S_2 \leftrightarrows 2RMgXS_2 + 2S$ S= THF

Addition of more coordinating solvents/ligands can switch the equilibrium to the left!

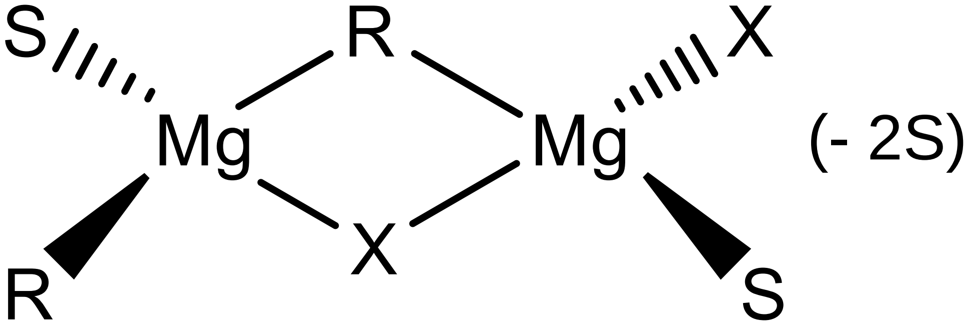
Schlenk equilibrium - kinetics

$$MgX_2 + MgR_2 \leftrightarrows 2RMgX$$

The reaction rate can be determined by e.g. following the reaction by ^{1}H-NMR.

The reaction rate varies with X (Cl > Br > I) and with the degree of branching of R (primary > secondary > tertiary), and decreases with the basicity of the solvent.

All this is explained by postulating a transition state like



R bridges the two Mg centers forming electron deficient bonds

Schlenk equilibrium - Zn

$$Zn_{(s)} + R\text{-}X \rightarrow R\text{-}Zn\text{-}X$$

$$ZnX_2 + ZnR_2\uparrow \leftrightarrows 2RZnX$$

A Schlenk-type equilibrium exists also for Zn, usually very shifted towards the halidoorganozinc compound; however, the equilibrium can be also shifted completely to the left by distilling off the diorganozinc compound (volatile).

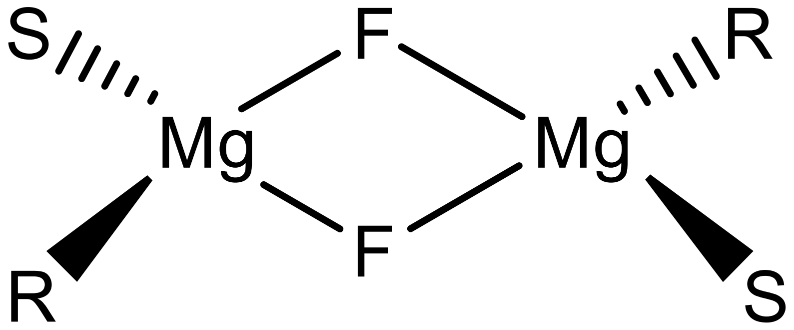
Association equilibria

$$n\mathrm{RMgXS_2} \leftrightarrows (\mathrm{RMgXS})_n + n\mathrm{S}$$

Evidence: solutions of Grignard reagents often exhibit anomalous colligative properties.

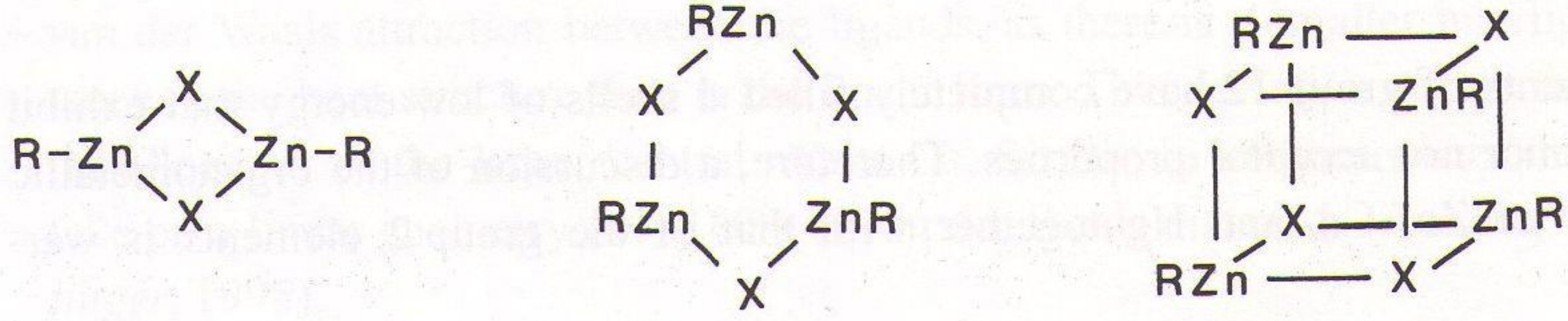
Generally n=2. The position of the equilibrium depends on the nature of X (shifts towards the monomer with larger X), on the basicity and steric bulkiness of the solvent (shifts towards the monomer with more basic, less bulky solvents), and on the concentration.

RMgF are dimers under all conditions!



Association equilibria

RZnX are also associated in the solid state and in solution in noncoordinating solvents.



X = halide, *t*-BuO$^-$

a heterocubane

ZnR_2 are instead <u>linear</u> molecules, low-melting and –boiling solids or liquids (not associated), though they promptly coordinate Lewis bases (coordinating solvents, ligands) in solution. The formation of dimers, at least transiently, is nevertheless invoked to interpret Schlenk type equilibria (see below) or <u>symmetrisation reactions</u>:
$2ZnRR' \leftrightarrows ZnR_2 + ZnR'_2$

Ionic dissociation equilibria

$$2RMgX \leftrightarrows RMg^+ + RMgX_2^-$$

Evidence: solutions of Grignard reagents are conductive (e.g. Λ EtMgBr 20 $\Omega^{-1}cm^2mol^{-1}$ in HMPA, much less with chloroderivatives).
This equilibrium makes it possible to electrolyse solutions of Grignard reagents:

Cathode: $RMg^+ \rightarrow Mg + R\bullet$
Anode: $RMgX_2^- \rightarrow MgX_2 + R\bullet$

If R• is sufficiently stable it dimerizes yielding R-R.
If the anode is made out of a sacrificial metal (Zn, Sn, Pb…), R• can react with the metal at the anode yielding a new organometallic compound by <u>electrochemical synthesis</u>:
$M + nR\bullet \rightarrow MR_n$

Organomagnesium compounds in the solid state

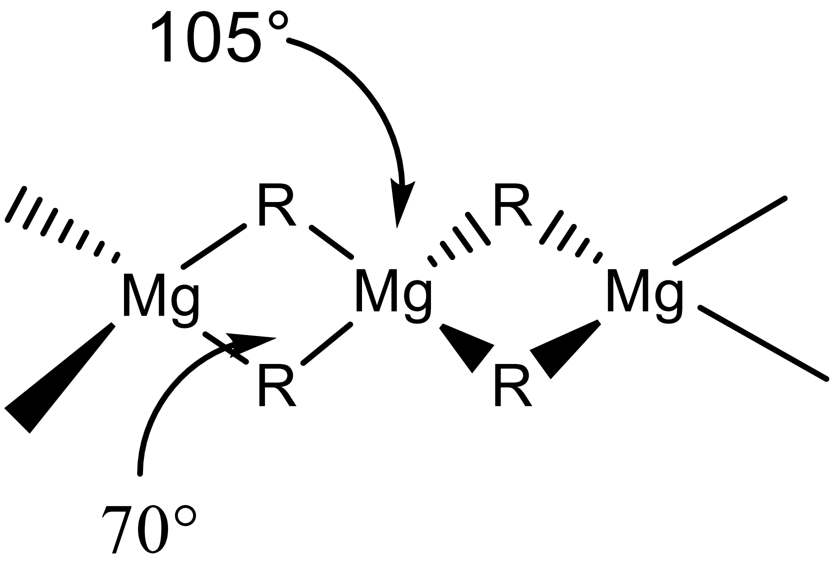
Organomagnesium compounds can in general be crystallised and isolated in the solid state. They crystallise as monomers or dimers, with enough solvent molecules coordinated to Mg to render it tetrahedral:

$RMgXS_2$ $(RMgXS)_2$ MgR_2S_2

The solvent (ether) in these compounds is a real ligand (distance Mg-C ~ 2.2 Å, Mg-O ~ 2.1 Å).

Upon solvent removal, solid Grignard reagents decompose, MgR_2 instead produce an amorphous powder insoluble in noncoordinating solvents. The same solid can be obtained by transmetallation in noncoordinating solvents.

Structure of solid, unsolvated MgR_2



Mg achieves also in this case the tetracoordination. R bridges two Mg centers forming electron deficient bonds (bond order 0.5).

The Mg-C-Mg angle of 70° is a compromise between the need for efficient orbital overlap and Mg-Mg repulsions.

Model structure for the transition state of the Schlenk equilibrium.

Synthetic applications

Use as strong bases (Li)

Lithiation of organic molecules for further reactions;

Deprotonation of organic cations (e.g. ylide formation).

Use as nucleophiles (Li, Mg, *Zn*)

Addition to organic molecules with carbon-heteroatom multiple bonds (ketones, esters, carboxylates, amides, nitriles…);

Addition to C-C multiple bonds (Li);

Use as reagents in organometallic synthesis/catalysis (Li, Mg, Zn)

Metathesis reaction

Use as reagents in carbon-carbon coupling reactions (cross-couplings) catalysed by transition metals

Synthetic applications – strong bases

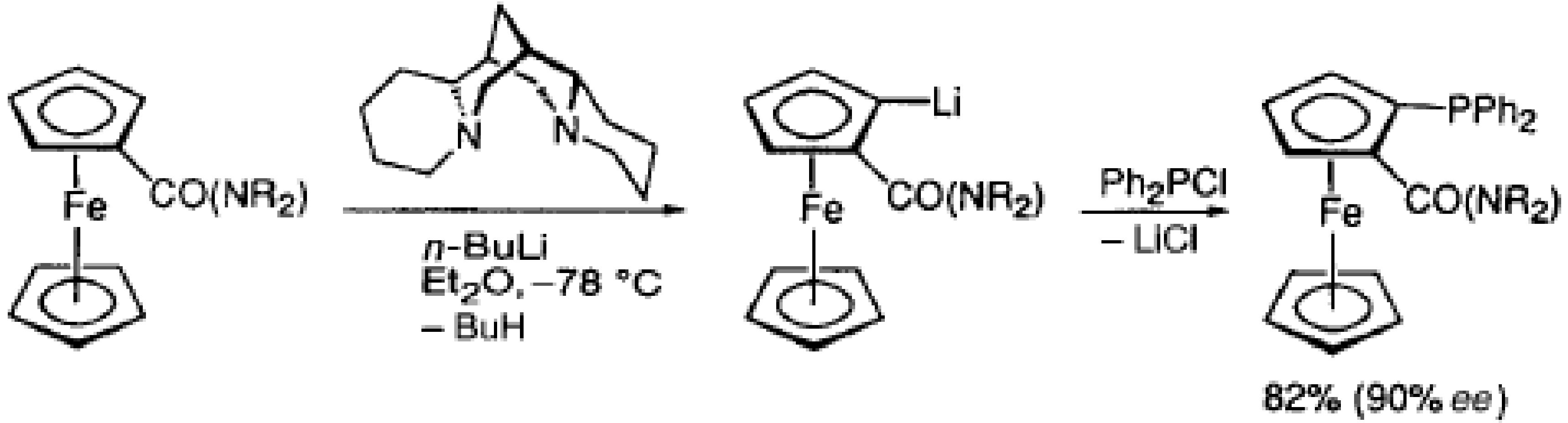
R'H with **pK_a up to 35** (with RMgX up to 25) can be metallated with RLi

Even stronger bases can be prepared *in situ* by metathesis reaction between a group 1 metal alkoxyde and Li-R, yielding species that are much more reactive than the starting Li-R (Lochmann-Schlosser superbases)

MOR' + LiR → MR + LiOR (or more complex aggregates)

Upon addition of a proper chiral ligand for Li, metallations can be conducted in an <u>enantioselective</u> way.

Synthetic applications – strong bases



General strategy for the preparation of chiral ferrocenylphosphines (e.g. Josiphos). The ligand:

- Increases the reactivity of *n*-BuLi (even at low T);
- Induces stereoselection;
- May be employed in catalytic quantities (ligand-accelerated catalysis)

Synthetic applications – Li nucleophiles

Addition to C-O multiple bonds:

- Selective 1,2-additions to α,β-unsaturated carbonyls;
- Addition to lithium carboxylates with formation of ketones;
- Addition to formamides with formation of aldehydes.

Addition to C-N multiple bonds:

- Addition to nitriles with formation of ketones (via ketimine);
- Ziegler alkylation of pyridines in 2-position;

-Possibility of performing stereoselective reactions using suitable chiral activating ligands for lithium (e.g. diamines).

Simple nucleophilic substitutions on e.g. alkyl halides are less efficient due to competing elimination (LiR are also strong bases!). See however below…

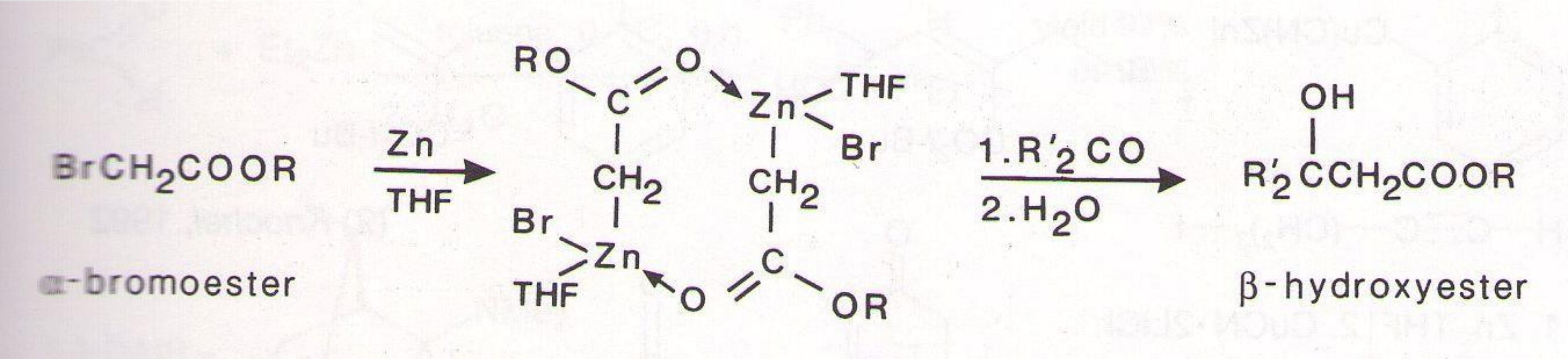
Synthetic applications – Mg and Zn nucleophiles

Addition to multiple carbon-heteroatom bonds: ketones, esters, anhydrides, amides, nitriles, imines, α,β-unsaturated compounds (selective 1,2-addition) etc.

Mg organyls are less reactive as nucleophiles than Li organyls, but are often more selective (e.. 1,4- addition to α,β-unsaturated compounds) and can include highly functionalized organic residues.

Zn organyls are much less reactive than Mg organyls as nucleophiles. They can be directly employed only in a handful of reactions.

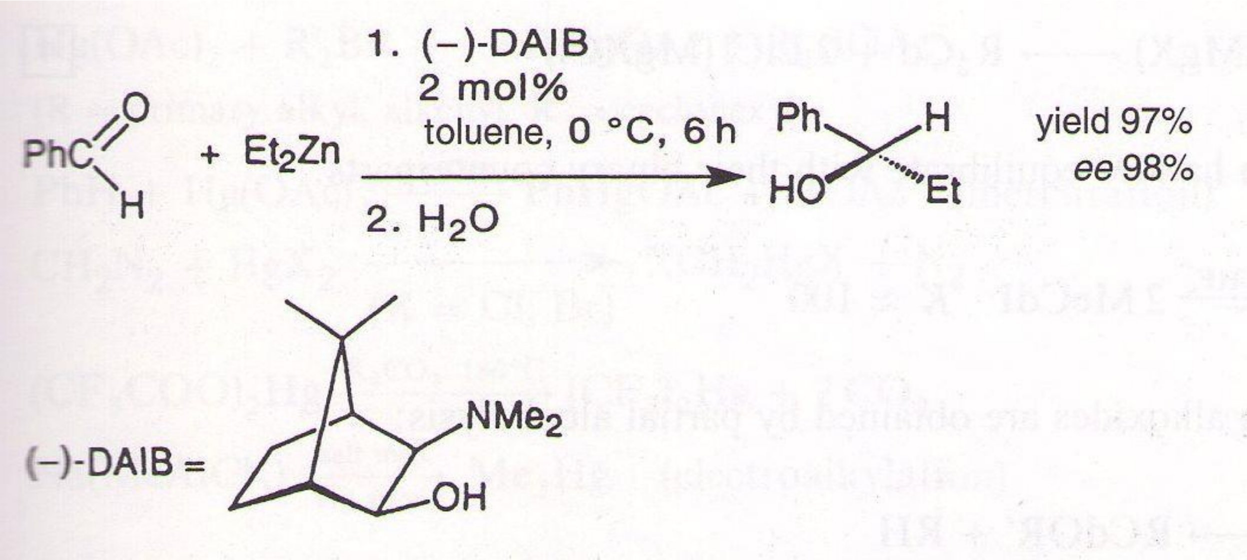
Zn nucleophiles: the Reformatsky reaction

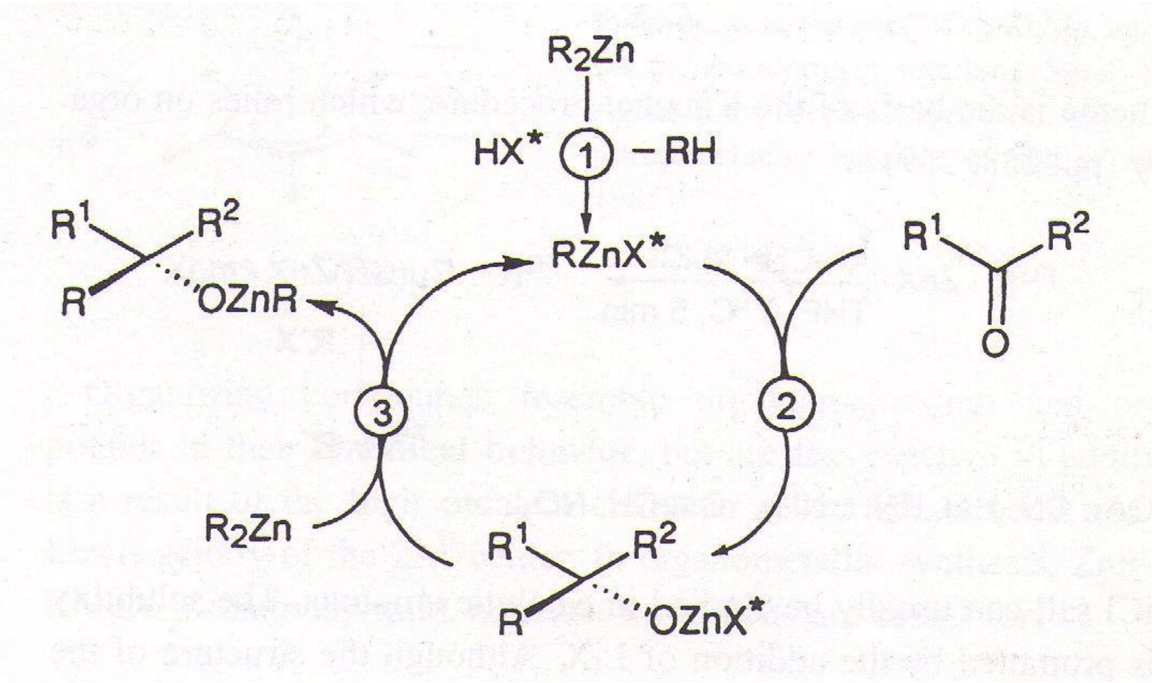


- Bromoester activated for direct synthesis;

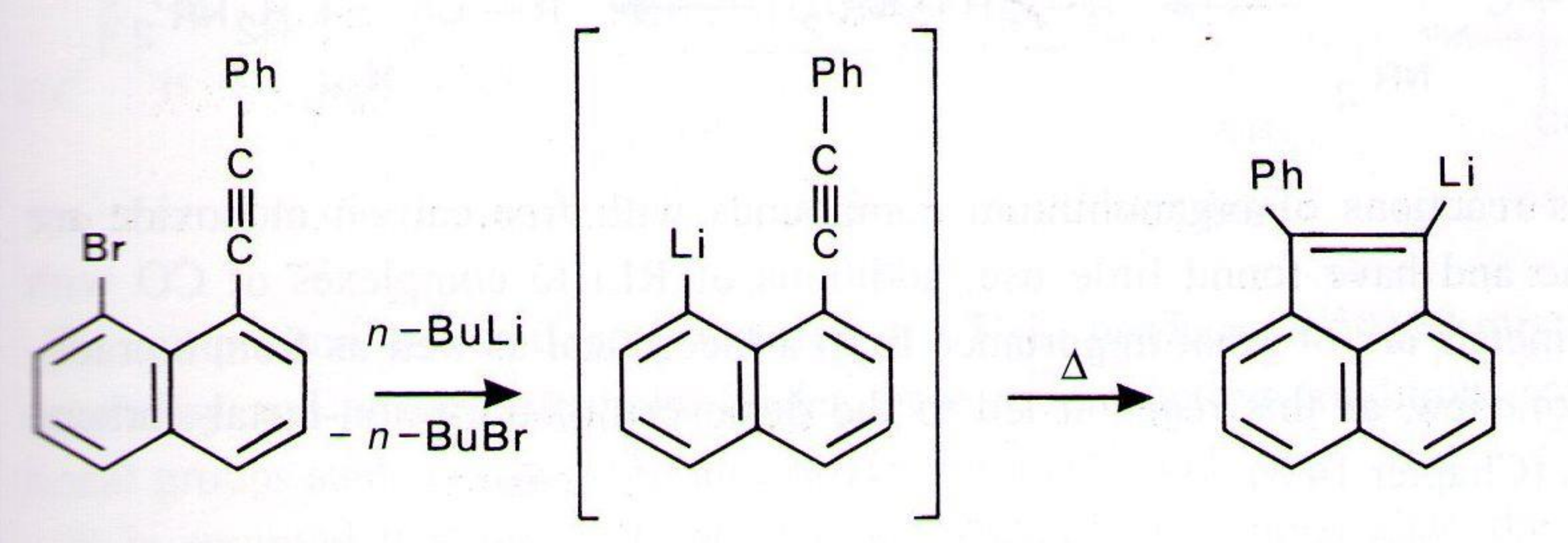
- The nucleophilicity of the organozinc compound is sufficient for the reaction.

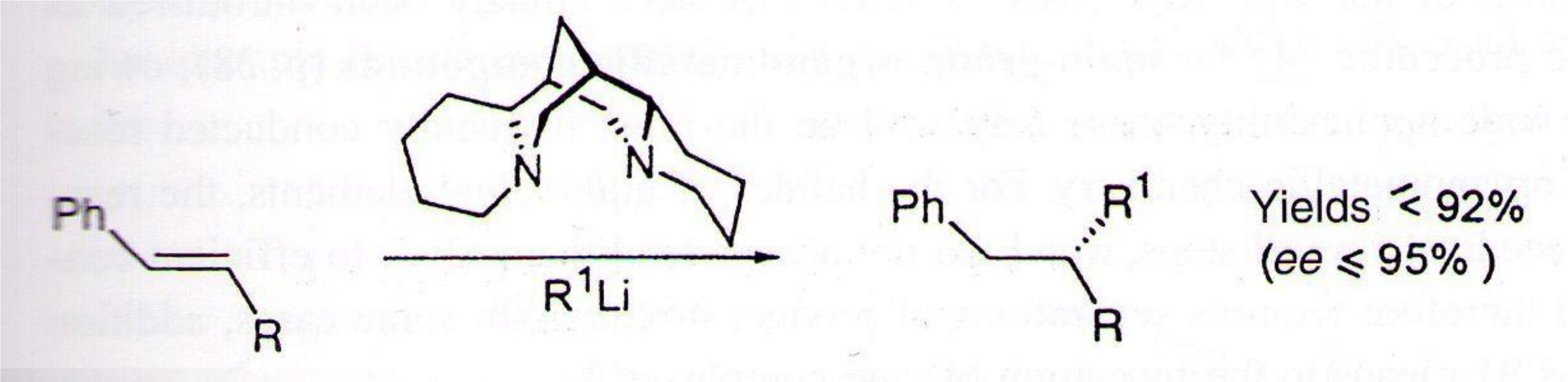
Synthetic applications: addition to aldehydes





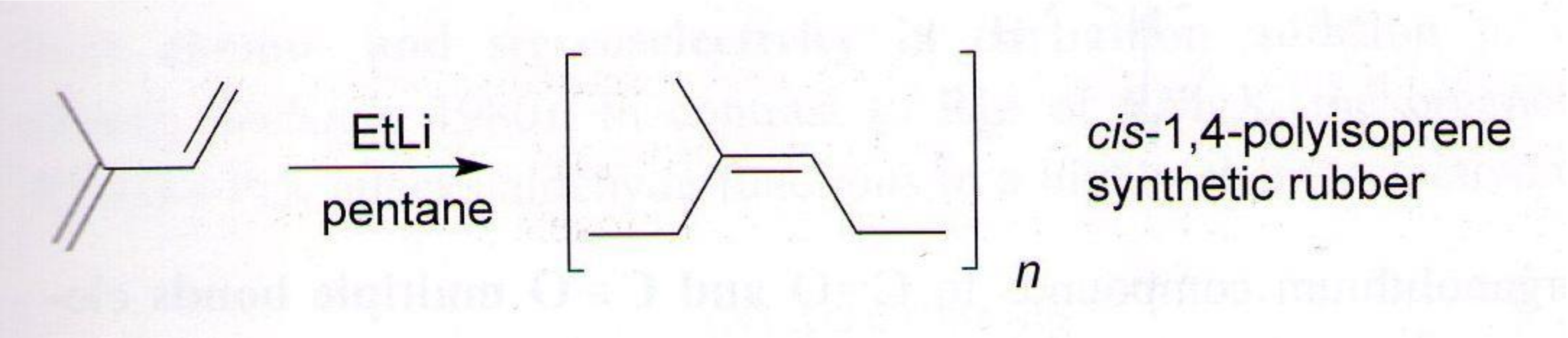
Carbolithiation of multiple C-C bonds





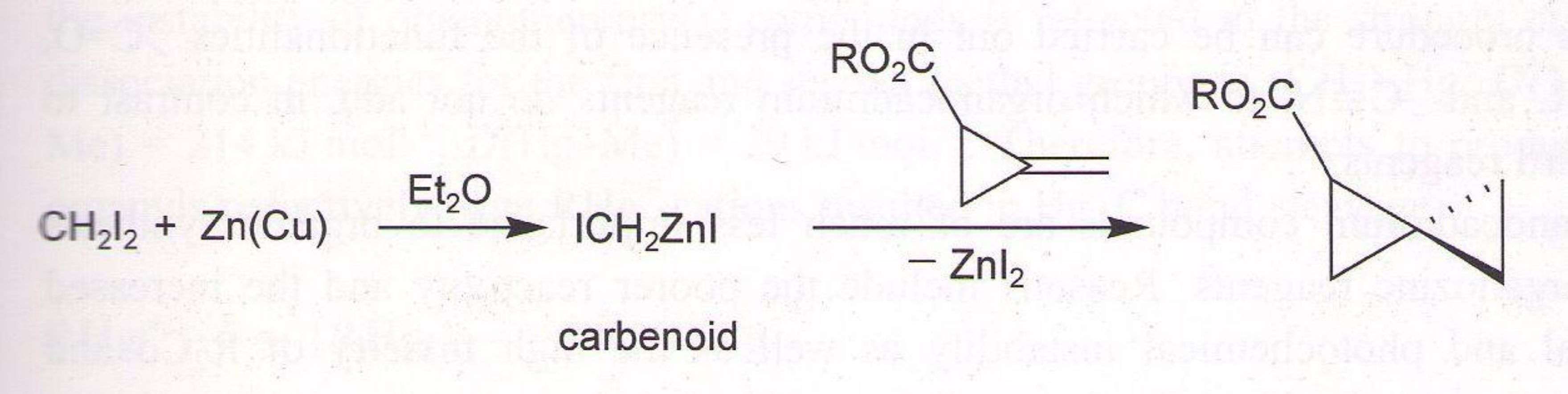
Forcing reaction conditions ad/or conjugated multiple bonds are necessary for successful reaction.

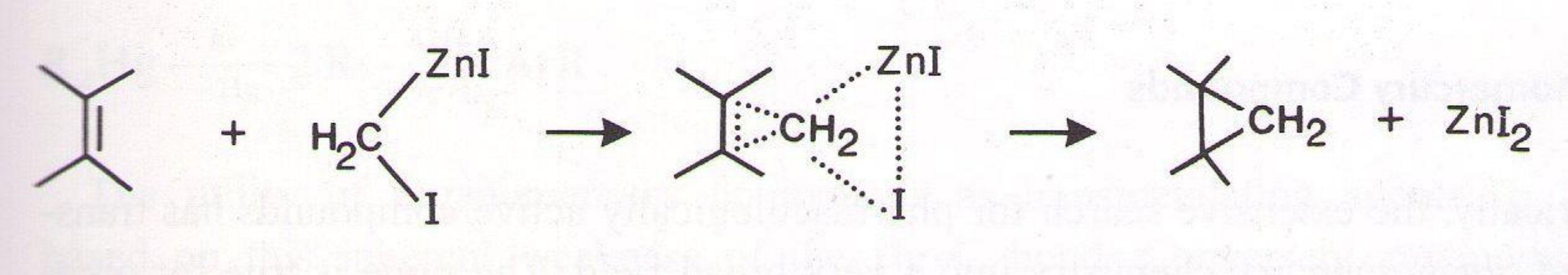
Carbolithiation and anionic polymerisation of dienes



Superior stereoselectivity with lithium compared with initiators based on other metals (RMgX, AlR_3). The stereoselectivity decreases significantly in coordinating solvents (e.g. ethers).

Zn: Simmons-Smith process





The reaction betweem the olefin and the organozinc compound («zinc carbenoid») proceed in concerted fashion. No evidence for the intermediation of free carbenes!

Less practical, related reactions possible also with organolithium and organomercury compounds.

Use as reagents in organometallic synthesis
Metathesis (*transmetallation*)

$$MX_n + RM' \leftrightarrows RMX_{n-1} + M'X'$$

- General reaction for the conversion of metal compounds with an electronegative anionic ligand X into organometallic compounds;

- The equilibrium is shifted towards the products if M is more electropositive than M’: most employed are Li organyls (LiCl precipitates) and Mg organyls; with transition metals, other organometallic reagents (e.g. RZnX) can be employed as well;

- The availability on Zn of low-energy empty orbitals allows for particularly efficient and fast metathesis reactions.

Metathesis to lithiocuprates (Gilman reagents)

$$2LiR + CuI \rightarrow (RCu)_n + LiI \rightarrow R_2CuLi$$

Nucleophiles featuring poor basicity, less competitiion with elimination reactions in nucleophilic substitutions on alkyl halides or tosylates.

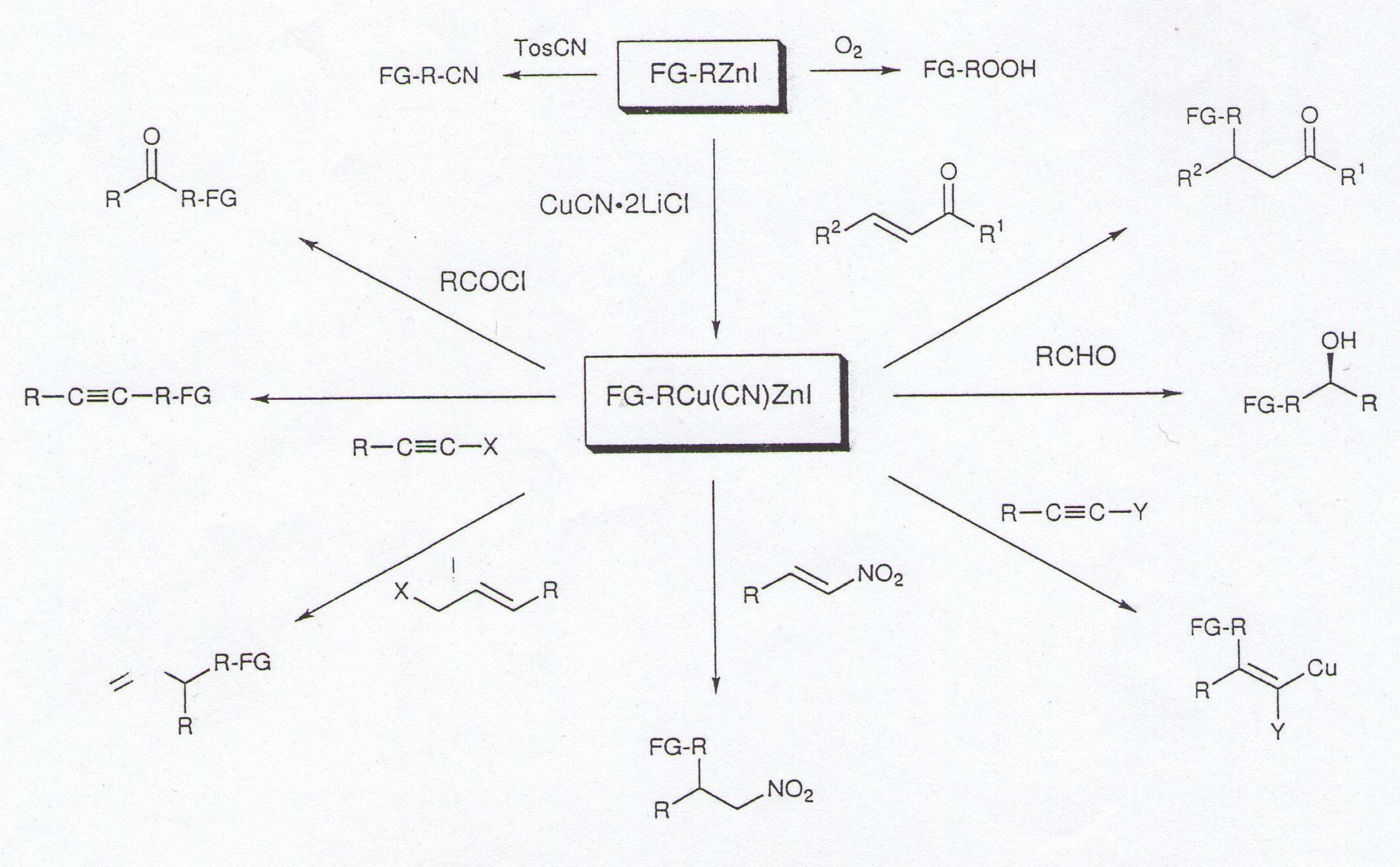
Nucleophilic substitution reactions (cross couplings) possible also with **vinyl** halides/tosylates (with retention of geometry at the double bond) and **aryl** iodides or bromides.

Conversion of acyl chlorides to ketones

Problems: excess reagent necessary (unstable), trasfer of only one residue R possible. Better with heterocuprates:

$$LiR + CuCN \rightarrow RCu(CN)Li$$

Metathesis to zinc-cuprates



Zinc-cuprates more nucleophilic than organozinc compounds!