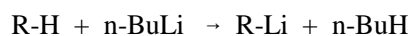


Simple organolithium reagents (MeLi, PhLi, *n*-BuLi, *sec*-BuLi, *t*-BuLi and a few others) are usually made by the reduction of halides, normally chlorides, with lithium. The direct reaction of lithium metal with more complex substrates is difficult. However, several very effective lithium-arene reagents or catalysts (such as 4,4-di-*t*-butylbiphenyl) have allowed a much wider range of lithium reagents to be prepared by reduction not only of halides, but also of sulfides, epoxides, oxetanes, and other ethers.^[17]

The principal enabling force in the development of organolithium chemistry is the commercial availability of inexpensive stable solutions of *n*-butyllithium. Many hundreds of functionalized organolithium reagents have become available by the metalation (Li/H exchange) reaction using *n*-butyllithium, or the more potent and selective (but also more expensive and difficult to handle) *t*-butyllithium and *sec*-butyllithium.^[1, 2]



The scope of the metalation reaction has been expanded by the use of complexing and chelating reagents such as hexamethylphosphoric triamide (HMPA), *N,N'*-dimethylpropyleneurea (DMPU) and tetramethylethylenediamine (TMEDA)^[2g] which increase the rate of metalation and thus extend the range of compounds which can be deprotonated. The polar cosolvents can also have substantial effects on the subsequent reactions of the organolithium reagents, e.g., increasing rates of S_N2 reactions, and changing ratios of 1,2- to 1,4-addition. However, side reactions such as proton transfers can also be favored by these cosolvents. A variety of potassium reagents can be prepared either by use of potassium hydride^[6] or the combination of butyllithium and potassium *t*-butoxide.^[11]

Many α -heteroatom substituted organolithium reagents have been used for C-C bond formation, with the heteroatom then facilitating subsequent transformations. Among the most widely used are metalated sulfones^[19] and dithianes.^[8] These and many others (such as thiazolium salts^[16] and homoenolates^[9]) have been used as reagents for umpolung of carbonyl reactivity (acyl anion equivalents^[8]). These reagents often have both nucleophilic as well as electrophilic character at the metalated carbon.^[20]

While the metalation reaction often provides the cheapest route to a lithium reagent,^[1, 2] many cannot be made this way either because the metalation process is too slow (i.e., proton not sufficiently acidic), or not sufficiently selective. In these situations the lithium/metalloid exchange reactions may provide the best route.^[3]



The Li/Br, Li/I, Li/Sn and Li/Se are the transmetalations most commonly used. The Li/M exchanges are extremely fast (especially Li/I, Li/Hg and Li/Te) and have been used to prepare unstable lithium reagents at very low temperature, and to generate lithium reagents in the presence of electrophiles.^[3a, 3e] The Li/Sn exchange is the most generally applicable since the trialkylstannane precursors undergo few side reactions during the reaction with the alkyllithium reagent and the byproducts (*n*-BuSnR₃) are inert. One disadvantage is the relatively high sensitivity to steric effects of the Li/Sn exchanges, which can become quite slow, especially in solvents less polar than THF (e.g., diethyl ether). Another is the toxicity of organotin compounds.

Organolithium reagents can also be prepared by additions of RLi to multiple bonds^[10] and by modified Shapiro reactions.^[15]

There has been substantial progress in the development of processes for the preparation of chiral and diastereomerically enriched organolithium reagents.^[18]

The easy availability of *n*-butyllithium provides routine access to another class of strong bases, the lithium dialkylamides (LiNR₂), of which lithium diisopropylamide (LDA) is the most widely used. Others having more or less steric hindrance, or basicity, or the potential for asymmetric deprotonations have been prepared by varying the R groups (e.g., isopropylcyclohexylamide, dicyclohexylamide, bistrimethylsilylamide (LiHMDS), 2,2,6,6-tetramethylpiperidine, (LiTMP)). The reactivity and selectivity of amide bases can be fine-tuned by use of other counter ions (e.g., Na⁺, K⁺, XMg⁺, R₂Al⁺) and by solvent effects.

The hindered amide bases such as LDA show a much greater selectivity for proton abstraction vs. nucleophilic addition, and thus are often preferred over *n*-butyllithium for the deprotonation of compounds which are susceptible to nucleophilic attack (carbonyl compounds, nitriles, sulfones, sulfoxides, phosphonates, or any compound containing 3rd, 4th or 5th row elements, olefinic or polyunsaturated substrates). For those compounds which can be deprotonated by either LDA or *n*-butyllithium, the amide bases usually react more rapidly and cleanly.

Lithium diisopropylamide and related bases have made routinely available solutions of regioisomerically pure lithium enolates derived from ketones, some aldehydes, carboxylic acids, esters, lactones, amides and lactams. Many di- and tri-anions have also been prepared.^[4] Hence many alkylations, acylations and other reactions of enolates

previously impossible can be routinely carried out.

Many metalations and other organometallic reactions can be carried out in the presence of electrophilic species such as Me_3SiCl , $\text{BF}_3\cdot\text{OEt}_2$, HgCl_2 , $\text{B}(\text{OMe})_3$, etc. This technique can provide substantial improvements in selectivity and rate.^[1d]

New reagents for the derivatization of lithium and other organometallic reagents with nitrogen, oxygen, halogen and other heteroatom electrophiles^[10] continue to be developed. Weinreb reagents (N-methoxy-N-methylamides) provide an effective method for acylation of carbanionic reagents.^[10d]

The conversion of lithium reagents to other organometallic species has made possible many useful synthetic transformations. Copper reagents promote the conjugate addition of carbanionic centers to α,β -unsaturated carbonyl compounds.^[5] Although lithium reagents generally add 1,2- (as opposed to 1,4-) to conjugated carbonyl compounds, some control over regioselectivity has been achieved.^[10c] Cerium reagents often give superior yields of addition products to ketones (they cause less enolization, and tend to promote 1,2-addition).^[14]

The Grignard reaction continues to be studied.^[12]

References

“Preparative Polar Organometallic Chemistry,” L. Brandsma, Springer-Verlag, 1986. “Organometallics in Synthesis,” Schlosser, M., Ed. Wiley: Chichester, U.K., 1994.

“Organolithium Methods,” B.J. Wakefield, Academic Press, San Diego, 1988. “Lithium Chemistry: A Theoretical and Experimental Overview,” A.-M Sapse, P. v. R. Schleyer, eds. NY, Wiley, 1995.

“Comprehensive Carbanion Chemistry,” E. Buncl and T. Durst, Ed. Academic Press, NY, 1983.

“Selective Carbanion Chemistry and Anion-cation Interactions in Solution: A Survey,” Seyden-Penne, J. *New J. Chem.* **1992**, 16, 251.

“Gas-phase Carbanion Chemistry,” Squires, R. R. *Acc. Chem. Res.* **1992**, 25, 461.

“Specific Transition State Stabilization by Metal Ions in Reactions of Functionalized Crown Ethers,” Cacciapaglia, R.; Mandolini, L. *Pure Appl. Chem.* **1993**, 65, 533-8. “Catalysis by Metal ions in Reactions of Crown Ether Substrates,” Cacciapaglia, R.; Mandolini, L. *Chem. Soc. Rev.* **1993**, 22, 221.

1. a) “Metalations by Organolithium Compounds,” Mallan, J. M.; Bebb, R. L. *Chem. Rev.* **1969**, 69, 693.

b) “Allylic and Benzylic Carbanions Substituted by Heteroatoms,” Biellmann, J. F.; Ducep, J. -B. *Org. React.* **1982**, 27, 1. “Polar Allyl Type Organometallics as Key Intermediates in Regio- and Stereocontrolled Reactions: Conformational Mobilities and Preferences,” Schlosser, M.; Desponds, O.; Lehmann, R.; Moret, E.; Rauchschalbe, G. *Tetrahedron* **1993**, 49, 10175. “Silylallyl Anions in Organic Synthesis: A Study in Regio- and Stereoselectivity,” Chan, T.H.; Wang, D. *Chem. Rev.* **1995**, 95, 1279-92. “Delocalized Carbanions in Synthesis,” Barry, C. E. III, Bates, R. B.; Beavers, W. A.; Camou, F. A.; Gordon, B. III; Hsu, H. F. J.; Mills, N. S. *Synlett* **1991**, 207. “Regioselectivity of the Reactions of Heteroatom-Stabilized Allyl Anions with Electrophiles,” Katritzky, A. R.; Piffl, M.; Lang, H.; Anders, E. *Chem. Rev.* **1999**, 99, 665-722.

c) “Heteroatom-Facilitated Lithiations,” H. W. Gschwend and H. R. Rodriguez *Org. React.* **1979**, 26, 1. “Lateral Lithiation Reactions Promoted by Heteroatomic Substituents,” Clark, R. D.; Jahangir, A. *Org. React.* **1995**, 47, 1-314. “ α -Heteroatom Substituted 1-Alkenyllithium Reagents: Carbanions and Carbenoids for C-C Bond Formation,” Braun, M. *Angew. Chem. Int. Ed. Engl.* **1998**, 37, 430-51.

d) “Lewis Acid Complexation of Tertiary Amines and Related Compounds: A Strategy for α -Deprotonation and Stereocontrol,” Kessar, S.V.; Singh, P. *Chem. Rev.* **1997**, 97, 721-38.

2. a) “Dipole Stabilized Carbanions,” P. Beak *Chem. Rev.* **1978**, 78, 275.

b) **Ortho Metalation.** “Directed Lithiation of Aromatic Tertiary Amides: An Evolving Synthetic Methodology for Polysubstituted Aromatics,” P. Beak and V. Snieckus *Acc. Chem. Res.* **1982**, 15, 306. “Heteroatom Directed Aromatic Lithiation,” N. S. Narasimhan, R. S. Mali *Top. Curr. Chem.* **1987**, 138, 63. “The Directed Ortho Metalation Reaction. Methodology, Applications, Synthetic Links, and a Non-aromatic Ramification,” V. Snieckus, *Pure Appl. Chem.* **1990**, 62, 2047. “Directed Ortho Metalation. Tertiary Amide and O-Carbamate Directors in Synthetic Strategies for Polysubstituted Aromatics,” Snieckus, V. *Chem. Rev.* **1990**, 90, 879. “Combined Directed *Ortho* Metalation-Cross Coupling Strategies. Design for Natural Product Synthesis,” Snieckus, V. *Pure Appl. Chem.* **1994**, 66, 2155-8.

c) **Ortho Metalation of Heterocycles:** “Directed ortho-Metalation of Pyridines,” Queguiner, G.; Marsais, F.; Snieckus, V.; Epszajn, L. *Adv. Heterocycl. Chem.* **1991**, 52, 187. “Metalation and Metal-Assisted Bond

Formation in π -Electron Deficient Heterocycles,” Undheim, K.; Benneche, T. *Act. Chem. Scand.* **1993**, *47*, 102. “Syntheses of Heterocyclic Compounds Involving Aromatic Lithiation Reactions in the Key Step,” Narasimhan, N. S.; Mali, R. S. *Synthesis* **1983**, 957. “Synthesis and reactions of lithiated monocyclic azoles containing two or more heteroatoms. Part I: Isoxazoles,” Iddon, B. *Heterocycles* **1994**, *37*, 1263. “Synthesis and reactions of lithiated monocyclic azoles containing two or more heteroatoms. Part II: Oxazoles,” Iddon, B. *Heterocycles* **1994**, *37*, 1321. “Synthesis and Reactions of Lithiated Monocyclic Azoles Containing Two or more Hetero-Atoms. Part 3: Pyrazoles,” Grimmett, M. R.; Iddon, B. *Heterocycles*, **1994**, *37*, 2087. “Synthesis and Reactions of Lithiated Monocyclic Azoles Containing 2 or more Hetero-Atoms. Part 4: Imidazoles,” Iddon, B.; Ngochindo, R. I. *Heterocycles*, **1994**, *38*, 2487. “Synthesis and Reactions of Lithiated Monocyclic Azoles Containing Two or More Hetero-atoms. Part V. Isothiazoles and Thiazoles,” Iddon, B. *Heterocycles* **1995**, *41*, 533. “Metalation of Diazines,” Turck, A.; Plé, N.; Quéguiner, G. *Heterocycles*, **1994**, *37*, 2149. “Synthesis and Reactions of Lithiated Monocyclic Azoles Containing Two or More Hetero-atoms. Part VI. Triazoles, Tetrazoles, Oxadiazoles, and Thiadiazoles,” Grimmett, M. R.; Iddon, B. *Heterocycles*, **1995**, *41*, 1525-74. “The Directed Ortho Metalation Cross-Coupling Symbiosis in Heteroaromatic Synthesis,” Green, L.; Chauder, B.; Snieckus, V. *J. Heterocycl. Chem.* **1999**, *36*, 1453-68. “Synthesis of Substituted Quinazolin-4(3H)-ones and Quinazolines via Directed Lithiation.” El-Hiti, G. A. *Heterocycles* **2000**, *53*, 1839-68. “Advances in the Directed Metallation of Azines and Diazines. Part 1: Metallation of Pyridines, Quinolines and Carbolines.” Mongin, F.; Queguiner, G. *Tetrahedron* **2001**, *57*, 4059-90. “Advances in the Directed Metalation of Azines and Diazines Part 2. Metalation of Pyrimidines, Pyrazines, Pyridazines and Benzodiazines.” Turck, A.; Ple, N.; Mongin, F.; Queguiner, G. *Tetrahedron* **2001**, *57*, 4489-505.

d) **Metalation α to Nitrogen:** “Metalation and Electrophilic Substitution of Amine Derivatives Adjacent to Nitrogen: α -Metallo Amine Synthetic Equivalents,” P. Beak, W. J. Zadjel, D. B. Reitz *Chem. Rev.* **1984**, *84*, 471. “New Metalation and Synthetic Applications of Isonitriles,” Ito, Y. *Pure & Appl. Chem.* **1990**, *62*, 583. “Metalation of Isocyanides,” Ito, Y. *Synlett* **1990**, 245. “Generation and Reactions of sp^2 -Carbanionic Centers in the Vicinity of Heterocyclic Nitrogen Atoms,” Rewcatle, G. W.; Katritzky, A. R. *Adv. Heterocyclic Chem.* **1993**, *56*, 157. “Benzotriazole-stabilized Carbanions: Generation, Reactivity, and Synthetic Utility,” Katritzky, A. R.; Yang, Z.; Cundy, D. J. *Aldrichimica Acta*, **1994**, *27*, 31-8. “The Generation and Reactions of Non-Stabilized α -Aminocarbanions,” Katritzky, A. R.; Qi, M. *Tetrahedron* **1998**, *54*, 2647-68. “Stereoselective Addition of Chiral α -Aminoorganometallics to Aldehydes,” Gawley, R. E. *Advances in Asymmetric Synthesis. Volume 3.* Hassner, A. JAI Press: Stamford, Connecticut, 1998.

e) “Stereo and Regiocontrol by Complex Induced Proximity Effects-Organolithium Compounds,” P. Beak, A. I. Meyers *Accounts Chem. Res.* **1986**, 356.

f) “The Synthetic Utility of α -Amino Alkoxides,” Comins, D. L. *Synlett* **1992**, 615.

g) “Is N,N,N',N'-Tetramethylethylenediamine a Good Ligand for Lithium?” Collum, D. B. *Acc. Chem. Res.* **1992**, *25*, 448.

h) “Asymmetric Carbon-Carbon Bond Formation Using Sulfoxide-stabilized Carbanions,” Walker, A.J. *Tetrahedron: Asymmetry* **1992**, *3*, 961. “Synthetic Utilization of Highly Stereoselective Conjugate Addition Reactions of Phosphorus and Sulfur Stabilized Allylic Carbanions,” Freeman, R.; Haynes, R. K.; Loughlin, W. A.; Mitchell, C.; Stokes, J. V. *Pure Appl. Chem.* **1993**, *65*, 647-54. “Stereochemistry of α -Sulfinyl Carbanion,” Ohno, A.; Higaki, M. *Rev. Heteroatom Chem.* **1995**, *13*, 1-24.

3. a) “Aromatic Organolithium Reagents Bearing Electrophilic Groups. Preparation by Halogen-Lithium Exchange,” Parham, W. E.; Bradsher, C. K. *Acc. Chem. Res.* **1982**, *15*, 300.

b) “Synthetic Methods using α -Heterosubstituted Organometallics,” A. Krief *Tetrahedron* **1980**, *36*, 2531.

c) “The Mechanism of the Lithium Halogen Interchange Reaction - A Review of the Literature,” Bailey, W.F.; Patricia, J. J. *J. Organomet. Chem.* **1988**, *352*, 1.

d) “Selenium Stabilized Carbanions,” H. J. Reich in “Organoselenium Chemistry,” D. Liotta, Ed. Wiley, 1987. “Selenium-Stabilized Carbanions,” Ponthieux, S.; Paulmier, C. *Top. Curr. Chem.* **2000**, *208*, 113-42.

e) “Preparation and some Applications of Functionalized Organo-Lithium Compounds in Organic Synthesis,” Barluenga, J. *Pure & Appl. Chem.* **1990**, *62*, 595.

f) “Synthesis and Some Properties of Alkenyl Carbanions Stabilized by an α -Boron Atom,” Pelter, A.; Smith, K.; Jones, K. *Pure & Appl. Chem.* **1991**, *63*, 403.

g) “Nucleophilic Perfluoroalkylation Using Perfluoroalkyllithiums,” Uno, H.; Suzukib, H. *Synlett* **1993**, 91-6. “Fluorinated organometallics: vinyl, alkynyl, allyl, benzyl, propargyl and aryl fluorinated organometallic reagents in organic synthesis,” Burton, D. J.; Yang, Z. Y.; Morken, P. A. *Tetrahedron* **1994**, *50*, 2993.

- “Polyfluorovinyl Lithium Reagents and Their Use in Synthesis. Coe, P. L. *J. Fluor. Chem.* **1999**, *100*, 45-52.
- h) “Oxiranyl Anions and Aziridinyl Anions,” Satoh, T. *Chem. Rev.* **1996**, *96*, 3303-25.
- i) “Stereoselective Syntheses of Heterocycles with Lithiated Methoxyallene.” Reissig, H.-U.; Hormuth, S.; Schade, W.; Amombo, M. O.; Watanabe, T.; Pulz, R.; Hausherr, A.; Zimmer, R. *J. Hererocyc. Chem.* **2000**, *37*, 597-606.
4. “Di- and Polyalkali Metal Derivatives of Heterofunctionally Substituted Organic Molecules,” E. M. Kaiser, J. D. Petty and P. L. A. Knutson *Synthesis* **1977**, 509. “Recent Advances in Dianion Chemistry,” Thompson, C. M.; Green, D. L. *Tetrahedron* **1991**, *47*, 4223. “Dianion Chemistry,” Thompson, C. M., CRC: Boca Raton, FL, 1994.
5. **Copper Reagents:** “Copper(I) Catalyzed Reactions of Organolithium and Grignard Reagents,” Erdik, E. *Tetrahedron* **1984**, *40*, 641. “Copper Assisted Nucleophilic Substitution of Aryl Halogen,” Lindley, J. *Tetrahedron* **1984**, *40*, 1433. “Organocopper Reagents: Substitution, Conjugate Addition, Carbo/Metallocupration, and Other Reactions,” Lipshutz, B. H.; Sengupta, S. *Org. Reactions* **1992**, *41*, 135. “Selective Synthesis by Use of Lewis Acids in the Presence of Organocopper and Related Reagents,” Yamamoto, Y. *Angew. Chem. I.E.* **1986**, *25*, 947. “S_N2’ Additions of Organocopper Reagents to Vinyloxiranes,” Marshall, J. A. *Chem. Rev.* **1989**, *89*, 1503. “New Tools in Synthetic Organocopper Chemistry,” Nakamura, E. *Synlett* **1991**, 539. “New Aspects of Organocopper Reagents: 1,3- and 1,2-Chiral Induction and Reaction Mechanism,” Ibuka, T.; Yamamoto, Y. *Synlett* **1992**, 769. “Transmetalation reactions in organocopper chemistry,” Wipf, P. *Synthesis* **1993**, 537. “Recent Progress in Higher Order Cyanocuprate Chemistry,” Lipshutz, B.H. *Adv. Metal-Organic Chem. Vol. 4*, **1995**, JAI: Greenwich, Connecticut. “Regioselective and Stereoselective Syntheses with Organocopper Reagents,” Krause, N.; Gerold, A. *Angew. Chem. Int. Ed. Engl.* **1997**, *36*, 187-204.
- Conjugate Addition:** “1,4-Addition Reactions of Organocuprates with α,β -Unsaturated Ketones,” Smith, R. A. J.; Vellekoop, A. S. *Advances in Detailed Reaction Mechanisms. Vol. 3.* James M. Coxon, Ed., JAI Press: Greenwich, CT 1994. “Phosphoramidites: Marvellous Ligands in Catalytic Asymmetric Conjugate Addition. (Cu catalyzed Organozinc Additions)” Feringa, B. L. *Acc. Chem. Res.* **2000**, *33*, 346-53. “Enantioselective Conjugate Additions.” Sibi, M. P.; Manyem, S. *Tetrahedron* **2000**, *56*, 8033-61. “Decoding the ‘Black Box’ Reactivity that is Organocuprate Conjugate Addition Chemistry.” Woodward, S. *Chem. Soc. Rev.* **2000**, *29*, 393-401.
6. “**Potassium Hydride** in Organic Synthesis,” H. W. Pinnick *Org. Prep. Proc. Int.* **1983**, *15*, 199.
7. “**The Barbier Reaction** - A One Step Alternative for Synthesis via Organomagnesium Compounds,” C. Blomberg, F.A. Hartog, *Synthesis* **1977**, 18. “The Barbier Reaction and Related One-Step Processes (Reactivity and Structure. Concepts in Organic Chemistry, Vol. 31),” Blomberg, C. *Springer-Verlag: Berlin*, **1994**. “Aqueous Barbier-Grignard Type Reaction: Scope, Mechanism, and Synthetic Applications,” Li, C. J. *Tetrahedron* **1996**, *52*, 5643-68.
8. **Acyl Anions.** “A Compilation of References on Formyl and Acyl Anion Synthons,” Hase, T.A.; Koskimies, J.K. *Aldrichim. Acta* **1981**, *14*, 73; **1982**, *15*, 35. “New Formyl Anion and Cation Equivalents,” Dondoni, A.; Colombo, L. *Adv. Use of Synthons in Org. Chem. Vol. 1*, Jai Press, 1993. “Acylvinyl and Vinylogous Synthons.” Chinchilla, R.; Najera, C. *Chem. Rev.* **2000**, *100*, 1891-928.
- Cyanohydrins:** “Reactions of Acyl Anion Equivalent Derived from Cyanohydrins, Protected Cyanohydrins, and α -Dialkylamino Nitriles,” Albright, J.O. *Tetrahedron* **1983**, *39*, 3207. “Cyanohydrins in Nature and the Laboratory: Biology, Preparations, and Synthetic Applications,” Gregory, R. J. H. *Chem. Rev.* **1999**, *99*, 3649-82.
- Dithianes:** “Synthetic Uses of the 1,3-Dithiane Grouping from 1977-1988,” P. C. B. Page, M. B. van Niel, J. C. Prodder *Tetrahedron* **1989**, *45*, 7643. “Ketene Dithioacetals in Organic Synthesis: Recent Developments,” M. Kolb *Synthesis* **1990**, 171. “Synthesis of Heterocycles from Ketene Dithioacetals,” Yokoyama, M.; Togo, H.; Kondo, S. *Sulfur Reports*, **1990**, *10*, 23. “New Synthetic Applications of the Dithioacetal Functionality,” Luh, T.Y. *Acc. Chem. Res.* **1991**, *24*, 257. “The Development and Application of 1,3-Dithiane 1-Oxide Derivatives as Chiral Auxiliaries and Asymmetric Building Blocks for Organic Synthesis. A Review,” Allin, S. M.; Page, P. C. B. *Org. Prep. Proc. Int.* **1998**, *30*, 145-76.
- Carbonylation:** “Organic Synthesis via Carbonylation of Organometallic Reagents with Carbon Monoxide,” Narayama, N. *Synthesis* **1985**, 253. “The Application of Transition Metal Catalysis for Selective Cyclocarbonylation Reactions. Synthesis of Lactones and Lactams,” El Ali, B.; Alper, H. *Synlett* **2000**, 161-71.
9. “**Homoenolate Anions** and Homoenolate Anion Equivalents. Mechanistic Aspects and Synthetic

Applications,” Werstruck, N. H. *Tetrahedron* **1983**, *39*, 205. “Homoenolates and Other Functionalized Organometallics,” Crimmins, M. T.; Nantermet, P. G. *Org. Prep. Proc. Int.* **1993**, *25*, 41. “Stereoselectivity of Chiral Homoenate Equivalents,” Ahlbrecht, H.; Beyer, U. *Synthesis* **1999**, 365-90.

10. **Electrophiles:**

(a) **Electrophilic Nitrogen:** “Electrophilic Amination of Carbanions,” Erdik, E.; Ay, M. *Chem. Rev.* **1989**, *89*, 1947. “Electrophilic Amination with Oxaziridines,” Andreae, S.; Schmitz, E. *Synthesis* **1991**, *5*, 327. “The Electrophilic Amination of Carbanions: an Unconventional New Entry to C-N Bond Formation.” Dembeck, P.; Seconi, G.; Ricci, A. *Chem. Europ. J.* **2000**, *6*, 1281-6.

(b) **Electrophilic Halogen:** “New Fluorinating Agents in Organic Synthesis,” L. German and S. Zemskov, Eds. Springer Verlag: Berlin, 1989. “N-Fluoropyridinium Salts”, Strekowski, L.; Kiselyov, A.S. *Adv. Heterocyclic Chem.* **1995**, *62*, 1-17. “N-Fluoroamines and Their Analogues as Fluorinating Agents in Organic Synthesis,” Furin, G.; Georgievich, F.; Al'bert, A. *Russ. Chem. Rev.* **1999**, *68*, 725-59. “Recent Advances in Electrophilic Fluorination,” Taylor, S. D.; Kotoris, C. C.; Hum, G. *Tetrahedron* **1999**, *55*, 12431-77.

(c) **Addition of Lithium Reagents to Double Bonds:** “Michael Addition of Organolithium Compounds. A Review,” D. A. Hunt *Org. Prep. Proc. Int.* **1989**, *21*, 705. “Generation and Cyclization of Unsaturated Organolithiums,” Bailey, W. F.; Ovaska, T. V. *Advances in Detailed Reaction Mechanisms. Vol. 3.* James M. Coxon, Ed., Jai Press: Greenwich, CT 1994.

(d) **Weinreb Amides:** “Chemistry of N-Methoxy-N-methylamides. Applications in Synthesis,” Sibi, M. P. *Org. Prep. Proc. Int.* **1993**, *25*, 15. “ α -Diones from Cyclic Oxamides and Organolithium Reagents: A New, General and Environmentally Beneficial Synthetic Method,” Mueller-Westerhoff, U.T.; Zhou, M. *Synlett*, **1994**, 975-84.

(e) **Ketenes:** “Silylketenes as Useful Building Blocks for Heterocycles,” Shioiri, T.; Takaoka, K.; Aoyama, T. *J. Heterocycl. Chem.* **1999**, *36*, 1555-63. “Amines via Nucleophilic 1,2-Addition to Ketimines. Construction of Nitrogen-Substituted Quaternary Carbon Atoms. A Review.” Steinig, A. G.; Spero, D. M. *Org. Prep. Proc. Int.* **2000**, *32*, 205-34.

(f) **Epoxides:** “Reactions of Epoxides with Ester, Ketone and Amide Enolates,” Taylor, S. K. *Tetrahedron* **2000**, *56*, 1149-63. “Kinetic Resolution of Terminal Epoxides via Highly Regioselective and Enantioselective Ring Opening with TMSN₃. An Efficient, Catalytic Route to 1,2-Amino Alcohols,” Rondon, A. C.; Panek, J. S. *CHEMTRACTS Org. Chem.* **1997**, *10*, 1058-61. “Asymmetric Catalysis of Epoxide Ring-Opening Reactions,” Jacobsen, E. N. *Acc. Chem. Res.* **2000**, *33*, 421-31. “Enantioselective Catalytic Ring Opening of Epoxides with Carboxylic Acids,” *CHEMTRACTS Org. Chem.* **1998**, *11*, 287-90. “Oxygen-Directed Carbocyclizations of Epoxides.” Marson, C. M. *Tetrahedron* **2000**, *56*, 8779-94.

(g) **Aziridines:** “Recent Synthetic Applications of Chiral Aziridines.” Coull, W. M.; Davis, F. A. *Synthesis* **2000**, 1347-65.

(h) **Isothiocyanates:** Reactions of Unsaturated Carbanions with Isothiocyanates: A New Avenue to Fundamental Heterocycles,” Trofimov, B. A. *J. Heterocycl. Chem.* **1999**, *36*, 1469-90.

11. “Alkali Metal Supramolecular Complexes and Their Significance in Organic Chemistry,” Jedlinski, Z. *Pure Appl. Chem.* **1993**, *65*, 483-8. “Unimetal Super Bases,” Caubere, P. *Chem. Rev.* **1993**, *93*, 2317.

12. **Grignard Reagents** “Mechanism of Grignard Reagent Formation. The Surface Nature of the Reaction,” Walborsky, H. M. *Acc. Chem. Res.* **1990**, *23*, 286. “Grignard Reagent Formation and Freely Diffusing Radical Intermediates,” Garst, J. F. *Acc. Chem. Res.* **1991**, *24*, 95. “The Nature of Radicals Involved in Grignard Reagent Formation,” Walling, C. *Acc. Chem. Res.* **1991**, *24*, 255. “X-Ray Structural Analyses of Organomagnesium Compounds,” Markies, P. R.; Akkerman, O. S.; Bickelhaupt, F.; Smeets, W. J. J.; Spek, A. L. *Adv. Organomet. Chem.* **1991**, *32*, 147. “Synthesis and Transformation of Non-Grignard Organomagnesium Reagents Obtained from 1,3-Dienes,” *J. Organomet. Chem.* **1991**, *406*, 1. “The Importance of (Intramolecular) Solvation in Organomagnesium Chemistry,” Bickelhaupt, F. *Act. Chem. Scand.* **1992**, *46*, 409. “Utilization of Grignard Reagents in Solid-Phase Synthesis: A Review of the Literature,” Franzen, R. G. *Tetrahedron* **2000**, *56*, 685-91. “New Polyfunctional Magnesium Reagents for Organic Synthesis,” Rottlander, M.; Boymond, L.; Berillon, L.; Lepretre, A.; Varchi, G.; Avolio, S.; Laaziri, H.; Queguiner, G.; Ricci, A.; Cahiez, G.; Knochel, P. *Chem. Europ. J.* **2000**, *6*, 767-70.

13. **Theory of Organolithium Reagents:** “The Lithium Bond Reexamined,” Sannigrahi, A. B.; Kar, T.; Niyogi, B. G.; Hobza, P.; Schleyer, P. v. R. *Chem. Rev.* **1990**, *90*, 1061. “Are Polar Organometallic Compounds “Carbanions”? The Gegenion Effect on Structure and Energies of Alkali-Metal Compounds,” Lambert, C.; Schleyer, P. v. R. *Angew. Chem., Int. Ed. Eng.* **1994**, *33*, 1129.

14. **Cerium Reagents** "Carbonyl Addition Reactions Promoted by Cerium Reagents," Imamoto, T. *Pure & Appl. Chem.* **1990**, *62*, 747. "Carbon-Carbon Bond-Forming Reactions Mediated by Cerium-(IV) Reagents," Nair, V.; Mathew, J. *Chem. Soc. Rev.* **1997**, *26*, 127-32. "Organocerium Compounds in Synthesis," Liu, H.-J.; Shia, K.-S.; Shang, X.; Zhu, B.-Y. *Tetrahedron* **1999**, *55*, 3803-30.
15. **Shapiro Reaction:** "Lithioalkenes from Arylsulphonylhydrazones," Chamberlin, A. R.; Bloom, S. H. *Org. React.* **1990**, *39*, 1. "Recent Applications of the Shapiro Reaction," A. G. M. Barrett, *Acc. Chem. Res.* **1983**, *16*, 55.
16. **Stetter Reaction:** "The Catalyzed Nucleophilic Addition of Aldehydes to Electrophilic Double Bonds," H. Stetter, H. Kuhlmann *Org. React.* **1991**, *40*, 407.
17. "Arene-catalysed Lithiation Reactions," Yus, M. *Chem. Soc. Rev.* **1996**, *25*, 155-62. "Reductive Opening of Saturated Oxa-, Aza- and Thia-Cycles by means of an Arene-Promoted Lithiation: Synthetic Applications." Yus, M.; Foubelo, F. *Rev. Heteroatom Chem.* **1997**, *17*, 73-108. "New Methodologies Based on Arene-Catalyzed Lithiation Reactions and Their Application to Synthetic Organic Chemistry," Ramon, D. J.; Yus, M. *Eur. J. Chem.* **2000**, 225-37. "From Arene-Catalyzed Lithiation to Other Synthetic Adventures." Yus, M. *Synlett* **2001**, 1197-205.
18. **Chiral Organolithiums:** "Enantioselective transformations and racemization studies of heteroatom substituted organolithium compounds," Aggarwal, V. K. *Angew. Chem. I. E. Engl.* **1994**, *33*, 175. "Enantioselective Synthesis via Sparteine-Induced Asymmetric Deprotonation," Hoppe, D.; Hintze, F.; Tebben, P.; Paetow, M.; Ahrens, H.; Schwerdtfeger, J.; Sommerfeld, P.; Haller, J.; Guarnieri, W.; Kolczewski, S.; Hense, T.; Hoppe, I. *Pure App. Chem.* **1994**, *66*, 1479. "Enantioselective Synthesis with Lithium/(-)-Sparteine Carbanion Pairs," Hoppe, D.; Hense, T. *Angew. Chem. Intl. Ed. Engl.* **1997**, *36*, 2282-316. "Some Stereochemical Aspects of Bisquinolizidine Alkaloids Sparteine Type," Boczoń, W. *Heterocycles* **1992**, *33*, 1101. "Regioselective, Diastereoselective, and Enantioselective Lithiation-Substitution Sequences—Reaction Pathways and Synthetic Applications," Beak, P.; Basu, A.; Gallagher, D.J.; Park, Y.S.; Thayumanavan, S. *Acc. Chem. Res.* **1996**, *29*, 552-60.
19. "Stereoselective and Enantioselective Synthesis of Five-Membered Rings via Conjugate Additions of Allylsulfone Carbanions." Hassner, A.; Ghera, E.; Yechezkel, T.; Kleiman, V.; Balasubramanian, T.; Ostercamp, D. *Pure. Appl. Chem.* **2000**, *72*, 1671-83.
20. "The Electrophilic Nature of Carbenoids, Nitrenoids, and Oxenoids." Boche, G.; Lohrenz, J. C. W. *Chem. Rev.* **2001**, *101*, 697-756.