Pergamon

Tetrahedron 54 (1998) 10827–10836

TETRAHEDRON

Convenient Preparation of Metals Deposited on Solid Supports and Their Use in Organic Synthesis

Mieczysław Mąkosza,* Piotr Nieczypor, Karol Grela

Institute of Organic Chemistry, Polish Academy of Sciences, Kasprzaka 44, PL 01-224 Warsaw, Poland

Received 11 May 1998; revised 22 June 1998; accepted 24 June 1998

Abstract: "High-surface alkali metals" can be conveniently prepared *via* deposition of corresponding metals on various supports such as sodium chloride, polyethylene, polypropylene and cross-linked polystyrene from their solutions in liquid ammonia. Alkali metals deposited on polymeric supports can be stored in form of stable suspensions in inert solvents and used for the acyloin and Dieckmann condensations and for preparation of organolithiums. Addition of the suspension of supported alkali metal to a solution of zinc chloride gave an active zinc on polymeric support, which can be used for the Reformatski and Barbier reactions. © 1998 Elsevier Science Ltd. All rights reserved.

INTRODUCTION

Alkali metals promote a variety of organic transformations of great value for organic synthesis and industrial processes.[1] Since most of these reactions proceed in heterogenous conditions on metal - solution interface, it is necessary that the surface of the metals is highly developed. Alkali metals are frequently used in a form of fine particles, colloids and dispersed on various solid supports.[2] Taking into account that these metals are very sensitive toward atmospheric oxygen and moisture, preparation of such active forms is connected with substantial difficulties. Recently, the applications of metals dispersed on solid carriers gained particular interest since they offer considerable benefits: the metal surface is highly developed so its activity is high, the reactions proceed selectively and the handling of reagents in such form as well as the separation of the reaction products from the support is a facile operation.[2d] Thus metals on carriers such as alumina, titanium dioxide, sodium chloride, charcoal, graphite *etc.* have found wide applications in many organic reactions.[2a-c]

Typical methods of preparation of high-surface metals consist in vigorous stirring of a molten metal with a support in inert organic solvents (toluene, xylene) or without any solvent.[2a-c] For obvious reasons these procedures are inconvenient and dangerous. Moreover the necessity to use molten metal limits this procedure to a very few cases of low-melting metals (potassium, sodium) and thermally stable supports. Many alkali and alkaline metals and also some others are readily soluble in liquid ammonia forming deep blue colored, stable solutions from which metal can be recovered upon evaporation of ammonia.[3] These solutions should be ideal means of deposition of the metals on the surface of a desired carrier.

0040-4020/98/$ - see front matter © 1998 Elsevier Science Ltd. All rights reserved.
PII: S0040-4020(98)00625-5

RESULTS AND DISCUSSION

In our preliminary communication we have described a simple, efficient and safe method of preparation of high-surface sodium *via* evaporation of ammonia from a suspension of solid supports in a solution of sodium in liquid ammonia.[4] The final removal of adsorbed ammonia was carried out under reduced pressure. The sodium dispersion obtained in this way was an effective condensing agent in the acyloin reaction.[4] In this paper a full account of our studies on preparation and application of high surface metals is presented. First of all it was shown that this method can be applied to deposit metal on various solid supports: glass powder, sodium chloride and polymers - polyethylene (PE), polypropylene (PP) and polystyrene cross-linked with divinylbenzene (PS/DVB). On these materials up to 5 wt. % of metal can be deposited, without risking any severe overloading. Other common supporting materials such as silica, charcoal, titanium, barium and magnesium oxides as well as barium sulphate were also tested and were found to be unsuitable for this procedure because they strongly adsorb ammonia and catalyze conversion of the metals into amides in some cases. Contrary to sodium, potassium and calcium which precipitate on powdered sodium chloride from liquid ammonia satisfactorily, lithium does not form a high-surface metal on this support. Evaporation of ammonia from a suspension of sodium chloride in a solution of lithium in liquid ammonia resulted in the crystallization of the metal on the walls of flask and not on the support. It is known that lithium associates strongly with ammonia forming so-called lithium bronze, $Li(NH_3)_n$, which is stable up to room temperature.[3b] On the other hand use of fine powdered polymeric supports: PE and PS/DVB resulted in the formation of desired high surface lithium. Microscopic observation of these materials revealed that great majority of lithium is indeed located on the surface of these carriers. Only a minor fraction, the highest not exceeding 10% of lithium used, was in the form of metal crystals 0.1–0.5 mm of size. Metals such as sodium, potassium and calcium form even more homogeneous materials with no evidence for the formation of free crystallites of metal.

Interestingly, high-surface lithium and sodium are not pyrophoric, but their exposure to air and moisture results in a slow decomposition. These powders can be stored and used under argon, but a prolonged storage of the powders in a dry form leads to a loss of the active metal. One of the most important properties of lithium, sodium and potassium supported on PE and PS/DVB is slow sedimentation of the suspension they form in toluene, heptane or tetrahydrofurane. After moderate shaking or stirring these suspensions can be used as a kind of "standard solutions" in which a "concentration" of the active metal can be determined by measuring of the volume of liberated hydrogen. These suspensions can be transferred to a reaction vessel with syringe using moderately wide bore needles. Suspensions of deposited metals in toluene or heptane are relatively stable - the particles do not show tendency to aggregate and the loss of the active metals is negligible if the suspensions are protected against oxygen and moisture. Thus they can be used as convenient "reagents-off-the-shelf" with reasonably long storage time. The suspensions of lithium and sodium on polymers have not lost activity significantly after three months of storage at +10°C under argon. The applicability of these suspensions was demonstrated in a few types of reactions promoted by alkali metals: acyloin condensation, Dieckmann reaction, synthesis of organolithium reagents and also in preparation of active zinc.[5]

As we have already reported in our preliminary communication, the high-surface sodium on various carriers is an excellent condensing agent for the acyloin reaction (Scheme 1).[4] The condensation proceeds under very mild conditions giving acyloins in good yields (Table 1).

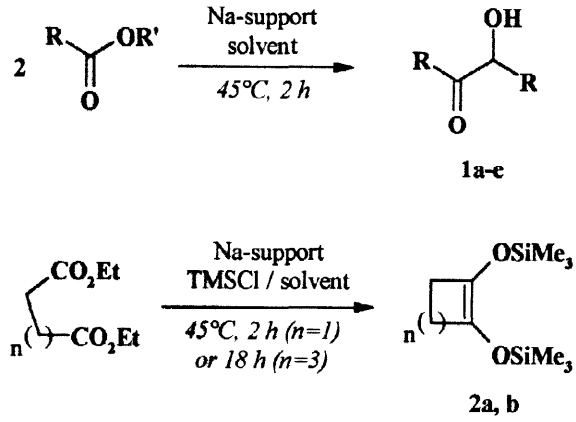
The colloidal potassium produced by ultrasonic irradiation of pieces of metal in toluene or xylene has been used *inter alia* in the Dieckmann condensation.[6] Under these conditions, the condensation is highly favored and much more rapid than by the usual technique.[7] We have found that effectiveness of the high-surface potassium on

Table 1. Acyloin Reaction with High-Surface Sodium

Product	Na-Support (wt. %)	Solvent	Yield (%)[a]
1a, R'=Et R=$(CH_2)_2CH_3$	NaCl (20)	THF	57
	NaCl (10)	Et_2O	63[b]
1b, R'=Me R=$(CH_2)_3CH_3$	NaCl (20)	benzene	65
1c, R'=Et R=$(CH_2)_6CH_3$	NaCl (20)	benzene	78
	PP (5)	toluene	75
	$BaSO_4$ (10)	toluene	48
	TiO_2 (10)	toluene	59
	MgO (10)	toluene	53
1e, R'=Me R=$(CH_2)_8CH=CH_2$	NaCl (20)	benzene	62
	PP (10)	benzene	76
	PE (10)	benzene	81
2a, n=1	TiO_2 (20)	THF	44
	Glass (5)	THF	70
	PE (10)	THF	62
	NaCl (10)	THF	58
2b, n=3	PE (16)	toluene	60[c]

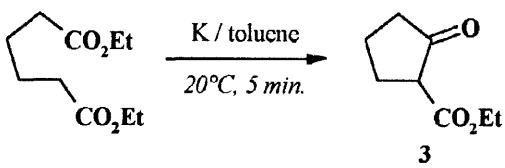
[a] Isolated yield, see experimental for reaction conditions.
[b] At reflux temperature. [c] Addition of substrates (16 h) and reaction (2 h) at 45°C.

PE in the intramolecular Dieckmann condensation is as high as colloidal potassium generated with use of ultrasound (Scheme 2).



Scheme 1

Alkyl- and aryllithium compounds are usually produced from organic halides *via* halogen-metal exchange using alkyllithiums or lithium metal.[1] The latter procedure is somewhat troublesome because lithium should be in form of small particles. The high-surface lithium readily prepared as described in this paper reacts easily with variety of alkyl and aryl halides producing lithium derivatives which can be trapped with electrophiles to give corresponding products in good yields. It is also possible to generate organolithiums directly in the presence of electrophilic partners to produce the corresponding products in a one step process according to the Barbier procedure. The results for selected reactions promoted by Li-PE suspension are given in Table 2.



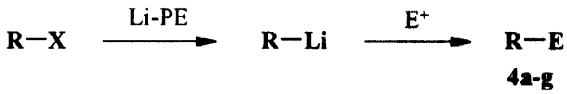
Yield of **3**	
colloidal K	83%[6]
K-PE	89%

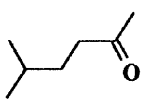
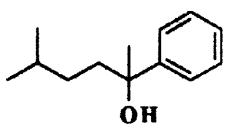
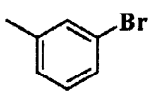
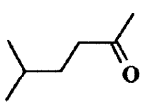
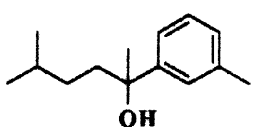
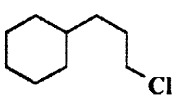
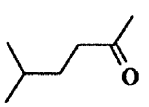
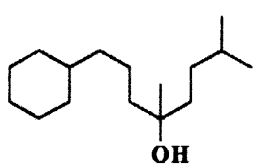
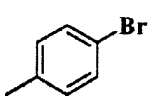
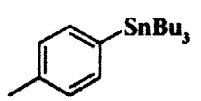
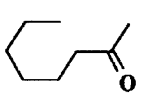
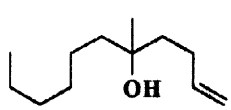
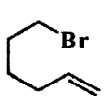
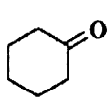
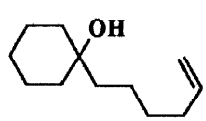
Scheme 2

We have found that the polymer-supported alkali metals can be also advantageously employed for the reduction of metals such as zinc to corresponding active metals. Zinc metal is used in many synthetically important transformations, *e.g.* the Barbier and Reformatski reaction and the preparation of alkylzinc compounds from alkyl iodides.[8] However, the outcome of these reactions is sensitive to the quality of zinc and is not always reproducible. Various methods for preparation of active zinc have been reported to overcome these difficulties. Most of them consist in the reduction of zinc salts with strong reducing agents, such as lithium naphthalenide or potassium laminate C_8K.[2a-c] Bouhlel and Rathke have found that the commercially available dispersion of lithium in mineral oil reacts directly with zinc chloride in ethyl ether to form metallic zinc, useful in the Reformatski reaction.[9]

Recently high-surface potassium and sodium were used for the generation of active titanium[10] and zinc[11] used in McMurry reaction and for the preparation of organozinc compounds. Supported zinc prepared by this method offers some advantages such as high reactivity, selectivity, easy handling and work-up.[11] This reagent was used for the preparation of secondary benzyl- and alkylzinc bromides directly from the corresponding benzyl and alkyl bromides under mild conditions.[11]

Table 2. Lithiation of Organic Halides by Lithium on Polymeric Supports.

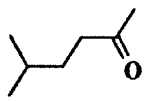
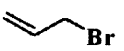
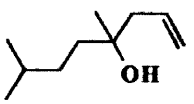
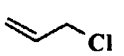
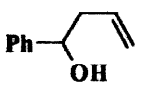
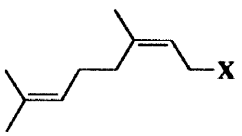
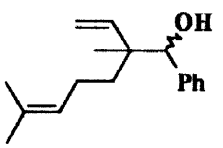
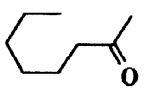
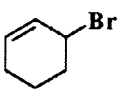
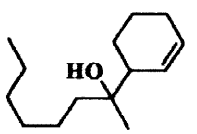
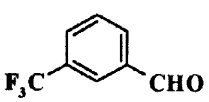
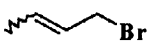
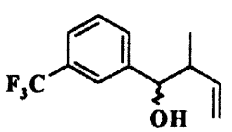
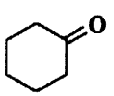
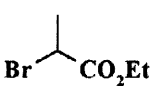
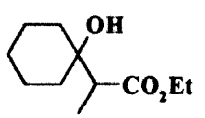
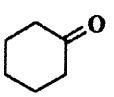
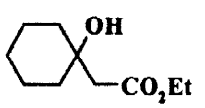
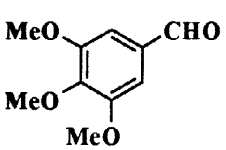
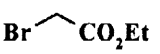
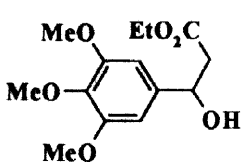
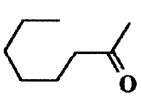
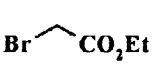
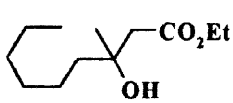
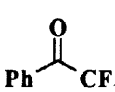
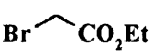
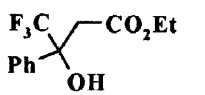
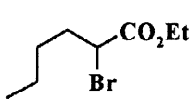
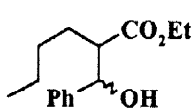


	Halide (R-X)	Electrophile (E^+)	Product (R-E, 4a-g)	Yield (%)[a]
a	PhBr			79
b				74 69 (B)[b]
c				76 56 (B)
d		Bu_3SnCl		62
e	Ph_3SnCl	Ph_3SnCl	Ph_6Sn_2	82 (B)
f				76 (B)
g				73 (B)

[a] Isolated yield based on the electrophile (E^+), see experimental for reaction conditions. [b] B = Preparation of organolithiums in the presence of electrophile (Barbier conditions).

Looking for an efficient method of preparation of active zinc we have studied the effects of the support, alkali metal, and zinc salt used on the reactivity of the metal in the model Barbier reaction of 5-methylhexanone with allyl bromide. After a number of preliminary experiments we have found that the most effective procedure consists in use of lithium on polyethylene. The addition of a THF solution of zinc chloride to the suspension of Li-PE leads to a zinc on polyethylene which is ready to use after 90–120 min of stirring. This active form of zinc was used for the Barbier and Reformatski type reactions of allylic bromides and α-bromoesters and gave the corresponding

Table 3. Reformatski and Barbier-Type Reactions Promoted by Active Zinc on Polyethylene

	Carbonyl Compound	Halide	Product (5a-h)	Yield (%)[a]
a				(40)[b] (90)[c] 91 (100)
b	PhCHO			81 (88)
c	PhCHO			X=Br 95[d] X=Cl 93[d]
d				99[e]
e				83[f]
f				93
g				78 (83)
h				80
i				84
j				84
k	PhCHO			91[g]

[a] Isolated yield, based on the carbonyl compound (RCOR'), see experimental for reaction conditions. GC yield in parenthesis. [b] The reaction was carried out with Zn*-MgO. [c] The reaction was carried out with Zn*-NaCl. [d] The proportion of diastereoisomers 1*R**,2*R** : 1*R**,2*S** was 71:29 (^{1}H NMR). [e] The diastereoisomeric ratio was 50:50 (^{1}H NMR). [f] The ratio of diastereoisomers 1*R**,2*R** : 1*R**,2*S** was 44:56 (^{1}H NMR). [g] The proportion of isolated diastereoisomers 2*R**,3*R** : 2*R**,3*S** was 45:55 (column chromatography).

homoallylic alcohols and β-hydroxyesters in excellent yields (Table 3).[7] The supported zinc generated by this method is also sufficiently active to promote the reaction of α-chloroester and allylic chlorides under mild conditions. In summary, the highly reactive zinc on PE can be easily and safety prepared by Li-PE reduction of zinc chloride solution. This reagent is as active as zinc prepared by potassium graphite or lithium suspension reduction.

In conclusion the results presented here prove that the low-temperature deposition of alkali metals from their solutions in liquid ammonia can be safe and convenient method for the preparation of high-surface metals.

ACKNOWLEDGEMENTS

This work was supported by the State Committee of Scientific Research (Grant No. 3T09A05911). K. G. thanks the Foundation for Polish Science for the FNP '98 Domestic Grant.

EXPERIMENTAL

General. All reactions were carried out in oven-dried glassware under atmosphere of purified argon. Gaseous technical ammonia was purified before condensation by passing through a column of granular potassium hydroxide. THF (potassium/benzophenone), benzene and toluene (sodium) were distilled directly before use. Zinc chloride (Fluka) was fused before use. Glass powder (BDH, 100 and 270 mesh), PP (100 mesh, Zakłady Azotowe Tarnów, Poland), PE (powder, Avocado) and PS/DVB (2%DVB, 200-400 mesh, Fluka) were used without further purification. Work-up was done by Extrelut® (E. Merck) procedure.[12]

Preparation of sodium on solid supports and their use in the acyloin reaction. Sodium (605 mg, 26.3 mmol) was added to a stirred suspension of corresponding support in liquid ammonia (10-30 mL). After 5-10 min. the ammonia was evaporated to dryness. Traces of ammonia were then removed under vacuum (90 min. at 45°C) and the residue was suspended in appropriate solvent (30-40 mL). To the stirred suspension a solution of ester (12.5 mmol) in the same solvent (10 mL) was added dropwise. The reaction mixture was stirred for 2 h at 45°C and then 2 *M* sol. of *aq.* HCl (25 mL) was added. The resulting mixture was extracted with ethyl acetate. The crude product was recrystallized or purified by distillation.

TMSCl modification of the acyloin reaction. After the reaction of supported sodium (84 mmol) with diester (20 mmol) and TMSCl (9.34 g, 86 mmol) in appropriate solvent (75 mL) the reaction mixture was diluted with *n*-pentane and filtered through column of Celite®. The clear organic solution was concentrated and the residue was purified by distillation.

5-Hydroxyoctan-4-one (**1a**). Yellow oil: b.p. 86-90°C/18 mm Hg, lit.[13] b.p. 80-86°C/18 mm Hg.

6-Hydroxydecan-5-one (**1b**). Pale yellow oil: b.p. 65-70/0.4 mm Hg, lit.[12] b.p. 90-92°C/3 mm Hg.

9-Hydroxyhexadecan-8-one (**1c**). Colorless crystals: m.p. 36.5-38°C (acetone), lit.[12] m.p. 39°C.

12-Hydroxydocosa-1,21-dien-11-one (**1d**). Colorless crystals: m.p. 45-46°C (acetone), lit.[12] b.p. 47°C.

1,2-Bis(trimethylsilanyloxy)cyclobutene (**2a**). Colorless oil: b.p. 90-92°C/18 mm Hg, lit.[12] b.p. 82-86°C/10 mm Hg.

1,2-Bis(trimethylsilanyloxy)cyclohexene (**2b**). Colorless oil: b.p. 98-102°C/20 mm Hg, lit.[14] b.p. 110-115°C/25 mm Hg.

General procedure for the preparation of lithium, sodium and potassium deposited on PE or PS/DVB. Alkali metal (0.2 g) was added to a stirred suspension of polymer (4-5 g) in liquid ammonia (10 mL). After complete dissolution of the metal (5-10 min.) the ammonia was evaporated to dryness. Traces of ammonia were removed under vacuum (90 min. at 45°C) and the residue was suspended in appropriate solvent (30-40 mL). The metal content was determined by hydrolysis of suspension aliquots with mixture of *n*-octanol/water and measuring the

amount of hydrogen liberated with a gas burette. Typical "concentrations" of the resulted suspensions (in *mmols of active metal per 1 mL*) are in range of 0.5–1.20 for Li, 0.25–0.45 for Na and 0.1 mmol/mL for K. These suspensions can be stored under argon and transferred to reaction vessels with syringe or double ended needle. Suspensions of deposited lithium and sodium in toluene or heptane are relatively stable and can be stored up to 3 months.

Dieckmann condensation with potassium on polyethylene. To the stirred suspension of K-PE in toluene (20 mL, 0.1 mmol/mL) a solution of diethyl adipate (404 mg, 2 mmol) in toluene (5 mL) was added at room temperature. After 5 min. the orange mixture was quenched with aqueous solution of NH_4Cl (2 mL), filtered through column of Extrelut® and concentrated *in vacuo*.
2-Oxocyclopentanecarboxylic acid ethyl ester **3** (278 mg, 89% after "bulb-to-bulb" distillation): b.p. 65°C (oven)/1.6 mm Hg, lit.[7] bp 83–88°C/5 mm Hg; **IR** (film) cm^{-1} 1756 (C=O), 1725 (C=O). **MS** (EI) *m/z* (%) 156 (7, $M^{+\cdot}$), 128 (56), 111 (46), 110 (42), 101 (24), 83 (23), 73 (75), 55 (100). **^{1}H NMR** 1.29 (3H, t, J=7.2 Hz), 1.75–2.70 (6H, m), 3.15 (1H, t, $J \cong 9$ Hz), 4.20 (2H, t, $J = 7.2$ Hz).

General procedure for the preparation of organolithium compounds using Li polymeric supports To a cooled (–78°C) suspension of Li-PE or Li-PS/DVB in THF (7.0 mL, 0.94 mmol/mL) a solution of organic halide (RX, 3.3 mmol) in THF (5 mL) was slowly added. After 5 min. the dry-ice/acetone bath was removed and the mixture was allowed to react at –78 to 0°C (alkyl halides) or 20° (aryl halides) for 15–30 min. Then the resulting mixture was cooled again (–78°C) and a solution of electrophile (3.0 mmol) in THF (5 mL) was added dropwise. After 15 min. aqueous solution of NH_4Cl (2 mL) was added, the resulting mixture was diluted with ethyl acetate (10 mL) and filtered through column of Extrelut® (3 g). The residue was purified by flash chromatography (hexane/ethyl acetate 9:1 or hexane) giving products **4a-d**.

General procedure for the preparation of organolithium compounds in the presence of electrophiles (Barbier conditions). To a cooled (–78°C) suspension of Li-PE or Li-PS/DVB in THF (7.0 mL, 0.94 mmol/mL) a solution of organic halide (RX, 3.3 mmol) and electrophile (3.0 mmol) in THF (5 mL) was added dropwise. After 15 min. aqueous solution of NH_4Cl (2 mL) was added and the resulting mixture was filtered through column of Extrelut®. The residue was purified by flash chromatography (hexane/ethyl acetate 9:1) or recrystallization giving pure products **4b, c, e-g**.

5-Methyl-2-phenylhexan-2-ol (**4a**).[15] Colorless oil: **IR** (film) cm^{-1} 3422 (OH). **MS** (EI) *m/z* (%) 192 (0.5, $M^{+\cdot}$), 174 (2), 121 (100), 105 (8), 91 (7), 77 (11). **^{1}H NMR** 0.81, 0.85 (6H, 2 × d, J = 6.6 Hz), 0.91–1.26 (2H, m), 1.46 (1H, sp, J = 6.6 Hz), 1.55 (3H, s), 1.69–1.92 (2H, m), 7.21–7.46 (5H, m).

5-Methyl-2-(3-methylphenyl)hexan-2-ol (**4b**). Colorless oil: **IR** (film) cm^{-1} 3430 (O–H). **MS** (EI) *m/z* (%) 206 (1, $M^{+\cdot}$), 191 (2), 173 (1), 135 (76), 119 (5), 105 (4), 91 (12), 65 (5), 43 (100). **^{1}H NMR** 0.82, 0.85 (6H, 2 × d, J = 6.6 Hz), 0.93–1.25 (2H, m), 1.46 (1H, sp, J = 6.6 Hz), 1.53 (3H, s), 1.67–1.91 (2H, m), 2.36 (3H, s), 7.01–7.10 (1H, m), 7.17–7.27 (3H, m). **^{13}C NMR** 21.6, 22.5 & 22.5, 28.3, 30.1, 32.8, 41.8, 74.6, 121.8, 125.4, 127.1, 128.0, 137.6, 148.0. $C_{14}H_{22}O$ (206.33), calcd: C (%) 81.50, H (%) 10.75 found: C (%) 81.38, H (%) 10.57.

1-Cyclohexyl-4,7-dimethyloctan-4-ol (**4c**). Colorless oil: **IR** (film) cm^{-1} 3391 (O–H). **MS** (EI) *m/z* (%) 225 (2, $[M-CH_3]^+$), 165 (19), 151 (17), 115 (100), 111 (20), 95 (47), 81 (20), 69 (20), 55 (60). **^{1}H NMR** 0.88 (6H, d, J = 6.5 Hz), 1.15 (3H, s), 1.05–1.80 (23H, m). **^{13}C NMR** 21.1, 22.7, 26.41, 26.7, 27.0, 28.5, 32.9, 33.4, 37.6, 38.0, 39.5, 42.0, 72.9. $C_{16}H_{32}O$ (240.43), Calcd: C (%) 79.93, H (%) 13.42 found: C (%) 79.89, H (%) 13.39.

Tributyl-(4-methylphenyl)stannane (**4d**).[16] Colorless oil: **IR** (film) cm^{-1} 2924 (C–H), 1464 (C–H). **MS** (EI) *m/z* (%) 380 (1, $M^{+\cdot}$), 348 (1), 325 (100, $[M-C_4H_9]^+$), 289 (53), 267 (37), 233 (47), 213 (47), 179 (39), 91 (5). **^{1}H NMR** 0.80–1.40 & 1.21–1.62 (27H, 2 × m), 2.33 (3H, s), 7.13–7.17 & 7.33–7.37 (4H, 2 × m).

Hexaphenyldistannane (**4e**).[17] Colorless crystals: m.p. (benzene) 230–231°C, lit.[15] m.p. 229–231°C.

5-Methyl-1-undecen-5-ol (**4f**).[18] Colorless oil: **IR** (film) cm^{-1} 3381 (O-H), 1641 (C=C). **MS** (EI) *m/z* (%) 184 (0.5, $M^{+\cdot}$), 169 (2), 129 (34), 113 (3), 99 (37), 81 (4), 69 (22), 55 (15), 43 (100). **^{1}H NMR** 0.89 (3H, t, *J* = 6.5 Hz), 1.17 (3H, s), 1.19-1.73 (13H, m), 2.05-2.19 (2H, m), 4.86-5.10 (2H, m), 5.85 (1H, ddt, *J* = 17.1, 10.2, 6.5 Hz).

1-Hex-5-enylcyclohexanol (**4g**).[19] Colorless oil: **IR** (film) cm^{-1} 3391 (O-H), 1641 (C=C). **MS** (EI) *m/z* (%) 182 (0.5, $M^{+\cdot}$), 164 (1), 153 (1), 139 (2), 127 (4), 99 (100), 98 (20), 81 (37), 69 (10), 55 (39). **^{1}H NMR** 1.16-1.68 (17H, m), 2.00-2.15 (2H, m), 4.89-5.06 (2H, m), 5.81 (1H, ddt, *J* = 17.1, 10.2, 6.6 Hz).

Preparation of deposited zinc and its use in the Reformatski and Barbier reaction. To the stirred solution of $ZnCl_2$ (409 mg, 3 mmol) in THF (15 mL) a suspension of Li-PS in toluene (6.7 mL, 6 mmol) was added. The reaction mixture was stirred for 90 min and then the solution of carbonyl compound (1 mmol) and allylic halide or α-haloester (2 mmol) in THF (5 mL) was added dropwise. The reaction mixture was stirred for 3 h at 20°C and then aqueous solution of NH_4Cl (2 mL) was added. The resulting mixture was diluted with ethyl acetate (10 mL) and filtered through column of Extrelut® (3 g). The crude product was purified by flash chromatography (hexane/ethyl acetate 9:1) giving the products **5a-k**.

4,7-Dimethyloct-1-en-4-ol (**5a**).[20] Colorless oil: **IR** (film) cm^{-1} 3450 (O-H), 1619 (C=C). **MS** (EI) *m/z* (%) 141 (1, $M^{+\cdot}$), 115 (25), 97 (37), 85 (16), 69 (9), 42 (100). **^{1}H NMR** 0.89 (6H, d, *J* = 6.3 Hz), 1.17 (3H, s), 1.19-1.61 (5H, m), 1.70 (1H, br. s, OH), 2.22 (2H, d, *J* = 7.4 Hz), 5.06-5.18 (2H, m), 5.76-5.97 (1H, m).

1-Phenyl-3-buten-1-ol (**5b**).[21] Colorless oil: **IR** (film) cm^{-1} 3391 (O-H), 1641 (C=C). **MS** (EI) *m/z* (%) 148 (0.5, $M^{+\cdot}$), 128 (2), 107 (100), 105 (9), 79 (75), 77 (46). **^{1}H NMR** 2.09 (1H, br. s), 2.40-2.60 (2H, m), 4.74 (1H, dd, *J* = 7.3, 5.7 Hz), 5.11-5.22 (2H, m), 5.80 (1H, ddt, *J* = 17.4, 10.1, 7.3), 7.25-7.39 (5H, m).

2,6-Dimethyl-1-phenyl-2-vinylhept-5-en-1-ol (**5c**).[22] Colorless oil: **IR** (film) cm^{-1} 3459 (OH), 1637 (C=C). **MS** (EI) *m/z* (%) 226 (0.5, $[M-H_2O]^{+\cdot}$), 158 (1), 140 (4), 138 (9), 123 (31), 107 (100), 95 (77), 79 (67). **^{1}H NMR**: (1*R**,2*R**)-**5c**: 0.92 (3H, s), 1.21-1.50 (2H, m), 1.55 & 1.65 (3H, 2 × s), 1.78-1.94 (2H, m), 2.05 (1H, d, *J* = 2.0 Hz), 4.42 (1H, d, *J* = 2.0 Hz), 4.98-5.10 (1H, m), 5.09 (1H, dd, *J* = 17.6, 1.5 Hz), 5.28 (1H, dd, *J* = 11.0, 1.5 Hz), 5.86 (1H, dd, *J* = 17.6, 11.0 Hz), 7.20-7.36 (5H, m). (1*R**,2*S**)-**5c**: 1.07 (3H, s), 1.21-1.50 (2H, m), 1.55 & 1.65 (6H, 2 × s), 1.78-1.94 (2H, m), ~2.0 (1H, d), ~4.4 (1H, d), 4.98-5.10 (1H, m), 5.01 (1H, dd, *J* = 17.6, 1.5 Hz), 5.19 (1H, dd, *J* = 11.0, 1.5 Hz), 5.79 (1H, dd, *J* = 17.6, 11.0 Hz), 7.20-7.36 (5H, m).

2-(2-cyclohexenyl)octan-2-ol (**5d**).[23] Colorless oil: **IR** (film) cm^{-1} 3412 (O-H), 1649 (C=C). **MS** (EI) *m/z* (%) 129 (100, $[M-C_6H_8]^+$), 124 (16), 113 (3), 81 (16), 69 (68). **^{1}H NMR** 0.89 (3H, t, *J*=6.4 Hz), 1.09 (3H, s, one diastereoisomer), 1.15 (3H, s, the other diastereoisomer) 1.19-1.61 (12H, m), 1.70-1.90 (2H, m), 1.92-2.04 (2H, m), 2.16-2.29 (1H, m), 5.64-5.91 (2H, m).

2-methyl-1-[3-(trifluoromethyl)phenyl]-3-buten-1-ol (**5e**). Colorless oil: **IR** (film) cm^{-1}: 3401 (OH), 1640 (C=C). **MS** (EI) *m/z* (%) 175 (100, $[M-C_4H_7]^+$), 147 (9), 127 (37), 56 (21). **^{1}H NMR**: (1*R**,2*R**)-**5e** 0.90 (3H, d, *J* = 6.8 Hz), 2.30 (1H, d, *J* = 2.4 Hz), 2.36-2.58 (1H, m), 4.43 (1H, dd, *J* = 7.6, 2.4 Hz), 5.02-5.27 (2H, m), 5.68-5.86 (1H, m), 7.40-7.63 (4H, m). (1*R**,2*S**)-**5e** 0.98 (3H, d, *J* = 6.8 Hz), 2.09 (1H, d, *J* = 3.5 Hz, OH), 2.50-2.68 (1H, m), 4.70 (1H, dd, *J* = 5.1, 3.6 Hz), 5.02-5.27 (2H, m), 5.68-5.86 (1H, m), 7.40-7.63 (4H, m). **^{13}C NMR:** (1*R**,2*R**)-**5e** 16.37, 46.43, 77.17, 117.64, 123.59 (q, $^3J_{C\text{-}F}$ = 3.8 Hz), 124.15 (q, $^1J_{C\text{-}F}$ = 271.0 Hz), 124.46 (q, $^3J_{C\text{-}F}$ = 3.8 Hz), 128.61, 130.25, ~130.55 (q, $^2J_{C\text{-}F} \approx$ 32 Hz), 139.78, 143.31. (1*R**,2*S**)-**5e** 13.48, 44.57, 76.42, 116.25, 123.24 (q, $^3J_{C\text{-}F}$ = 3.8 Hz), 124.10 (q, $^3J_{C\text{-}F}$ = 3.8 Hz), 124.15 (q, $^1J_{C\text{-}F}$ = 271.0 Hz), 128.47, 129.81, 130.39 (q, $^2J_{C\text{-}F}$ = 32.0 Hz), 139.65, 143.47. **HRMS** for $C_8H_6F_3O$ ($[M-C_4H_7]^+$) calcd 175.0371; found 175.0382.

2-(1-Hydroxycyclohexyl)propionic acid, ethyl ester (**5f**).[23] Colorless oil: **IR** (film) cm^{-1} 3540 (O-H), 1730 (C=O). **MS** (EI) *m/z* (%) 200 (3, $M^{+\cdot}$), 182 (1), 157 (41), 144 (37), 111 (22), 102 (100), 81 (55), 74 (68), 56 (35). **^{1}H NMR** 1.19 (3H, d, *J* = 7.2 Hz), 1.28 (3H, t, *J* = 7.2 Hz), 1.25-1.72 (10H, m), 2.49 (1H, q, *J* = 7.2 Hz), 3.04 (1H, s), 4.17 (2H, q, *J* = 7.2 Hz).

(1-Hydroxycyclohexyl)acetic acid, ethyl ester(**5g**).[24] Colorless oil: **IR** (film) cm^{-1} 3516 (O-H), 1718 (C=O). **MS** (EI) ***m/z*** **(%)** 186 (2, $M^{+\cdot}$), 168 (4), 157 (4), 143 (92), 130 (100), 123 (20), 115 (20), 99 (78), 97 (67), 81 (66), 70 (30), 55 (86). **^{1}H NMR** 1.28 (3H, t, J = 7.2 Hz), 1.25-1.77 (10H, m), 2.47 (2H, s), 3.43 (1H, s), 4.17 (2H, q, J = 7.2 Hz).

3-Hydroxy-3-(3,4,5-trimethoxyphenyl)propionic acid, ethyl ester (**5h**).Colorless crystals, m.p. 55.5-57.5°C (petroleum ether – ethyl ether), lit.[25] m.p. 57-58°C. **IR** (KBr) cm^{-1} 3476 (O-H), 1735 (C=O). **MS** (EI) ***m/z*** **(%)** 284 (30, $M^{+\cdot}$), 239 (10), 210 (4), 197 (100), 169 (95), 154 (32), 138 (35). **^{1}H NMR** 1.28 (3H, t, J = 7.1 Hz), 2.65-2.83 (2H, m), 3.39 (1H, d, J = 3.2 Hz), 3.83 (3H, s), 3.86 (6H, s), 4.20 (2H, q, J = 7.1 Hz), 5.02-5.13 (1H, m), 6.61 (2H, s).

3-Hydroxy-3-methylnonanoic acid, ethyl ester (**5i**).[26] Colorless oil: **IR** (film) cm^{-1} 3518 (O-H), 1718 (C=O). **MS** (EI) ***m/z*** **(%)** 201 (10, $[M-CH_3]^+$), 153 (4), 131 (100), 113 (12), 85 (40), 69 (10). **^{1}H NMR** 0.88 (3H, t, J = 6.2 Hz), 1.22-1.33 (8H, m), 1.23 (3H, s), 1.28 (3H, t, J = 7.1 Hz), 1.45-1.56 (2H, m), 2.27-2.63 (2H, m), 3.53 (1H, s), 4.18 (2H, q, J = 7.1 Hz).

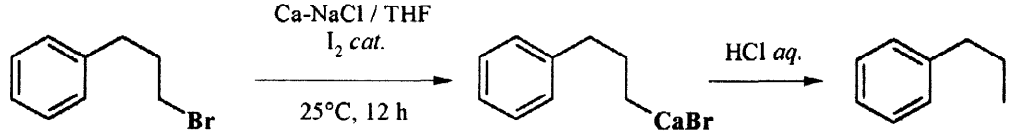
3-Hydroxy-3-phenyl-4,4,4-trifluorobutanoic acid, ethyl ester (**5j**).[27] Colorless oil: **IR** (film) cm^{-1} 3454 (OH), 1714 (C=O). **MS** (EI) *m/z* (%): 262 (1, $[M]^{+\cdot}$), 217 (3), 194 (7), 193 (56), 175 (18), 147 (14), 127 (4), 105 (100), 91 (6), 77 (22). **^{1}H NMR** 1.17 (3H, t, J= 7.1 Hz), 3.16 (2H, s), 4.11 (2H, dq, J= 1.1, 7.1 Hz), 5.29 (1H, s), 7.35-7.63 (5H, m).

2-Butyl-3-hydroxy-3-phenylpropionic acid, ethyl ester (**5k**).[28] (2*R**,3*R**)-**5k** Colorless oil: **TLC** (hexane : ethyl acetate 9:1): R_f 0.15. **MS** (EI) *m/z* (%) 250 (3, $M^{+\cdot}$), 193 (5), 159 (3), 144 (60), 115 (12), 101 (100), 79 (38). **IR** (film) cm^{-1} 3457 (OH), 1730 (C=O). **^{1}H NMR** 0.83 (3H, t, J = 6.7 Hz), 1.13 (3H, t, J = 7.1 Hz), 1.08-1.35 (6H, m), 2.64-2.74 (1H, m), 2.83 (1H, d, J = 2.7 Hz), 4.06 (2H, q, J = 7.1 Hz), 4.93 (1H, dd, J = 5.5, 2.7 Hz), 7.27-7.37 (5H, m). (2*R**,3*S**)-**5k** Colorless oil: **TLC** (hexane : ethyl acetate 9:1): R_f 0.09. **IR** (film) cm^{-1} 3463 (OH), 1733 (C=O). **MS** (EI) *m/z* (%) 250 (2, $M^{+\cdot}$), 193 (3), 159 (5), 144 (60), 115 (12), 101 (100), 79 (39). **^{1}H NMR** 0.82 (3H, t, J = 6.7 Hz), 1.1-1.75 (2H, m), 1.21 (3H, t, J = 7.1 Hz), 2.67-2.80 (1H, m), 2.90 (1H, d, J = 5.7 Hz), 4.16 (2H, q, J = 7.1 Hz), 4.79 (1H, dd, J = 7.6, 5.7 Hz), 7.30-7.38 (5H, m).

REFERENCES AND NOTES

1. *Organometallics in Synthesis*, M. Schlosser; Ed.; J. Wiley & Sons: Chichester; 1994.
2. For reviews, see: (a) Fürstner, A. *Angew. Chem. Int. Ed. Engl.* **1993**, *32*, 164; (b) Fürstner, A. *Active Metals. Preparation, Characterization, Applications*; VCH: Weincheim, 1996; (c) Csuk, R.; Glänzer, B. I.; Fürstner, A. *Adv. Organomet. Chem.* **1988**, *28*, 85; (d) Setton, R. in *Preparative Chemistry Using Supported Reagents*; Laszlo, P.; Ed., Academic Press: New York, 1987; (e) Ley, S. V.; Low, C. M. R. *Ultrasound in Synthesis*; Springer: Berlin, 1989; (f) Klabunde, K. J. *Chemistry of Free Atoms and Particles*; Academic Press: New York, 1980; (g) Romanowski, W. *Highly Dispersed Metals*; Ellis Horwood/Wiley: Chichester, 1987; (h) Bönneman, H.; Braun, G.; Brijoux, W.; Brinkmann, R.; Schulze-Tilling, A.; Seevogel, K.; Siepen, K. *J. Organomet. Chem.* **1996**, *520*, 143.
3. (a) Johnson, W. C.; Meyer, A. W. *Chem. Rev.* **1931**, *8*, 273; (b) Jander, J. in *Anorganische und allgemeine Chemie in flüssigem Ammoniak*; Jander, G.; Spandau, H.; Addison, C. C.; Ed., Fried. Vieweg & Sohn: Braunschweig 1966.
4. Mąkosza, M.; Grela, K. *Synlett* **1997**, 267.
5. Direct formation of organocalcium compounds (RCaX) from metallic calcium and organic halides is limited to simple alkyl iodides (X = I) due to the low reactivity of calcium. In contrast, the highly reactive Rieke-Calcium™ reacts readilly with alkyl and aryl bromides or chlorides at temperatures as low as -78°C (Wu, T.-C.; Xiong, H.; Rieke, R. D. *J. Org. Chem.* **1990**, *55*, 5045 and references cited therein). We have found, that supported calcium can be readily prepared by its deposition from liquid ammonia, but this reagent

shows a low reactivity, similar to commercially available calcium powder. For example, 3-phenylbromopropane reacts with the calcium on sodium chloride to form corresponding alkylbromocalcium reagent in 34% yield, as determined by GC after hydrolysis with diluted HCl.



6. Luche, J.-L., Pétrier, C., Dupuy, C. *Tetrahedron Lett.* **1984**, *25*, 753.
7. Pinkey, P. S. *Org. Synth. Coll. Vol. II*, **1943**, 116.
8. (a) Erdik, E. *Organozinc Reagents in Organic Synthesis*; CRC Press: New York, 1996; (b) Erdik, E. *Tetrahedron* **1987**, *43*, 2203.
9. Bouhlel, E.; Rathke, M. W. *Synth. Commun.* **1991**, *21*, 133.
10. (a) Fürstner, A.; Seidel, G. *Synthesis* **1995**, 63.; (b) Fürstner, A.; Seidel, G.; Gabor, B.; Kopiske, C.; Krüger, C.; Mynott, R. *Liebigs Ann.* **1996**, 665.
11. Stadtmüller, H.; Greve, B.; Lennick, K.; Chair, A.; Knochel, P. *Synthesis* **1995**, 69.
12. In this protocol the quenched reacting mixture was diluted with ethyl acetate and filtered through a small column of Extrelut®. The column was then washed twice with ethyl acetate and combined filtrates were evaporated to dryness giving the crude product. Procedure using Extrelut® is equal to typical extractive work-up (*i.e.* dilution with water, extraction, washing with brine, drying with $MgSO_4$ *etc.*) but is operationally easier, more environmentally benign and economical.
13. (a) McElvain, S. M. *Org. React.* **1948**, *4*, 256; (b) Bloomfield, J. J., Owsley, D. C., Nielke, J. M. *Org. React.* **1976**, *23*, 259.
14. Hadjiarapoglou, L.; Klein, I.; Spitzner, D.; de Meijere, A. *Synthesis* **1996**, 525.
15. Hartzler, H. D. *J. Am. Chem. Soc.* **1961**, *83*, 4990.
16. Wardell, J. L.; Ahmed, S. *J. Organomet. Chem.* **1974**, *78*, 395.
17. Ingham, R. K.; Rosenberg, S. D.; Gilman, H. *Chem. Rev.* **1960**, *60*, 459.
18. Ho, T.-S. *Synth. Commun.* **1982**, *12*, 53.
19. Kreuchanas, A. *J. Am. Chem. Soc.* **1953**, *75*, 4278.
20. Fujita, T.; Watanabe, S.; Suga, K.; Inaba, T. *J. Chem. Tech. Biotechnol.* **1979**, *29*, 100.
21. Gaudemar, M. *Bull. Soc. Chim. Fr.* **1962**, 974.
22. Yanagisawa, A.; Habaue, S.; Yasue, K.; Yamamoto, H. *J. Am. Chem. Soc.* **1994**, *116*, 6130.
23. Hamann, B.; Namy, J.-L.; Kagan, H. B. *Tetrahedron* **1996**, 52, 14225.
24. Shiner, R. L. *Org. React.* **1942**, *1*, 1.
25. Rabusic, E. *Spisy Prirodovek. Fak. Univ. Brne* **1967**, *480*, 71 (*Chem. Abstr.* **1968**, *68*, 87422q).
26. Adams, D. R.; Barnes, A. F.; Cassidy, F.; Thompson, M. *J. Chem. Soc., Perkin Trans. 1* **1984**, 2061.
27. Haas, A.; Lieb, M.; Zwingenberger, J. *Liebigs Ann. Chem.* **1995**, *11*, 2027.
28. Mukaiyama, T.; Inomata, K.; Muraki, M. *J. Amer. Chem. Soc.* **1973**, *95*, 967.