

Supporting Information

Reactions of Organomagnesates and Aryl Halides: Metalation and Nucleophilic Substitution

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This supporting information begins with the results (summarized briefly in the note) of reactions with pyridine, quinolines, and 2-cyclohexen-1-one. This is followed by experimental information for these reactions and for the observations reported in the note.

Reactions of Organomagnesates with Pyridine, Quinolines, and 2-Cyclohexen-1-one

Reactions with Pyridine. Reactions of pyridine and dialkylmagnesium compounds ordinarily furnish only traces of a 2-alkylpyridine and no observable amounts of a 4-alkylpyridine. Reactions of pyridine and R_2Mg -macrocycle¹ or $R_2Mg-RLi^2$ organomagnesate preparations form significantly greater amounts of 2-alkylpyridine and some 4-alkylpyridine (reactions of RLi and pyridine form only a 2-alkylpyridine). Formation of an alkylpyridine involves an addition that (after hydrolysis) would produce a dihydroalkylpyridine. Alkyldihydropyridines are not ordinarily

observed, however, because oxidation to an alkylpyridine has occurred at some stage before investigation of the products. Reactions (Table 1) of pyridine and R_2Mg -salt preparations shown³ to contain organomagnesates now are found to also form some of 4-alkylpyridine and enhanced amounts of 2-alkylpyridine. Yields generally are low, at least in part due to competing metalation of pyridine and of the alkylpyridine products. For example, MS analysis (using parent peaks) of a reaction with an Et_2Mg -NaOMe preparation (first NaOMe entry in Table 1) that was hydrolyzed with D_2O indicated that 23% of recovered pyridine molecules and 20% of 2-ethylpyridine molecules had incorporated a deuterium. That reactions of pyridine with preparations obtained from Np_2Mg and KOMe, KO-*t*-Bu, or LiO-*t*-Bu (Np_2Mg :additive:pyridine = 1:2:1) did not give significant amounts of addition products probably is a consequence of significant metalation of pyridine; GC/MS analysis of a reaction with a Np_2Mg -LiO-*t*-Bu preparation after hydrolysis with D_2O found that 65% of the pyridine molecules had incorporated a deuterium.

Combinations of R_2Mg with an alkali metal (M) or with KH which form³ R_3MgM also reaction with pyridine to give some 4-alkylpyridine and enhanced amounts of 2-alkylpyridine, although yields (Table 2) again are low.⁴ Solutions prepared from (neopentyl) $_2Mg$ and potassium or sodium did not produce detectable amounts of products; MS analysis of a sodium reaction hydrolyzed with D_2O indicated that 64% of the pyridine molecules had incorporated a deuterium.

Reactions with Quinoline and 2-Alkylquinolines. Et_2Mg reacts slowly with quinoline to form 2-ethylquinoline.² The oxidation necessary for formation of this compound is not as facile as with pyridines, and significant amounts of 1,2-dihydro-2-ethylquinoline often are isolated. Earlier observations² found that addition of crown ethers to Et_2Mg led to faster reactions with quinoline and to some 4-substitution as well as 2-substitution. Addition of EtLi to Et_2Mg also led to enhanced rates though not to significant amounts of 4-substitution. In this work, reactions (Table 3) with Et_2Mg -salt preparations also produce only 2-ethyl products. Study of a reaction with KOMe as the additive, however, showed this additive to *increase addition rate* >100-fold.

Reactions of 2-alkylquinolines with Et_2Mg alone or with Et_2Mg -crown ether or Et_2Mg -EtLi preparations led only to recovered reactant but MS analysis following hydrolysis with D_2O of a

reaction of 2-methylquinoline with Et_2Mg alone showed a majority of molecules to be deuterated.² Reactions of 2-methylquinoline with Et_2Mg plus KOMe or of 2-ethylquinoline with Et_2Mg plus KOMe, KO-*t*-Bu, or NaOMe led only to recovered reactant. MS analysis of a reaction of 2-methylquinoline with a Et_2Mg -KOMe preparation that had been hydrolyzed with D_2O , however, revealed significant incorporation of deuterium in the recovered reactant.⁵

Reactions with 2-Cyclohexen-1-one. Reactions of 2-cyclohexen-1-one with Et_2Mg result in formation mainly of the 1,2-addition product (1-ethyl-2-cyclohexen-1-ol). Reactions of preparations involving an alkali metal alkoxide (Table 4), however, give larger amounts of the 1,4-addition product (3-ethylcyclohexanone).

References

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2. Richey, H. G., Jr.; Farkas, J., Jr. *Organometallics* **1990**, *9*, 1778.
3. Hanawalt, E. M.; Farkas, J., Jr.; Richey, H. G., Jr. Submitted to *Organometallics*.
4. Small amounts of bipyridyls observed in the reactions involving preparations using potassium and sodium probably are not due to reactions of pyridine with residual amounts of these metals since the preparations were filtered before contacting pyridine. Note that small amounts of bipyridyls also were found in reactions of pyridine with preparations from R_2Mg compounds and alkali metal alkoxides (Table 1).
5. Recovered 2-methylquinoline was 27% monodeuterated, 37% dideuterated, 17% trideuterated, and 6% tetradeuterated (values only approximate since isotopically normal 2-methylquinoline has a significant M-1 peak (9%), requiring corrections for an M-1 contribution).

Table 1. Products from Reactions with Pyridine in Diethyl Ether at 25 °C of Reactants Prepared from R₂Mg and Salts.^a

R	additive	R ₂ Mg:additive: pyridine	(2-R)pyridine %	(4-R)pyridine %
Et	---	1:0:1	0.3	0
Et ^{b,c}	KOMe	1:2:1	16	9
Et ^{b,d}	KO- <i>t</i> -Bu	1:2:1	16	3
Et ^{b,e}	KO- <i>t</i> -Bu	1:2:2	13	5
Et ^b	KOPh	2:4:1	10	3
Et ^b	NaOMe	1:2:1	12	3
Et ^b	NaOMe	1:2:2	17	5
Et	LiO- <i>t</i> -Bu	4:2:1	39	6
Et	LiO- <i>t</i> -Bu	2:4:1	37	2
Et	LiO- <i>t</i> -Bu	2:2:1	38	3
<i>t</i> -Bu	---	1:0:1	0.1	0
<i>t</i> -Bu ^b	KO- <i>t</i> -Bu	1:2:1	8	15
<i>t</i> -Bu ^b	NaOMe	1:2:1	4	17
Et ^b	LiNMe ₂	2:4:1	30	0
Et ^f	LiNEt ₂	2:4:1	22	1
Et	LiN(<i>i</i> -Pr) ₂	2:4:1	22	2
Et ^g	LiN(C ₆ H ₁₁) ₂	2:4:1	35	14
Et	LiN(Me)Ph	2:4:1	19	5
Et ^b	Bu ₄ NBr	2:4:1	1	7

^a Reactions times were ca. 24 h. Yields are based on pyridine. ^b The reaction was heterogeneous. ^c An additional product was identified as 2,2-bipyridyl (1%).

^d An additional product was identified as 2,2-bipyridyl (9%). ^e An additional product

was identified as 2,2-bipyridyl (12%). ^f An additional product was identified as 2,4-bipyridyl (2%). ^g An additional product was identified as 2,4-bipyridyl (2%).

Table 2. Products from Reactions with Pyridine in Diethyl Ether at 25 °C of Reactants Prepared from R₂Mg and an Alkali Metal or Potassium Hydride.^a

R	additive	R ₂ Mg:additive: pyridine	(2-R)pyridine %	(4-R)pyridine %
Et	---	1:0:1	0.3	0
Et ^{b,c}	K	1:3:1	8	4
Et ^{b,d}	Na	1:5:1	16	3
Hexyl ^e	KH	3:40:1	12	1

^a Reactions times were ca. 20 h. Yields are based on pyridine. ^b The reaction of Et₂Mg and the metal was stirred for ca. 24 h and then filtered prior to the addition of pyridine. ^c An additional product was 2,2-bipyridyl (11%). ^d An additional product was 4,4-bipyridyl (14%). ^e The solvent was benzene.

Table 3. Products from Reactions with Quinoline in Diethyl Ether at 25 °C of Reactants Prepared from Et₂Mg and Alkali Metal Alkoxides.^a

additive	R ₂ Mg:additive: quinoline	time (h)	2-ethylquinoline ^b %	quinoline %
KOMe	4:4:1	0.25	88	0
KO- <i>t</i> -Bu	4:4:1	2	84	6
NaOMe	4:4:1	2	72	4

^a Yields are based on quinoline. ^b These yields include 2-ethyl-1,2-dihydroquinoline.

Table 4. Products from Reactions with 2-Cyclohexen-1-one in Diethyl Ether at 25 °C of Reactants Prepared from Et₂Mg and Alkali Metal Alkoxides.^a

additive	R ₂ Mg:additive: cyclohexenone	1-ethyl-2-cyclo- hexen-1-ol %	3-ethylcyclo- hexanone %
---	2:0:1	67	1
KOMe	4:2:1	75	10
KOMe ^b	2:2:1	85	9
KOMe ^b	2:4:1	75	5
KO- <i>t</i> -Bu	4:2:1	62	30
KO- <i>t</i> -Bu ^b	2:2:1	48	26
KOPh	4:2:1	58	16
KOPh ^b	2:2:1	58	35
KOPh ^b	2:4:1	64	21
NaOMe ^b	4:2:1	65	11
NaOMe ^b	2:2:1	76	14
NaOMe ^b	2:4:1	70	17
LiO- <i>t</i> -Bu	4:2:1	60	15
LiO- <i>t</i> -Bu	2:2:1	62	17
LiO- <i>t</i> -Bu	2:4:1	58	31

^a Reactions times were ca. 2 h. Yields are based on 2-cyclohexen-1-one. 2-Cyclohexen-1-one was not observed in the GC traces from any of the reactions. ^b The reaction was heterogeneous.

Experimental Section

Reactions involving organomagnesium compounds were performed under an atmosphere of purified nitrogen using Schlenk techniques, a glovebox, and a vacuum line. Glassware was dried for a minimum of 4 h at 135 °C prior to use. NMR spectra were recorded at ca. 23 °C. The solvent was benzene-*d*₆ except where otherwise noted. ¹H NMR absorption positions are relative to internal C₆D₅H (δ 7.15) for benzene-*d*₆ solutions and to internal TMS (δ 0) for solutions in other solvents; notations used are as follows: s, singlet; d, doublet; t, triplet; q, quartet; m, a more complex multiplet; c, complex overlapping absorptions; br, broad. Solutions for NMR analysis were prepared in a glovebox and transferred into NMR tubes to which an extension of routine glass tubing had been added to facilitate sealing with a flame. An NMR tube was capped temporarily with a septum, removed from the glovebox, immersed in liquid nitrogen, and sealed at the extension. Mass spectra were obtained by electron impact at 70 eV. Areas of peaks were obtained using a Kratos DS-90 Raw Data Acquisition and Integration Software Package. GC analysis used a flame ionization detector and the following columns: A, 3% SE-30 on 100-120 mesh Supelcoport (6 ft. x 2 mm id); B, 20% SE-30 on 100-120 mesh Supelcoport (10 ft x 2 mm id); C, 5% SP-2401 on 100-120 mesh Supelcoport (6 ft x 2 mm id); D, 5% SP-2401-DB on 100-120 mesh Supelcoport (10 ft x 2 mm id); E, 20% SE-30 on 80-100 mesh Gas Chrom Q (10 ft x 2 mm id); F, capillary column with SPB-1 bonded coating (1.5 μm, 15 m x 0.53 mm id). Preparative GC used a thermal conductivity detector and the following columns: G, 20% SE-30 on 80-100 mesh Gas Chrom P (10 ft x 0.25 in id); H, 15% SE-30 on 80-100 mesh Gas Chrom Q (10 ft x 0.25 in id); 5% SP-2401-DB on 100-120 mesh Supelcoport (6 ft x 0.25 in id). Response factors for reactants and major products were established experimentally by comparisons of GC peak areas obtained using solutions containing known quantities of these compounds.

Compounds for which preparations are not given were commercial samples. Diethyl ether and THF were distilled from sodium benzophenone ketyl immediately prior to use. PhBr, EtBr, 1-bromooctane, PhCl, neopentyl chloride, *t*-BuCl, PhF, PhI, and 2-cyclohexen-1-one were dried

(CaCl₂), distilled, and stored over molecular sieves (4 Å). 1-Bromohexane, neopentyl bromide, and EtI were distilled from molecular sieves (4 Å). Dioxane, pyridine, *i*-BuBr, *p*-bromotoluene, *p*-iodotoluene, benzene, and benzene-*d*₆ were distilled from CaH₂ prior to use. Quinoline and 2-methylquinoline were distilled and then stored over molecular sieves (4 Å). CH₃OH was distilled prior to use. Pentane was dried (Na wire) or distilled from CaH₂. PhOH was recrystallized from a benzene-pentane (1:1, v:v) solution prior to use. LiO-*t*-Bu and KO-*t*-Bu were sublimed prior to use. KCl and CsNO₃ (both 99.999%) were heated at 135 °C for 10 h prior to use. Bu₄NBr was heated at 135 °C for ≥5 h before use. KH was a 30% dispersion in mineral oil; prior to use, the dispersion was washed repeated with pentane to remove the mineral oil. Potassium was stored under mineral oil and sodium was stored under toluene. Magnesium was small pieces (1/8 in, Cerac, 99.99%) or turnings (1 cm and less, John Matthey, Puratronic Division, 99.98%). KOPh, NaOPh, and active KH were prepared as previously described.¹

Organomagnesium Reactants. The preparations of dialkylmagnesium compounds generally followed a procedure already described.¹ In the preparation of neopentylmagnesium chloride, the reaction mixture was heated at reflux for 15 h. (Neopentyl)₂Mg was ordinarily sublimed (100 °C at 10⁻³ Torr) before use; it sometimes still contained traces of dioxane.

Lithium N-Methylanilide.² A hexane solution of butyllithium (2.5 M, 4.4 mL, 11.0 mmol) was added to a solution of N-methylaniline (1.25 g, 12.0 mmol) in THF (60 mL) cooled in an ice bath. After 30 min, the preparation was allowed to warm to ambient temperature. The solvent was removed at reduced pressure leaving a solid.

***p-t*-Butylchlorobenzene.** The preparation was adapted from a literature procedure.³ PhCl (76.4 mL, 0.75 mol) and FeCl₃ (0.50 g, 3.1 mmol) were placed in a flask and heated to 40 °C. Then *t*-BuCl (27.2 mL, 0.25 mol) was added dropwise over a period of 2 h. The temperature was maintained at 40 °C for 4 more hours and then quenched by pouring the mixture into aqueous Na₂CO₃ (200 mL). The layers were separated, the aqueous layer was extracted with hexane (3 x 25 mL), and the combined extracts were dried (MgSO₄). The solvent was removed under reduced pressure and the residue was distilled to give *p-t*-butylchlorobenzene (27 g): 64% yield; bp 106-

107 °C at 30 Torr [lit.³ 112 °C at 30 Torr]. ¹H NMR (CCl₄) δ 1.28 (s, CH₃), 7.20 (s, CH).

2-Ethylquinoline. A diethyl ether solution of Et₂Mg (0.53 M, 15.2 mL, 8.1 mmol) was added to KO-*t*-Bu (904 mg, 8.1 mmol) and diethyl ether (5 mL). The mixture was stirred for 5 min. Then a diethyl ether solution of quinoline (0.34 M, 6.0 mL, 2.0 mmol) and undecane (GC standard) was added and the mixture was stirred for 24 h. It then was cooled in an ice bath and hydrolyzed with a saturated aqueous NH₄Cl solution (10 mL). Aqueous NaOH (1 M) was added to adjust the aqueous solution to pH 10. The ether layer was separated and placed into a flask containing FeCl₃ (810 mg, 5.0 mmol). The mixture was refluxed for 1.5 h (to oxidize 2-ethyl-1,2-dihydroquinoline to 2-ethylquinoline). The mixture was filtered and washed with aqueous NaOH (1 M, 2 x 10 mL). GC analysis (see ref 4 for procedure) indicated the presence only of undecane and 2-ethylquinoline (70%). The solution was diluted with diethyl ether to produce a 0.06 M solution. Molecular sieves (4A) were added to dry the solution which then was used in subsequent reactions.

Reactions of Halobenzenes and Dihalobenzenes. The scale of reaction varied, but for typical reactions of preparations with alkali metal alkoxides or NH₄Br, the additive (ca. 1 mmol) and diethyl ether (3 mL) were added to a vial. The mixture was stirred (magnetic stirring bar) for 5 min and then the R₂Mg solution was added dropwise using a syringe. The mixture was stirred for 5 min and then a diethyl ether solution of the halobenzene that also contained a known amount of an alkane (GC standard) was added. The concentration of halobenzene in the reactions was ca. 0.1 M. Stirring was continued for the desired amount of reaction time and then the vial was cooled in an ice bath and the contents were hydrolyzed by adding a saturated NH₄Cl solution (ca. 5 mL). The aqueous layer was extracted with diethyl ether (2 x 5 mL). The extracts were combined and dried (Na₂SO₄).

For reactions of preparations that used an alkali metal, a typical procedure involved adding a diethyl ether solution of the R₂Mg compound (1 mmol) to a stirred (magnetic stirring bar) mixture of the alkali metal (4 mmol) in diethyl ether (6 mL). Stirring was continued for 20 h and then the mixture was filtered through a fritted filter. A diethyl ether solution of the halobenzene which also

contained a known amount of an alkane (GC standard) was added. The concentration of halobenzene in the reactions was ca. 0.1 M. The workup procedure was as described above.

GC analysis of reactions of PhBr or PhI with preparations derived from Et₂Mg used column A (4 min at 45 °C, then an increase of 40 °C/min to 160 °C). Typical retention times (min): PhH (1.7), PhEt (5.3), PhBr (5.9), PhI (6.6), tridecane (7.9). GC analysis of reactions of PhCl with preparations derived from Et₂Mg used column A (5 min at 45 °C, then an increase of 40 °C/min to 150 °C). Typical retention times (min): PhH (1.7), PhCl (5.6), PhEt (6.0), tridecane (9.1), an ethylbiphenyl (10.9). GC analysis of reactions of PhF with preparations derived from Et₂Mg used column A (3 min at 40 °C, then an increase of 40 °C/min to 160 °C). Typical retention times (min): PhH (1.9), PhF (2.1), PhEt (4.8), a product whose mass spectrum is virtually identical to that reported⁵ for *s*-butylbenzene (5.7), tridecane (7.1), biphenyl (7.7), an ethylbiphenyl (8.4). GC analysis of reactions of PhBr with preparations derived from (octyl)₂Mg used column A (4 min at 45 °C, then an increase of 40 °C/min to 160 °C). Typical retention times (min): PhH (1.6), PhBr (5.9), 1-bromooctane (7.1), a product whose mass spectrum is virtually identical to that reported⁵ for *s*-butylbenzene (5.7), tridecane (7.9), 1-phenyloctane (9.2). GC analysis of reactions with 2,6-dimethylhalobenzenes and dihalobenzenes used column F (2 min at 100 °C, then an increase of 10 °C/min to 200 °C). Typical retention times (min): PhF (1.39), PhCl (2.31), PhEt (2.45), 1,3-dimethylbenzene (2.50), 2,6-dimethylchlorobenzene (4.91), 2,6-dimethylbromobenzene (6.26), pentadecane (11.5). Significant amounts of the dihaloaromatic reactants were not present (typical retention times: *p*-fluorochlorobenzene (2.22), *m*-fluorobromobenzene (2.22), *m*-bromochlorobenzene (2.65)).

Products were identified by mass spectra and (except for *s*-butylbenzene, 1-phenyloctane, and the ethylbiphenyl⁶) to retention times of authentic samples.

Carbonation of PhBr–Et₂Mg–KOME Reaction. A diethyl ether solution of Et₂Mg (0.42 M, 2.6 mL, 1.09 mmol) was added dropwise using a syringe to a stirred mixture of KOME (155 mg, 2.21 mmol) and diethyl ether (8 mL). The preparation was stirred for 5 min and then a diethyl ether solution of PhBr (1.60 mL, 0.54 mmol, 0.34 M) containing a known amount of

octane (GC standard) was added and stirring was continued for 0.5 h. CO₂ then was bubbled into the reaction through a fritted gas delivery tube for 1.5 h while the temperature was maintained at 0–5 °C. The mixture then was hydrolyzed by addition of aqueous HCl (0.1 M, 25 mL). The aqueous layer was extracted with diethyl ether (2 x 5 mL) and the combined extracts were dried (Na₂SO₄) and then subjected to GC analysis using column B (100 °C for 3 min, then an increase of 40 °C/min to 220 °C). Retention times (min): PhH (3.5), octane (5.3); PhEt (5.9), PhCO₂H (8.2).

Reaction of *p*-*t*-Butylchlorobenzene. KOMe (65 mg, 0.93 mmol) and diethyl ether (4 mL) were added to a vial. A Et₂Mg solution (0.42 M, 1.10 mL, 0.46 mmol) was added dropwise using a syringe. The mixture was stirred (magnetic stirrer) for 5 min and then a diethyl ether solution of *p*-*t*-butylchlorobenzene (0.72 M, 0.32 mL, 0.23 mmol) that contained a known amount of pentadecane (GC standard) was added. After stirring had continued for 17 h, the reaction was cooled in an ice bath and hydrolyzed by addition of a saturated aqueous NH₄Cl solution (5 mL). The aqueous layer was extracted with diethyl ether (2 x 5 mL). The extracts were combined and dried (Na₂SO₄). GC analysis used column C (3 min at 50 °C, then an increase of 30 °C/min to 140 °C). Retention times (min): *t*-butylbenzene (5.5), *m*-ethyl-*t*-butylbenzene and *p*-methyl-*t*-butylbenzene (6.5), *p*-chloro-*t*-butylbenzene (7.0), pentadecane (8.5). The peak at 6.5 min was resolved into two peaks on preparative GC column G (100 °C) and the material responsible for each peak was collected. *m*-Ethyl-*t*-butylbenzene (first to elute): ¹H NMR (200 MHz, CDCl₃) δ 1.25 (t, *J* = 7.6 Hz, CH₃CH₂), 1.32 (s, (CH₃)₃C), 2.63 (q, *J* = 7.6 Hz, CH₂), 6.92–6.98 (m, 1, CH), 7.14–7.16 (c, 3 CH). *p*-Ethyl-*t*-butylbenzene: ¹H NMR (200 MHz, CDCl₃) δ 1.23 (t, *J* = 7.6 Hz, CH₃CH₂), 1.30 (s, (CH₃)₃C), 2.60 (q, *J* = 7.6 Hz, CH₂), 7.07 (d, *J* = 8.4 Hz, 2 CH's), 7.25 (d, *J* = 8.4 Hz, 2 CH's). A separation of the isomers also was effected by injection of the original sample on analytical GC column B (110 °C for 5 min at 110 °C, then an increase of 5 °C/min to 150 °C). The retention times for the meta and para isomer were 17.0 and 17.9 min, respectively, and the relative peak areas were 2:1.

Reaction of Chlorobenzene–Chlorobenzene-*d*₅. Et₂Mg (36 mg, 0.44 mmol) was

added to a suspension of KOMe (61 mg, 0.87 mmol) in diethyl ether (4 mL). The mixture was stirred (magnetic stirring bar) for 5 min and then a solution of chlorobenzene-*d*₅ (507 mg, 4.31 mmol) and chlorobenzene (494 mg, 4.39 mmol) in diethyl ether (4 mL) was added. Stirring was continued for 22 h. Then the vial was cooled in ice and the mixture hydrolyzed by addition of a saturated aqueous NH₄Cl solution (5 mL). The aqueous layer was extracted with diethyl ether (2 x 5 mL) and the ether extracts were combined and dried (Na₂SO₄). The composition of the product was determined by GC analysis using column F (100 °C for 2.0 min, then an increase of 10 °C/min to 200 °C). Retention times (min) for the (isotopically mixed) compounds: benzene (1.68), chlorobenzene (2.77), ethylbenzene (2.94). Product composition for this particular experiment: benzene (5.4%), chlorobenzene (56.3%), and ethylbenzene (38.4%). MS data (parent peaks) indicated the ratio of chlorobenzene-*d*₅ to chlorobenzene to be 6.54 and the ratio of ethylbenzene to ethylbenzene-*d*₄ to be 5.13. The ratio of chlorobenzene-*d*₅ to chlorobenzene determined by MS analysis of the reactant chlorobenzene-*d*₅-chlorobenzene solution was similar to that of the amounts used in its preparation.

PhX-R₂Mg-Macrocycle Reactions.

PhI-*i*-Bu₂Mg-14N4. *i*-Bu₂Mg (21 mg, 0.15 mmol) was added to a solution prepared from PhI (31 mg, 0.15 mmol), 14N4 (38 mg, 0.15 mmol), and benzene-*d*₆ (0.5 mL) [14N4 is 1,4,8,11-tetramethyl-1,4,8,11-tetraazacyclotetradecane]. ¹H NMR (300 MHz) δ [*i*-BuMg(14N4)⁺] -0.88 (d, *J* = 6.4 Hz, CH₂Mg), 1.08 (d, *J* = 6.3 Hz, CH₃), 1.63 (s, CH₃N), 3.06 (b, CHHCH₂CHH); [L₋₁MgPh₋₂⁻] 7.28 (t, *J* = 8.5 Hz, *p*-H), 7.43 (t, *J* = 7.3 Hz, *m*-H), 8.70 (d, *J* = 7.0 Hz, *o*-H); [*i*-BuI] 0.71 (d, *J* = 6.6 Hz, CH₃), 2.68 (d, *J* = 5.9 Hz, CH₂); [isobutane] 0.85 (d, *J* = 6.6 Hz, CH₃), 1.27 (m, CH); [isobutene] 1.58 (s, CH₃), 4.72 (m, *J* = 1.1 Hz, CH₂); [free 14N4] 2.11 (s, CH₃N); other absorptions of the species listed above are in the range δ 1.0-2.5.

PhBr-*i*-Bu₂Mg-14N4. A similar preparation used PhBr instead of PhI. ¹H NMR (300 MHz) δ [*i*-BuMg(14N4)⁺] -0.75 (d, *J* = 6.3 Hz, CH₂Mg), 1.15 (d, *J* = 6.3 Hz, CH₃), 1.84 (s, CH₃N), 3.62 (b, CHHCH₂CHH); [Br₋₂MgPh₋₁⁻] 7.22 (bt, *p*-H), 7.32 (t, *J* = 7.3 Hz, *m*-H), 8.45 (br, *o*-

H); [*i*-BuBr] 0.74 (d, $J = 6.7$ Hz, CH₃), 2.87 (d, value of J inadvertently not recorded, CH₂); [isobutane] 0.85 (d, $J = 6.6$ Hz, CH₃); [isobutene] 1.58 (s, CH₃), 4.71 (m, CH₂); [free 14N4] 2.11 (s, CH₃N); other absorptions of the species listed above are in the range δ 1.0-2.5.

PhI-(Neopentyl)₂Mg-14N4. A similar preparation used (neopentyl)₂Mg and PhI. ¹H NMR (200 MHz) δ [NpMg(14N4)⁺] -0.69 (bs, CH₂Mg), 1.11 (s, (CH₃)₃C), 1.68 (br s, CH₃N); [Ph₃Mg⁻] 7.27 (br t, $J = 6.8$ Hz, *p*-H), 7.42 (br d, $J = 7.0$ Hz, *m*-H), 8.68 (br d, $J = 6.0$ Hz, *o*-H); [NpI] 0.81 (s, CH₃), 2.74 (s, CH₂); absorptions of free 14N4 and other absorptions of the species listed above were in the range δ 0.8-2.6.

Reactions with Pyridine. In a typical procedure, the additive (ca. 1 mmol) and diethyl ether (3 mL) were added to a vial and the organomagnesium solution was added dropwise using a syringe. The mixture was stirred for 5 min and then a diethyl ether solution of pyridine that also contained a known amount of an alkane (GC standard) was added. The concentration of pyridine in the reactions was typically 0.2 M. Stirring was continued for ca. 24 h and then the vial was cooled in ice bath and the contents were hydrolyzed by addition of a saturated NH₄Cl solution (ca. 5 mL). Aqueous NaOH (1.0 M) was added to adjust the solution to pH 10. The aqueous layer was extracted with diethyl ether (2 x 5 mL). The extracts were combined and dried (Na₂SO₄).

For reactions of Et₂Mg-K or Et₂Mg-Na preparations, a diethyl ether solution of Et₂Mg was added to a stirred (magnetic stirring bar) suspension of the alkali metal (ca. 4 mmol) in diethyl ether (ca. 4 mL). The mixture was stirred for 20 h and then filtered through a fritted funnel before addition of the diethyl ether solution of pyridine. The concentration of pyridine in the reactions was ca. 0.05 M. Reactions with (neopentyl)₂Mg-K and (neopentyl)₂Mg-Na were carried out in a similar fashion except that the solvent was benzene-*d*₆ and the (neopentyl)₂Mg-metal preparation was stirred for 72 h before filtering. For the reaction involving a preparation from (hexyl)₂Mg and KH, PhH (3 mL), and (hexyl)₂Mg (0.060 g, 0.31 mmol) were added to KH (0.18 g, 4.5 mmol) and the resulting suspension was stirred for 23 h and then filtered through a fritted glass filter before addition of the PhH solution of pyridine.

GC analysis of most reactions with Et₂Mg and of reactions with (*t*-Bu)₂Mg and

(neopentyl)₂Mg used column B (4 min at 100 °C, then an increase of 40 °C/min to 185 °C).

Typical retention times (min): pyridine (4.4), octane ((neopentyl)₂Mg reactions, 5.7), 2-ethylpyridine (6.8), nonane ((*t*-butyl)₂Mg reactions, 6.8 min), 4-ethylpyridine (7.5), 2-*t*-butylpyridine (7.9), 4-*t*-butylpyridine (9.3), tridecane (Et₂Mg reactions, 13.2), 2,2-bipyridyl (18.6), 2,4-bipyridyl (22.0). With these GC conditions, the retention time of 4,4-bipyridyl was 22.9 min, but the retention times of 3-ethylpyridine and 4-ethylpyridine are identical. Separation of the ethylpyridine isomers was achieved using column D (isothermally at 90 °C): 3-ethylpyridine (7.5 min), 4-ethylpyridine (8.1 min); GC analysis of reactions with Et₂Mg–KOME or Et₂Mg–KO-*t*-Bu indicated that 3-ethylpyridine was absent. GC analysis of reactions with (neopentyl)₂Mg also used column B (4 min at 100 °C, then an increase of 40 °C/min to 195 °C). Typical retention times (min): pyridine (4.4), octane (5.7), trace amounts of unidentified products (9.5 and 10.7).

For reactions with Et₂Mg–K, Et₂Mg–Na, (neopentyl)₂Mg–K, and (neopentyl)₂Mg–Na preparations, GC analysis used column D (3 min at 80 °C, then an increase of 20 °C/min to 180 °C). Typical retention times (min): pyridine (3.2), 2-ethylpyridine (4.7), 4-ethylpyridine (6.6), pentadecane (9.2); 2,2-bipyridyl (11.5), 4,4-bipyridyl (16.5). The retention time of 2,4-bipyridyl was 15.6 min, but this compound was not observed in the products. The (neopentyl)₂Mg reactions had minor unidentified components (6.8 and 8.7 min).

For the reaction with a (hexyl)₂Mg–KH preparation, GC analysis used column D (3 min at 60 °C, then an increase of 20 °C/min to 170 °C). Retention times (min): 2-hexylpyridine (8.2), pentadecane (8.7), 4-hexylpyridine (9.5). The products were identified by comparison of retention times with those of samples obtained by preparative GC separation using column I (isothermal, 100 °C): 2-hexylpyridine (2.5 min); 4-hexylpyridine (6.0 min). 2-Hexylpyridine: ¹H NMR (benzene-*d*₆, 200 MHz) δ 0.88 (t, *J* = 6.5 Hz, CH₃), 1.32 (br, (CH₂)₄CH₃), 2.78 (t, *J* = 7.8 Hz, CH₂(CH₂)₄CH₃), 7.10 (dd, *J*_{ab} = 4.9 Hz, *J*_{bc} = 7.5 Hz, H_b), 7.14 (d, *J*_{cd} = 7.5 Hz, H_d), 7.59 (dt, *J*_{bc} = *J*_{cd} = 7.5 Hz, *J*_{ac} = 1.7 Hz, H_c), 8.52 (dd, *J*_{ab} = 4.9 Hz, *J*_{ac} = 1.7 Hz, H_a). 4-Hexylpyridine: ¹H NMR (benzene-*d*₆, 200 MHz) δ 0.89 (t, *J* = 6.5 Hz, CH₃), 1.32 (br m, (CH₂)₃CH₃), 1.63 (br m, CH₂(CH₂)₃CH₃), 2.60 (t, *J* = 7.6 Hz, CH₂(CH₂)₄CH₃), 7.12 (d, *J*_{ab}

= 5.0 Hz, H_b), 8.5 (br, H_a).

For the reactions of Et₂Mg–lithium amide preparations, GC analysis used column D (3 min at 80 °C, then an increase of 20 °C/min to 180 °C). Retention times (min): 2-ethylpyridine (3.6), 4-ethylpyridine (5.6), pentadecane (8.5).

Reactions with Quinoline, 2-Methylquinoline, and 2-Ethylquinoline. The procedure was essentially identical to that used routinely with pyridine. GC analysis followed a literature procedure (the peak due to 2-methylquinoline was at 7.2 min).⁴ Samples for ¹H NMR spectra were collected on preparative GC column H (isothermal 130 °C): 2-ethylquinoline (7.8 min), 2-ethyl-1,2-dihydroquinoline (10.2 min).

Reactions with 2-Cyclohexen-1-one. To the Et₂Mg–alkoxide preparation (prepared as described for reactions with pyridine) was added a diethyl ether solution of 2-cyclohexen-1-one containing a known amount of undecane (GC standard). The concentration of cyclohexenone in the reactions was ca. 0.1 M. After the contents had been stirred for 2 h, the vial was cooled in an ice bath and the contents were hydrolyzed as described for reactions with aryl halides. GC analysis used column E (100 °C for 4 min, then an increase of 40 °C/min to 185 °C). Typical retention times (min): 1-ethyl-2-cyclohexen-1-ol (8.3), 3-ethylcyclohexanone (8.9), undecane (9.4). Products were identified by comparison of retention times and mass spectra with those of authentic samples.

References

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