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Aryliminodimagnesium Reagents. XV.[1] Condensation with Nitrobenzene. Formation of Unsymmetrical Azobenzenes Favored by Long-Chain *p*-Alkoxy-Substituted Reagents

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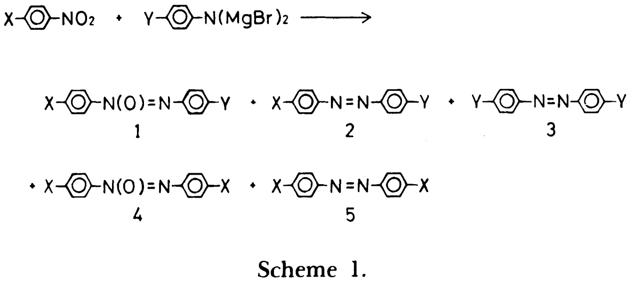
In the reaction of *p*-$MeC_6H_4N(MgBr)_2$ with *p*-alkoxynitrobenzene, no effect of alkoxyl chain length on the relative yields of azoxy and azo products was observed. In contrast, in the reaction of *p*-alkoxy-$C_6H_4N(MgBr)_2$ with *p*-nitrotoluene, C_{12}- and C_{18}-alkoxyl chains led to the corresponding unsymmetrical azobenzenes in unexpectedly high yields. This result, arising from efficient condensation and deoxygenation processes, was explained in terms of cooperation of reagent molecules through their aggregation assisted by a novel tying effect of their long chains.

The most important reaction of aryliminodimagnesium ($ArN(MgBr)_2$, IDMg) is the condensation with nitroarenes (Scheme 1). The *ONN* and *NNO* isomers of the unsymmetrical azoxyarene (**1**) are prepared by interchange of the substituents X and Y,[2] and the lack of interconversion of the isomers in the presence of IDMg is of significance for synthetic purposes. The reaction is applied to functionalization of azoxy- and azoarenes. If the compound **1** having a long chain alkyl or alkoxyl group (X or Y) is photoconverted into *o*-hydroxyazoarene,[3] it will be a useful chelating agent in micelle systems. The compound **2** having a long chain substituent will also be useful in micelle systems, by means of *Z*–*E* photoisomerization, as a probe for physicochemical studies.[4]

By use of molar excess of IDMg in the reaction with nitrobenzene (Scheme 1), the compound **1** is formed and successively deoxygenated to give **2**.[5] Single electron transfer (SET) from reagent to substrate is involved, and causes formation of minor coupling products: **3** frequently via oxidation of IDMg,[2,6] and **4** and **5** occasionally via reduction of nitroarene.[7] The coupling of nitroarene to give **4** is expected from the basic nature of IDMg because the coupling in basic medium[8] is well-known. The principal factor governing the relative yield of major and minor products is the relative SET efficiency estimated by oxidation and reduction potentials of reactants.[9,10] The precise mechanism remains to be studied.

In this study, the effect of the *p*-alkoxy (RO) chain length on the relative yield of **1** and **2** was examined using the combination of *p*-$ROC_6H_4NO_2$ with *p*-MeC_6H_4-IDMg (X=RO, Y=Me) and that of *p*-$MeC_6H_4NO_2$ with *p*-ROC_6H_4-IDMg (X=Me, Y=RO). Interestingly, "the long chain of the IDMg reagent was proved to be efficient for the formation of **2**." The reason for the variation of product yields will be discussed in this paper.



Scheme 1.

Results and Discussion

Product yields obtained by a typical treatment with 4.2 molar equivalents of IDMg (8.4 mmol in 50 ml THF at 55 °C for 3 h) are summarized in Table 1 (S1—S6 and R1—R10), which includes those affected by reaction conditions (R11—R14). Relative yields of **1**—**3** in the same combinations with S1 and R1[2] were reproduced.

The relative yield of **1**—**3** in S1—S6 (S-series) is essentially unaffected by the chain length of *p*-$ROC_6H_4NO_2$. The results of R1—R10 (R-series) using *p*-ROC_6H_4-IDMg are different from those of S-series, and are distinguished by two features. The first feature is the presence of *p,p'*-Me_2-azoxy- and -azobenzenes (**4** and **5**) in some cases of R-series (R1—R5, R7—R9), in contrast to the absence of the corresponding *p,p'*-$(MeO)_2$ products in S-series. The estimated relative SET efficiency in the combination of R1 is higher than that in S1,[2,9,10] and the electron-donating ability of *p*-ROC_6H_4-IDMg must be comparable to that of *p*-MeO reagent. Thus, the presence of **4** (or **5**) in R-series is ascribed to the rapid SET and not to any effect of chain length.

The second feature relates to the peculiar results of R6 and R10 among R-series. By use of the C_{12} and C_{18} alkoxy-substituted reagents, the yields of **2** are unusually elevated (at the expense of **1**) and concurrently the yields of **3**—**5** are reduced. The absense of **1** indicates its efficient deoxygenation to give **2**, and the appreciable yields of **3**—**5** arise usually from rapid SET.[2,10] It is thus recognized that the unusual reduction of the yields of **3** and **4** (or **5**) in R6 and R10, in spite of rapid SET (vide supra), accompanies the efficient formation of **2**. "The novel effect of reagent's chain length on the efficiency of condensation and deoxygenation processes"

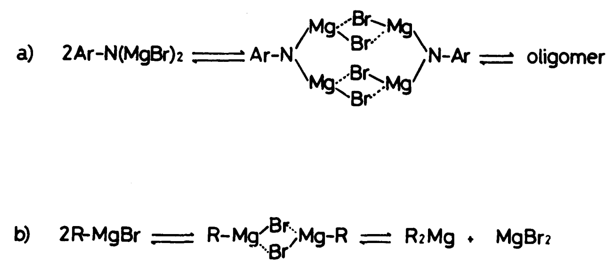
Table 1. Yields of Products in the Reaction of Scheme 1

Run No.	X	Y	Yield/%[a)]					Recovery/%
			1	**2**	**3**	**4**	**5**	
S1	CH_3O-	CH_3-	22.2	35.0	14.4	0	0	0
S2	n-$C_8H_{17}O-$	CH_3-	40.0	38.4	16.6	0	0	6.4
S3	n-$C_{10}H_{21}O-$	CH_3-	43.4	36.5	14.9	0	0	Trace
S4	n-$C_{12}H_{25}O-$	CH_3-	38.4	37.2	19.4	0	0	Trace
S5	n-$C_{18}H_{37}O-$	CH_3-	31.1	46.3	11.0	0	0	Trace
S6	n-$C_{22}H_{45}O-$	CH_3-	44.2	41.1	12.5	0	0	Trace
R1	CH_3-	CH_3O-	30.5	24.7	18.6	1.5	6.7	0
R2	CH_3-	n-$C_6H_{13}O-$	30.2	38.1	13.6	3.9	Trace	Trace
R3	CH_3-	n-$C_8H_{17}O-$	42.6	36.4	18.7	0	2.3	0
R4	CH_3-	n-$C_{10}H_{21}O-$	24.2	37.2	13.3	3.7	3.0	0
R5	CH_3-	n-$C_{11}H_{23}O-$	27.7	56.9	12.0	Trace	Trace	Trace
R6	CH_3-	n-$C_{12}H_{25}O-$	Trace	71.3	8.6	0	0	Trace
R7	CH_3-	n-$C_{13}H_{27}O-$	19.8	44.5	10.3	8.1	3.3	Trace
R8	CH_3-	n-$C_{15}H_{31}O-$	35.2	39.2	5.4	9.0	2.5	Trace
R9	CH_3-	n-$C_{17}H_{33}O-$	11.3	66.2	1.3	9.3	0	3.4
R10	CH_3-	n-$C_{18}H_{37}O-$	Trace	87.2	Trace	1.2	0	Trace
R11[b)]	CH_3-	n-$C_{12}H_{25}O-$	1.9	33.4	7.0	0.7	0	33.5
R12[c)]	CH_3-	n-$C_{12}H_{25}O-$	36.3	41.0	2.8	4.3	0	Trace
R13[d)]	CH_3-	n-$C_{12}H_{25}O-$	37.9	37.9	3.2	5.4	1.4	0
R14[e)]	CH_3-	n-$C_{12}H_{25}O-$	0	6.8	0	Trace	Trace	89.0

a) [IDMg]/[$ArNO_2$]=4.2, THF 50 ml, 55 °C, and 3 h. b) [IDMg]/[$ArNO_2$]=2.0. c) THF 200 ml. d) 55 °C and 0.5 h. e) Room temp and 10 min.

is discussed in what follows.

The conditions efficient for the two processes were reported. In the reaction with *o*-MeO- and *o*-halonitrobenzenes,[1)] "normal addition" of them to a large molar excess of IDMg favors the condensation giving **1** and **2** (cf. Scheme 1), whereas "reverse addition" of a small molar excess of IDMg to the substrate favors, instead, the replacement of substituents leaving the nitro group unchanged. In order to deoxygenate azoxybenzenes to sufficient degree, the treatment with a 5-fold molar excess of the strongly electron-donating *p*-$MeOC_6H_4$-IDMg at 55 °C for 3 h[5,11)] is needed. Even under these conditions, azoxybenzenes having a *p*-MeO-C_6H_4 group remote to the azoxy nitrogen (electronically resembling **1** formed in R-series) are sluggishly deoxygenated. The cited results reveal that high concentration in the proximity of nitro and/or azoxy groups is required for all the processes leading to **1** and **2**. At the usual concentrations (3—10 mmol in 50 ml THF), at least a part of IDMg molecules aggregate and "cooperate" for the condensation and also for the deoxygenation.



Scheme 2.

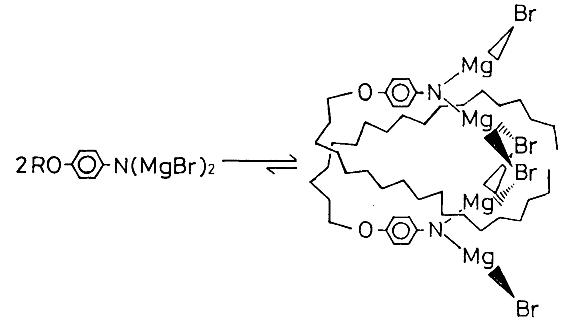


Fig. 1. Depiction of a Dimerized Species of *p*-n-$C_{18}H_{37}OC_6H_4$-IDMg.

The aggregation arises from the equilibrium between monomeric and dimeric (or oligomeric) species of IDMg (Scheme 2a) resembling that in Grignard solution proposed early by Schlenk (Scheme 2b).[12)] The deposition of IDMg crystals by cooling of the clear solution (of the concentration used in the previous[2,5)] and present studies) to 0 °C is due to the formation of -Br···Mg< coordination bond, and indicates the presence of an equilibrium involving the bond formation and breaking, i.e., ligand exchange with THF molecule. Since a molecular model of *p*-alkoxyaniline shows that its C^{10} atom can locate close to the amino nitrogen of the same molecule, it is suggested that a long *p*-alkoxyl chain having more than eleven methylenes twists around the -$N(MgBr)_2$ group of the other molecule to tie the dimer (or oligomer); i.e., the dissociation is prevented and the

Table 2. Melting Points and ^{1}H NMR Data of Azoxyarenes
p-X-C_6H_4-N(O)=N-C_6H_4-Y-p

X	Y	Mp θ_m/°C	^{1}H NMR Data/δ
n-$C_6H_{13}O$-	CH_3-	102.5—103.5	8.20—7.90 (4H, m), 7.34—6.74 (4H, m), 3.96 (2H, t), 2.37 (3H, s), 2.00—0.60 (11H, m).
n-$C_8H_{17}O$-	CH_3-	88—89	8.34—7.97 (4H, m), 7.40—6.77 (4H, m), 3.95 (2H, t), 2.40 (3H, s), 2.10—0.67 (15H, m).
n-$C_{10}H_{21}O$-	CH_3-	85—86	8.34—7.95 (4H, m), 7.32—6.85 (4H, m), 3.94 (2H, t), 2.37 (3H, s), 2.10—0.62 (19H, m).
n-$C_{12}H_{25}O$-	CH_3-	85.5—86	8.20—7.84 (4H, m), 7.24—6.70 (4H, m), 3.92 (2H, t), 2.38 (3H, s), 2.10—0.67 (23H, m).
n-$C_{18}H_{37}O$-	CH_3-	83—83.5	8.30—7.94 (4H, m), 7.34—6.77 (4H, m), 3.98 (2H, t), 2.38 (3H, s), 1.94—0.64 (35H, m).
n-$C_{22}H_{45}O$-	CH_3-	84.5—85.5	8.22—8.07 (4H, m), 7.24—6.91 (4H, m), 3.99 (2H, t), 2.40 (3H, s), 1.84—0.86 (43H, m).
CH_3-	n-$C_6H_{13}O$-	70—71	8.30 and 6.97 (4H, ABq, J=9.5Hz), 8.17 and 7.27 (4H, ABq, J=8.8Hz), 4.02 (2H, t), 2.44 (3H, s), 1.86—0.87 (11H, m).
CH_3-	n-$C_8H_{17}O$-	61—62	8.29 and 6.96 (4H, ABq, J=9.2Hz), 8.16 and 7.27 (4H, ABq, J=8.5Hz), 4.02 (2H, t), 2.43 (3H, s), 1.86—0.87 (15H, m).
CH_3-	n-$C_{10}H_{21}O$-	54.5—55	8.29 and 6.95 (4H, ABq, J=9.2Hz), 8.16 and 7.25 (4H, ABq, J=8.5Hz), 3.99 (2H, t), 2.41 (3H, s), 1.81—0.86 (19H, m).
CH_3-	n-$C_{11}H_{23}O$-	65—66	8.28 and 6.93 (4H, ABq, J=9.5Hz), 8.15 and 7.24 (4H, ABq, J=8.8Hz), 3.98 (2H, t), 2.41 (3H, s), 1.83—0.85 (21H, m).
CH_3-	n-$C_{12}H_{25}O$-	56.5—57	8.29 and 6.93 (4H, ABq, J=9.2Hz), 8.15 and 7.23 (4H, ABq, J=8.5Hz), 3.97 (2H, t), 2.39 (3H, s), 1.82—0.85 (23H, m).
CH_3-	n-$C_{13}H_{27}O$-	66—67	8.29 and 6.97 (4H, ABq, J=9.5Hz), 8.17 and 7.28 (4H, ABq, J=8.8Hz), 4.03 (2H, t), 2.44 (3H, s), 1.86—0.85 (25H, m).
CH_3-	n-$C_{15}H_{31}O$-	77.5—73	8.29 and 6.97 (4H, ABq, J=9.3Hz), 8.17 and 7.27 (4H, ABq, J=8.8Hz), 4.02 (2H, t), 2.44 (3H, s), 1.86—0.85 (29H, m).
CH_3-	n-$C_{17}H_{35}O$-	74.5—75	8.29 and 6.96 (4H, ABq, J=9.3Hz), 8.17 and 7.27 (4H, ABq, J=8.8Hz), 4.02 (2H, t), 2.44 (3H, s), 1.86—0.85 (33H, m).
CH_3-	n-$C_{18}H_{37}O$-	—[a]	8.30 and 6.97 (4H, ABq, J=9.2Hz), 8.17 and 7.28 (4H, ABq, J=8.5Hz), 4.03 (2H, t), 2.44 (3H, s), 1.83—0.85 (35H, m).

a) Undetermined.

self-aggregation is assisted. Figure 1 shows a tentative depiction of a dimeric aggregate tied by the p-octadecyloxyl group causing an ideal cooperation responsible for the high yield of **2** in R10. The cooperation will be initiated by efficient binding of nitroarene molecule with the IDMg aggregate through the coordination of nitro (and/or azoxy) oxygen to Mg atoms.

The effect of even-numbered chains (R6, R10) is somewhat different from that of odd-numbered ones (R5, R7—R9) probably due to different conformations more or less favoring the twist. Another mode of twist, i.e., that of a reagent's long chain around a substrate molecule seems possible, but may be excluded by the notable formation of **4** in R7—R9 (probably arising from a dissociation, after SET, of σ-complex formed at the initial stage of reaction[10)]). The twist of substrate's long chain around a reagent molecule is excluded by the lack of chain length effect in S-series. Physical evidence for IDMg aggregation was difficultly obtained by means of the expected shift of n-π^* electronic absorption band or ^{1}H NMR signal. An advanced measurement of ^{14}N and/or ^{15}N NMR spectra, which may be hopeful, remains to be carried out. However, the suggestion of IDMg cooperation and some previous observations (vide infra) are supported, as shown below, by the variation of the yields of C_{12}-substituted **1** and **2** in R11—R14, the reaction conditions being changed from that of R6.

The use of 2.0 molar equivalents of reagent in R11 leads expectedly[2)] to the fair amount of recovery (34%), but the suggestion is supported by the still much higher yield (33%) of **2** than that (2%) of **1**. Fair yields of **1** at the expense of **2** were obtained by use of four-fold volume of solvent (200 ml, R12) and by use of shorter time of heating (0.5 h, R13; the mixture is the same with R6). The result of R12 indicates the effect of reduced population of dimer (or oligomer) due to left-hand side shift of the equilibrium of Scheme 2a by dilution. The result of R13 supports a previous observation,[5)] i.e., sluggish deoxygenation of **1** compared to its formation. In spite of the great amount of recovery (89%) in R14 due to quite a low conversion after stirring (the mixture is the same with R6) for 10 min at room temperature,[2)] a low yield (7%) of **2** is still accompanied by an undetectable amount of **1**.

As discussed above, the major factor (relative SET efficiency), governing a variety of both Grignard and IDMg reactions,[10)] was modified by the effect of cooperation of reagent molecules as one of the minor factors. The effect evokes a similar cooperation proposed from structures and behavior of intermediates of Grignard addition to benzil and benzophenone,[14] and the unified view of reactions of the two magnesium reagents[10] will be elaborated. The other minor factor, based on the effect of coordination of substrate's oxygen to reagent's Mg,[10,13] was disclosed owing to the mild electron-donating ability of IDMg.[9] The major and minor factors, determining the product yields, will be utilized for mechanistic and synthetic studies.

Experimental

Materials and Procedures. The *p*-alkoxynitrobenzenes were prepared by treatment of dried potassium *p*-nitrophenolate with appropriate alkyl bromides in refluxing cyclopentanone.[15] The *p*-alkoxyanilines were prepared in yields higher than 80% by the reduction of the corresponding nitrobenzenes by zinc powder in refluxing ethanol.[16] Longer times of refluxing are needed for efficient reduction of nitrobenzenes having longer alkoxyl chains: 1 h for C_6 and C_8, 2 h for C_{10} and C_{11}, 3 h for C_{12} and C_{13}, 4 h for C_{15}, and 5 h for C_{17} and C_{18}. By heating C_6 nitrobenzene for 3 h, some decomposition leading to 38% yield was observed. Some attempts to reduce *p*-$C_8H_{17}O$-nitrobenzene by use of $NaBH_2S_3$[17] gave poor results.

A preparation of IDMg reagents from the corresponding anilines and their reaction with nitrobenzenes were carried out according to the reported procedures.[2] The products were separated by column and thin-layer chromatographies on silica gel (Wako Gel C-200 and C-300 and Merck Kieselguhr 60G). In Table 2, the melting points (uncorrected) and ^1H NMR data of **1** (obtained in S2—S6 and R2—R10) are summarized. The other products are known.

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