Mechanism of Reaction between Grignard Reagents and Nitroarenes. Product Distribution and Relative Reactivities of Grignard Reagents with Nitronaphthalene System

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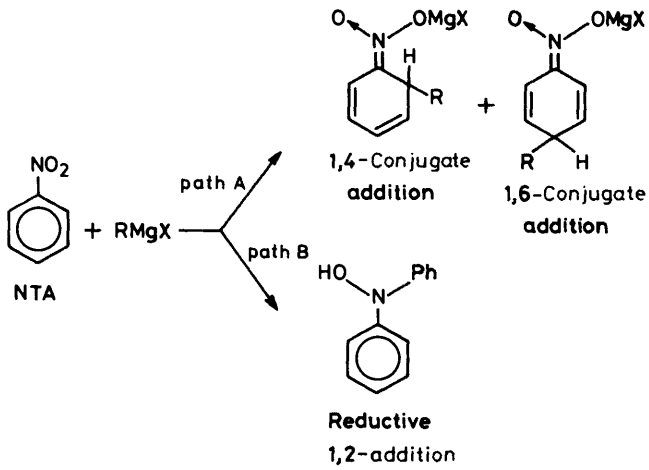
The reaction of 2-methoxy-1-nitronaphthalene with various Grignard reagents has been examined. Alkylmagnesium halides such as CH_3MgBr, $PhCH_2MgBr$, $PhCH_2CH_2MgBr$, C_2H_5MgBr, and $i\text{-}C_3H_7MgBr$ give 1,6-addition products almost exclusively, while PhMgBr gives instead comparable amounts of 1,4-addition and reductive 1,2-addition products. Hex-5-enylmagnesium bromide reacts giving two 1,6-addition products, one containing a straight chain and the other one a cyclized alkyl fragment, where the ratio of the two decreases with decreasing temperature. The reactivity order ($i\text{-}C_3H_7 > PhCH_2 \simeq C_2H_5 > PhCH_2CH_2 > CH_3$) established by competitive reactions along with the reactivity pattern shown by hex-5-enylmagnesium bromide was taken as clear evidence for a single-electron transfer (s.e.t.) process. A mechanism involving s.e.t. from Grignard reagent to nitroarene followed by collapse within the solvent cage of the two radicals thus formed (geminate combination) or, to a lesser extent, out of the cage (non-geminate combination), is suggested. The reaction of 1-nitronaphthalene with methyl-, isopropyl- and hex-5-enyl-magnesium bromides indicates that the distribution of isomeric 2- and 4-alkylated products is determined by the reactivity of the ring positions for both geminate and non-geminate combination. No firm mechanistic conclusions were reached regarding the reaction of PhMgBr.

Until a few years ago the reaction of organomagnesium compounds with mononitroarenes was regarded as complex[1] and, therefore, not very useful in organic synthesis. Careful analysis of reaction products as well as systematic control of experimental conditions led recently to the recognition that a nitroarene (NTA) can react with Grignard reagents through two different pathways,[2] *i.e.* conjugate addition (path A) and reductive 1,2-addition (path B). The choice of the reaction path is determined mainly by the nature of the carbanionic moiety of RMgX: alkyl Grignard reagents are reported to follow path A almost exclusively,[3] while PhMgX and related compounds[4] are said to follow path B.

Both types of reactivity have been studied largely from a synthetic point of view,[3] no significant investigation having been devoted to mechanisms. The main question to be answered concerning the transfer of an alkyl or aryl group from a Grignard reagent to an electron-poor aromatic substrate is whether this reaction proceeds through nucleophilic attack of the carbanionic moiety of RMgX on an electrophilic centre of the substrate (polar mechanism) or instead through the formation of a radical pair by single-electron transfer from RMgX to the substrate (s.e.t. mechanism) followed by collapse of the radicals formed, or by other types of reaction initiated by radical species, *i.e.* chain reactions. Since the ability to participate in electron-transfer reactions strongly decreases in going from alkyl to aryl Grignard reagents,[5] it is possible that the difference in the observed reactivity pattern with nitroarenes is due to a change in the mechanism (from s.e.t. to polar). It may be, however, that the apparently different reactivities can be rationalized on the basis of a unified mechanism. A satisfactory approach to these problems requires ascertaining whether the alkyl reagents can be considered to be undergoing s.e.t. reactions.

In this contest, we recently reported a preliminary study[6] of the reaction of 2-methoxy-1-nitronaphthalene (1) with hex-5-enylmagnesium bromide, a primary radical probe.[7] 36% of the



Scheme 1.

1,6-addition product formed showed incorporation of the cyclopentylmethyl group. Since this alkyl framework can only result from cyclization of a free hex-5-enyl radical, the findings clearly indicated that a considerable amount of the ring alkylation at the 4-position of (1) proceeds by a radical mechanism. However, cyclization of the hex-5-enyl system can only occur in processes involving a reaction time longer than 10^{-5} s,[7a] and the question remains whether the formation of uncyclized 1,6-addition product (64%) occurs *via* a radical or a polar pathway.

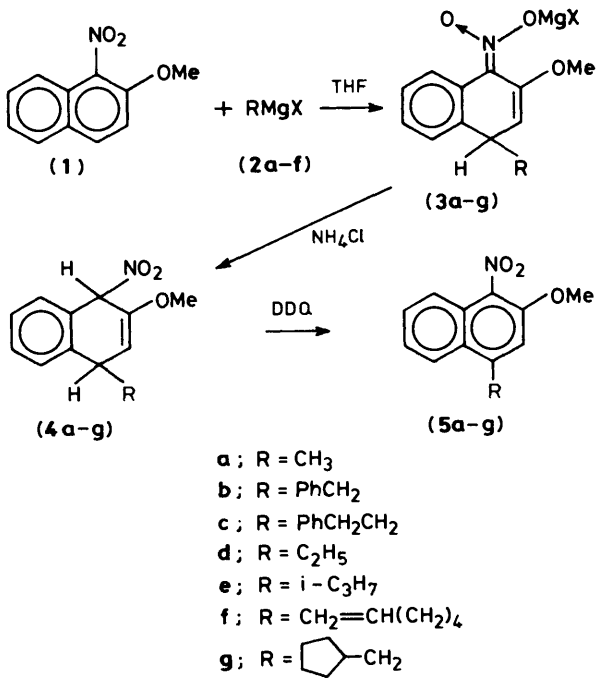
In the present work we have examined the reactivity of hex-5-enylmagnesium bromide more thoroughly and, in addition, obtained other kinds of evidence for an s.e.t. mechanism through analysis of the reactivity of various Grignard reagents with 1-nitro- and 2-methoxy-1-nitro-naphthalene.

Results

Competitive Reaction of two Alkyl Grignard Reagents (**2a—e**) *with* 2-*Methoxy*-1-*nitronaphthalene* (**1**).—Previous results have shown that the reaction of (**1**) with alkylmagnesium halides proceeds almost exclusively by 1,6-conjugate addition, affording, after quenching with NH_4Cl, a mixture of *cis*- and *trans*-dihydro-derivatives (**4**).[8]

This reaction has now been reinvestigated with the aim of determining the reactivity order of various Grignard reagents (**2a—e**) through competitive runs of (**1**) with mixtures of two RMgX reagents. In each case a tetrahydrofuran (THF) solution of (**1**) (1 equiv.) was added dropwise at 0 °C to a THF solution of a mixture of the two Grignard reagents in large excess (5 equiv. each), and the reaction was immediately quenched with NH_4Cl. Since the analysis of the reaction products formed under these conditions can be extremely troublesome due to the formation of a pair of diastereoisomers for each compound, the mixture of products (**4**) was quantitatively oxidized to 4-alkyl-2-methoxy-1-nitronaphthalenes (**5**) by treatment with DDQ in dry THF at reflux.

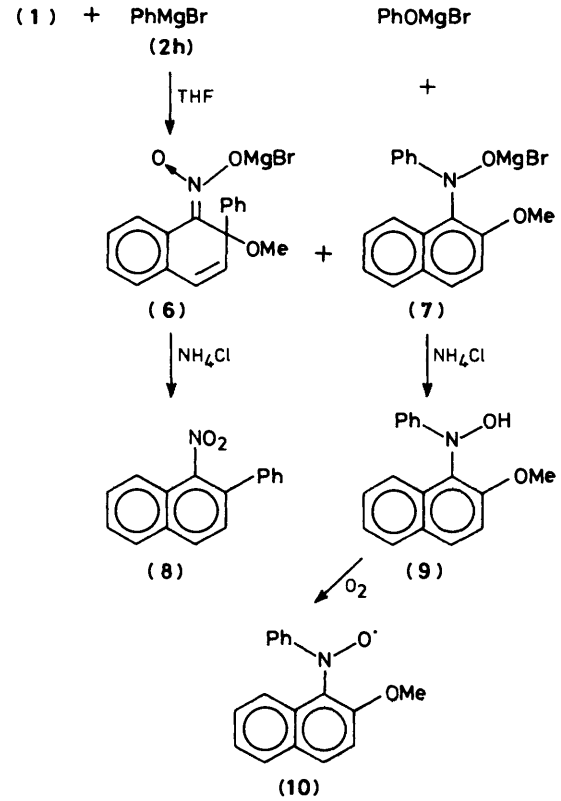
The relative reactivity of the two Grignard reagents under examination was determined by quantitative ^1H n.m.r. analysis of the mixture of the two products (**5**). Overall yields and relative proportions of compounds (**5**) are reported in Table 1. Furthermore, yields for each Grignard reagent reacting separately with (**1**) were determined by control runs. The results, reported in Table 2, demonstrate that 1,6-conjugate addition predominates in each case, and that the yields are comparable for all compounds (**2a—e**). Therefore, the data reported in Table 1 can be taken to provide an accurate measure of the relative reactivities of the compounds RMgX toward (**1**).



Scheme 2.

Reaction of (**1**) *with Phenylmagnesium Bromide* (**2h**).—Phenylmagnesium bromide (**2h**) behaves in a quite different manner from the alkyl derivatives. When this reagent was allowed to react with (**1**), two products were isolated after quenching with NH_4Cl followed by chromatographic separation on silica gel. These products were identified as 1-nitro-2-phenylnaphthalene (**8**) and (2-methoxy-α-naphthyl)phenyl nitroxide (**10**), derived from 1,4- and reductive 1,2-addition respectively.

The latter product was characterized by e.s.r. spectroscopy



Scheme 3.

Table 1. Competitive reaction of (**1**) with two Grignard reagents at 0 °C in THF

R^1MgX	R^2MgX	1,6-addition products and relative amounts[a]	Overall yields (%)[b]
$i\text{-}C_3H_7MgBr$	C_2H_5MgBr	(**5e**):(**5d**) = 70:30	78
C_2H_5MgBr	$PhCH_2MgBr$	(**5d**):(**5b**) = 51:49	76
C_2H_5MgBr	$PhCH_2CH_2MgBr$	(**5d**):(**5c**) = 66:34	76
$PhCH_2MgBr$	$PhCH_2CH_2MgBr$	(**5b**):(**5c**) = 66:34	72
C_2H_5MgBr	CH_3MgBr	(**5d**):(**5a**) = 97:3	73

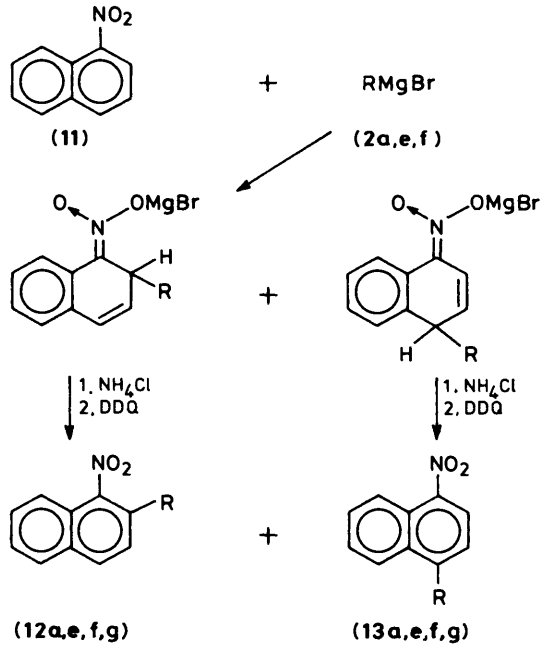
[a] Determined by ^1H n.m.r. analysis. [b] Determined on the mixture of the products on the basis of the relative proportions of the two obtained compounds as calculated from ^1H n.m.r.

Table 2. Reaction of 2-methoxy-1-nitronaphthalene (0.1M) with alkylmagnesium halides (0.2M) in THF at 0 °C[a]

RMgX	Product	Yield (%)
CH_3MgBr	(**5a**)	76
$PhCH_2MgBr$	(**5b**)	75
$Ph(CH_2)_2MgBr$	(**5c**)	78
C_2H_5MgBr	(**5d**)	73
$i\text{-}C_3H_7MgBr$	(**5e**)	69

[a] Reaction time 0.5 min.

(see Experimental section) and presumably formed during the chromatographic separation, by air oxidation of the corresponding hydroxylamine (**9**), no paramagnetic signals having been observed in the crude reaction mixture. Yields of (**8**) and (**10**), reported in Table 3, were determined at low percentages of conversion (<30%) so that secondary reduction and *N*-arylation of intermediates (**6**) and (**7**) by PhMgBr would not compete with the primary reaction. It is worth noting that PhMgBr, compared with the alkyl reagents, shows an extremely low reactivity. Reactions with alkylmagnesium halides were always found to be complete within few seconds after mixing of the reactants, while large amounts of unchanged material (*ca.* 66%) were recovered after 20 min in the reaction with (**2h**) under the same experimental conditions.



Scheme 4.

Reaction of (**1**) *with Hex-5-enylmagnesium Bromide* (**2f**).—The reaction of (**1**) with hex-5-enyl Grignard reagent (**2f**) followed by the usual treatment of the intermediate adduct gives a mixture of 4-(hex-5-enyl)- (**5f**) and 4-cyclopentylmethyl-2-methoxy-1-nitronaphthalene (**5g**), corresponding to uncyclized and cyclized products respectively. Yields and relative proportions of (**5f** and **g**) at various reaction temperatures and using different initial concentrations of reactants are summarized in Table 4.

Reaction of 1-*Nitronaphthalene* (**11**) *with Methyl-* (**2a**), *Isopropyl-* (**2e**) *and Hex-5-enyl-magnesium Bromide* (**2f**).—Product distributions from the conjugate addition of various RMgX reagents (**2a**, **e**, and **f**) to 1-nitronaphthalene (**11**) were examined at 0 °C in THF where initial reaction products were oxidized to aromatic derivatives prior to analysis, as in system (**1**).

Data reported in Table 5 show that, for all RMgX examined, (**11**) undergoes a considerable amount of both 1,4- and 1,6-conjugate addition. Moreover, in the case of hex-5-enylmagnesium bromide, products containing both uncyclized (**12f**) and (**13f**) and cyclized alkyl fragments (**12g**) and (**13g**) were isolated. Cyclic products account for 14% of the 1,4- and for 16% of the 1,6-addition, respectively.

Table 3. Reaction of 2-methoxy-1-nitronaphthalene (0.1M) with phenylmagnesium bromide (0.2M) in THF at 0 °C

Reaction time (min)	Unchanged material (%)	Yield (%) 1,4-Addition product (**8**)	Yield (%) Reductive 1,2-addition product (**10**)
0.5	95	2.5	2.5
10	76	11	11
20	66	15	14

Table 4. Reaction of (**1**) with hex-5-enylmagnesium bromide (**2f**)

[(1)]/M	[(2f)]/M	Temperature (°C)	Yield (%)[d] (5f) + (5g)	(5f):(5g)[e]
1×10^{-1}	2×10^{-1}	0[a]	76	75:25
5×10^{-4}	1×10^{-3}	0[b]	75	74:26
1×10^{-4}	2×10^{-4}	0[c]	76	75:25
1×10^{-1}	2×10^{-1}	+20[a]	78	64:36
1×10^{-1}	2×10^{-1}	−30[a]	75	85:15

[a] Reaction time 0.5 min. [b] By adding dropwise (**2f**) to (**1**) during 1 h. [c] By adding dropwise (**1**) to (**2f**) during 1 h. [d] See footnote to Table 1. [e] Determined by ^{1}H n.m.r. analysis.

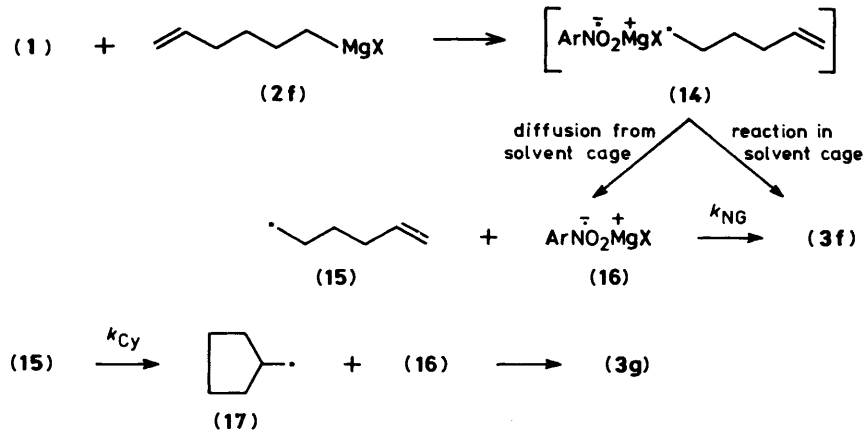
Discussion

The relative reactivity order of an organomagnesium derivative has been shown to be critical in determining whether it reacts through a polar or an s.e.t. pathway.[5,9]

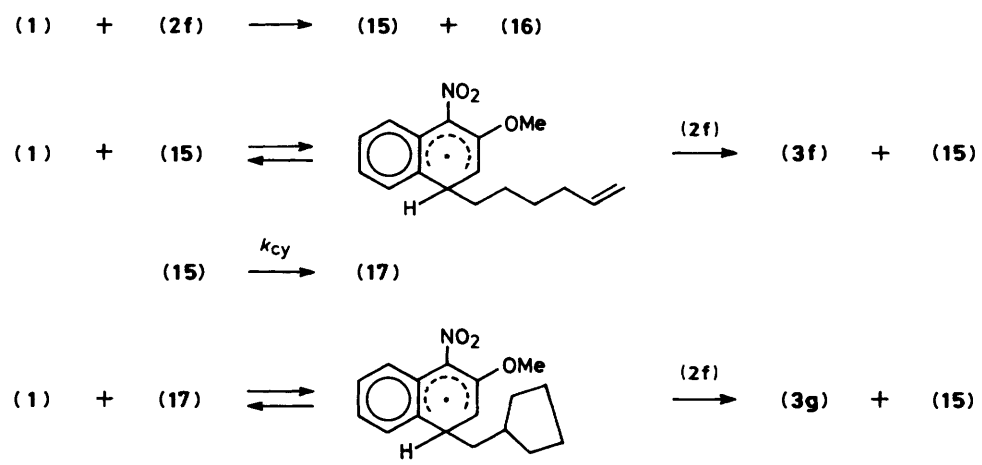
If the mechanism is s.e.t., then the relative rates must be consistent with the electron-donating power of the Grignard reagents, *i.e.* i-C_3H_7 > $PhCH_2$ ≥ C_2H_5 > CH_3 ≫ Ph as indicated by oxidation potentials of RMgX.[9] On the other hand, in reactions known to proceed through a polar pathway, such as 1,2-addition to acetone, the reverse reactivity order is commonly observed.[9a] In our case, based on product distributions in competitive reactions (Table 1), or on an approximate estimation of the reaction rate in the case of PhMgBr, it is clear that the reactivity of the Grignard reagents with respect to (**1**) decreases in the order: i-C_3H_7 > C_2H_5 ≃ $PhCH_2$ > $PhCH_2CH_2$ > CH_3 ≫ Ph. This sequence clearly supports the hypothesis that the reaction has s.e.t. characteristics. A cautionary remark has, however, to be made about the last member of the sequence: although PhMgBr is, indeed, less reactive than CH_3MgBr as required by the difference in oxidation potential,

Table 5. Reaction of 1-nitronaphthalene (**11**) with various Grignard reagents (**2a**,**e**,**f**) in THF at 0 °C

RMgX	Products and yield (%)	Relative amounts between 1,4- and 1,6-addition products
CH_2=$CH(CH_2)_4MgBr$	(**12f**) 24 + (**12g**) 4 + (**13f**) 26 + (**13g**) 5	(**12f**) + (**12g**):(**13f**) + (**13g**) = 47:53 (**12f**):(**13f**) = 48:52 (**12g**):(**13g**) = 44.5:55.5
CH_3MgBr	(**12a**) 35.5 + (**13a**) 32.5	(**12a**):(**13a**) = 52:48
i-C_3H_7MgBr	(**12e**) 30.8 + (**13e**) 39.2	(**12e**):(**13e**) = 44:56



Scheme 5.

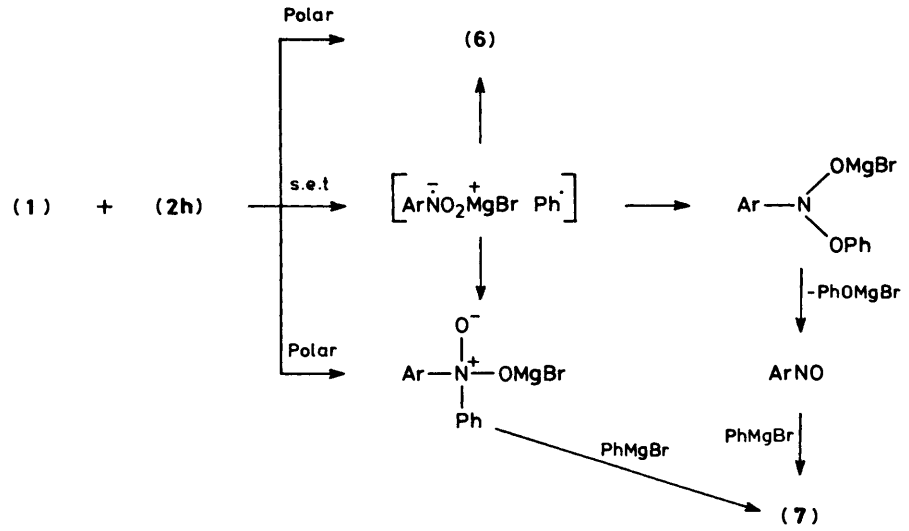


Scheme 6.

the reaction also leads to different products in the phenyl case, which could be indicative of reaction proceeding by a totally different mechanism. We shall come back to this point after outlining the general features of the s.e.t. mechanism.

The reaction of (1) with hex-5-enylmagnesium bromide gives both the uncyclized and cyclized product. In order to explain these findings in terms of a complete s.e.t. pathway of the reaction, we recently suggested a mechanism[6] in which an initial electron transfer from (2f) to (1) gives a nitroarene radical anion and hex-5-enyl radical pair (see Scheme 5). Uncyclized product (3f) would be expected to derive from a rapid combination of these geminate radicals within the solvent cage, while cyclized product (3g) must arise from escaped radicals, when the nitroarene radical anion (16) couples with cyclopentyl methyl radical (17), available as a result of subsequent cyclization of free hex-5-enyl radical (15). Alternatively, a radical chain mechanism might be proposed as shown in Scheme 6. Here, s.e.t. interaction between (1) and (2f) forms free radicals (15) and (16). The straight-chain radical (15) attacks the nitroarene (1) to give a cyclohexadienyl-substituted radical. Chain propagation occurs to regenerate the alkyl radical (15), when this intermediate undergoes an electron transfer from the Grignard reagent (2f), leading to uncyclized products (3f).

Alternatively, the straight-chain radical (15) can cyclize before attacking nitroarene (1). This competitive pathway gives ultimately the cyclized product (3g). Such mechanistic hypothesis would appear reasonable considering that the attack of an alkyl radical to a nitroarene substrate can be estimated to occur very rapidly.[10] However, the present results, showing that dilution of starting nitroarene (1) below 10^{-1}M [the limit of solubility of (1) in THF] has no effect on the (5f):(5g) ratio, seem to rule out the mechanistic proposal suggested in Scheme 6. If such a mechanism is operative, a definite decrease of uncyclized to cyclized product ratio should be expected whenever the concentration of (1) is reduced in the reaction medium, since cyclization of hex-5-enyl radical would then more effectively compete with direct reaction with (1). The same findings can be easily rationalized on the basis of the recombination mechanism, suggested in Scheme 5. If such a mechanism is operative, any cage reaction must be complete within *ca.* 10^{-9} s (the limit of diffusion coefficient),[11] hence cyclization of hex-5-enyl radical (k_{cy} 5×10^{-5} s^{-1})[7a] cannot precede geminate combination. Cyclization must therefore be indicative of radicals which combine after they escape from their geminate partners. For non-geminate recombination the ratio of uncyclized to cyclized product (d[(3f)]/d[(3g)]) is governed by the following equation, $d[(3f)]/d[(3g)] = k_{NG}[(16)]/k_{cy}$ where k_{NG} is the second-order constant rate for combination of escaped alkyl radicals with free nitroarene radical anion (16). k_{NG} has been estimated to be *ca.* 10^8 l mol^{-1} s^{-1} from coupling between ketyls and hex-5-enyl radicals,[12] and a comparable value can be reasonably assumed as an upper limit for the more stable nitroarene radical anion (16).[13] Thus a steady concentration of (16) lower than *ca.* 5×10^{-3}M would



Scheme 7.

allow most of the straight-chain free radical (**15**) to cyclize before coupling with (**16**).

It follows that as long as the concentration of (**16**) is below this threshold, the cyclized to uncyclized product ratio must be determined exclusively by the rate ratio between geminate combination and diffusion from the solvent cage, which is virtually independent of the concentration of starting materials. Since it is very reasonable to assume that the above threshold is not exceeded even when concentration of (**1**) reaches its solubility limit (1×10^{-1} M), we can conclude therefore that the mechanistic proposal of Scheme 5 is in good agreement with experimental data.

On the other hand, various attempts were made by us in order to detect the formation in system (**1**) of radical species by e.s.r. spectroscopy. However, even in the most favourable conditions (low temperatures) a weak unresolved non-persistent signal only was observed.

The ratio of cyclized to uncyclized product is, however, affected by the reaction temperature (see Table 4): at low temperature an increased amount of uncyclized product is observed, while the overall yield remains substantially unchanged. Since the amount of cage combination must increase with decreasing temperature,[14] these findings provide further support for the idea that the ratio of uncyclized to cyclized product can be taken as a measure of the ratio of geminate to non-geminate reaction.

A radical coupling reaction would be favoured by high spin densities at the interacting centres. As shown by both theoretical calculations and e.s.r. measurements[15] the unpaired electron in a nitroaromatic radical anion is delocalized mainly on the oxygen and nitrogen atoms of the nitro group and the *ortho*- and *para*-carbons of the aromatic ring. The observed reaction products indicate, however, that the attack of alkyl radicals occurs almost exclusively at ring carbons for both systems (**1**) and (**11**). Thus, the more stable carbon–carbon bond is formed. Such high selectivity is not surprising for non-geminate recombination,[16] but the same behaviour in the cage reaction implies that movements of geminate partners within the solvent cage are faster than coupling reactions.

In other words, assuming that electron transfer occurs directly from RMgX to the nitro group as would be expected from theoretical calculations on the LUMO distribution of a nitroaromatic system,[17] it becomes necessary to propose that the alkyl radical does not bind immediately to the nitrogen or oxygen atoms, but rather that it must have a lifetime long enough to permit it to migrate within the solvent cage and to bind at the most reactive position or escape out of the solvent cage.

Following this reasoning, and on the basis of e.s.r. coupling constants which assign very similar π-spin densities at C-2 and C-4 in the 1-nitronaphthalene radical anion,[18] *ortho*- and *para*-alkylation would be expected to occur to comparable extents both in cage and non-cage reactions. Experimental data from the reaction of (**11**) with hex-5-enylmagnesium bromide, as a probe for relative amounts of cage and non-cage reaction, support the above reaction model. In fact the *ortho*:*para* ratio of ring-alkylated products is close to (**1**) both in products from geminate recombination [uncyclized (**12f**) and (**13f**) compounds] and products from non-geminate recombination [cyclized (**12g**) and (**13g**) compounds]. In addition, the *ortho*:*para* ratio remains substantially unchanged even in the case of CH_3MgBr and i-C_3H_7MgBr demonstrating that, even with a less (methyl) and a more stable (isopropyl) alkyl radical than hex-5-enyl, the rate of movements within the solvent cage is higher than geminate recombination at every position.

Following these conclusions, a logical explanation can be given for the lack of reactivity at C(2)–OMe position in compound (**1**).

If we assume in fact that in system (**1**) the alkyl radical can select the more reactive positions both in in-cage and out-of-cage recombination the preference for collapsing the alkyl radical at C-4 can be accounted for in terms of lesser steric hindrance for attacking at a unsubstituted carbon.

The present results do not provide conclusive evidence about the nature of the reaction with PhMgBr. Nevertheless it is worth noting that an s.e.t. pathway, as well as a polar one, might explain the 1,2- and the 1,4-additions observed in this case. If the proposed radical mechanism is operative here as well it is reasonable that the extremely reactive phenyl radical would very rapidly bind to the nearest reactive centres of its geminate partner, *i.e.* the nitro group and C-2. Attack at C-2 leads to (**6**), while attack at oxygen or nitrogen atoms leads ultimately to (**7**), through either of the two reaction pathways depicted in Scheme 7.

The lack of even traces of nitroso derivative among the reaction products does not distinguish between these pathways, because PhMgBr in a fashion of s.e.t. mechanism should react with a nitrosoarene to give products like (**7**) much faster than

with a nitroarene, based on differences in oxidation potentials between nitroso and nitro compounds.[13]

Experimental

^{1}H N.m.r. spectra were recorded for $CDCl_3$ solutions at 100 MHz on a Varian XL-100 instrument operating in the continuous wave mode. Proton shifts are given from Me_4Si. The e.s.r. spectrum of nitroxide (**10**) in C_6H_6 was recorded with a Varian E-109 spectrometer. The mass spectrum reported was recorded with a JEOL JMS-D100 mass spectrometer.

Materials.—Tetrahydrofuran (THF), dried over sodium and distilled, was redistilled from $LiAlH_4$ immediately before use. Grignard reagents were prepared by classical methods without initiators from freshly distilled alkyl bromide and m4N Pierce and Warriner magnesium chips (99.99%); their exact concentrations were determined by Bergbreiter's procedure.[19] 2-Methoxy-1-nitronaphthalene (**1**) was prepared and purified by the reported method.[20] 1-Nitronaphthalene (**11**) is a commercial product and was crystallized before use.

Reaction of (**1**) *with Grignard Reagents* (**2a—e**).—A 0.4M solution (25 ml) of alkylmagnesium halides (**2a—e**) in THF was added dropwise under stirring at 0 °C to 25 ml of a 0.2M solution of (**1**) in the same solvent while flushing with nitrogen. After 30 s the reaction mixture was quenched with saturated aqueous NH_4Cl solution, extracted with methylene dichloride, dried over anhydrous Na_2SO_4, and evaporated under reduced pressure. The crude dihydro derivatives (**4**) were dissolved in dry THF (20 cm^3) and 1.2 equiv. of 2,3-dicyano-5,6-dichloro-1,4-benzoquinone (DDQ) were added. After refluxing for *ca.* 4 h the reaction mixture was filtered, evaporated under reduced pressure, and submitted to chromatographic separation on a silica gel column using light petroleum (b.p. 40—60 °C)–ethyl acetate (90:10) as eluant. Yields are reported in Table 2. Physical data for compounds (**5a–c**) have been previously reported.[3b,8] Data for compounds (**5d,e**) follow: (**5d**), m.p. 78—80 °C; δ($CDCl_3$) 1.12 (3 H, t, CH_3, $J_{CH_3CH_2}$ 7.0 Hz), 2.84 (2 H, q, CH_2), 3.78 (3 H, s, OMe), and 6.9—7.8 (5 H, m, arom) (Found: C, 67.6; H, 5.6; N, 6.0. $C_{13}H_{13}NO_3$ requires C, 67.5; H, 5.7; N, 6.1%): (**5e**), m.p. 85—86 °C; δ($CDCl_3$) 1.36 (6 H, d, 2 CH_3, J_{CH_3CH} 6.0 Hz), 3.70 (1 H, m, CH), 4.00 (3 H, s, OMe), and 7.2—8.2 (5 H, m, arom); (Found: C, 68.6; H, 6.0; N, 5.8. $C_{14}H_{15}NO_3$ requires C, 68.55; H, 6.15; N, 5.7).

Competitive Reactions.—A 0.05M solution (25 ml) of (**1**) in THF was added dropwise to a mixture of two Grignard reagents (5 equiv. each) in the same solvent, with stirring at 0 °C, under nitrogen. After 30 s the crude mixture was treated as described above. The reactive proportions of compounds (**5**) were determined by ^{1}H n.m.r. analysis; data are reported in Table 1.

Reactions of (**1**) *with Hex-5-enylmagnesium Bromide* (**2f**).—The reaction was carried out by the usual experimental procedure. Yields and relative amounts of products (**5f** and **g**) were determined by ^{1}H n.m.r. spectroscopy on the product mixture; data at various temperatures and reactant concentrations are collected in Table 4. Physical data have been previously reported.[6]

Reaction of (**1**) *with Phenylmagnesium Bromide* (**2h**).—A 0.4M solution (25 ml) of (**2h**) in THF were mixed with a 0.2M solution (25 ml) of (**1**) in the same solvent, using stirring and nitrogen flushing at 0 °C.

Reactions were quenched after various times (see Table 3) with saturated aqueous NH_4Cl solution, extracted with methylene dichloride, dried, evaporated under reduced pressure and submitted to chromatographic separation on a silica gel column [light petroleum (b.p. 40—60 °C)–ethyl acetate (90:10) as eluant].

The elution order was the following: (**8**), (**1**), phenol, (**10**). Yields are reported in Table 3. Physical data for compounds (**8**) and (**10**) follow: (**8**), m.p. 125—126 °C (lit.,[21] 126—127 °C); ν_{NO_2} (KBr) 1 530—1 365 cm^{-1}; δ($CDCl_3$) 7.3—8.1 (10 H, m, arom): (**10**), computer simulation assisted analysis of the e.s.r. spectrum in benzene provided the following hyperfine splitting constants (gauss): a^N = 9.76, a^H = 2.61 (quartet), 0.85 (triplet), 0.52 and 0.22 (doublets). These e.s.r. data are in good agreement with those reported on α-naphthylphenyl nitroxide radical (a^N 10.8, a^H 2.4, quartet).[22] The mass spectrum showed *m/e* 264 (M^+), 249, 234, 216, 204, 145, 127, and 77 (Found: C, 77.3; H, 5.4; N, 5.3. $C_{17}H_{14}NO_2$ requires C, 77.25; H, 5.3; N, 5.3%).

Reaction of Compound (**11**) *with Compounds* (**2a,e,f**).—The reaction was carried out in the usual manner. The crude reaction product was separated from tars by elution from a short silica gel column [n-hexane–ethyl acetate (95:5) as eluant]. ^{1}H N.m.r. analysis gave the relative proportions for compounds (**12**) and (**13**) reported in Table 5. Separation of the two isomers [four in the case of (**2f**)] was performed by submitting a 0.3 g sample of the mixture to high-pressure liquid chromatography on a Cromatospac Ivon Jobin prep column [n-hexane–benzene (95:5) as eluant]. The isomers were separated in unaltered proportions, and characterized by their ^{1}H n.m.r. spectra.

The structure of 1,4-substituted isomer was assigned to compounds (**13**) on the basis of the downfield shifted H-8 signal.[23] Yields are reported in Table 5. Physical data for compounds (**12**) and (**13**) follow: (**12a**), m.p. 77—80 °C (lit.,[21] 81—82 °C); δ($CDCl_3$) 2.30 (3 H, s, CH_3) and 6.9—7.8 (6 H, m, arom): (**12e**), oil; δ($CDCl_3$) 1.30 (6 H, d, 2 CH_3, J_{CH_3CH} 7.0 Hz), 3.08 (m, 1 H, CH), and 7.3—7.9 (m, 6 H, arom); (Found: C, 72.6; H, 6.0; N, 6.5. $C_{13}H_{13}NO_2$ requires C, 72.5; H, 6.1; N, 6.5%): (**12f**), oil; δ($CDCl_3$) 1.2—2.2 (6 H, m, aliph), 2.68 (2 H, t, CH_2, $J_{CH_2CH_2}$ 8.0 Hz), 4.8—5.1 (2 H, m, $=CH_2$), 5.5—6.0 (1 H, m, –CH=), and 7.2—7.9 (6 H, m, arom) (Found: C, 75.4; H, 6.7; N, 5.2. $C_{16}H_{17}NO_2$ requires C, 75.3; H, 6.7; N, 5.5%): (**12g**), oil; δ($CDCl_3$) 0.9—2.3 (9 H, m, aliph), 2.74 (2 H, d, CH_2, J_{CH_2CH} 7.5 Hz), and 7.2—8.1 (6 H, m, arom): (Found: C, 75.2; H, 6.6; N, 5.6. $C_{16}H_{17}NO_2$ requires C, 75.3; H, 6.7; N, 5.5%): (**13a**), m.p. 69—71 °C (lit.,[21] 71—72 °C); δ($CDCl_3$) 2.44 (3 H, s, CH_3), 6.9—7.8 (5 H, m, arom), and 8.24—8.46 (1 H, m, H-8): (**13e**), oil; δ($CDCl_3$) 1.34 (6 H, d, 2 CH_3, J_{CH_3CH} 7.0 Hz), 3.70 (1 H, m, CH), 7.3—8.2 (5 H, m, arom), 8.40—8.60 (1 H, m, H-8) (Found: C. 72.3; H, 6.1; N, 6.6. $C_{13}H_{13}NO_2$ requires C, 72.5; H, 6.0; N, 6.5%): (**13f**), m.p. 26—27 °C; δ($CDCl_3$) 1.2—2.3 (6 H, m, aliph), 3.06 (2 H, t, CH_2, J_{CH_2CH} 8.0 Hz), 4.8—5.2 (2 H, m, $=CH_2$), 5.6—6.0 (1 H, m, –CH=), 7.2—8.2 (5 H, m, arom), and 8.48—8.68 (m, 1 H, H-8) (Found: C, 75.2; H, 6.8; N, 5.5. $C_{16}H_{17}NO_2$ requires C, 75.3; H, 6.7; N, 5.5%): (**13g**), oil; δ($CDCl_3$) 0.7—2.4 (9 H, m, aliph), 3.08 (2 H, d, CH_2, J_{CH_2CH} 7.5 Hz), 7.2—8.2 (5 H, m, arom), 8.50—8.68 (1 H, m, H-8) (Found: C, 75.1; H, 6.8; N, 5.4. $C_{16}H_{17}NO_2$ requires C, 75.3; H, 6.7; N, 5.5%).

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