DOI: 10.1002/ejoc.200700931

Reactions of Arenediazonium *o*-Benzenedisulfonimides with Aliphatic Triorganoindium Compounds

Margherita Barbero,[a] Silvano Cadamuro,[a] Stefano Dughera,*[a] and Giovanni Ghigo*[a]

Keywords: Indium / Amines / Diazo compounds / Nucleophilic addition / Density functional calculations

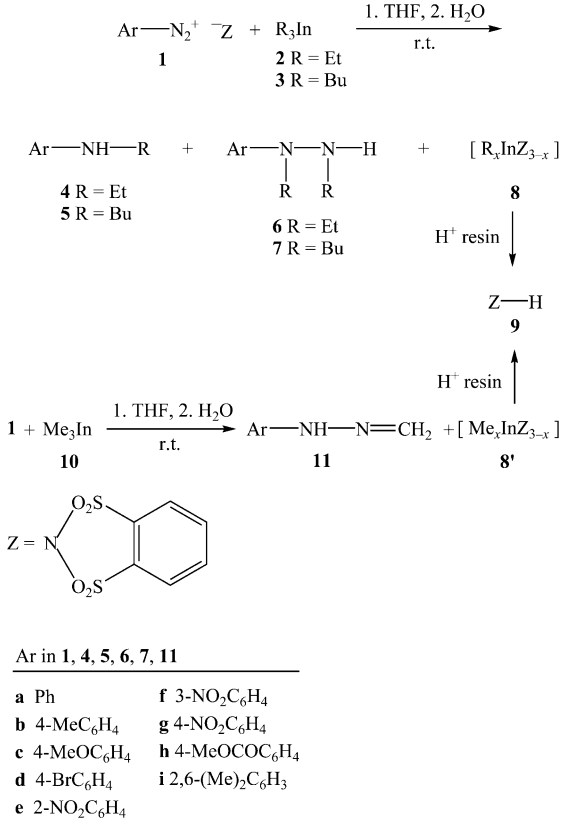
The reaction of various arenediazonium *o*-benzenedisulfonimides with aliphatic triorganoindium compounds is described. Surprisingly, with triethyl- or tributylindium we obtained *N*-ethyl- or *N*-butylanilines, respectively. This is the first case in which, at least formally, the reactive site of a diazonium salt is the nitrogen atom directly bonded to the aromatic ring. In contrast, with trimethylindium we obtained only formaldehyde (aryl)hydrazones. In order to explain the difference between trimethyl- and triethylindium we have proposed some reaction mechanisms, supported by detailed density functional (DFT) calculations. The possible role of diazene/hydrazone tautomerism initially assumed was discarded and therefore three mechanisms for the key step (nucleophilic addition of the trialkylindium to the N=N double bond of diazene) were studied. For the favoured mechanism there is a difference in the energy barriers of 2 kcal mol^{-1} between the reactions with trimethyl- and triethylindium. This difference is explained on the basis of the different C–In bond energies in the two organometallics and it is assumed to be enough to explain their different behaviour under the experimental conditions.

Introduction

Recently we reported the reactions between arenediazonium *o*-benzenedisulfonimides and aromatic triorganoindium compounds; depending on the reaction conditions, it was possible to obtain two different products, biaryls or diaryldiazenes.[1]

As a follow-up of previous research, in this paper we report a study of the reactions of arenediazonium *o*-benzenedisulfonimides **1** with aliphatic triorganoindium compounds [triethyl- (**2**) and tributylindium (**3**)]. To our great surprise, an aqueous treatment of the reaction mixtures gave, in good yields, *N*-ethyl- **4** and *N*-butylanilines **5**, respectively, and not the expected diazenes. Furthermore, with trimethylindium (**10**) we obtained formaldehyde (aryl)-hydrazones **11** and not the expected *N*-methylanilines (Scheme 1). Therefore, in order to explain these unusual results, we have proposed some reaction mechanisms, supported by detailed density functional (DFT) calculations.

Currently, the main method of preparing indium organometallics involves the reaction of indium(III) chloride with readily available lithioorganic compounds or Grignard reagents. In this way it is possible to obtain a large variety of



Scheme 1.

[a] Dipartimento di Chimica Generale ed Organica Applicata dell'Università,
Corso M. d'Azeglio 48, 10125 Torino, Italy
Fax: +39-011-6707642
E-mail: stefano.dughera@unito.it
giovanni.ghigo@unito.it

Supporting information for this article is available on the WWW under http://www.eurjoc.org or from the author.

indium organometallic compounds.[2] Moreover, they have attracted the attention of organic chemists because of the ease with which they can be prepared,[2] their remarkable reactivity[3] and low toxicity.[4] A wide variety of indium organometallics have been recently used in fundamental reactions in the field of organic synthesis with excellent results.[5]

It must be stressed that arenediazonium *o*-benzenedisulfonimides **1**[6] have several advantages over other diazonium salts, mainly due to their high stability and easy preparation, but also there are ecological and economic advantages as it is possible to recover, at the end of reactions, *o*-benzenedisulfonimide (**9**) which can be reused to prepare other salts, with.

Results and Discussion

First, we treated 4-methoxybenzenediazonium *o*-benzenedisulfonimide (**1c**) with an equimolar amount of tributylindium (**3**) at room temperature in anhydrous THF and under a continuous flow of N_2 in order to exclude moisture (Table 1, entry 1). As has been said before, we obtained *N*-butyl-4-methoxyaniline (**5c**) in a poor yield (0.05 g, 6%) with weak traces by GC-MS of 1-(4-methoxyphenyl)-2-butyldiazene (**13c**) and 1,2-dibutyl-1-(4-methoxyphenyl)hydrazine (**7c**).

The formation of **5c** was very surprising since, to the best of our knowledge, no reactions have been reported in which, at least formally, the reactive site of the diazonium salt is the nitrogen atom bonded directly to the aromatic ring.

First of all, it must be stressed that **5c** was formed only in the reaction cited above; in fact by using other common organometallics, as reported in the experimental section, **1c** did not react with tetrabutyltin, butylboronic acid or tributylborane, even in drastic conditions (collateral proof a). In contrast, with butyllithium or butylmagnesium chloride we observed only the decomposition of **1c** without obtaining any significant product (collateral proof b).

On this basis, we decided to study the reaction in more depth, first of all in order to explain the mechanism and then to improve the yield of the final products **4** or **5**. No *N*,*N*-dialkylanilines were detected or isolated, even in traces. This is very interesting since numerous procedures have been proposed for the preparation of *N*-monoalkylanilines.[7,8] However, such procedures can have drawbacks, mainly the formation of *N*,*N*-dialkylation products alongside *N*-monoalkylation products.

We made many attempts to improve the reaction yields (Table 1). The optimal reaction conditions (entry 3) involve a 1:2.5 molar ratio of reagents. Under these conditions, we recovered a good yield of **5c** (95%). Note that in entries 4 and 5 (Table 1), with a high excess of **3**, we observed an increased yield of **7c** which could be isolated and characterized.

Table 1. Trial reactions between **1c** and **3**.

Entry	Molar ratio	% yield	
	1c/3	**5c**	**7c**
1	1:1	6[a]	Tr[b]
2	1:2	51[a]	Tr[b]
3	1:2.5	95[a]	Tr[b]
4	1:3	73[c]	12[c]
5	1:5	14[c]	51[c]

[a] Yields refer to the product isolated by washing with pentane and filtering through a Büchner funnel. [b] Tr = Traces. [c] Yields refer to the pure products isolated by column chromatography. The eluent was petroleum ether/diethyl ether (9:1).

Table 2. Synthesis of *N*-alkylanilines **4** and **5**.

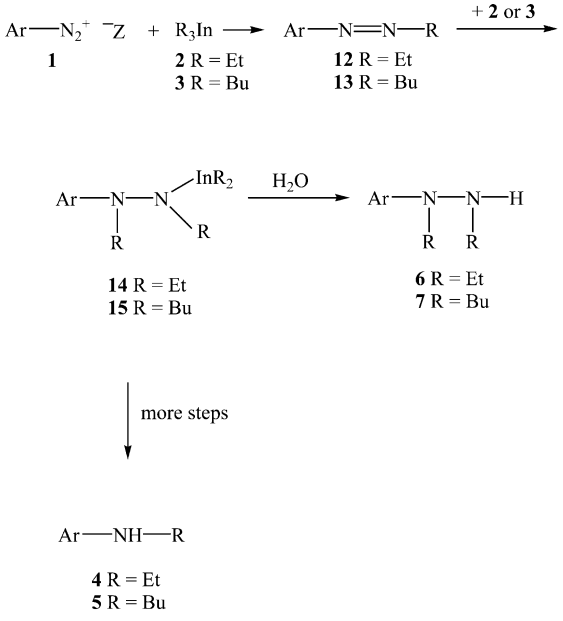
Entry	*N*-Alkylanilines			% yield[a,b]		*N*-Alkylanilines **4** and **5**	
	4, **5**	Ar	R	**4**, **5**	*m*/*z* $[M]^+$	M.p.[c] or b.p. [°C/Torr]	Lit. m.p. or b.p. [°C/Torr]
1	**4a**	Ph	Et	82	121	57–58/0.4	204/760[22]
2	**5a**	Ph	Bu	87	149	60–61/0.5	59–60/0.1[23]
3	**4b**	4-MeC_6H_4	Et	89	135	63–64/0.5	96/10.2[24]
4	**5b**	4-MeC_6H_4	Bu	93	163	70–71/0.5	74–79/0.5[25]
5	**4c**	4-$MeOC_6H_4$	Et	86	151	67–68/0.5	120–122/9[26]
6	**5c**	4-$MeOC_6H_4$	Bu	95	179	80–81/0.5	142–145/6[27]
7	**4d**	4-BrC_6H_4	Et	71	201	77–78/0.5	131–132/10[26a][d]
8	**5d**	4-BrC_6H_4	Bu	75	229	95–96/0.5	95–96/0.5[28]
9	**4e**	2-$NO_2C_6H_4$	Et	69	166	70–71/0.5	93/13.5[24]
10	**5e**	2-$NO_2C_6H_4$	Bu	78	194	81–82/0.6	162–164/8[29]
11	**4f**	3-$NO_2C_6H_4$	Et	75	166	52–53	53–54[30]
12	**5f**	3-$NO_2C_6H_4$	Bu	82	194	87–88/0.5	[30][e]
13	**4g**	4-$NO_2C_6H_4$	Et	84	166	69–70	69[31]
14	**5g**	4-$NO_2C_6H_4$	Bu	85	194	95–96	96–97[32]
15	**4h**	4-$MeOCOC_6H_4$	Et	79	179	140–141	138–139[33]
16	**5h**	4-$MeOCOC_6H_4$	Bu	92	207	104	104–105[34]
17	**4i**	2,6-$Me_2C_6H_3$	Et	71	149	62–63/0.5	51–54/0.1[35][f]
18	**5i**	2,6-$Me_2C_6H_3$	Bu	75	177	91–92/0.5	116–118/0.1[36]

[a] Yields refer to the pure products. [b] In all the reactions, traces of the corresponding diazenes **12** and **13** and hydrazines **6** and **7** are always detected in the MS analysis. [c] Crystallization solvent: MeOH. [d] No NMR spectroscopic data for product **4d** have been reported in the literature. [e] Product **5f** is known in the literature, but only the spectroscopic data have been reported. [f] No NMR spectroscopic data for product **4i** have been reported in the literature.

Having found the optimal reaction conditions, numerous and variously substituted arenediazonium *o*-benzenedisulfonimides **1** were treated with **2** or **3**. All the reactions were carried out in THF at room temperature (Scheme 1). The results are listed in Table 2. The reaction is not affected by electronic effects. In fact, **4** and **5** were obtained in high yields starting from diazonium salts bearing either electron-donating or -withdrawing groups. Moreover, it seems that the reaction is not drastically influenced by steric effects; the hindered **4i** and **5i** were obtained in moderate yields (Table 2, entries 17 and 18).

From all the reactions we also recovered *o*-benzenedisulfonimide (**9**) (about 70%). Product **9** is probably derived from hypothetical intermediates **8** (reported in brackets in Scheme 1), but these were never detected in spectral analyses. Product **9** could be recycled and used to prepare other salts **1.**

In our previous research,[9] we set up a general procedure for the preparation of *N*-monoalkylanilines by reacting (*Z*)-(*tert*-butylsulfanyl)(aryl)diazenes with various alkyllithium derivatives. We proposed a reaction mechanism that can be used, however partly, also in this case (Scheme 2).



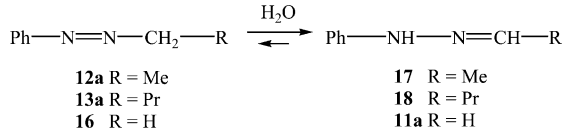
Scheme 2.

We assume that the reaction can take place through the formation of diazene **12** or **13** by electrophilic carbon-coupling between **1** and **2** or **3**. Diazene **12** or **13**, by nucleophilic addition of **2** or **3** to the N=N double bond, may give rise to intermediate **14** or **15**, which probably decomposes to afford **4** or **5**. In order to explore in depth the mechanism by which **4** or **5** form**,** further investigations are in progress.

In the same paper,[9] we reported that the reaction of (*Z*)-(*tert*-butylsulfanyl)(aryl)diazenes with methyllithium led to *N*-methylanilines, but, to our great surprise, in this research (Scheme 1) the reaction of salt **1c** with trimethylindium (**10**) led to only formaldehyde (4-methoxyphenyl)hydrazone (**11c**) in good yield; no *N*-methylaniline was found. Also, with other salts **1** we obtained the same good results, as reported in Table 3; we recovered good amounts of **9** too.

Tautomerism between diazenes and hydrazones is well known, with the latter unable to undergo nucleophilic addition. A theoretical study[10] has shown for methyldiazene and formaldehyde methylhydrazone that the most stable tautomer is formaldehyde hydrazone. At the highest level of theory, formaldehyde hydrazone is 2.0 kcal/mol more stable than methyldiazene. However, no definite and unequivocal data have been reported for more complex diazenes and hydrazones.[11]

In our case, with triethyl- and tributylindium we assume that the tautomerism is shifted towards **12a** or **13a** which can react with **2** or **3** to afford **4** or **5** (Scheme 3). On the other hand, with trimethylindium the tautomerism could be shifted towards **11a** which cannot further react with **10** to form *N*-methylaniline. In order to verify this hypothesis, we performed a theoretical study on the tautomerism involving compounds **12a** and **16**. The results (see the Supporting Information) show that in both cases the tautomers **11a** and **17** (and likely **18**) are more stable than the tautomers **16** and **12a** (and **13a**). However, the energy barrier for the intramolecular proton transfer is very high (almost



Scheme 3.

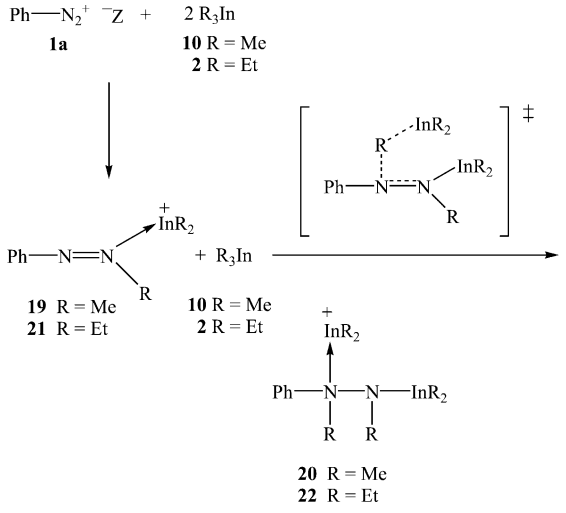
Table 3. Synthesis of formaldehyde (aryl)hydrazones **11**.

Entry	Formaldehyde (aryl)hydrazones **11**	Ar	% yield[a]	*m/z* $[M]^+$	M.p.[b] [°C]	Lit. m.p. [°C]
1	**11a**	Ph	79	120	31–32	32[37]
2	**11b**	4-MeC_6H_4	84	134	43–44	[c]
3	**11c**	4-$MeOC_6H_4$	83	150	38–39	[c]
4	**11d**	4-BrC_6H_4	89	200	77–78	[38][d]
5	**11e**	2-$NO_2C_6H_4$	76	165	87–88	85–86[39][e]
6	**11f**	3-$NO_2C_6H_4$	77	165	94–95	[c]
7	**11g**	4-$NO_2C_6H_4$	88	165	179–180	181–182[40]
8	**11h**	4-$MeOCOC_6H_4$	81	194	56–57	[c]
9	**11i**	2,6-$Me_2C_6H_3$	69	148	33–34	[c]

[a] Yields refer to the pure products. [b] Crystallization solvent: MeOH. [c] Products **11b**,**c**, **11f** and **11h**,**i** are unknown in the literature. [d] Product **11d** is known in the literature but only the spectroscopic data have been reported. [e] No NMR spectroscopic data have been reported in the literature for product **11e**.

60 kcal mol^{-1}). Such a barrier, which we assume cannot change significantly for **12** (and **13**), should prevent tautomerism in both cases. Thus, we assume that this process would take place only with the catalytic effect of water added at the end of the reaction. The explanation for the different behaviour of **10** must be found in the key step: nucleophilic addition to the N=N double bond.

Three different mechanisms for the addition were studied (see the Supporting Information). The more promising (Scheme 4, Table 4) starts from the N–In complexes formed during the electrophilic carbon-coupling in which the remaining dialkylindium cation binds to the same nitrogen atom bonded to the alkyl group. This step, studied for trimethylindium only, presents an energy barrier (**TS-1/19**) of less than 1 kcal mol^{-1} and is very exoergic and very fast. The IRC confirmed the formation of complex **19**. Complexes **19** and **21** are quite reactive towards a second trialkylindium molecule. The energy barriers for this step are 22.7 and 20.7 kcal mol^{-1}, respectively, for **TS-19/20** (Figure 1) and **TS-21/22** and differ by 2 kcal mol^{-1}. This difference is enough to make the reaction of **10** 25 times slower than the reaction of **2**. Owing to the decomposition of the diazenes and **10** (see the Exp. Sect.), this delay could be enough to prevent the addition reaction of **10**. Quenching with water, which catalyzes the tautomerism of diazene to the unreactive hydrazone, would finally stop the reaction.



Scheme 4.

Table 4. Zero-point corrected energies for the addition mechanism.[a]

Structure		E [kcal mol^{-1}]
Phenyldiazonium$^+$ + 2 $InMe_3$	**1** + 2 **10**	0.0
TS C-coupling	**TS-1/19** + **10**	0.8
N–In$^+$ complex + $InMe_3$	**19** + **10**	–48.1
TS addition	**TS-19/20**	–25.4
Adduct + $InMe_3$	**20**	–56.4
Phenyldiazonium$^+$ + $InEt_3$	**1** + 2 **2**	0.0
N–In$^+$ complex + $InEt_3$	**21** + **2**	–56.8
TS addition	**TS-21/22**	–36.1
Adduct + $InEt_3$	**22**	–64.0

[a] See Scheme 4.

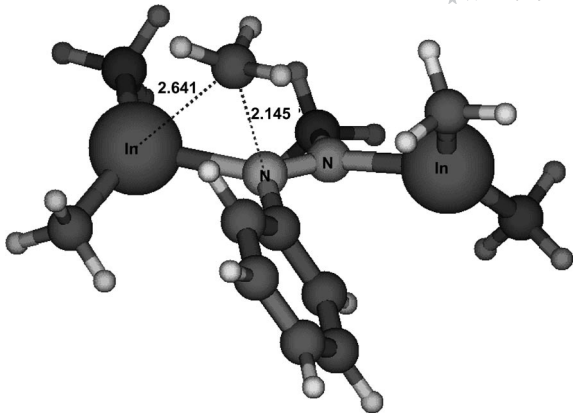


Figure 1. The transition-state structure for the third addition mechanism.

We believe that the reason for the differences in the energy barriers can be found in the different C–In bond energies in the alkylindium molecules: D_0 = 55 and 47 kcal mol^{-1} for trimethyl- and triethylindium, respectively. The energy of the transition-state structures involving the methyl group are higher because the C–In bond-breaking in **10** requires 8 kcal mol^{-1} more energy than that in **2**.

Conclusions

In conclusion, we have developed a new procedure for the synthesis of *N*-monoalkylanilines **4** or **5** or formaldehyde (aryl)hydrazones **11** in good yields. It must be emphasized that i) among the most common aliphatic organometallics, only indium organometallics **2**, **3** and **10** can yield such reactions, ii) to the best of our knowledge, no reactions of diazonium salts have been reported in the literature in which, at least formally, the reactive site is the nitrogen atom directly bonded to the aromatic ring and iii) the reaction with trimethylindium (**10**) only yields formaldehyde (aryl)hydrazones. The different behaviour of **10** has been explained on the basis of its stronger C–In bond in the organometallic. This different bond energy leads to a higher energy barrier for the nucleophilic addition step and, therefore, to a slower reaction. Decomposition of the reactants and quenching with water prevent the nucleophilic addition of **10**.

Experimental Section

General Remarks: Column chromatography and TLC were performed on Merck silica gel 60 (70–230 mesh ASTM) and GF 254, respectively. Petroleum ether (PE) refers to the fraction boiling in the range 40–70 °C. ^{1}H NMR spectra were recorded with a Bruker Avance 200 spectrometer. Mass spectra were recorded with an HP 5989B mass-selective detector connected to an HP 5890 GC, cross-linked methylsilicone capillary column. All the reactions were performed under a continuous flow of N_2 in oven-dried glassware and anhydrous THF was used as solvent. Room temperature (room temp.) is 20–25 °C. Chromatographic solvent, yields and physical and spectroscopic data of the pure (GC, GC-MS, TLC, ^{1}H NMR)

isolated *N*-alkylanilines **4** and **5** and formaldehyde (aryl)hydrazones **11** are reported in Table 2 and Table 3. The structures and purity of all the products obtained in this research were confirmed by comparison of their physical (m.p. or b.p.) and spectroscopic data with those reported in the literature.

Indium chloride, 1.6 M methyllithium solution in diethyl ether, 0.5 M ethyllithium solution in benzene/cyclohexane, 1.6 M butyllithium solution in hexanes, tetrabutyltin, butylboronic acid, 1.0 M tributylborane in diethyl ether, 2.0 M butylmagnesium chloride solution in THF and all of the amines and solvents were purchased from Aldrich. Dowex 50X8 ion-exchange resin was purchased from Fluka.

Dry arenediazonium *o*-benzenedisulfonimides **1** were prepared as described previously by us.[6c] The crude salts were virtually pure (by ^{1}H NMR spectroscopy) and were used in subsequent reactions with indium organometallics **2** and **3** without further crystallization.

CAUTION! In our laboratory there was no case of sudden decomposition during the preparation, purification or handling of salts **1**. Nevertheless it must be borne in mind that all diazonium salts in the dry state are potentially explosive. Therefore they must be carefully stored and handled.

Indium Organometallics. General Procedure: As reported in the literature,[2] a solution of indium chloride (1.11 g, 5 mmol) in dry THF (20 mL) was cooled to 0 °C under N_2. The appropriate alkyllithium derivative (15 mmol) was added dropwise over a period of 10 min. Stirring at 0 °C was continued for 45 min until the complete formation of indium organometallic derivatives. In this way, triethyl- (**2**), tributyl- (**3**) and trimethylindium (**10**) were synthesized and used directly, without isolation, in the subsequent step.

***N*-Butyl-4-methoxyaniline (5c). Typical Procedure:** 4-Methoxybenzenediazonium *o*-benzenedisulfonimide (**1c**) (5 mmol, 1.76 g) was added in one portion to a solution of tributylindium (**3**) in THF (12.5 mmol), prepared as reported above, under a N_2 flow with vigorous stirring and at room temp. The salt dissolved at once and the resultant solution became dark. Stirring at room temp. was maintained for 5 min. The completion of the reaction was confirmed by the absence of azo-coupling with 2-naphthol. GC, GC-MS and TLC (petroleum ether/diethyl ether, 9:1) analyses of the reaction mixture showed *N*-butyl-4-methoxyaniline (**5c**) {MS (EI): m/z = 179 $[M]^+$} as the major product besides small traces of (*E*)-2-butyl-1-(4-methoxyphenyl)diazene (**13c**) {MS (EI): m/z = 192 $[M]^+$} and 1,2-dibutyl-1-(4-methoxyphenyl)hydrazine (**7c**) {MS (EI): m/z = 250 $[M]^+$} as minor products. The reaction mixture was poured into diethyl ether/water (100 mL, 1:1). The aqueous layer was separated and extracted with diethyl ether (2 × 50 mL). The combined organic extracts were washed with water (2 × 50 mL), dried with Na_2SO_4 and evaporated under reduced pressure. The crude residue was washed with pentane and filtered through a Büchner funnel. The obtained solid was pure **5c** (0.85 g, 95% yield). The aqueous layer and aqueous washings were collected and the solvent evaporated under reduced pressure. The black tarry residue was passed through a column of Dowex 50X8 ion-exchange resin (1.6 g/1 g of product), eluting with water (about 50 mL). After removal of the water under reduced pressure, virtually pure (^{1}H NMR) *o*-benzenedisulfonimide (**9**) was recovered (0.78 g, 72% yield): m.p. 192–194 °C (toluene) (ref.[1] m.p. 192–194 °C). All the *N*-alkylanilines **4** and **5** reported in entries 1–18 of Table 2 were prepared according to this procedure.

***N*-Ethyl-4-bromoaniline (4d):** ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C): δ = 7.25 and 6.34 (2d, 1:1, J = 9.20 Hz, 4 H), 3.81 (br. s, 1 H), 3.00 (q, J = 7.10 Hz, 2 H), 1.03 (t, J = 7.10 Hz, 3 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$, 25 °C): δ = 146.8, 132.8, 115.9, 111.3, 36.8, 16.5 ppm.

***N*-Ethyl-2,6-dimethylaniline (4i):** ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C): δ = 6.71–6.65 (m, 2 H), 6.40–6.33 (m, 1 H), 3.85 (br. s, 1 H), 2.98 (q, J = 7.10 Hz, 2 H), 2.29 (s, 6 H), 0.99 (t, J = 7.10 Hz, 3 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$, 25 °C): δ = 144.8, 126.6, 125.9, 116.4, 38.1, 15.6, 15.0 ppm.

Formaldehyde (4-Methoxyphenyl)hydrazone (11c). Typical Procedure: Following the above procedure a solution of trimethylindium (**10**) in THF (12.5 mmol) at room temp. was added in one portion with vigorous stirring to 4-methoxybenzenediazonium *o*-benzenedisulfonimide (**1c**, 5 mmol, 1.76 g). The salt dissolved at once and the resultant solution became very dark. Stirring at room temp. was maintained for 5 min until a test for azo-coupling with 2-naphthol proved negative. GC, GC-MS and TLC (petroleum ether/diethyl ether, 9:1) analyses of the reaction mixture showed formaldehyde (4-methoxyphenyl)hydrazone (**11c**) {MS (EI): m/z = 150 $[M]^+$} as the sole product. The above work-up furnished a crude residue that was washed with pentane and filtered through a Büchner funnel. The obtained solid was pure **11c** (0.62 g, 83% yield). ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C): δ = 7.96 (br. s, 1 H), 6.83 (d, J = 11.18 Hz, 1 H), 6.75 and 6.55 (2d, 1:1, J = 9.19 Hz, 4 H), 6.40 (d, J = 11.18 Hz, 1 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$, 25 °C): δ = 154.8, 152.8, 135.6, 117.9, 114.9, 56.8 ppm. $C_8H_{10}N_2O$ (150.18): calcd. C 63.98, H 6.71, N 18.65; found C 64.05, H 6.63, N 18.72. Also, in this case, after the usual work-up, *o*-benzenedisulfonimide (**9**) (0.74 g, 68% yield) was recovered. We recovered **11c** in a lower yield (0.45 g, 60%) when the reaction time at room temp. was lengthened to 2 h; we recovered only tars when reaction time at room temp. was increased to 8 h.

All the formaldehyde (aryl)hydrazones **11** reported in entries 1–9 of Table 3 were prepared according to the above procedure.

Formaldehyde (4-Tolyl)hydrazone (11b): ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C): δ = 7.99 (br. s, 1 H), 6.95 (d, J = 8.25 Hz, 2 H), 6.86 (d, J = 11.18 Hz, 1 H), 6.52 (d, J = 8.25 Hz, 2 H), 6.37 (d, J = 11.18 Hz, 1 H), 2.33 (s, 3 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$, 25 °C): δ = 154.5, 142.8, 129.7, 129.1, 115.9, 26.7 ppm. $C_8H_{10}N_2$ (134.18): calcd. C 71.61, H 7.51, N 20.88; found C 71.65, H 7.58, N 20.77.

Formaldehyde (2-Nitrophenyl)hydrazone (11e): ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C): δ = 8.14–8.11 (m, 1 H), 7.94 (br. s, 1 H), 7.58–7.54 (m, 1 H), 6.98–6.90 (m, 2 H), 6.85 and 6.38 (2d, 1:1, J = 11.18 Hz, 2 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$, 25 °C): δ = 154.7, 144.2, 136.7, 135.9, 122.3, 119.9, 117.4 ppm.

Formaldehyde (3-Nitrophenyl)hydrazone (11f): ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C): δ = 7.98 (br. s, 1 H), 7.67–7.57 (m, 2 H), 7.48–7.43 (m, 1 H), 7.08–7.04 (m, 1 H), 6.87 and 6.41 (2d, 1:1, J = 11.18 Hz, 4 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$, 25 °C): δ = 154.9, 149.9, 145.1, 130.9, 122.3, 111.7, 110.4 ppm. $C_8H_{10}N_2$ (165.15): calcd. C 50.91, H 4.27, N 25.44; found C 50.65, H 4.28, N 25.47.

Methyl 4-(2-Methylidenehydrazono)benzoate (11h): ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C): δ = 8.00 (br. s, 1 H), 7.91 (d, J = 8.85 Hz, 2 H), 6.86 (d, J = 11.18 Hz, 2 H), 6.80 (d, J = 8.85 Hz, 2 H), 6.40 (d, J = 11.18 Hz, 2 H), 3.89 (s, 3 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$, 25 °C): δ = 166.6, 154.6, 147.5, 130.8, 121.3, 115.7, 52.5 ppm. $C_9H_{10}N_2O_2$ (178.19): calcd. C 60.66, H 5.66, N 15.72; found C 60.74, H 5.68, N 15.79.

Formaldehyde (2,6-Dimethylphenyl)hydrazone (11i): ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C): δ = 8.01 (br. s, 1 H), 6.86 (d, J =

11.18 Hz, 2 H), 6.81–6.79 (m, 2 H), 6.51–6.47 (m, 1 H), 6.36 (d, *J* = 11.18 Hz, 2 H), 2.29 (s, 6 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$, 25 °C): δ = 154.8, 148.5, 128.6, 126.1, 117.9, 15.9 ppm. $C_9H_{12}N_2$ (148.21): calcd. C 72.94, H 8.16, N 18.90; found C 73.01, H 8.14, N 18.85.

Trial Reactions: All the reactions reported in Table 1 (entries 1–5) were carried out according to the general procedure described above, treating 4-methoxybenzenediazonium *o*-benzenedisulfonimide (**1c**) with tributylindium (**3**) (5 mmol) at room temp. with various reagent molar ratios. In entries 1–3 the crude residues were washed with pentane and filtered through a Büchner funnel. In entries 4 and 5 the crude residues were purified by chromatography on a short column, eluting with petroleum ether/diethyl ether (9:1). The first eluted product was 1,2-dibutyl-1-(4-methoxyphenyl)hydrazine (**7c**). Details are reported in Table 1.

1,2-Dibutyl-1-(4-methoxyphenyl)hydrazine (7c): Viscous colourless oil. ^{1}H NMR (200 MHz, $CDCl_3$, 25 °C): δ = 6.73 and 6.58 (2 d, 1:1, *J* = 9.00 Hz, 4 H), 3.85 (s, 3 H), 3.00 (t, *J* = 7.00 Hz, 2 H), 2.85 (t, *J* = 7.00 Hz, 2 H), 1.58–1.45 (m, 4 H), 1.38–1.29 (m, 4 H), 1.01–0.95 (m, 6 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$, 25 °C): δ = 149.8, 139.7, 113.9, 58.3, 55.7, 48.9, 30.2, 29.7, 20.4, 20.2, 13.5 ppm. MS (EI): *m*/*z* = 250 $[M]^+$. $C_{15}H_{26}N_2O$ (250.38): calcd. C 71.96, H 10.47, N 11.19; found C 71.99, H 10.42, N 11.21.

Collateral Proof a: 4-Methoxybenzenediazonium *o*-benzenedisulfonimide (**1c**) (5 mmol, 1.77 g) in THF (20 mL) was added in one portion to a solution of tetrabutyltin, butylboronic acid or 1.0 M tributylborane in diethyl ether (15 mmol, 5.20 g, 1.53 g or 15 mL) under vigorous stirring at room temp. The obtained suspension was stirred at room temp. for 24 h. A test for azo-coupling with 2-naphthol was positive. The suspension was then refluxed for 8 h but still a test for azo-coupling was positive. The unreacted 4-methoxybenzenediazonium *o*-benzenedisulfonimide (**1c**) was recovered by filtration through a Buchner funnel.

Collateral Proof b: THF (20 mL) was added to a 2.0 M butylmagnesium chloride solution in THF (15 mmol 7.5 mL) or a 1.6 M butyllithium solution in hexanes (15 mmol, 9.4 mL). Then, 4-methoxybenzenediazonium *o*-benzenedisulfonimide (**1c**, 5 mmol, 1.77 g) was added in one portion at room temp. with vigorous stirring. The salt dissolved at once and the resultant solution became very dark. Stirring at room temp. was maintained for 5 min until a test for azo-coupling with 2-naphthol proved negative. GC, GC-MS and TLC (petroleum ether/diethyl ether, 9:1) analyses of the reaction mixture showed the presence of 4-methoxybenzene as the only product. After the usual work-up only tars were recovered.

Theoretical Methods: The stable and transition-state structures (TS) were optimized by density functional theory (DFT),[12] making use of the composite functional B3LYP[13] with Becke's exchange functional[14] and Lee, Yang and Parr's gradient-corrected correlation functional.[15] This functional is of widespread use and, even if prone to underestimate some reaction barriers, has generally performed well as regards geometries and energetics.[16] This method was used with a correlation-consistent polarized double-zeta (cc-pVDZ) basis set for H, C and N atoms[17] and a correlation-consistent basis set in conjunction with small-core relativistic pseudopotentials for the indium atom.[18] The nature of the critical points was checked by vibrational analysis[19] and in some cases an IRC calculation[20] helped to confirm the connection with the adjacent energy minimum.

All calculations were carried out by using the GAUSSIAN 03 system of programs.[21]

Supporting Information (see also the footnote on the first page of this article): Total (a.u.) and relative (kcal mol^{-1}) electronic and zero-point corrected (ZPE) energies.

Acknowledgments

This work was supported by the Ministero dell'Università e Ricerca and by the University of Torino.

[1] M. Barbero, S. Cadamuro, S. Dughera, C. Giaveno, *Eur. J. Org. Chem.* **2006**, 4884–4890.
[2] M. A. Pena, J. Perez Sestelo, L. A. Sarandeses, *Synthesis* **2003**, 780–784.
[3] a) P. Cintas, *Synlett* **1995**, 1087–1096, and references cited therein; b) J. A. Marshall, *Chemtracts: Org. Chem.* **1997**, *10*, 481–496; c) C.-J. Li, T.-H. Chan, *Organic Reactions in Aqueous Media*, Wiley, New York, **1997**, pp. 64–114.
[4] L. A. Paquette in *Green Chemistry, Frontiers in Benign Chemical Synthesis and Processing* (Eds.: P. T. Anastas, T. C. Williamson), Oxford University Press, Oxford, **1998**, pp. 250–264.
[5] a) I. Perez, J. Perez Sestelo, M. A. Maestro, A. Mourinho, L. A. Sarandeses, *J. Org. Chem.* **1998**, *63*, 10074–10076; b) S. Araki, K. Shimizu, S.-J. Jin, Y. Butsugan, *J. Chem. Soc. Chem. Commun.* **1991**, 824–825; c) S. Araki, A. Imai, K. Shimizu, M. Yamada, A. Mori, Y. Butsugan, *J. Org. Chem.* **1995**, *60*, 1841–1847; d) N. Fujiwara, Y. Yamamoto, *J. Org. Chem.* **1999**, *64*, 4095–4101; e) E. Klaps, W. Schmid, *J. Org. Chem.* **1999**, *64*, 7537–7546; f) K. Takami, H. Yorimitsu, K. Oshima, *Org. Lett.* **2002**, *4*, 2993–2995; g) D. Rodriguez, J. Perez Sestelo, L. A. Sarandeses, *J. Org. Chem.* **2003**, *68*, 2518–2520; h) I. Perez, J. Perez Sestelo, L. A. Sarandeses, *J. Am. Chem. Soc.* **2001**, *123*, 4155–4160; i) I. Perez, J. Perez Sestelo, L. A. Sarandeses, *Org. Lett.* **1999**, *1*, 1267–1269; j) D. Rodriguez, J. Perez Sestelo, L. A. Sarandeses, *J. Org. Chem.* **2004**, *69*, 8136–8139; k) M. A. Pena, I. Perez, J. Perez Sestelo, L. A. Sarandeses, *Chem. Commun.* **2002**, 2246–2247; l) M. A. Pena, J. Perez Sestelo, L. A. Sarandeses, *Synthesis* **2005**, 485–492; m) E. Font-Sanchis, F. J. Cespedes-Guirao, A. Sastre-Santos, F. Fernandez-Lazaro, *J. Org. Chem.* **2007**, *72*, 3589–3591.
[6] a) S. Dughera, *Synthesis* **2006**, 1117–1124, and references cited therein; b) E. Artuso, M. Barbero, I. Degani, S. Dughera, R. Fochi, *Tetrahedron* **2006**, *62*, 3146–3157, and references cited therein; c) M. Barbero, I. Degani, S. Dughera, R. Fochi, P. Perracino, *Synthesis* **1998**, 1235–1237.
[7] R. N. Salvatore, C. H. Yoon, K. W. Jung, *Tetrahedron* **2001**, *57*, 7785–7811, and references cited therein.
[8] For some recent examples on the *N*-monoalkylation of anilines, see: a) S. Naskar, M. Bhattacharjee, *Tetrahedron Lett.* **2007**, *48*, 3367–3370; b) W. J. Ebenezer, M. G. Hutchings, K. Jones, D. A. Lambert, I. Watt, *Tetrahedron Lett.* **2007**, *48*, 1641–1643; c) J.-H. Kim, M.-S. Park, *Yakhak Hoechi* **2005**, *49*, 162–167 [*Chem. Abstr.* **2006**, *144*, 212472]; d) J. L. Romera, J. M. Cid, A. A. Trabanco, *Tetrahedron Lett.* **2004**, *45*, 8797–8800; e) H. Sajiki, T. Ikawa, K. Hirota, *Org. Lett.* **2004**, *6*, 4977–4980; f) M. Selva, P. Tundo, A. Perosa, *J. Org. Chem.* **2001**, *66*, 677–680; g) C. S. Cho, J. S. Kim, H. S. Kim, T. J. Kim, S. C. Shim, *Synth. Commun.* **2001**, *31*, 3791–3797.
[9] M. Barbero, I. Degani, S. Dughera, R. Fochi, *Synthesis* **2003**, 742–750.
[10] Z. A. Tomasic, G. E. Scuseria, *Chem. Phys. Lett.* **1990**, *170*, 21–25.
[11] a) A. J. Bellamy, R. D. Guthrie, *J. Chem. Soc.* **1965**, 2788–2795, and references cited therein; b) A. J. Bellamy, R. D. Guthrie, *J. Chem. Soc.* **1965**, 3528–3533, and references cited therein; c) A. J. Bellamy, R. D. Guthrie, C. J. F. Chittenden, *J. Chem. Soc.* **1966**, 1989–1993, and references cited therein.

[12] R. G. Parr, W. Yang, *Density Functional Theory of Atoms and Molecules*, Oxford University Press, New York, **1989**.
[13] a) A. D. Becke, *J. Chem. Phys.* **1993**, *98*, 5648–5652; b) W. Koch, M. C. Holthausen, *A Chemist's Guide to Density Functional Theory*, Wiley, Weinheim, **2000**, ch. 6.
[14] A. D. Becke, *Phys. Rev. A* **1988**, *38*, 3098–3100.
[15] C. Lee, W. Yang, R. G. Parr, *Phys. Rev. B* **1988**, *37*, 785–789.
[16] W. Jensen, *Introduction to Computational Chemistry*, Wiley, Chichester, **1999**, ch. 6.
[17] T. H. Dunning, *J. Chem. Phys.* **1989**, *90*, 1007–1023.
[18] K. A. Peterson, D. Figgen, E. Goll, H. Stoll, M. Dolg, *J. Chem. Phys.* **2003**, *119*, 11113–11123.
[19] Reaction enthalpies and free energies have been computed as outlined, for instance, in: J. B. Foresman, Æ. Frisch, *Exploring Chemistry with Electronic Structure Methods*, Gaussian, Inc., Pittsburgh, PA, **1996**, pp.166–168.
[20] C. Gonzalez, H. B. Schlegel, *J. Chem. Phys.* **1990**, *94*, 5523–5527.
[21] M. J. Frisch, G. W. Trucks, H. B. Schlegel, G. E. Scuseria, M. A. Robb, J. R. Cheeseman, J. A. Montgomery, Jr., T. Vreven, K. N. Kudin, J. C. Burant, J. M. Millam, S. S. Iyengar, J. Tomasi, V. Barone, B. Mennucci, M. Cossi, G. Scalmani, N. Rega, G. A. Petersson, H. Nakatsuji, M. Hada, M. Ehara, K. Toyota, R. Fukuda, J. Hasegawa, M. Ishida, T. Nakajima, Y. Honda, O. Kitao, H. Nakai, M. Klene, X. Li, J. E. Knox, H. P. Hratchian, J. B. Cross, V. Bakken, C. Adamo, J. Jaramillo, R. Gomperts, R. E. Stratmann, O. Yazyev, A. J. Austin, R. Cammi, C. Pomelli, J. W. Ochterski, P. Y. Ayala, K. Morokuma, G. A. Voth, P. Salvador, J. J. Dannenberg, V. G. Zakrzewski, S. Dapprich, A. D. Daniels, M. C. Strain, O. Farkas, D. K. Malick, A. D. Rabuck, K. Raghavachari, J. B. Foresman, J. V. Ortiz, Q. Cui, A. G. Baboul, S. Clifford, J. Cioslowski, B. B. Stefanov, G. Liu, A. Liashenko, P. Piskorz, I. Komaromi, R. L. Martin, D. J. Fox, T. Keith, M. A. Al-Laham, C. Y. Peng, A. Nanayakkara, M. Challacombe, P. M. W. Gill, B. Johnson, W. Chen, M. W. Wong, C. Gonzalez, J. A. Pople, *GAUSSIAN 03*, Gaussian, Inc., Wallingford CT, **2004**.
[22] a) J. Barluenga, J. M. Concellon, G. Asensio, *Synthesis* **1975**, 467–469 (b.p.); b) J. J. Eisch, J. F. McNulty, X. Shi, *J. Org. Chem.* **1994**, *59*, 7–9 (NMR spectroscopic data).
[23] J. Barluenga, F. J. Fanañas, J. Villamaña, M. Yus, *J. Org. Chem.* **1982**, *47*, 1560–1564 (b.p. and NMR spectroscopic data).
[24] G. Verardo, A. G. Giumanini, P. Strazzolini, M. Poiana, *Synthesis* **1993**, 121–125 (b.p. and NMR spectroscopic data).
[25] Y. Watanabe, Y. Tsuji, H. Ige, Y. Ohsugi, T. Ohta, *J. Org. Chem.* **1984**, *49*, 3359–3363 (b.p. and NMR spectroscopic data).
[26] a) R. E. Lyle, H. J. Troscianiec, *J. Org. Chem.* **1955**, *20*, 1757–1760 (b.p.); b) M. Ortiz-Marciales, L. D. Rivera, M. De Jesus, S. Espinosa, J. A. Benjamin, O. E. Casanova, I. G. Figueroa, S. Rodriguez, W. Correa, *J. Org. Chem.* **2005**, *70*, 10132–10134 (NMR spectroscopic data).
[27] W. S. Emerson, W. D. J. Robb, *J. Am. Chem. Soc.* **1939**, *61*, 3145–3148 (b.p.); NMR spectroscopic data are reported in ref.[26b]
[28] Bp and NMR spectroscopic data are reported in ref.[9]
[29] a) M. Gladys, W. R. Knappe, *Chem. Ber.* **1974**, *107*, 3568–3573 (b.p.); b) K. Okano, H. Tokuyama, T. Fukuyama, *Org. Lett.* **2003**, *5*, 4987–4990 (NMR spectroscopic data).
[30] A. R. Katritzky, B. Rachwal, S. Rachwal, *Recl. Trav. Chim. Pays-Bas* **1990**, *109*, 337–345 (m.p. and NMR spectroscopic data for product **4f**; NMR spectroscopic data for product **5f**).
[31] K. Haga, M. Oohashi, R. Kaneko, *Bull. Chem. Soc. Jpn.* **1984**, *57*, 1586–1590 (m.p.); NMR spectroscopic data are reported in ref.[25]
[32] M.p. and NMR spectroscopic data are reported in ref.[29b]
[33] a) A. R. Surrey, H. F. Hammer, *J. Am. Chem. Soc.* **1944**, *66*, 2127–2128 (m.p.); b) M. J. Kornet, P. A. Thio, S. L. Tan, *J. Org. Chem.* **1968**, *33*, 3637–3639 (NMR spectroscopic data).
[34] M.p. are reported in ref.[33a] and NMR spectroscopic data are reported in ref.[9]
[35] P. D. Mc Master, E. W. Byrnes, H. S. Feldman, H. Bertil, P. A. Tenthorey, *J. Med. Chem.* **1979**, *22*, 1177–1182 (b.p.).
[36] a) M. Matter, A. Rossi, H. v. Sprecher, US Patent 2769838, **1958** [*Chem. Abstr.* **1958**, *52*, 6736]; b) A. S. Abd-El-Aziz, C. C. Lee, A. Piorko, R. G. Sutherland, *J. Organomet. Chem.* **1988**, *348*, 95–107 (NMR spectroscopic data).
[37] a) S. R. Johns, J. A. Lamberton, E. R. Nelson, *Aust. J. Chem.* **1971**, *24*, 1859–1871 (m.p.); b) J. Arriau, J. P. Campillo, J. Deschamps, G. Tarrago, R. Jacquier, *Bull. Soc. Chim. Fr.* **1973**, 1398–1400 (NMR spectroscopic data).
[38] S. R. Johns, J. A. Lamberton, E. R. Nelson, *Aust. J. Chem.* **1973**, *26*, 1297–1305 (NMR spectroscopic data).
[39] F. Arndt, W. Partale, *Ber. Dtsch. Chem. Ges.* **1927**, *60*, 446–456 (m.p.).
[40] M.p. are reported in ref.[37a]: B. L. Shapiro, S. J. Ebersole, G. J. Karabatsos, F. M. Mane, S. L. Manatt, *J. Am. Chem. Soc.* **1963**, *85*, 4041–4042 (NMR spectroscopic data).

Received: October 1, 2007
Published Online: December 11, 2007

