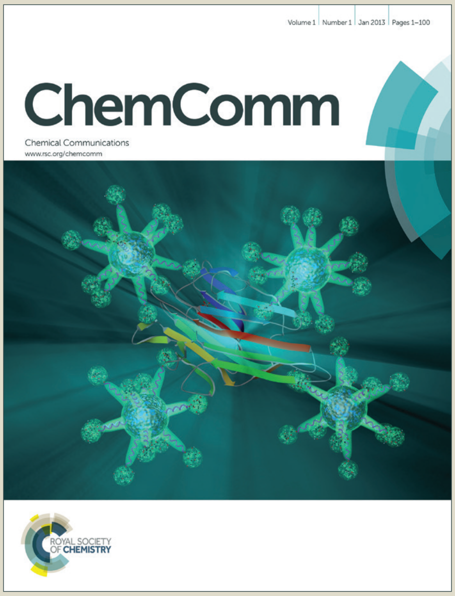
ChemComm

This article can be cited before page numbers have been issued, to do this please use: G. Rauch and S. Hoeger, *Chem. Commun.*, 2014, DOI: 10.1039/C4CC02124J.



Chemical Communications ChemComm

Dynamic Article Links ►

Cite this: DOI: 10.1039/c0xx00000x

www.rsc.org/xxxxxx

View Article Online
DOI: 10.1039/C4CC02124J

ARTICLE TYPE

# N-Alkylated and N,N-Dialkylated 1,6-Diaminoperylene Diimides *via* Copper Catalyzed Direct Aromatic Amination

**Gesche Rauch and Sigurd Höger***

***Dedicated to Professor Fritz Vögtle on the occasion of his 75th birthday***

***Received (in XXX, XXX) Xth XXXXXXXXX 20XX, Accepted Xth XXXXXXXXX 20XX***
**DOI: 10.1039/b000000x**

**Perylene diimides (PDIs) and naphthylene diimides (NDIs) can be efficiently aminated with primary or secondary amines under mild conditions using Cu(II) salts as catalysts and air as oxidant. Depending on the substrate and the amine, yields over 80 % can be obtained by simply stirring the reaction mixture at room temperature for one hour.**

Perylene diimides (PDIs) have outstanding physical properties such as strong absorption, high fluorescent yields and thermal as well as photochemical stability and are important chromophores in dye chemistry and electronic devices like photovoltaic cells and light emitting diodes (OLEDS).[1-4] Variations of the perylene, e.g. by core expansion along or perpendicular to the molecule axes,[5] or introduction of oxy or amino substituents at the core alter the physicochemical properties and the aggregation behavior of the dyes, thus expanding possible application.[6-10] Core substitutions are usually performed in two steps; the halogenation of the bay position is followed by a nucleophilic substitution with N or O nucleophiles.[11] If only two bay positions are substituted, the separation of regioisomers (1,6 and 1,7 disubstituted products are generally obtained in a 1:3 to 1:4 ratio) is sometimes tedious. Nevertheless, e. g. green 1,7-bis-(dialkylamino) PDIs and blue 1,6-bis-(dialkylamino) PDIs can be obtained in pure form.[12, 13] An alternative route is a nitration in the first step followed by an *ipso*-substitution of the nitro group.[14] In this case also a twofold amination in 1- and 6-position starting from a mono nitro PDI was reported, although in low yield. Depending on the reaction conditions, or alternatively by reduction of the nitro group and subsequent alkylation, also mono(dialkylamino) PDIs are accessible. The high interest in PDI derivatives lead also to increased activities in the search for direct core functionalization *via* C-H activation to circumvent the halogenation or nitration step. The tetra borolation,[15] tetra arylation[16] and tetra alkylation[17] of PDIs with Ru-complexes as catalyst are described in the 2,5,8,11-positions. Furthermore, a mono alkylation in bay position of PDIs is reported *via* catalytic C-H activation with Pd-complexes[18] and a catalyst-free mono- and diamination at the 2- and 2,11-position, respectively, was proposed recently.[19] However, to the best of our knowledge, aminations of PDIs in the bay position without prior functionalization have not been described so far.

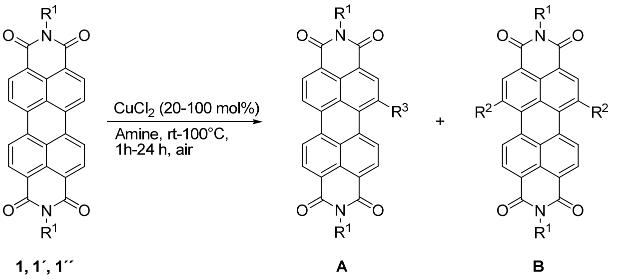
Herein, we describe a new synthetic route towards N-alkylated and N,N-dialkylated 1-amino and 1,6-diamino PDIs in one step starting from the unsubstituted PDIs (in the following we will describe the products simply as 1-amino- and 1,6-diamino PDIs and ignore the alkyl groups at the amino group).[20] The reaction is achieved by simply stirring the corresponding PDI in the amine with copper(II) salts as catalysts and oxygen (air) as oxidant (Scheme 1). PDIs react with primary amines, secondary amines, morpholine and 1-methylpiperazine in moderate to excellent yields to 1-amino PDIs or to 1,6-diamino PDIs. In contrast to previous protocols by which the diamino substituted compounds are obtained *via* bromination/nucleophilic substitution as a mixture of the 1,6- and 1,7-regioisomers (in a ratio of 1:3 to 1:4),[12, 13] we obtain the twofold amination selectively in the 1,6-position. We investigated three different PDIs with branched alkyl (**1**) and aromatic (**1´**, **1´´**) substituents at the imide nitrogen (compound numbers without apostrophe bear the alkyl substituents, compounds with one apostrophe the dibromo-tert-butyl phenyl groups and compounds with two apostrophes the di-tert-butyl phenyl groups).

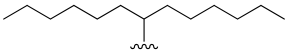
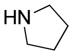
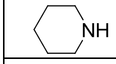
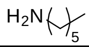
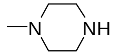
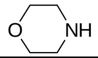
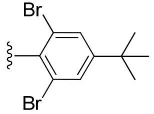
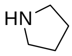
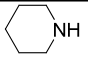
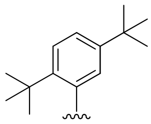
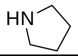
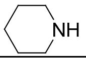
In all cases are either the 1-substituted products (denoted as a) or the 1,6-disubstituted products (denoted as b), or mixtures of them are formed. No other regioisomers could be identified. The product structure is unambiguously proven by spectroscopic and spectrometric methods and comparison of the spectra of 1,7 and 1,6 disubstituted PDIs that were independently synthesized according to literature procedures (see SI).

The high interest in direct aryl aminations prompted us to investigate if other metal salts also catalyze the reaction. However, neither iron ($Fe(acac)_3$) nor palladium ($Pd(PPh_3)_2Cl_2$) salts lead under our conditions to an observable conversion. Best results are achieved with Cu(II) salts, although the reaction worked with Cu(I) salts and copper powder, too, in all cases in the presence of air. The counter ion has no effect on the reaction, as different Cu(II) salts gave similar yields (Table 1, product **2b**).

The yields, reaction times and reaction temperatures depend on the PDI derivative and the specific amines (see Table 1). Cyclic secondary amines like pyrrolidine and piperdine gave the highest yields of disubstituted products. For example, pyrrolidine lead to the formation of the corresponding 1,6-diamino substituted PDI **3b** at room temperature within one hour in very good yields up to 82 %.

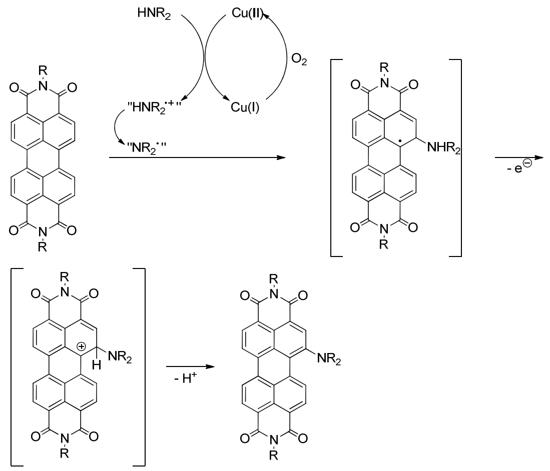
View Article Online
DOI: 10.1039/C4CC02124J



| | | | | |
|---|---|---|---|---|
| **1 R=**  | | | | |
| Amine | T [°C] | T [°C] | **A** | **B** |
|  | 95 °C | 24 h | - | **2b**<br>**(49 %, $CuCl_2$)**<br>**(52 %, $Cu(OAc)_2$)** |
|  | 60 °C | 24 h | **3a (60 %)** | **3b (28 %)** |
|  | 60 °C | 48 h | **4a (9 %)** | - |
|  | 110 °C | 24 h | **5a (25 %)** | - |
|  | 110 °C | 24 h | **6a (18 %)** | - |
| **1´ R=**  | | | | |
| Amine | T [°C] | T [°C] | **A** | **B** |
|  | rt | 1 h | - | **2´b (82 %)** |
|  | rt | 24 h | - | **3´b (89 %)** |
| **1´´ R=**  | | | | |
| Amine | T [°C] | T [°C] | **A** | **B** |
|  | rt | 3 h | - | **2´´b (68 %)** |
|  | 80 °C | 14 h | **3´´a (56 %)** | **3´´b (7 %)** |

**Scheme 1 and Table 1** N-alkylated (denoted without prime) PDIs (**1**) and N-arylated PDIs (denoted with one or two primes, respectively; e.g. **1´**, **1´´**) give the mono (denoted as **a**) or diamino (denoted as **b**) PDIs, depending on the PDI and the respective amine.

With piperidine we obtained a mixture of mono and diamino DPIs, depending on the substrate. **1** gave mainly the monosubstituted product **3a**. **1´** leads selectively to the 1,6-diamino substituted PDI in excellent yield. **1´´** gave the 1-amino PDI **3´´a** as main product and the 1,6-diamino PDI **3´´c** in only small amounts. 1-hexylamine, morpholine and 1-methylpiperazine did not give clean reactions with either of the PDIs, and the monoamino substituted products were obtained in only moderate yields.[21] In all cases, the compounds were purified by column chromatography and subsequently by recycling GPC (recGPC), when necessary. Although only a limited amount of different compounds were prepared, it became clear that PDIs with aromatic substituents at the imide nitrogen seem to be more reactive towards the formation of disubstituted products and that pyrrolidine and piperidine are favorable amines for that transformation.



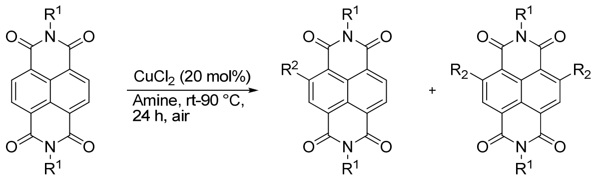
**Scheme 2** Proposed simplified mechanism for the perylene amination.

At present, the exact mechanism for this transformation is not clear. After our initial experiments we first speculated that the Cu(II) might be coordinated to the imide oxygen and activate the nearby CH-bond. However, this assumption does not agree with the substitution pattern in the products. At present we propose a non-coordinative mechanism at the less electron deficient bay positions. Cu(II) is coordinated by the amine[22] and oxidizes it to the ammonium radical which is acidic enough to be deprotonated in the amine solvent.[23] Addition of the amino radical to the PDIs[24] followed by a proton coupled electron transfer (PCET) leads to the aminoperylene.[25, 26] Reoxidation of the Cu(I) to Cu(II) is performed by oxygene.

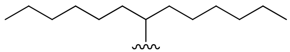
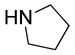
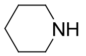
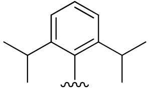
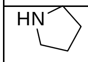
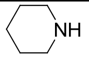
We also tried to expand the protocol to other substrates. Electron deficient aromatics as *N*-butylphthalimide and benzophenone did not give any detectable reaction under the condition we used so far. Also toluene and naphthalenes (2,7-dimethylnaphthaline) did not react. However, our protocol allows the functionalization of naphthalene diimids (NDI) with secondary amines in core position in one synthetic step (Scheme 4). NDIs are also of significant interest, e.g. for organic electronics[2] and in supramolecular chemistry.[27, 28] As for the perylene dyes, core-substituted NDIs are mostly obtained in a two-step synthesis, either after chlorination[29] or bromination.[30] Only few examples of aminated NDIs are described,[19, 31-35] and the products of the two-step synthesis are generally substituted in the 2 and 6 position. Contrary, 2,7-diamino substituted NDIs are just briefly explored.[36] By applying the previous protocol, mono and disubstituted NDIs are obtainable in which the disubstitution leads exclusively to the 2,7-diamino compounds. An optimization of the reaction conditions has not been performed so far and reaction yields are yet only moderate (12 % and 36 % for double amination). However, the simple reaction conditions already give access to dyes which are otherwise difficult to prepare. The lower

View Article Online
DOI: 10.1039/C4CC02124J

yield in the case of the NDIs and the absence of any reaction in the case of the non-condensed aromatics indicate that the reaction works best for large electron-deficient π-systems.



**7. 7´** **A** **B**

| | | | | |
|---|---|---|---|---|
| **7 R=** |  | | | |
| Amine | T [°C] | T [°C] | **A** | **B** |
|  | rt | 24 h | **8a (22 %)** | **8b (12 %)** |
|  | 90 °C | 24 h | **9a (6 %)** | - |
| **7´ R=** |  | | | |
| Amine | T [°C] | T [°C] | **A** | **B** |
|  | rt | 24 h | **8´a (20 %)** | **8´b (36 %)** |
|  | 60 °C | 24 h | **9´b (19 %)** | - |

**Scheme 3 and Table 2** Copper catalyzed amination of NDIs.

## Conclusions

In summary, we have demonstrated a new synthetic route to receive amino substituted PDIs and NDIs. The synthesis requires rather low cost copper salts as catalysts, is easy to perform since it is neither air nor moisture sensitive, is fast and, depending on the specific product, gives high compound yields. Since the disubstituted products are no mixtures of isomers, purification is much simpler than in the classical route *via* bromination/substitution. The selectivity of the reaction protocol allows the amination of the PDIs and NDIs in the presence of other aromatic substituents at the imide nitrogen and thus may give access to amino substituted PDIs (NDIs) that are parts of more complex structures containing several other aromatic elements. Although the exact mechanism is not clear at present, we speculate about a radical aromatic substitution reaction mechanism and not about a CH activation mechanism. Further studies in this direction are in progress.

## Notes and references

*G. Rauch, Prof. Dr. S. Höger, Kekulé-Institut für Organische Chemie und Biochemie, Rheinische Friedrich-Wilhelms-Universität Bonn, Gerhard-Domagk-Strasse 1, 53121 Bonn (Germany). Fax: +49 228 735662; Tel: +49 228 736127; E-mail: hoeger@uni-bonn.de*

Financial Support by the Volkswagenstiftung is gratefully acknowledged.

† Electronic Supplementary Information (ESI) available: [details of any supplementary information available should be included here]. See DOI: 10.1039/b000000x/

1. E. Kozma and M. Catellani, *Dyes Pigm.*, 2013, **98**, 160-179.
2. X. Zhan, A. Facchetti, S. Barlow, T. J. Marks, M. A. Ratner, M. R. Wasielewski and S. R. Marder, *Adv. Mater.*, 2011, **23**, 268-284.
3. C. Li and H. Wonneberger, *Adv. Mater.*, 2012, **24**, 613-636.
4. C. Huang, S. Barlow and S. R. Marder, *J. Org. Chem.*, 2011, **76**, 2386-2407.
5. T. Weil, T. Vosch, J. Hofkens, K. Peneva and K. Müllen, *Angew. Chem.*, 2010, **122**, 9252-9278.
6. V. Casagrande, E. Salvati, A. Alvino, A. Bianco, A. Ciammaichella, C. D'Angelo, L. Ginnari-Satriani, A. M. Serrilli, S. Iachettini, C. Leonetti, S. Neidle, G. Ortaggi, M. Porru, A. Rizzo, M. Franceschin and A. Biroccio, *J. Med. Chem.*, 2011, **54**, 1140-1156.
7. Y. Shibano, T. Umeyama, Y. Matano and H. Imahori, *Org. Lett.*, 2007, **9**, 1971-1974.
8. F. Yukruk, A. L. Dogan, H. Canpinar, D. Guc and E. U. Akkaya, *Org. Lett.*, 2005, **7**, 2885-2887.
9. J. Fortage, M. Séverac, C. Houarner-Rassin, Y. Pellegrin, E. Blart and F. Odobel, *J. Photochem. Photobiol. A*, 2008, **197**, 156-169.
10. F. Würthner, *Chem. Commun.*, 2004, 1564-1579.
11. Y. Zhao and M. R. Wasielewski, *Tetrahedron Lett.*, 1999, **40**, 7047-7050.
12. L. Fan, Y. Xu and H. Tian, *Tetrahedron Lett.*, 2005, **46**, 4443-4447.
13. F. Würthner, V. Stepanenko, Z. Chen, C. R. Saha-Möller, N. Kocher and D. Stalke, *J. Org. Chem.*, 2004, **69**, 7933-7939.
14. X. Kong, J. Gao, T. Ma, M. Wang, A. Zhang, Z. Shi and Y. Wei, *Dyes Pigm.*, 2012, **95**, 450-454.
15. G. Battagliarin, C. Li, V. Enkelmann and K. Müllen, *Org. Lett.*, 2011, **13**, 3012-3015.
16. S. Nakazono, S. Easwaramoorthi, D. Kim, H. Shinokubo and A. Osuka, *Org. Lett.*, 2009, **11**, 5426-5429.
17. S. Nakazono, Y. Imazaki, H. Yoo, J. Yang, T. Sasamori, N. Tokitoh, T. Cédric, H. Kageyama, D. Kim, H. Shinokubo and A. Osuka, *Chem. Eur. J.*, 2009, **15**, 7530-7533.
18. W. Yue, Y. Li, W. Jiang, Y. Zhen and Z. Wang, *Org. Lett.*, 2009, **11**, 5430-5433.
19. H. Langhals, S. Christian and A. Hofer, *J. Org. Chem.*, 2013, **78**, 9883-9891 .
20. G. Rauch and S. Höger, *Pending Ger. Patent*, 2013.
21. Preliminary experiments with primary amines using different reaction conditions indicate that pure triamino PDIs are accessible in high yields using our method
22. J. R. Clifton and J. T. Yoke, *Inorg. Chem.*, 1968, **7**, 39-46.
23. D. Mackay and W. A. Waters, *J. Chem. Soc. C*, 1966, 813-816.
24. P. Neta, P. Maruthamuthu, P. M. Carton and R. W. Fessenden, *J. Phys. Chem.*, 1978, **82**, 1875-1878.
25. A. Gansäuer, M. Behlendorf, D. von Laufenberg, A. Fleckhaus, C. Kube, D. V. Sadasivam and R. A. Flowers, *Angew. Chem.*, 2012, **124**, 4819-4823.
26. J. M. Mayer, *Acc. Chem. Res.*, 2011, **44**, 36-46.
27. S. V. Bhosale, C. H. Jani and S. J. Langford, *Chem. Soc. Rev.*, 2008, **37**, 331-342.
28. N. Sakai, J. Mareda, E. Vauthey and S. Matile, *Chem. Commun.*, 2010, **46**, 4225-4237.
29. S. Chopin, F. Chaignon, E. Blart and F. Odobel, *J. Mater. Chem.*, 2007, **17**, 4139-4146.
30. R. S. K. Kishore, V. Ravikumar, G. Bernardinelli, N. Sakai and S. Matile, *J. Org. Chem.*, 2007, **73**, 738-740.
31. L. Shen, X. Lu, H. Tian and W. Zhu, *Macromolecules*, 2011, **44**, 5612-5618.
32. X. Lu, W. Zhu, Y. Xie, X. Li, Y. Gao, F. Li and H. Tian, *Chem. Eur. J.*, 2010, **16**, 8355-8364.
33. S. Gabutti, S. Schaffner, M. Neuburger, M. Fischer, G. Schafer and M. Mayor, *Org. Biomol. Chem.*, 2009, **7**, 3222-3229.
34. M. Lista, J. Areephong, N. Sakai and S. Matile, *J. Am. Chem. Soc.*, 2011, **133**, 15228-15231.
35. X. Lu, H.-W. Liu and W. Zhu, *Imaging Sci. Photochem.*, 2011, **29**, 344-352.
36. S.-L. Suraru and F. Würthner, *J. Org. Chem.*, 2013, **78**, 5227-5238.