

HETEROCYCLES, Vol. 60, No. 8, 2003, pp. 1805 - 1810

Received, 23rd April, 2003, Accepted, 1st July, 2003, Published online, 7th July, 2003

A SIMPLE PREPARATIVE METHOD OF *N*-ARYLINDIGOS AND SUBSTITUTION EFFECT IN UV/VISIBLE ABSORPTION

Yukihiro Matsumoto and Hitoshi Tanaka*

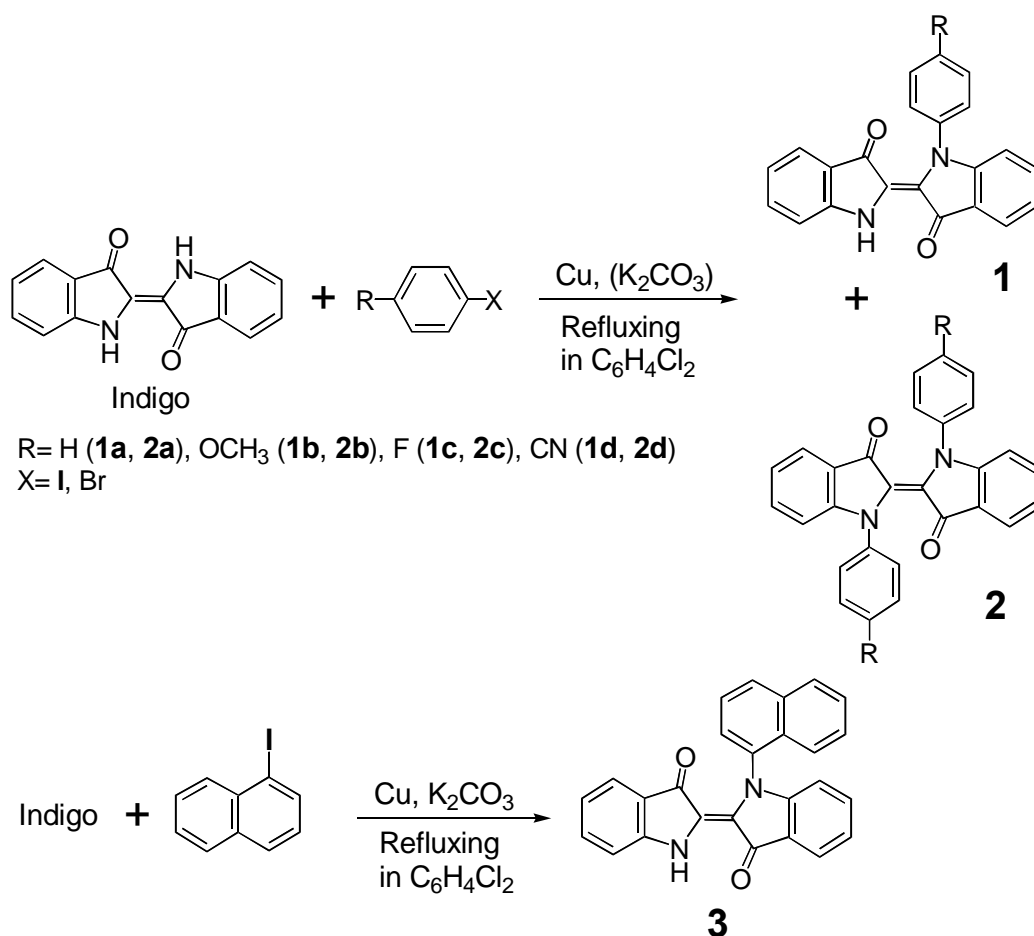
Department of Optical Science and Technology, Faculty of Engineering,
Tokushima University, 2-1 Minamijosanjima, Tokushima 770-8506, Japan

Abstract- *N*-Aryl- and *N, N'*-diarylindigos were prepared by refluxing corresponding aryl iodides or bromide with indigo in *o*-dichlorobenzene. Variation of their UV/visible spectra with the ring-substitution was discussed on the basis of the captodative and steric effects.

Organic pigments have recently been looked over again as new functional materials including optical components.¹ Among them, indigos including *N, N'*-dialkylindigos and *N, N'*-diacylindigos exhibit characteristic behaviors in matrices² or under light irradiation.^{3,4} A large bathochromic shift of the longest-wavelength absorption maximum, for instance, was observed in the UV/visible spectrum when NH hydrogens in indigo were replaced by alkyl groups, which was first recognized to be the inductive effect of the alkyl groups.⁵ After that, however, such a bathochromism was considered to be due less to the inductive effect than to the steric interaction (Brunnings-Corvin effect)⁶ with the carbonyl group, i.e. twisting of the central C-C double bond.⁷ Studies on the UV/visible spectral change of indigos are thereby now focused on the existence and quantification of an inductive or mesomery effect (captodative effect)⁸ as well as a steric effect. Fitjer and coworkers⁹ examined an extent of the mesomery effect using various vinylogous *N, N'*-dialkylindigos with stereochemically identical and planar structure. Unfortunately, however, a configuration of vinylogous *N, N'*-dialkylindigos prepared varied with the alkyl substituents, i.e. the *cis/trans* and nonplanar/planar structures, which makes it difficult to quantify the effects.

In addition, in our continuous work on the captodative (cd) effect,^{8,10} the electronic push and pull powers of each cd substituent and the synergistic cd power have often been discussed to elucidate a cd stabilization effect in reaction. Estimation of such an electronic power has been attempted theoretically and empirically on the basis of the ESR spectral data,¹¹ but it is rather impractical. Recently, we could prepare *N*-mono- and *N, N'*-diarylindigos through one step reaction by improving the Ullmann-Goldberg reaction.¹² *N*-Arylindigos are of particular interest in connection with the bathochromic and cd substituent study of *N*-substituted indigos as well as a construction of new types of indigo π -system. In the present study, we deal with the synthesis and light absorption of the arylindigos (**1**~**5**) in an approach to quantify the electronic and steric effects.

Refluxing an iodobenzene with indigo in *o*-dichlorobenzene containing Cu powder and K₂CO₃ for 10 h gave reddish purple needles in 91.7% yield, which was assigned to *N, N'*-diphenylindigo (**2a**) by the NMR



and MS spectra. Products and their yield greatly depended on the reaction conditions, and the decrease in molar ratio of iodobenzene/indigo or reaction time resulted relatively in the increase of the amounts of *N*-phenylindigo (**1a**), and the decrease of *N,N'*-disubstituted analogue (**2a**). Reduction of the reaction time to 5 h, for instance, produced mainly *N*-monophenyl substituted indigo (**1a**) in 53.5% yield, accompanied by

Table 1. Preparation of *N*-aryl indigos (**1**) and (**2**)^{a)}

R ^{b)}	X ^{b)}	$\frac{[\text{aryl halide}]^{\text{c)}}}{[\text{indigo}]}$	Time (h)	Yield (%)		mp (Åé)	
				1	2	1	2
H	I	1.1	4	26.1	0	265	-
H	I	2.1	5	53.5	31.1	-	326 ^{d)}
H	I	2.1	10	0	91.7	-	-
OCH ₃	I	1.1	4	11.4	trace	-	-
OCH ₃	I	1.1	10	34.5	13.0	245 ^{d)}	-
OCH ₃	I	2.1	10	0	73.8	-	258 ^{d)}
F	I	2.1	10	43.4	16.7	264 ^{d)}	271 ^{d)}
CN	Br	2.1	10	14.2	trace	-	-
CN ^{e)}	Br	2.1	34	56.7	4.9	318 ^{d)}	325 ^{d)}

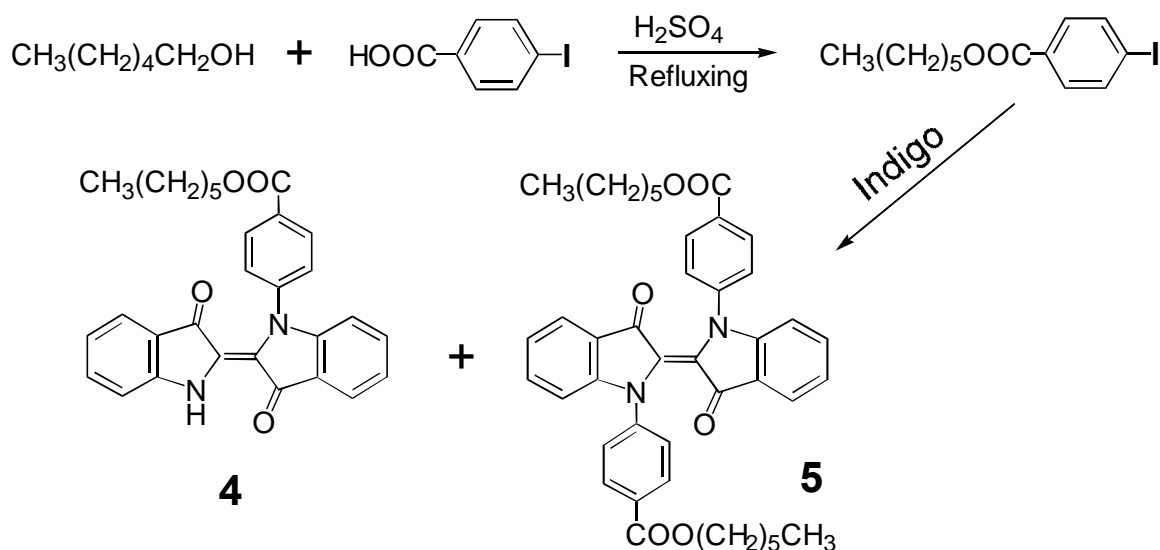
a) Refluxing with Cu powder and K₂CO₃ in *o*-dichlorobenzene

b) R and X in **1** and **2**

c) Molar ratio

d) Decomposition point

e) Reaction without K₂CO₃



N, *N'*-disubstituted one (**2a**) in 31.1% yield. The reaction with various *p*-substituted iodobenzenes also gave *N*-mono- and/or *N*, *N'*-di(*p*-substituted)phenylindigos as shown in Table 1. The reaction with 1-naphthyl iodide, however, afforded preferentially a mono-substituted indigo (**3**) and no di-substituted one even in the presence of large amounts of naphthyl iodide, i.e., naphthyl iodide/indigo=4 molar ratio, and longer reaction time, e.g., 15 h, probably because of the steric hindrances such as twisting of the central C-C double bond and torsion of the naphthyl carbon-nitrogen bond.¹³

It has been known that the electron-donating substituents including OCH₃ group limit the reaction in conventional Ullmann-Goldberg reaction.¹⁴ Reaction with *p*-methoxyiodobenzene, however, can afford the corresponding disubstituted indigo (**2b**) in good yield (Table 1). Moreover, bromobenzene bearing an electron-withdrawing CN group is also usable for the reaction, and *p*-cyanophenylindigos (**1d**) and (**2d**) were obtained from *p*-cyanobromobenzene in moderate yield (Table 1).

Another preparative method of *N*-arylindigos, i.e., the reaction through the intermediates of *N*, *N*-diphenylglycine and indoxyl using diphenylamine as a starting material, was also carried out according to the procedure usually been applied to indigo.¹⁵ However, such a process takes several reaction steps, and the yield in each step was very low and sometimes finally reached totally to nil. *N*, *N*-Diphenylglycine, for instance, was obtained through the reaction of diphenylamine and ethyl chloroacetate subsequently followed by hydrolysis only in *ca.* 10% yield.

The reaction is also applicable to the synthesis of a naphthylindigo and the phenylindigos bearing a long alkyl chain on the *N*-phenyl ring. *N*-Mono- and *N*, *N'*-di(*p*-hexanoxy-carbonyl)phenylindigos, (**4**) and (**5**) respectively, were prepared in moderate yield. An indigo skeleton has been known to become a mesogen in thermotropic liquid crystals.¹⁶ Obtaining the phenylindigo bearing a long alkyl chain, therefore, may enable an indigo to provide highly π -conjugated functional liquid crystals. Unfortunately, however, *p*-hexanoxy-carbonylphenylindigos obtained in the present study would not show liquid crystal behavior probably because of a shorter alkyl chain.

Table 2 lists the absorption maxima (λ_{max}) of the longest-wavelength absorption band of phenylindigos in various solvents. λ_{max} of *N*-aryl and *N*, *N'*-diarylindigos is between *N*-methyl- (636.5 nm)⁷ or *N*, *N'*-dimethyl (654.5 nm)⁷ indigos and parent indigo (604 nm)⁷ in chloroform. For **1a** ~ **1d** and **4**, it is clear that λ_{max} shifts to a longer wavelength region with the *p*-substituents in the order, CN < COO(CH₂)₅CH₃ < F < H

Table 2. Absorption maxima (λ_{\max}) of the longest-wavelength absorption band of indigos^{a)}

Indigo ^{b)}	1a	1b	1c	1d	3	4	2a	2b	2c	2d	5
Solvent	(H)	(OCH ₃)	(F)	(CN)		(CO ₂ C ₆ H ₁₃)	(H)	(OCH ₃)	(F)	(CN)	(CO ₂ C ₆ H ₁₃)
C ₆ H ₆	611.5	615.0	610.5	604.0	610.5	607.5	630.0	636.5	624.0	621.0	628.0
CHCl ₃	617.0	624.0	616.5	609.0	617.0	615.0	637.0	644.0	631.0	627.5	634.5
C ₂ H ₅ OH	611.5	615.5	608.0	604.0	611.0	608.5	633.0	641.0	630.5	623.5	632.5

a) λ_{\max} : nmb) Groups in the parentheses indicate a *p*-substituent on *N*-phenyl ring.

< OCH₃, which is compatible with an electron-donating power of the substituents, e.g., 0.66, 0.45, 0.06, 0.00, and -0.27 of the Hammett σ_p substituent constants respectively.¹⁷ Such a bathochromic shift can be recognized to originate almost from an enhanced resonance stabilization, i.e., the captodative effect, since molar extinction coefficient (ϵ) of **1a**~**1d** and **4** varied little (ϵ =15,300~16,900 in CHCl₃) and the difference in steric hindrance between them is negligibly small, i.e., their *p*-substituents are far apart each other from the central C-C double bond of the indigo skeleton. While, in cyanophenylindigos (**1d**) and (**2d**), λ_{\max} is longer in di-substituted **2d** than mono-substituted **1d** in spite of the decreasing captodative effect of **2d**, suggesting a bathochromic shift due to the steric hinderance. It is concluded thereby that the bathochromism observed in the *N*-substituted indigos originates not only from the Brunnings-Corvin effect but also from the captodative effect.

EXPERIMENTAL

Measurements

Melting points were determined on a Japan Hightech THM 600 hot-stage apparatus with a cooling system. ¹H-NMR spectra were measured in CDCl₃ at 23 °C on a JEOL JNM-EX400 (400 MHz) spectrometer using tetramethylsilane as an internal standard. UV/visible spectra were recorded on a Shimadzu UV-1600PC using 1cm light-path length quartz cell. MS spectra were taken with Shimadzu QP 1000 spectrometer. Analytical TLC was performed on Merck silica gel RP-18F₂₅₄S plates. Column chromatography was carried out on Cica silica gel 60, 0.063~0.210 mm.

Materials

General procedure for the synthesis of compounds (1) and (2)

1 and **2** were generally prepared by refluxing *o*-dichlorobenzene solution containing commercially available indigo, iodobenzene, copper powder, and potassium carbonate in a round bottom flask equipped with a condenser for given time. The reaction was traced by TLC analysis. After the reaction dilute HCl (1 N) was poured into the reaction mixture, following the filtration and washing with chloroform. Solvents including *o*-dichlorobenzene and chloroform were removed from the residue under reduced pressure. Then,

the products were isolated by a column chromatography using chloroform for compounds **a** ~ **c** and chloroform/acetonitrile (20/1) for **d** as developing solvents.

***N*-Phenyl- and *N, N'*-diphenylindigos (**1a**) and (**2a**)**

The mixture of indigo 1.05 g (4.0 mmol), iodobenzene 0.92 mL (8.4 mmol), copper powder 0.027 g (0.42 mmol), and potassium carbonate 1.17 g (8.4 mmol) was refluxed in *o*-dichlorobenzene (20 mL) in a round bottom flask equipped with a condenser for 5 h. Isolation by a column chromatography gave 0.722 g (53.5%) of **1a** and 0.515 g (31.1%) of **2a**. Longer reaction time (10 h) afforded preferentially **2a** in 91.7% yield. Recrystallization from chloroform and dichloromethane gave deep blue needles (**1a**) and reddish purple needles (**2a**); mp 265 and 326°C (decomp) respectively. ¹H-NMR of **1a**: δ 6.88 (1H, t, *J*=7.6 Hz), 6.94 (1H, d, *J*=8.3 Hz), 6.99 (1H, d, *J*=8.1 Hz), 7.07 ppm (1H, t, *J*=7.3 Hz), 7.36~7.54 (8H, m), 7.82 (1H, d, *J*=7.6 Hz), 10.57 ppm (1H, s); MS (70 eV): *m/z* (%) 338 (M⁺, 100), 309 (30), 179 (14), 104 (11), 77 (24), 76 (22), 51 (16); Anal. Calcd for C₂₂H₁₄N₂O₂: C, 78.09; H, 4.17; N, 8.28. Found: C, 78.17; H, 4.41; N, 8.22. ¹H-NMR of **2a**: δ 6.59~7.87 (18H, m); MS (70 eV): *m/z* (%) 414 (M⁺, 100), 397 (33), 385 (51), 369 (11), 267 (42), 207 (15), 195 (15), 152 (10), 102 (10), 77 (47), 51 (22); Anal. Calcd for C₂₈H₁₈N₂O₂: C, 81.14; H, 4.38; N, 6.76. Found: C, 80.88; H, 4.62; N, 6.68.

***N*-naphthylindigo (**3**)**

Preparation of **3** was similar to that of **1** and **2**, in which 1-naphthyl iodide was used instead of iodobenzene. In the reaction in naphthyl iodide/indigo=2.1 molar ratio for 13 h reaction, **3** was obtained in 60.0% yield. Recrystallization from acetonitrile gave reddish purple plates; mp 258°C (decomp). ¹H-NMR of **3**: δ 6.50 (1H, d, *J*=8.1 Hz), 6.79 (1H, t, 8H, *J*=7.3 Hz), 6.96 (1H, d, *J*=8.1 Hz), 7.06 (1H, t, *J*=7.3 Hz), 7.32~8.02 (11H, m), 10.69 ppm (1H, s); Anal. Calcd for C₂₆H₁₆N₂O₂: C, 80.40; H, 4.15; N, 7.21. Found: C, 80.64; H, 4.40; N, 7.11.

***N-p*-Hexanoxycarbonylphenyl and *N, N'*-di(*p*-hexanoxycarbonylphenyl)indigos (**4**) and (**5**)**

p-Iodobenzoic acid hexyl ester was prepared by refluxing *p*-iodobenzoic acid 2 g (8 mmol) and 1-hexanol 15 mL (24 mmol) in the presence of a few drops of H₂SO₄ for 1 h in a three-necked round bottom flask equipped with a Dean-Starks apparatus. Colourless oily ester was obtained in 70.3% yield after evaporating excess 1-hexanol. **4** was obtained by the reaction with *p*-iodobenzoic acid hexyl ester in a similar manner to that of **1** in 24.1% yield, accompanied by trace amount of **5**, in which the molar ratio of the ester to indigo was 1.5 and the reaction time was 13 h. After reaction, **4** was isolated as bluish purple needles by a column chromatography using chloroform/dichloromethane (10/1) as developing solvents and following recrystallization from acetonitrile; mp 178°C (decomp). In the conditions in 3.0 molar ratio of the ester to indigo and the reaction time of 17 h, **5** was obtained selectively in 80.7% yield without a column chromatography. Recrystallization from acetone gave reddish purple needles (**5**): mp 153~154°C. ¹H-NMR of **4**: δ 0.92 (3H, t, *J*=7.0 Hz), 1.35~1.82 (8H, m), 4.34 (2H, t, *J*=6.6 Hz), 6.91 (1H, t, *J*=7.6 Hz), 7.01 (1H, d, *J*=8.1 Hz), 7.02 (1H, d, *J*=8.3 Hz), 7.11 (1H, t, *J*=7.3 Hz), 7.43 (2H, d, *J*=8.4 Hz), 7.41~7.50 (3H, m), 7.84 (1H, d, *J*=7.6 Hz), 8.19 (2H, d, *J*=8.4 Hz), 10.49 ppm (1H, m); Anal. Calcd for C₂₉H₂₆N₂O₄: C, 74.66; H, 5.62; N, 6.00. Found: C, 74.40; H, 5.80; N, 5.86. ¹H-NMR of **5**: δ 0.92 (6H, t, *J*=7.1 Hz),

1.34~1.80 (16H, m), 4.34 (4H, t, $J=6.6$ Hz), 7.04 (2H, t, $J=7.5$ Hz), 7.10 (2H, d, $J=8.3$ Hz), 7.42 (1H, dd, $J=7.5, 8.3$ Hz), 7.59 (2H, d, $J=7.5$ Hz), 7.63 (4H, d, $J=8.5$ Hz), 8.23 ppm (4H, d, $J=8.5$ Hz); Anal. Calcd for $C_{29}H_{28}N_2O_4$: C, 75.20; H, 6.31; N, 4.18. Found: C, 75.00; H, 6.37; N, 4.05.

ACKNOWLEDGEMENT

The authors are grateful to Prof. Y. Miura of Osaka City University for the measurement of X-Ray diffraction.

REFERENCES

1. A. Mishra, R. K. Behera, P. K. Behera, B. K. Mishra, and G. B. Behera, *Chem. Rev.*, 2000, **100**, 1973.
2. K. Tanaka, F. Toda, and T. Higuchi, *Mol. Cryst. Liq. Cryst.*, 1992, **219**, 135; S. Ganapathy, R. G. Zimmermann, and R. G. Weiss, *J. Org. Chem.*, 1986, **51**, 2529.
3. H. Gorner, J. Pouliquen, and J. Kossanyi, *Can. J. Chem.*, 1978, **65**, 708.
4. C. R. Giuliano, L. D. Hess, and J. D. Margerum, *J. Am. Chem. Soc.*, 1968, **90**, 587.
5. K. J. Braakmann, *Dissertation*, Amsterdam, 1943.
6. K. J. Brunings and A. H. Corvin, *J. Am. Chem. Soc.*, 1942, **64**, 593.
7. G. Mieke, P. Susse, V. Kupcik, E. Egert, M. Nieger, G. Kunz, R. Gerke, B. Knierien, M. Niemeyer and W. Luttko, *Ang. Chem., Int. Ed. Engl.*, 1991, **30**, 964.
8. H. Tanaka, *Trends Polym. Sci.*, 1993, **1**, 361; *ibid.*, 1996, **4**, 106; L. Stella, Z. Janousek, R. Merenyi, and H. G. Viehe, *Angew. Chem., Int. Ed. Engl.*, 1978, **17**, 691.
9. L. Fitjer, R. Gerke, W. Luttko, P. Muller, and I. Uson, *Tetrahedron*, 1999, **55**, 14421.
10. H. Tanaka, *Prog. Polym. Sci.*, 2003, **28**, 1171.
11. J. M. Dust and D. R. Arnold, *J. Am. Chem. Soc.*, 1983, **105**, 1221, 6531; J. C. Walton, *J. Chem. Soc., Perkin Trans. II*, 1983, 1043.
12. I. Goldberg and M. Nimerovsky, *Ber.*, 1907, **40**, 2448; F. D. Hager, *Org. Syn., Coll. Vol.*, 1941, **I**, 544.
13. Structural analysis of platelet crystals (**3**) by X-Ray diffraction indicated primitive monoclinic crystals, and trans-anti form of **3**, i.e., *trans*-position of each C=O group and anti-position of naphthyl group and hydrogen. Space group: $P2_1/n$, cell constants: $a=14.370(5)$, $b=11.150(3)$, $c=11.780(4)$, $\beta=96.220(7)^\circ$, and $V=1876(1)$ Å³ for $Z=4$ and $F.W.=388.42$. Details of the structural analyses including the twisting of the central C-C double bond and bending and coplanarity of each aromatic ring for **3** as well as other indigos will be reported in the near future.
14. R. Gujadhur, D. Venkataraman, and J. T. Kintigh, *Tetrahedron Lett.*, 2001, **42**, 4791.
15. G. Heller, *Ber.*, 1944, **77**, 163.
16. J. Z. Vlahakis, K. E. Maly, and R. P. Lemieux, *J. Mater. Chem.*, 2001, **11**, 2459.
17. R. W. Alder, R. Baker, and J. M. Brown, "Mechanism in Organic Chemistry", John Wiley & Sons Ltd., London, 1971, p. 30.