Electronic supplementary materials *Mendeleev Commun.*, 2024, **34**, 335–337

A new fluorescent and colorimetric sensor for copper(II) ion detection based on a 4-styryl-1,8-naphthalimide derivative

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CONTENTS

2-(Chloromethyl)pyridine hydrochloride (Scheme S1) was prepared starting from 2-pyridinemethanol following the described procedure.[S1] Compound NI was prepared starting from 2-bromo-1,8-naphthalic anhydride following the described procedure.[S2] All other reagents were purchased from commercial sources. Acetonitrile used in spectroscopic studies was of HPLC grade.

Melting points were measured on Melt-temp melting point electrothermal apparatus and were uncorrected.

The reaction course and purity of the final products was followed by TLC on silica gel (DC-Alufolien Kieselgel 60 F_{254}, Merck). Column chromatography was conducted over silica gel (Kieselgel 60, particle size 0.063-0.200 mm, Merck).

^{1}H and ^{13}C NMR spectra were recorded on an Avance 400 (Bruker) and Inova 400 (Agilent) spectrometers. The measurements were performed in DMSO-d_6, $CDCl_3$ and CD_2Cl_2 solutions. The chemical shifts (given as δ) were determined with an accuracy of 0.01 ppm relative to the signals corresponding to the residual solvents and recalculated to the internal standard (TMS); the spin-spin coupling constants (J) were measured with an accuracy of 0.1 Hz. The numbering of carbon atoms in the compounds used by us for the description of ^{1}H and ^{13}C NMR spectra below is shown in Figure S1.

LC-ESI-MS analyses were performed using acetonitrile solutions on a Shimadzu LCMS-2020 liquid chromatography mass spectrometer.

The absorption spectra were taken on a Cary 300 spectrophotometer (Agilent Technologies). The fluorescence quantum yield measurements were performed using a Fluorolog3-221 spectrofluorimeter (Horiba Jobin Yvon). Spectral measurements were carried out in air-saturated acetonitrile solutions at ambient temperature. All measured fluorescence spectra were corrected for the nonuniformity of detector spectral sensitivity. Coumarin 481 in acetonitrile (φ^{fl} = 0.08)[S3] was used as reference for the fluorescence quantum yield measurements. The fluorescence quantum yields were calculated by the Eq. (S1),[S4]

$$\varphi^{\mathrm{fl}} = \varphi_{\mathrm{R}}^{\mathrm{fl}} \frac{S}{S_{\mathrm{R}}} \cdot \frac{(1 - 10^{-A_{\mathrm{R}}})n^2}{(1 - 10^{-A})n_{\mathrm{R}}^2} \tag{S1}$$

wherein φ^{fl} and $\varphi_{\mathrm{R}}^{\mathrm{fl}}$ are the fluorescence quantum yields of the studied solution and the standard compound respectively; A and A_{R} are the absorptions of the studied solution and the standard respectively; S and S_{R} are the areas underneath the curves of the fluorescence spectra of the studied solution and the standard respectively; and n and n_{R} are the refraction indices of the solvents for the substance under study and the standard compound.

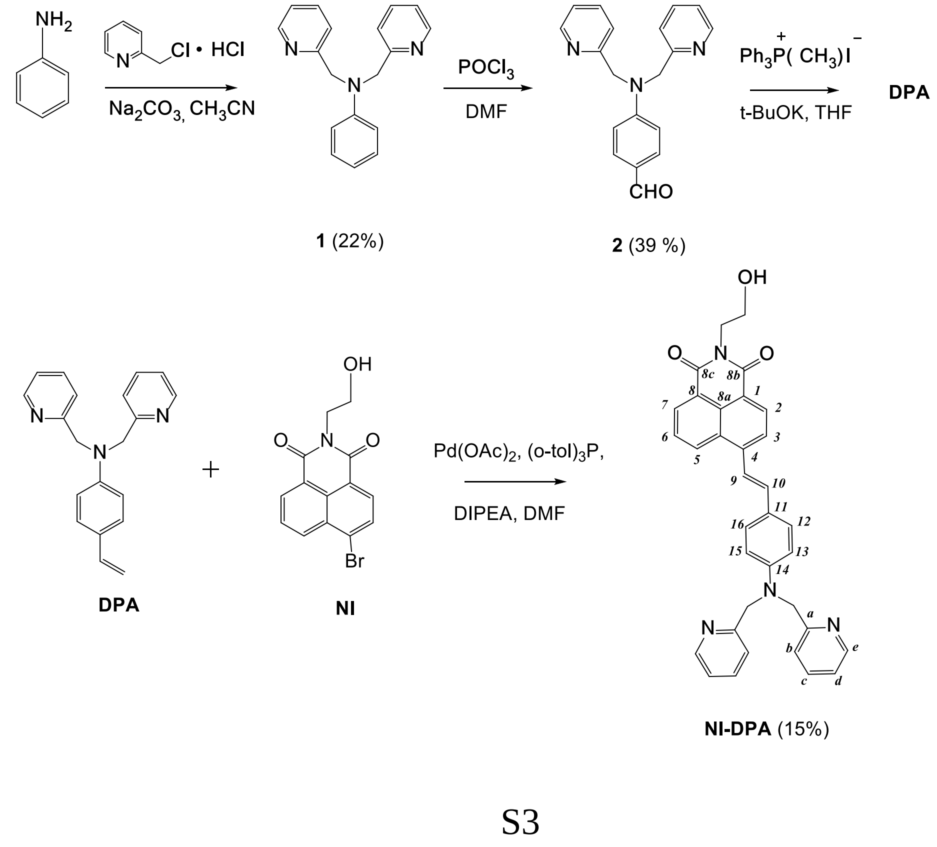
Complex formation of compound NI-DPA with Cu^{2+} was studied by spectrofluorometric and spectrophotometric titration.[S5,S6] A stock solution of the ligand NI-DPA in DMSO (2·10^{-3} mol dm^{-3}) was added to 2.5 ml of Tris-HCl buffer solution to obtain a solution of the ligand for titration. The ratio of NI-DPA to Cu^{2+} was varied by adding aliquots of a solution of copper(II) perchlorate in water of known concentration to a solution of ligand NI-DPA in the Tris-HCl buffer (0.01M, pH = 7.0). The fluorescence spectrum of each solution was recorded, and the stability constants of the complexes were determined using the SPECFIT/32 program (Spectrum Software Associates, West Marlborough, MA).

The detection limit was calculated using fluorometric titration data of NI-DPA with copper(II) perchlorate in Tris-HCl buffer using the previously described standard deviation method at low concentrations.[S5] For the calculation, a linear section of the dependence of the fluorescence intensity of the ligand in the region of 700 nm on a Cu^{2+} concentration in solution of up to 1.4·10^{-5} M (0.7 eq.) was chosen. The value of the Detection Limit (DL) was obtained using formula (2):

$$DL=3\sigma/K \quad (2),$$

where σ is the standard deviation when measuring the fluorescence intensity of the ligand, K is the slope of the linear section of the graph of the dependence of the fluorescence intensity of the solution at 700 nm on the concentration of Cu^{2+}.

Scheme S1



Compound 1. Aniline (240 μl, 2.61 mmol) was dissolved in acetonitrile, then 2-(chloromethyl)pyridine hydrochloride (1.2 g, 7.32 mmol) and Na_2CO_3 (2.0 g, 19.03 mmol) were added in an argon atmosphere. The mixture was refluxed for 18 hours. Then the solvent was removed in vacuum, and the residue was extracted with ethyl acetate. The combined organic extracts were washed with water. After removing the solvent in vacuum the resulting dry residue was chromatographed on Al_2O_3 (gradient elution from CH_2Cl_2 to CH_2Cl_2 : MeOH = 20:1) to give 0.3 g of product **1** (41% yield). M.p. = 111-112°C ([S6]: M.p. = 111 – 112°C). ^1H NMR (400.13 MHz, $CDCl_3$, 19 ºC): δ = 4.84 (s, 4H, 2xCH_2), 6.65-6.79 (m, 3H, 3H(Ph)), 7.11-7.25 (m, 4H, 2H(c), 2H(Ph)), 7.25-7.34 (m, 2H, 2H(b)), 7.60-7.69 (m, 2H, 2H(d)), 8.59 (d, 2H, 2H(e), J = 3.8).

Compound 2. $POCl_3$ (1 ml, 17 mmol) was added dropwise to DMF (2 ml, 26 mmol) over 30 minutes while cooling on an ice bath. The solution is then kept under stirring for 30 minutes on ice bath, then compound **1** (0.60 g, 2.18 mmol) was added in portions. After stirring for 3 hours at 90℃, the reaction mixture was cooled to r.t. and diluted with water (5 ml). The 5% (wt.) Na_2CO_3 solution was added to pH 6-8. Then the mixture was extracted with dichloromethane, the combined organic extracts were washed with water and left overnight over Na_2SO_4. Then the drying agent was filtered off from the extract and after removing the solvent in vacuum, the resulting dry residue was chromatographed on SiO_2 (gradient elution from CH_2Cl_2 to CH_2Cl_2 : EtOH = 20:1) to give 0.26 g of product **2** as a yellow oil (40% yield). ^1H NMR (400.13 MHz, $CDCl_3$, 19 ºC): δ = 4.94 (s, 4H, 2×CH_2), 6.78 (d, 2H, 2H(Ph), J = 8.9), 7.20-7.27 (m, 4H, 2H(c), 2H(b)), 7.63-7.73 (m, 4H, 2H(Ph), 2H(d)), 8.62 (d, 2H, 2H(e), J = 3.8), 9.73 (s, 1H, -CHO).

Compound DPA. To a suspension of methyltriphenylphosphonium iodide (0.334 g, 0.83 mmol) in dry THF (3 ml), Bu^tOK (0.094 g, 0.838 mmol) was added, the solution turns to be bright yellow. Immediately a solution of aldehyde **2** (0.126 g, 0.42 mmol) in dry THF (3.5 ml) was quickly added to the reaction mixture, and it was left overnight with stirring at room temperature. Then light precipitates are filtered out from the reaction mixture, and the filtrate was evaporated. The resulting yellow oil was filtered from hot hexane to remove a triphenylphosphine oxide precipitate. After hexane removing in vacuum, a yellow oil (187 mg) was obtained, which was used at the next stage of the synthesis without additional purification. The formation of styrene was established by the by the presence of characteristic signals of the double bond –CH=CH- in ^1H NMR spectrum (400.13 MHz, CD_2Cl_2, 21ºC): δ = 4.97 (d, 1H, CH=CH_2 (proton in *trans*- position to the aromatic part), J = 11.3), 5.47 (d, 1H, CH=CH_2, J = 16.8), 6.56 (dd, 1H $C\underline{H}=CH_2$, J_2 = 11.3, J_3 = 16.8).

NI-DPA. Compound NI (0.1288 g, 0.402 mmol) was added to a suspension of $Pd(OAc)_2$ (1.08 mg, 4.822 μmol) and (*o*-Tol)$_3$P (6.73 mg, 22.124 μmol) and DIPEA (0.77 ml) in DMF (4.30 ml).

Then styrene NI (0.1454 g, 0.482 mmol) was added. The reaction mixture was stirred for 17 hours at 110 ℃ in an argon atmosphere and then was cooled to r. t. Then the reaction mixture was diluted with water and extracted with dichloromethane. The combined organic extracts were washed with water and left over Na_2SO_4 overnight. After removing the solvent in vacuum, the resulting dry residue was chromatographed on SiO_2(gradient elution from CH_2Cl_2 to CH_2Cl_2 : MeOH = 4:1) to give 33.00 mg of **NI-DPA** (15% yield). M.p. 227-229 ºC. ^{1}H NMR (400.02 MHz, CD_2Cl_2, 18 ºC): δ = 3.86-3.94 (m, 2H, $CH_2\underline{CH_2}OH$), 4.36-4.44 (m, 2H, $\underline{CH_2}CH_2OH$), 4.89 (s, 4H, 2×CH_2), 6.77 (d, 2H, H(13), H(15), J = 9.0), 7.17-7.24 (m, 2H, 2H(d)), 7.24-7.37 (m, 3H, 2H(b), H(10)), 7.48 (d, 2H, H(12), H(16), J = 9.0), 7.62-7.71 (m, 2H, 2H(c)), 7.71-7.82 (m, 2H, H(9), H(6)), 7.99 (d, 1H, H(3), J = 7.8), 8.54 (d, 1H, H(7), J = 8.6), 8.56-8.66 (m, 4H, H(2), H(5), 2H(e)). ^{13}C NMR (100.60 MHz, DMSO-d_6, 18 ºC): δ =: 41.79, 56.96, 57.82, 112.39, 117.99, 119.66, 121.20, 122.28, 122.48, 125.00, 126.68, 128.32, 128.81, 128.93, 130.61, 130.72, 130.75, 135.43, 136.88, 141.83, 148.61, 149.41, 158.68, 163.38, 163.69. ESI-mass m/z: calculated: 541.22 ($[M+H]^+$), found: 541.45.

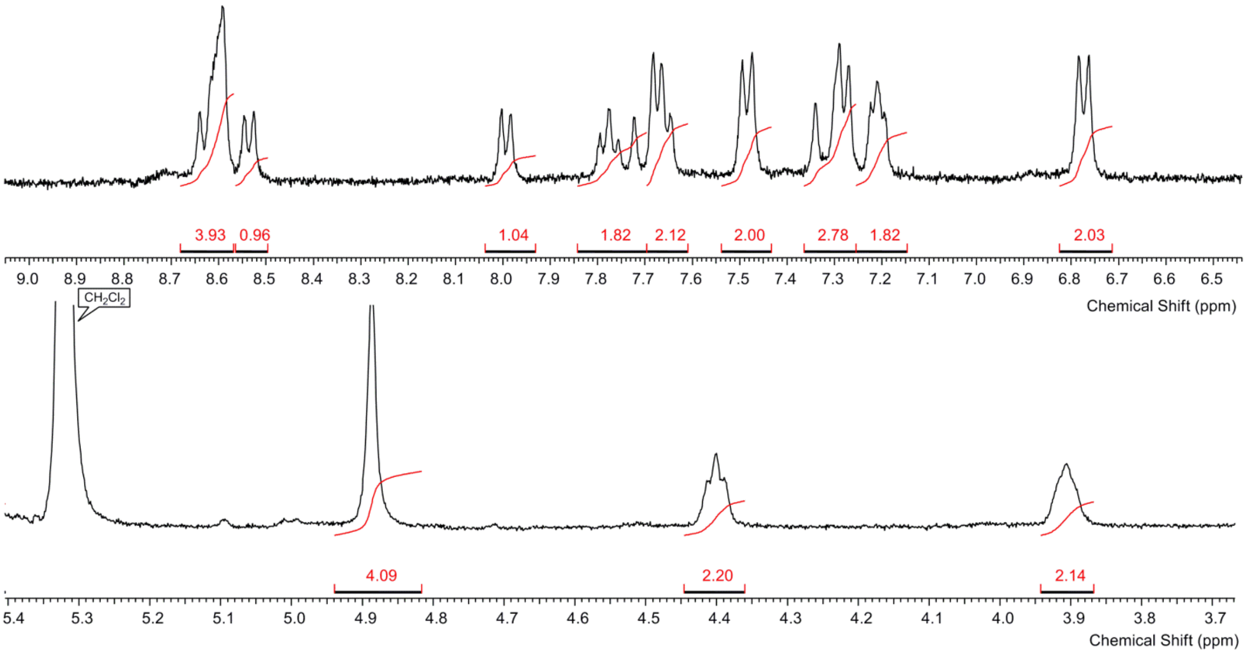


Figure S1. ^{1}H NMR spectra (400.02 MHz, CD_2Cl_2, 18 ºC) for **NI-DPA**.

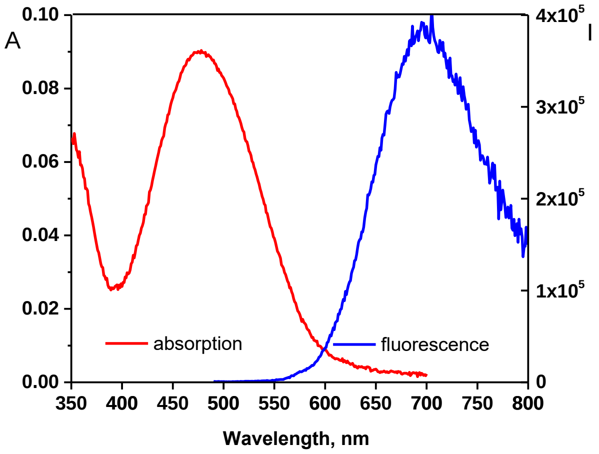


Figure S2. Absorption and fluorescence spectra of **NI-DPA** in Tris-HCl buffer solution (0.01M, pH = 7.00), excitation wavelength 480 nm, concentration $6 \cdot 10^{-6}$ M.

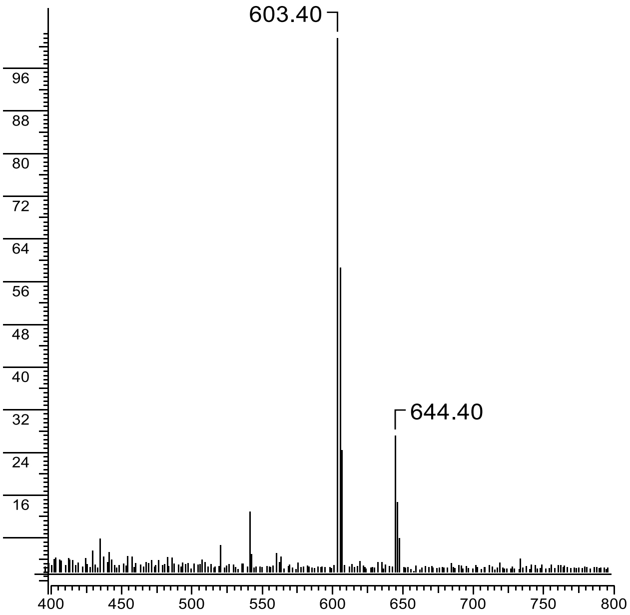


Figure S3. ESI-mass spectrum of **NI-DPA** in H_2O **(**$2 \cdot 10^{-5}$ M) in presence of $Cu(ClO_4)_2$ ($1 \cdot 10^{-4}$ M, 5 equivalents).

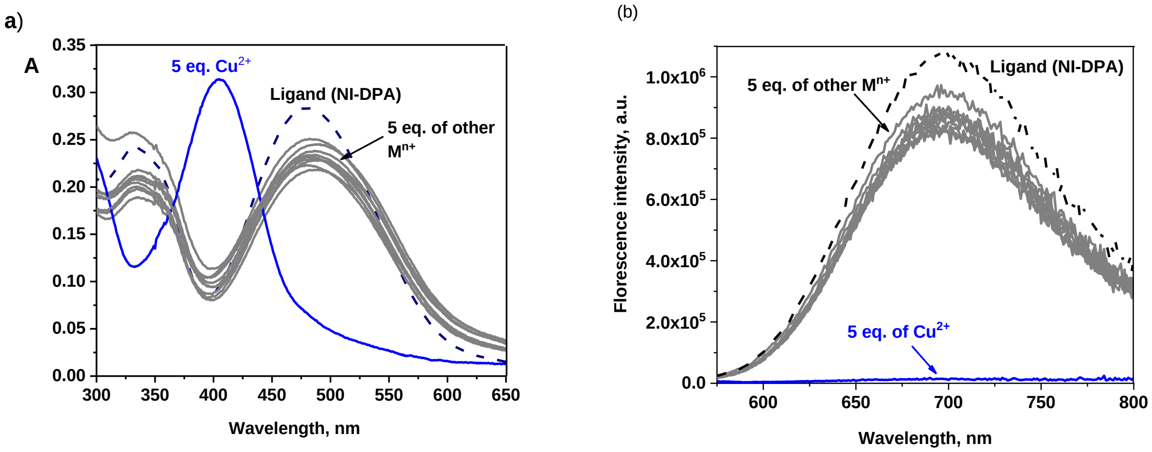


Figure S4. Changes in the absorption (*a*) and fluorescence (*b*) spectra of **NI-DPA** after the addition of 5 equivalents of Cu^{2+} and other metal cations (Ni^{2+}, Cd^{2+}, Fe^{2+}, Ag^{+} и Zn^{2+}, Ca^{2+}, Mg^{2+}, Hg^{2+}, Pb^{2+}), Tris-HCl, 0.01M, pH=7.0.

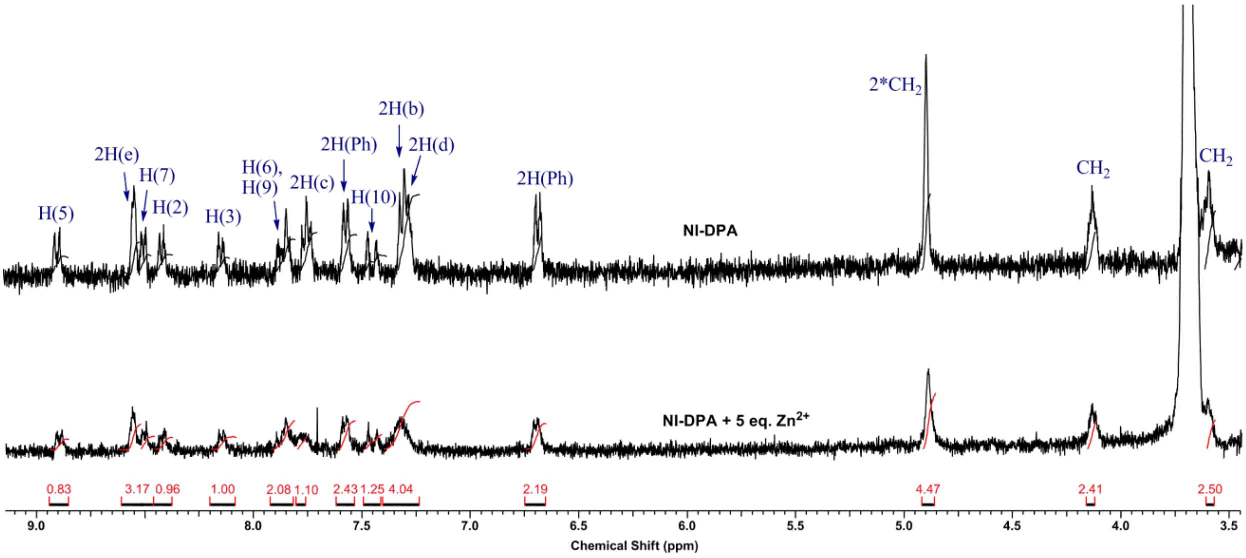


Figure S5. ^{1}H NMR spectra (400.13 MHz, DMSO-d_6/D_2O = 90/10 (v/v), 18 ºC) for **NI-DPA** ($1\cdot10^{-3}$ M) in absence and in presence of Zn^{2+} ($5\cdot10^{-3}$ M).

References

S1. J. Zhang, H. Cui, M. Hojo, S. Shuang and C. Dong, *Bioorg. Med. Chem. Let.*, 2012, **22**, 343.

S2. P. A. Panchenko, M. A. Grin, O. A. Fedorova, M. A. Zakharko, D. A. Pritmov, A. F. Mironov, A. N. Arkhipova, Yu. V. Fedorov, G. Jonusauskas, R. I. Yakubovskaya, N. B. Morozova, A. A. Ignatova and A. V. Feofanov, *Phys. Chem. Chem. Phys.*, 2017, **19**, 30195.

S3. S. Nad, M. Kumbhakar and H. Pal, *J. Phys. Chem. A.*, 2003, **107**, 4808.

S4. C. L. Renschler and L. A. Harrah, *Anal. Chem.*, 1983, **55**, 798.

S5. Q. Mei, Y. Shi, Q. Hua and B. Tong, *RSC Adv.*, 2015, **5**, 74924.

S6. T. Maruyama, Y. Fujie, N. Oya, E. Hosaka, A. Kanazawa, D. Tanaka, Y. Hattori and J. Motoyoshiya, *Tetrahedron*, 2011, **67**, 6927.