

Communication

Mechanosynthesis of Diaminobiphenyls-Based Schiff's Bases as Simple Probes for the Naked-Eye Detection of Cyanide Ion

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Abstract: Cyanide ions are known to be lethal for insects and mammals and harmful for the environment, and new methods for their selective detection are in high demand. Herein, the mechanosynthesis of simple Schiff's bases-based probes **S1–S3** for visual detection of CN^- anion is reported. These probes were obtained by means of a reaction between isomeric 4,4-, 3,3- and 2,2-diaminobiphenyls and 4-nitrobenzaldehyde under ball milling conditions. The probes showed high selectivity and sensitivity toward CN^- anion via a dramatic “yellow-to-dark purple” color change with a detection limit of 26×10^3 , 8.7×10^3 and 14×10^3 ppm for **S1–S3**, respectively. The proposed mechanism of the detection suggests the deprotonation of a proton from an imine moiety, followed by the formation of charge transfer complexes (CTC).

Keywords: mechanosynthesis; Schiff bases; cyanide ion detection; color change



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1. Introduction

CN^- ion donors are heavily involved in a wide variety of industrial processes, for instance, for the manufacturing of synthetic fibers, resins, and herbicides in mining and metallurgical branches such as gold extraction and in galvanic processes, accompanied by potential environmental contamination [1,2]. In nature, cyanides are produced by cyanobacteria, certain fungi, and algae [3]. In the form of cyanogenic glycosides cyanides are presented as antifeedants in a number of plants and plant seeds, such as cassava, seeds of bitter almonds, apples, and apricots [4,5]. According to the World Health Organization (WHO, Geneva, Switzerland), the allowed level of cyanide in drinking water should not exceed $2 \mu\text{g/L}$ [6]. The high toxicity of cyanide is associated with its ability to inhibit the enzyme cytochrome-c oxidase, which prevents the transport of electrons from cytochrome-c to oxygen and interrupts the generation of aerobically produced ATP to cause histotoxic hypoxia [7].

Based on all of the above, there is a demand for analytical systems for CN^- detection and/or monitoring at potential pollution sources for early warning of seepage of hazardous wastes. Nowadays, numerous methods and equipment have found an application in the purpose of analyzing soil, water, and air [8]. The instrumental methods have several drawbacks; for instance, they are bulky, expensive, require specific qualification, and are inappropriate for prompt analysis. However, colorimetric chemosensor tests are the most widespread because of their fast response, high sensitivity and selectivity, visual/naked-eye detection, ease of use, high selectivity, cheapness, and wide range of target analytes [9]. In addition to a large number of reports on chemical sensors that are able to detect cyanide by means of reversible binding to a receptor site to cause the generation of a visual signal

via fluorescence or color change [10], many reports are published on the rational design of various probes that are able to detect cyanide via nucleophilic addition to a receptor site. Recently, many molecular probes for the visual cyanide detection were reported [11], including indoles [12] or bisindoles [13], 2-(trifluoroacetyl amino)anthraquinone [14], cyanine dyes and related indoliminium NIR dyes [15], acyltriazene [16], squarane [17], acridinium salt [18], benzils [19], (het)aryl-substituted dienes [20,21], etc. Even though some of these chemosensors/probes could be very efficient and selective, their preparation requires multistep synthesis, which sometimes involves expensive metal catalysts or reagents and/or tedious methods for the purification.

(Aza) Schiff's bases [22,23] provide different mechanisms for the cyanide detection. In the most common scenario, the deprotonation of (aza) Schiff's base molecules [24–26] takes place to cause a dramatic color change. The mechanism involved hydrogen bonding formation followed by hydrogen abstraction by CN^- . To ensure efficient hydrogen abstraction in most cases the strong hydrogen bond donors, such as hydroxy- or NH-moieties, as well as strong acceptors, such as nitro-group(s) need to be introduced into the structure of Schiff's bases [27–31]. In most cases, the above-mentioned Schiff's bases could be prepared via multi-step synthesis by using organic solvents and column chromatography. In addition, the most probes exhibited an almost identical colorimetric response towards both CN^- and F^- ions.

In this manuscript, we wish to report a method for the preparation of Schiff's bases, such as bis(4-nitrobenzylidene)-[1,1'-biphenyl]-4,4'-diamine **S1**, bis(4-nitrobenzylidene)-[1,1'-biphenyl]-3,3'-diamine **S2**, and bis(4-nitrobenzylidene)-[1,1'-biphenyl]-2,2'-diamine **S3** (also available from several vendors) as simple highly selective colorimetric probes for the CN^- anion, by using both traditional solvent-based and mechanochemical (under ball milling conditions) synthesis.

2. Materials and Methods

Unless otherwise indicated, all common reagents and solvents were used from commercial suppliers without further purification. Benzidine, 2-nitroaniline, 3-nitroaniline, $\text{Pd}(\text{OAc})_2$, Pd/C , 4-nitrobenzaldehyde were purchased from Sigma-Aldrich, Merck. Iodo-2-nitrobenzene (m.p. 48–49 °C [32]), and iodo-3-nitrobenzene [32], 3,3'-dinitro-1,1'-biphenyl [33], m.p. 178–180 °C, and corresponding [1,1'-biphenyl]-diamines **B2** and **B3** [34] were synthesized according to the reported procedures. Mechanochemical reactions were performed in the ball mill Retsch PM100 by using a 25 mL stainless steel jar with 4 stainless steel 10 mm-diameter milling balls at 500 rpm. TLC and column chromatography were carried out on SiO_2 . ^1H NMR and ^{13}C NMR spectra were recorded at room temperature at 400 and 100 MHz, respectively, on a Bruker DRX-400 spectrometer using CDCl_3 or $\text{DMSO}-d_6$ as the solvents. Hydrogen chemical shifts were referenced to the hydrogen resonance of the corresponding solvent ($\text{DMSO}-d_6$, $\delta = 2.50$ ppm, or CDCl_3 , $\delta = 7.26$ ppm). Carbon chemical shifts were referenced to the carbon resonances of the solvent (CDCl_3 , $\delta = 77.16$ ppm). Peaks were labeled as singlet (s), doublet (d), triplet (t), and multiplet (m). Melting points were measured by the Stuart SMP10 melting point apparatus. Mass spectra were recorded on a SHIMADZU GCMS-QP2010 Ultra with electronic ionization (EI). UV–Vis absorption spectra were recorded on a Shimadzu UV-1800 spectrophotometer by using quartz cells with a 1 cm path length at room temperature. For UV/Vis titration experiments, tetrabutylammonium cyanide (TBACN) and tetrabutylammonium hydroxide (TBAOH) purchased from Sigma-Aldrich were used.

2.1. General Methods for the Synthesis of Probes S1–S3

2.1.1. Method A

A mixture of corresponding diamino-biphenylene (450 mg, 1 mmol, 1 eq), 4-nitrobenzaldehyde (302 mg, 2 mmol, 2 eq), and 3 drops of acetic acid in methanol (10 mL) was stirred at 68 °C for 8 h. Then ethyl acetate (10 mL) and water (20 mL) were added to the reaction mixture, and the product was extracted. The organic layer was dried over sodium

sulfate and concentrated under reduced pressure. Product yields for **S1**, **S2**, and **S3** were 70.0%, 65.4%, and 60.3%, respectively.

2.1.2. Method B

The mixture of the corresponding diamino-biphenylene (225 mg, 0.5 mmol, 1 eq) and 4-nitrobenzaldehyde (151 mg, 1 mmol, 2 eq) and 3 drops of acetic acid was ball milled at 500 rpm for 1 h at room temperature. The reaction mixture was dissolved in ethyl acetate (20 mL) and washed with water (3 × 10 mL). The organic layer was dried over sodium sulfate, filtered, and concentrated under reduced pressure. Product yields for **S1**, **S2**, and **S3** were 94.8%, 87.5%, and 76.7%, respectively.

*N*⁴,*N*^{4'}-bis(4-nitrobenzylidene)biphenyl-4,4'-diamine **S1**: ¹H NMR (DMSO-*d*₆, 400 MHz) δ: 8.92 (s, 2 H, N=CH), 8.38–8.24 (m, 8 H, Ph-NO₂), 7.85–7.50 (m, 8 H, biphenyl). IR (KBr, cm^{−1}) ν: 1342 (−NO₂), 1531 (C=C), 1683 (C=N). ¹³C NMR (DMSO-*d*₆, 100 MHz) δ 158.72, 149.73, 148.86, 141.56, 137.97, 129.65, 127.38, 124.01, 122.05. MS (*m/z*, %): 450 (M⁺, 100), 434 (7.36), 433 (22.92), 402 (7.90), 356 (7.98), 317 (6.78), 254 (11.37), 241 (11.56), 225 (13.49), 178 (14.39), 152 (37.65), 127 (17.09), 113 (6.00), 77 (12.34), 65 (7.10), 51 (7.31), 39 (2.71). m.p. 246–248 °C. Yellow powder.

*N*³,*N*^{3'}-bis(4-nitrobenzylidene)biphenyl-3,3'-diamine **S2**: ¹H NMR (DMSO-*d*₆, 400 MHz) δ: 8.95 (s, 2 H, N=CH), 8.39 (d, ³J = 8.0 Hz, 4 H, Ph-NO₂), 8.24–8.20 (d, ³J = 8.0 Hz, 8 H, Ph-NO₂), 7.73–7.69 (d, 4 H, biphenyl), 7.57 (m, 2 H, biphenyl), 7.39–7.37 (m, 2 H, biphenyl). ¹³C NMR (DMSO-*d*₆, 100 MHz) δ 159.50, 151.26, 148.87, 141.49, 140.83, 129.85, 125.25, 123.99, 121.00, 119.19. MS (*m/z*, %): 450 (M⁺, 100), 434 (7.36), 433 (22.92), 402 (7.90), 356 (7.98), 317 (6.78), 254 (11.37), 241 (11.56), 225 (13.49), 178 (14.39), 152 (37.65), 127 (17.09), 113 (6.00), 77 (12.34), 65 (7.10), 51 (7.31), 39 (2.71). m.p. > 250 °C. Yellow powder.

*N*²,*N*^{2'}-bis(4-nitrobenzylidene)biphenyl-2,2'-diamine **S3**: ¹H NMR (DMSO-*d*₆, 400 MHz) δ: 8.41(s, 2 H, N=CH), 8.21 (d, ³J = 8.0 Hz, 4 H, Ph-NO₂), 7.64 (d, ³J = 8.0 Hz, 4 H, Ph-NO₂), 7.51–7.37 (m, 6 H, biphenyl), 7.19 (d, ³J = 8.0 Hz, 2 H, biphenyl). ¹³C NMR (DMSO-*d*₆, 100 MHz) δ 158.17, 149.79, 148.60, 141.33, 134.35, 130.97, 129.09, 128.83, 126.24, 123.88, 118.08. MS (*m/z*, %): 450 (M⁺, 100), 434 (7.36), 433 (22.92), 402 (7.90), 356 (7.98), 317 (6.78), 254 (11.37), 241 (11.56), 225 (13.49), 178 (14.39), 152 (37.65), 127 (17.09), 113 (6.00), 77 (12.34), 65 (7.10), 51 (7.31), 39 (2.71). m.p. 227–229 °C. Yellow powder.

Limits of detection (*LOD*) for the CN[−] by the probes **S1–S3** were calculated according to Equation (1) [35]:

$$LOD = \frac{3 \times \sigma}{k} \quad (1)$$

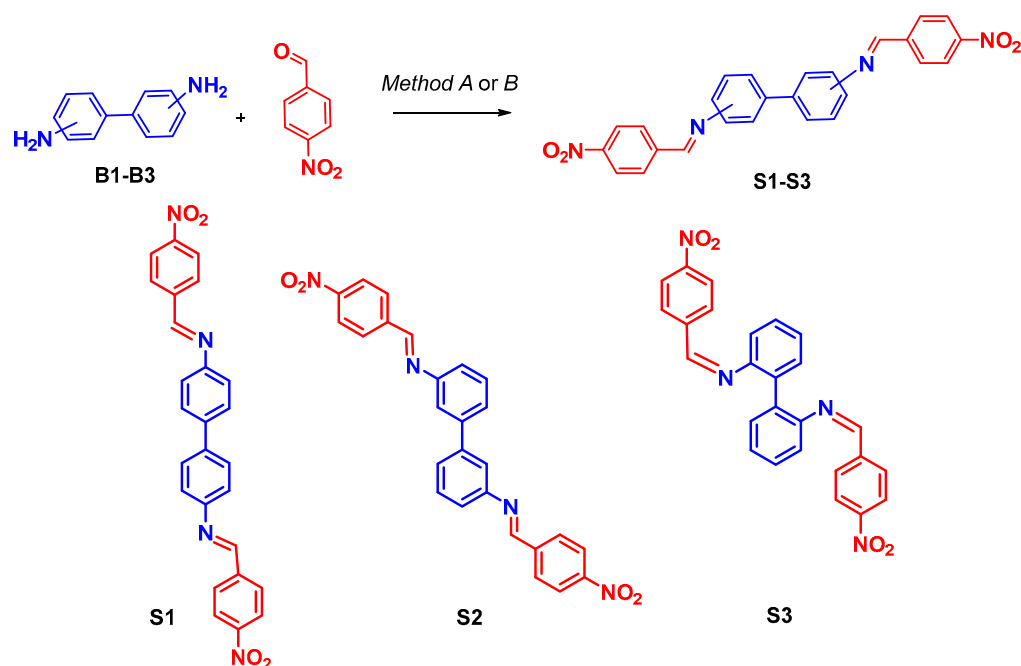
Equation (1): The calculation of *LOD*, where σ is the standard deviation of the chromophore intensity in the absence of an analyte (TBACN) and *k* is the slope of the linear calibration curve.

3. Results and Discussion

Since the first report of H. Schiff [36], the most common way (a conventional method) for their preparation [37] is the acid-catalyzed reaction of nucleophilic addition of aliphatic or aromatic amines to carbonyl compounds in solution upon heating to result in hemiaminals, followed by dehydration. Compared to the conventional methods, the ball milling under solvent-free conditions for the Schiff's base preparation looks more attractive due to the shorter reaction times [38,39].

It should be noted that the synthesis of *N*⁴,*N*^{4'}-bis(4-nitrobenzylidene)biphenyl-4,4'-diamine **S1** was reported previously [40,41], however, with much prolonged reaction time (48 h) or in absolute ethanol with comparable reaction yields.

Based on the above, to prepare the probes **S1–S3**, we used solvent-free conditions under ball milling as the most preferable method. The probes **S1–S3** were synthesized by means of the reaction between the corresponding isomeric 4,4- (**B1**), 3,3- (**B2**), and 2,2- (**B3**) diamino-biphenyls and 4-nitrobenzaldehyde (Scheme 1).



Scheme 1. Reagents and conditions: Method A: MeOH, TFA (3 drops), reflux, 12 h, up to 70%; Method B: ball-milling, TFA (3 drops), 500 rpm, 1 h, up to 95%.

For comparison, we carried out the same reaction in methanol under reflux. As we expected, the ball milling conditions proved to be more efficient in many respects, such as reaction time (1 h), reaction yield (up to 95%), reduced solvent consumption (only for purification), and room temperature conditions, while for the solvent-based reaction (in our case) a more prolonged reaction time (8 h) was required and much lower reaction yields (70%) were observed.

The structures of the products **S1–S3** were confirmed by ^1H , ^{13}C NMR, and IR-spectroscopy (see Supporting Information for details).

As a next step, the visual response of the probes **S1–S3** to CN^- in solution was studied. Thus, in a DMSO solution of **S1–S3** (1.1×10^{-3} M) upon the addition of tetrabutylammonium cyanide (TBACN, 1.4×10^{-2} M) a dramatic color change from yellow to orange-purple was observed (Figure 1). Depending on the structure of **S1–S3**, the colors varied from dark orange (**S1**) to dark purple (**S3**). The plausible mechanism for this interaction is presented below (Figure 2). Thus, the interaction involves the initial partial deprotonation of the $\text{CH}=\text{N}$ moiety of the probes **S1–S3** by the CN^- ion. This deprotonation was observed by means of a ^1H NMR experiment in the case of **S3** (Figure S30 ESI[†]). Thus, in DMSO-*d*₆, the addition of 3.0 eq. of TBACN results in the complete disappearance of the proton signal of $\text{CH}=\text{N}$ moiety at 8.45 ppm, which confirms the deprotonation of this moiety. Most probably, the presence of strong electron-withdrawing NO_2 group in the *para*-position of an aromatic moiety in the structure of **S1–S3** polarizes strongly the imine bond, which makes this imine proton more acidic. After that, the formation of deeply colored charge-transfer complexes with another molecule of **S1–S3** takes place. This concept was confirmed by a similar color change after the addition of 0–1.35 μM of tetrabutylammonium hydroxide (TBAOH) as a strong base in DMSO as well as UV-titration studies (Figures S31–S34 ESI[†]).



Figure 1. Visible detection of CN^- ion (1.4×10^{-2} M) by the probes **S1–S3** (1.1×10^{-3} M).

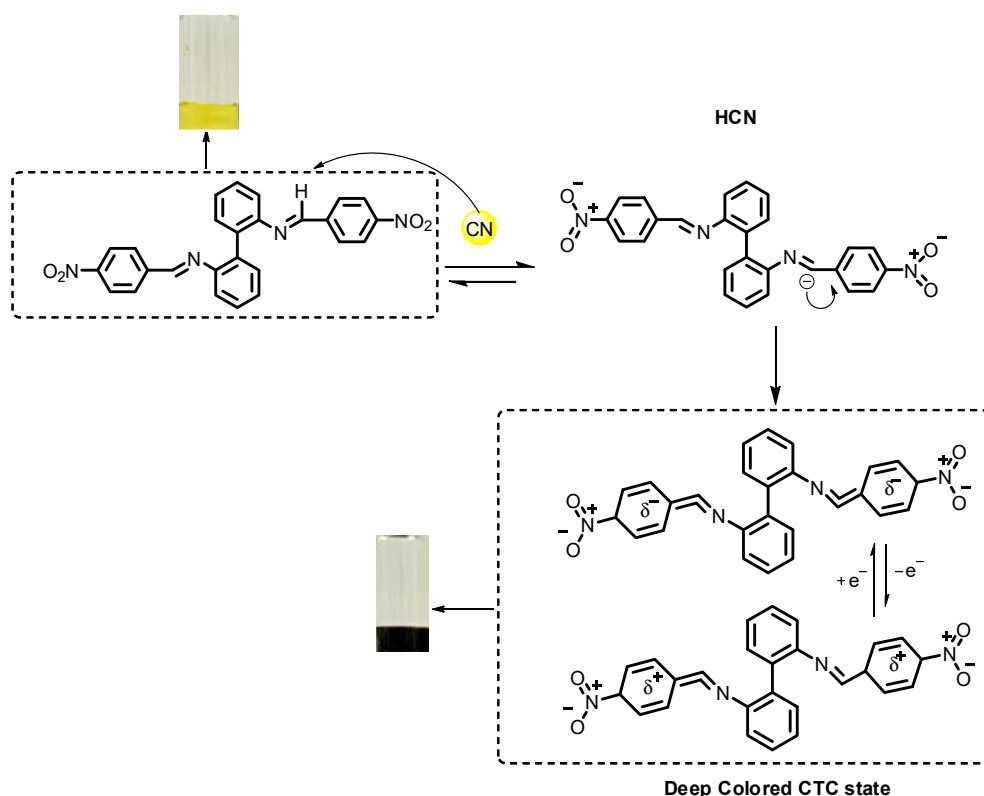


Figure 2. Plausible mechanism for the CN^- ion detection by probes **S1–S3**.

To gain more evidence, the photophysical studies of **S1–S3** were carried out. Thus, in UV spectra of DMSO solution, probe **S1** (22 μM) exhibits an absorption band with a maximum at 295 nm, and the addition of TBACN in concentrations 0–1.35 mM results in the appearance of a new absorption band at 575 nm, which can be attributed to the formation of the charge-transfer complex (Figure S35 ESI†). In the case of probe **S2**, one absorption peak at 275 nm was observed, and a new growing peak at 475 nm was detected upon the addition of TBACN (Figure S36 ESI†). For the probe **S3**, one absorption peak at 295 nm was observed, and a new peak at 555 nm was observed upon the addition of TBACN (Figure 3a). For the most representative probe, **S3**, we attempted to carry out Job plot experiment in order to determine the stoichiometry of the complex and the binding mode between **S3** and the CN^- ion. However, the increasing hypochromic shift with the increasing concentration of the TBACN never reached a steady state, and the mathematical representation ($A = e^x$) where A—absorbance; X—concentration (see Figure S37 ESI†) can be seen as an exponential dependence. The observed result corresponds to the literature data [42–46] according to which the job plot method could not be fully validated in the case of supramolecular assemblies with low to moderate association constants. In addition, for

the probes **S1–S3**, the CN^- detection limit (LOD) was calculated according to Equation (1), which was found to be 26×10^3 , 8.7×10^3 and 14×10^3 ppm, respectively.

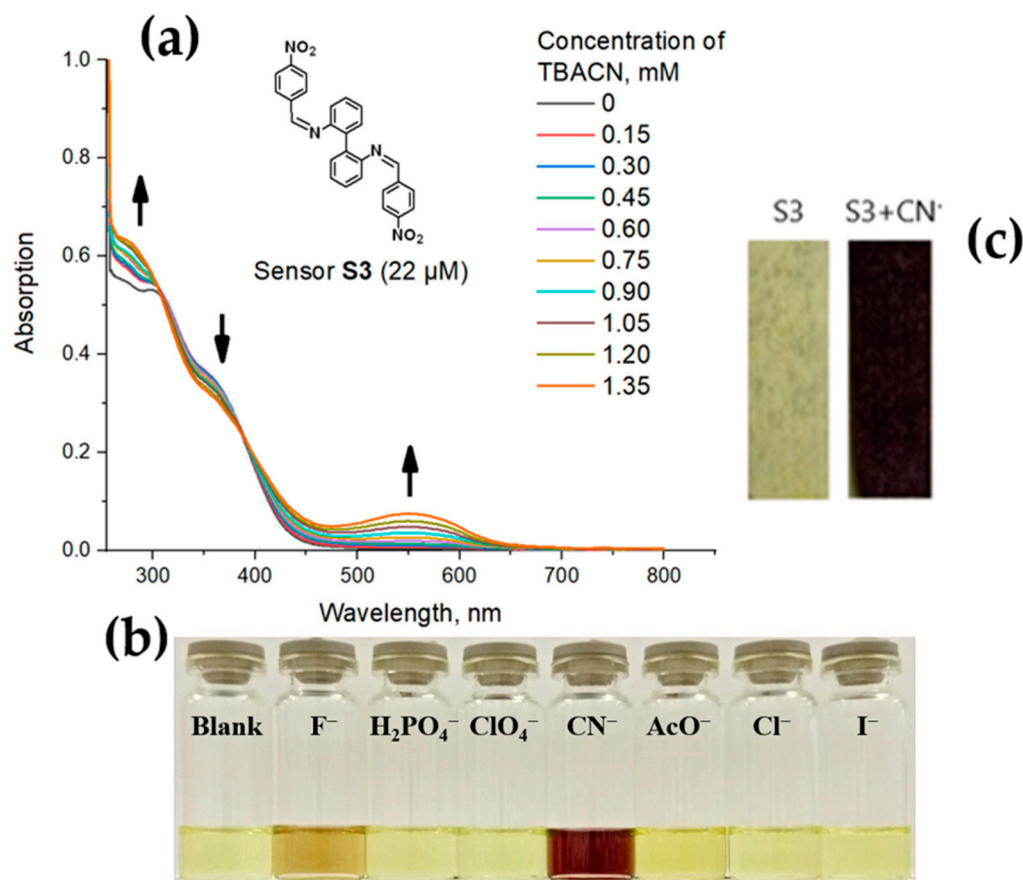


Figure 3. (a) UV-titration of **S3** (22 μM) with TBACN (0–1.35 mM) in DMSO; (b) The selective response of **S3** (1×10^{-3} M) to CN^- vs. other anions (1×10^{-3} M); (c) **S3**-impregnated test stripe before (left) and after (right) the treatment with CN^- ion-containing solution.

It is worth mentioning that the addition of other anions, such as Cl^- , HPO_4^- , I^- , ClO_4^- , CH_3CO_2^- , and even F^- , to the solution of the most representative probe **S3** in DMSO results in no color change or only subtle color changes (Figure 3b), while the presence of CN^- can be easily distinguished by the naked eye due to the dramatic color change, which is detectable in the UV/Vis scale. All of the above-mentioned confirms the high selectivity of **S3** toward the CN^- anion among other anions.

As a final step, to explore the potential application of the herein reported probes for environmental monitoring, the test strips for the CN^- ion detection were prepared by means of impregnation of filter paper with the solution of the most representative probe **S3** in DMSO (0.014 M) with the following air-drying. As a result, the **S3**-impregnated test strips demonstrated the selectivity and sensitivity to CN^- (14 mM) ions via a dramatic color change (Figure 3c).

4. Conclusions

In summary, simple Schiff's base probes **S1–S3** for the detection of cyanide ions were prepared by using a reaction between isomeric 4,4-, 3,3-, and 2,2-diaminobiphenyls and 4-nitrobenzaldehyde under ball milling conditions. The obtained probes demonstrated a selective visual response to the CN^- ion over other anions in a solution of DMSO via a dramatic color change with a detection limit of 26×10^3 , 8.7×10^3 and 14×10^3 ppm for **S1–S3**, respectively. The plausible mechanism of the reaction suggests a deprotonation of $\text{CH}=\text{N}$ moieties of **S1–S3** with the following formation of a deeply colored charge

transfer complex with another molecule of **S1–S3**, which is detectable by means of ^1H NMR and UV/vis-methods. To confirm the practical application of the obtained probes for the detection of CN^- , **S3**-impregnated test strips were prepared, which demonstrated the selective detection of CN^- via a dramatic color change.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/chemistry5020066/s1>, Figures S1–S30: ^1H and ^{13}C NMR spectra, mass spectra, IR spectra of the chemosensors **S1–S3** and the corresponding precursors, Figures S31–S33: UV-Vis spectra of chemosensors **S1–S3** with various concentration of TBAOH, Figure S34: a photo of chemosensor **S1** with and without TBAOH, Figures S35 and S36: UV-Vis spectrum of **S1** and **S2** with various concentration of TBACN, Figure S37: Relationship between the absorption of **S3** and the concentration of TBACN.

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Data Availability Statement: The data presented in this study are available upon request from the corresponding author.

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Conflicts of Interest: The authors declare no conflict of interest.

References

1. Dash, R.R.; Gaur, A.; Balomajumde, C. Cyanide in industrial wastewaters and its removal: A review on biotreatment. *J. Hazard. Mat.* **2009**, *163*, 1–11. [\[CrossRef\]](#)
2. Jaszcak, E.; Polkowska, Z.; Narkowicz, S.; Namieśnik, J. Cyanides in the environment-analysis-problems and challenges. *Environ. Sci. Pollut. Res. Int.* **2017**, *24*, 15929–15948. [\[PubMed\]](#)
3. Stewart, I.; Webb, P.M.; Schluter, P.J.; Shaw, G.R. Recreational and occupational field exposure to freshwater cyanobacteria—A review of anecdotal and case reports, epidemiological studies and the challenges for epidemiologic assessment. *Environ. Health* **2006**, *5*, 6. [\[CrossRef\]](#)
4. Vetter, J. Plant cyanogenic glycosides. *Toxicon* **2000**, *38*, 11–36. [\[CrossRef\]](#)
5. Ballhorn, D.J. Cyanogenic glycosides in nuts and seeds. In *Nuts & Seeds in Health and Disease Prevention*, 1st ed.; Preedy, V.R., Watson, R.R., Patel, V.B., Eds.; Academic Press: London, UK, 2011; pp. 129–136.
6. World Health Organization. *Guidelines for Drinking-Water Quality*; WHO: Geneva, Switzerland, 1996; Volume 2, pp. 6–8.
7. Biller, J. Chapter 163. In *Interface of Neurology and Internal Medicine (Illustrated Ed.)*; Lippincott Williams & Wilkins: Philadelphia, PA, USA, 2007; p. 939, ISBN 978-0-7817-7906-7.
8. Ma, J.; Dasgupta, P.K. Recent developments in cyanide detection: A review. *Anal. Chim. Acta* **2010**, *673*, 117–125. [\[CrossRef\]](#) [\[PubMed\]](#)
9. Wang, B.; Anslyn, E.V. (Eds.) *Chemosensors: Principles, Strategies, and Applications*; John Wiley & Sons, Inc.: New York, NY, USA, 2011. [\[CrossRef\]](#)
10. Xu, Z.; Chen, X.; Kima, H.N.; Yoon, J. Sensors for the optical detection of cyanide ion. *Chem. Soc. Rev.* **2010**, *39*, 127–137. [\[CrossRef\]](#)
11. Badugu, R.; Lakowicz, J.R.; Geddes, C.D. Cyanide-sensitive fluorescent probes. *Dye. Pigment.* **2005**, *64*, 49–55. [\[CrossRef\]](#)
12. Yin, C.; Huo, F.; Xu, M.; Barnes, C.L.; Glass, T.E. A NIR, special recognition on HS[−]/CN[−]-colorimetric and fluorescent imaging material for endogenous H₂S based on nucleophilic addition. *Sens. Actuators B Chem.* **2017**, *252*, 592–599. [\[CrossRef\]](#)
13. Kumari, N.; Jha, S.; Bhattacharya, S. An efficient probe for rapid detection of cyanide in water at parts per billion levels and naked-eye detection of endogenous cyanide. *Chem. Asian J.* **2014**, *9*, 830–837. [\[CrossRef\]](#)
14. Niu, H.T.; Su, D.; Jiang, X.; Yang, W.; Yin, Z.; He, J.; Cheng, J.P. A simple yet highly selective colorimetric sensor for cyanide anion in an aqueous environment. *Org. Biomol. Chem.* **2008**, *6*, 3038–3040. [\[CrossRef\]](#)
15. Barare, B.; Babahan, I.; Hijji, Y.M.; Bonyi, E.; Tadesse, S.; Aslan, K. A highly selective sensor for cyanide in organic media and on solid surfaces. *Sensors* **2016**, *16*, 271. [\[CrossRef\]](#)

16. Chen, Y.; Shi, W.; Hui, Y.; Sun, X.; Xu, L.; Feng, L.; Xie, Z. A new highly selective fluorescent turn-on chemosensor for cyanide anion. *Talanta* **2015**, *137*, 38–42. [\[CrossRef\]](#)
17. Chung, S.Y.; Nam, S.W.; Lim, J.; Park, S.; Yoon, J. A highly selective cyanide sensing in water via fluorescence change and its application to in vivo imaging. *Chem. Commun.* **2009**, 2866–2868. [\[CrossRef\]](#) [\[PubMed\]](#)
18. Yang, Y.-K.; Tae, J. Acridinium salt based fluorescent and colorimetric chemosensor for the detection of cyanide in water. *Org. Lett.* **2006**, *8*, 5721–5723. [\[CrossRef\]](#)
19. Sessler, J.L.; Cho, D.-G. The benzil rearrangement reaction: Trapping of a hitherto minor product and its application to the development of a selective cyanide anion indicator. *Org. Lett.* **2008**, *10*, 73–75. [\[CrossRef\]](#)
20. Li, H.; Chen, T.; Jin, L.; Kan, Y.; Yin, B. Colorimetric and fluorometric dual-modal probes for cyanide detection based on the doubly activated Michael acceptor and their bioimaging applications. *Anal. Chim. Acta* **2014**, *852*, 203–211. [\[CrossRef\]](#) [\[PubMed\]](#)
21. Nandhini, C.; Kumar, P.S.; Shanmugapriya, R.; Satheeshkumar, A.; Vennila, K.N.; Elango, K.P. A multi-site probe for selective detection of cyanide and sulphite ions via different mechanisms with concomitant different fluorescent behaviors. *Results Chem.* **2022**, *4*, 100312. [\[CrossRef\]](#)
22. Junaid, H.M.; Batool, M.; Harun, F.W.; Akhter, M.S.; Shabbir, N. Naked Eye Chemosensing of Anions by Schiff Bases. *Crit. Rev. Anal. Chem.* **2022**, *52*, 463–480. [\[CrossRef\]](#) [\[PubMed\]](#)
23. Lee, M.; Moon, J.H.; Swamy, K.M.K.; Jeong, Y.; Kim, G.; Choi, J.; Lee, J.Y.; Yoon, J. A new bis-pyrene derivative as a selective colorimetric and fluorescent chemosensor for cyanide and fluoride and anion-activated CO₂ sensing. *Sens. Actuators B Chem.* **2014**, *199*, 369–376. [\[CrossRef\]](#)
24. Orojloo, M.; Amani, S. Naked-eye detection of cyanide ions in aqueous media based on an azo-azomethine chemosensor. *Comptes Rendus Chim.* **2017**, *20*, 415–423. [\[CrossRef\]](#)
25. Dey, S.; Sen, C.; Sinha, C. Chromogenic Hydrazide Schiff Base Reagent: Spectrophotometric Determination of CN⁻ Ion. *Spectrochim. Acta Part A Mol. Biomol. Spectrosc.* **2020**, *225*, 117471. [\[CrossRef\]](#)
26. Kodlady, S.N.; Narayana, B.; Sarojini, B.K.; Gauthama, B.U. Aromatic aldehyde based chemosensors for fluoride and cyanide detection in organic and aqueous media: As confirmed by characterization, spectroscopic and DFT studies. *Inorg. Chim. Acta* **2019**, *494*, 245–255. [\[CrossRef\]](#)
27. Elsafy, A.G.; Al-Easa, H.S.; Hijji, Y.M. Substituted 2-aminobenzothiazoles salicylidene synthesis and characterization as cyanide sensors in aqueous medium. *Sensors* **2018**, *18*, 2219. [\[CrossRef\]](#)
28. Yildirim, N.; Yildiz, M. A Schiff base sensor selective to anions, biological activity and spectral studies. *J. Turk. Chem. Soc. Sec. A Chem.* **2018**, *5*, 1271–1278. [\[CrossRef\]](#)
29. Dini, S.; Khanmohammadi, H. A new azo-azomethine sensor for detection of CN⁻ and AcO⁻ anions: Highly selective chemosensor for naked eye detection of sodium diclofenac. *Spectrochim. Acta Part A* **2019**, *222*, 117157. [\[CrossRef\]](#) [\[PubMed\]](#)
30. Li, Q.; Guo, Y.; Xu, J.; Shao, S. Novel indole based colorimetric and “turn on” fluorescent sensors for biologically important fluoride anion sensing. *J. Photochem. Photobiol. B Biol.* **2011**, *103*, 140–144. [\[CrossRef\]](#)
31. Moghadam, F.N.; Amirnasr, M.; Meghdadi, S.; Eskandari, K.; Buchholz, A.; Plass, W. A new fluorene derived schiff-base as a dual selective fluorescent probe for Cu²⁺ and CN⁻. *Spectrochim. Acta Part A Mol. Biomol. Spectrosc.* **2019**, *207*, 6–15. [\[CrossRef\]](#)
32. Shrivastava, A.; Gupta, V.B. Methods for the determination of limit of detection and limit of quantitation of the analytical methods. *Chron. Young Sci.* **2011**, *2*, 21–25. [\[CrossRef\]](#)
33. Dong, C.; Nakamura, K.; Taniguchi, T.; Mita, S.; Kodama, S.; Kawaguchi, S.; Nomoto, A.; Ogawa, A.; Mizuno, T. Synthesis of Aryl Iodides from Arylhydrazines and Iodine. *ACS Omega* **2018**, *3*, 9814–9821. [\[CrossRef\]](#)
34. Roy, P.-P.; D’Souza, K.; Cuperlovic-Culf, M.; Kienesberger, P.C.; Touaibia, M. New Atglistatin Closely Related Analogues: Synthesis and Structure-Activity Relationship towards Adipose Triglyceride Lipase Inhibition. *Eur. J. Med. Chem.* **2016**, *118*, 290–298. [\[CrossRef\]](#)
35. Wang, L.; Lu, W. Preparation of Unsymmetrical Biaryls by Pd(II)-Catalyzed Cross-Coupling of Aryl Iodides. *Org. Lett.* **2009**, *11*, 1079–1082. [\[CrossRef\]](#) [\[PubMed\]](#)
36. Schiff, H. Mitteilungen aus dem Universitäts-laboratorium in Pisa: 2. Eine neue Reihe organischer Basen. *Ann. Chem. Pharm.* **1864**, *131*, 118–119. [\[CrossRef\]](#)
37. Qin, W.; Long, S.; Panunzio, M.; Biondi, S. Schiff bases: A short survey on an evergreen chemistry tool. *Molecules* **2013**, *18*, 12264–12289. [\[CrossRef\]](#)
38. Nafee, S.S.; Hagar, M.; Ahmed, H.A.; Alhaddad, O.A.; El-Shishtawy, R.M.; Raffah, B.M. New two rings Schiff base liquid crystals; ball mill synthesis, mesomorphic, Hammett and DFT studies. *J. Mol. Liq.* **2020**, *299*, 112161. [\[CrossRef\]](#)
39. El-Sayed, T.H.; Aboelnaga, A.; Hagar, M. Ball milling assisted solvent and catalyst free synthesis of benzimidazoles and their derivatives. *Molecules* **2016**, *21*, 1111. [\[CrossRef\]](#)
40. Iqbal, A.; Siddiqui, H.L.; Ashraf, C.M.; Bukhari, M.H.; Akram, C.M. Synthesis, Spectroscopic and Cytotoxic Studies of Biologically Active New Schiff Bases Derived from p-Nitrobenzaldehyde. *Chem Pharm. Bull.* **2007**, *55*, 1070–1072. [\[CrossRef\]](#)
41. Eshghi, H.; Rahimizadeh, M.; Eshkil, F.; Hosseini, M.; Bakavoli, M.; Sanei-Ahmadabad, M. Synthesis of novel bis(β-aminocarbonyl) compounds and some β-aminocarbonyls by catalyst-free multicomponent Mannich reactions. *J. Iran. Chem. Soc.* **2014**, *11*, 685–692. [\[CrossRef\]](#)
42. Ingham, K.C. On the application of Job’s method of continuous variation to the stoichiometry of protein-ligand complexes. *Anal. Biochem.* **1975**, *68*, 660–663. [\[CrossRef\]](#)

43. Gil, V.M.S.; Oliveira, N.C. On the use of the method of continuous variations. *J. Chem. Educ.* **1990**, *67*, 473. [[CrossRef](#)]
44. Landy, D.; Tetart, F.; Truant, E.; Blach, P.; Fourmentin, S.; Surpateanu, G. Development of a competitive continuous variation plot for the determination of inclusion compounds stoichiometry. *J. Incl. Phenom. Macrocycl. Chem.* **2007**, *57*, 409–413. [[CrossRef](#)]
45. Olson, E.J.; Bühlmann, P. Getting more out of a job plot: Determination of reactant to product stoichiometry in cases of displacement reactions and n:n complex formation. *J. Org. Chem.* **2011**, *76*, 8406–8412. [[CrossRef](#)] [[PubMed](#)]
46. Ulatowski, F.; Dąbrowa, K.; Bałakier, T.; Jurczak, J. Recognizing the limited applicability of job plots in studying host–guest interactions in supramolecular chemistry. *J. Org. Chem.* **2016**, *81*, 1746–1756. [[CrossRef](#)] [[PubMed](#)]

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