



Communication

# New 5-Chloro-Maleonitrile-Salen Ligand and Relative Co(II) Complex

Alessia Cavallaro <sup>1</sup>, Rossella Santonocito <sup>1</sup> , Roberta Puglisi <sup>1</sup>, Andrea Pappalardo <sup>1,2</sup> and Giuseppe Trusso Sfrazzetto <sup>1,2,\*</sup> 

<sup>1</sup> Department of Chemical Sciences, University of Catania, Viale A. Doria 6, 95125 Catania, Italy

<sup>2</sup> National Interuniversity Consortium for Materials Science and Technology (I.N.S.T.M.) Research Unit of Catania, 95125 Catania, Italy

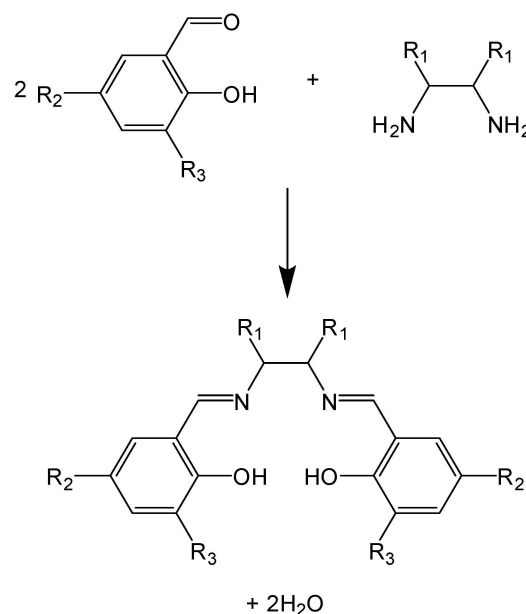
\* Correspondence: giuseppe.trusso@unict.it; Tel.: +39-0957385201

**Abstract:** Salen ligands and relative metal complexes are widely used in many fields, such as catalysis, sensing, optical and electronic materials. The introduction of a wide range of substituents in different positions, both in the salen scaffold and in the diamine bridge, allows the tuning of chemical, catalytic and spectroscopic properties. In this contribution, we report the synthesis and characterization of a new salen ligand and relative Co(II) complex bearing a maleonitrile bridge and two chlorine atoms in the salen backbone.

**Keywords:** salen; cobalt complex; maleonitrile

## 1. Introduction

The term *Salen* is an acronym widely employed to indicate a class of organic molecules which present a structure deriving from *N,N'*-bis(salicylidene)ethylenediamine (Scheme 1).



**Scheme 1.** General reaction for the synthesis of a salen ligand.

Most preparative and catalytic studies on this family of compounds have been dedicated to salen ligands with C2 symmetry, according to the procedure developed by Jacobsen and reported in Scheme 1 [1].



**Citation:** Cavallaro, A.; Santonocito, R.; Puglisi, R.; Pappalardo, A.; Trusso Sfrazzetto, G. New 5-Chloro-Maleonitrile-Salen Ligand and Relative Co(II) Complex. *Molbank* **2023**, *2023*, M1639. <https://doi.org/10.3390/M1639>

Academic Editor: Nicholas E.

Leadbeater

Received: 16 April 2023

Revised: 2 May 2023

Accepted: 4 May 2023

Published: 8 May 2023



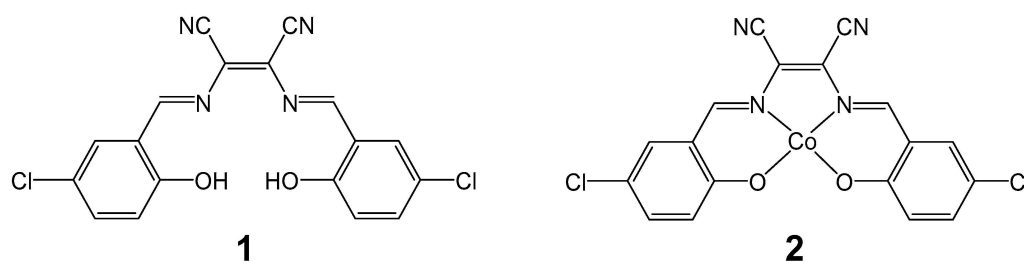
**Copyright:** © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

Common diamines used for the aforementioned synthesis are 1,2-cyclohexyldiamine, ethylenediamine, 1,2-diphenylethylenediamine and maleonitrile diamine [2–4]. The substituents on the aromatic rings can be different, although the most used have *t*-butyl groups in positions 3 and 5, and hydroxymethyls or halo substituents in position 5. Salen ligands may also be asymmetrical when they display different substituents on the two aromatic rings, leading to several advantages [5–11].

Furthermore, because of the complexation between metal ions and salen ligands, the imine groups increase their stability in acidic conditions since they are generally susceptible to acid-catalyzed hydrolysis in the presence of water.

For several years, salen ligands have been considered essential for catalysis, either symmetrical or asymmetrical [12–17], and sensing [18–22]. In particular, asymmetrical catalysis, also known as chiral synthesis, facilitates the formation of a specific stereoisomer during a chemical reaction. This is important in the field of pharmaceutical synthesis since enantiomers or diastereomers of the same molecule often have different biological activities.

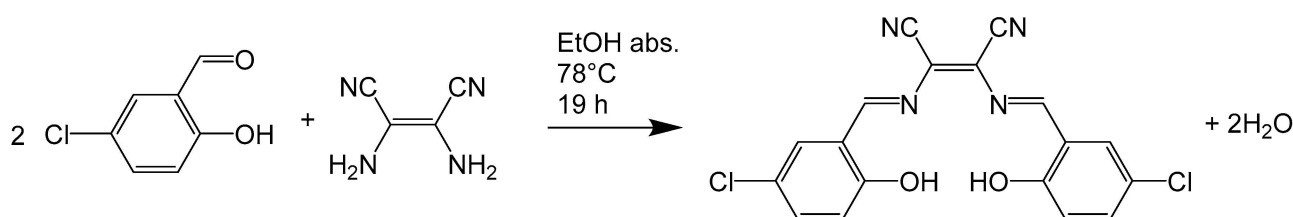
Here, we report the synthesis and characterization of a new salen ligand **1** (Figure 1), having a malonitrile bridge and two chlorine atoms in 5-5' positions, and its relative Co(II) metal complex **2** (Figure 1). These molecules can be used as precursors to obtain Lewis Acid receptors, thus used for sensoristic applications due to the intriguing fluorescence properties of the malonitrile and cobalt-based compounds. In addition, the presence of chlorine atoms in 5-5' positions lead to the possibility of further functionalization [23].



**Figure 1.** Chemical structures of ligand **1** and its Co-metal complex **2**.

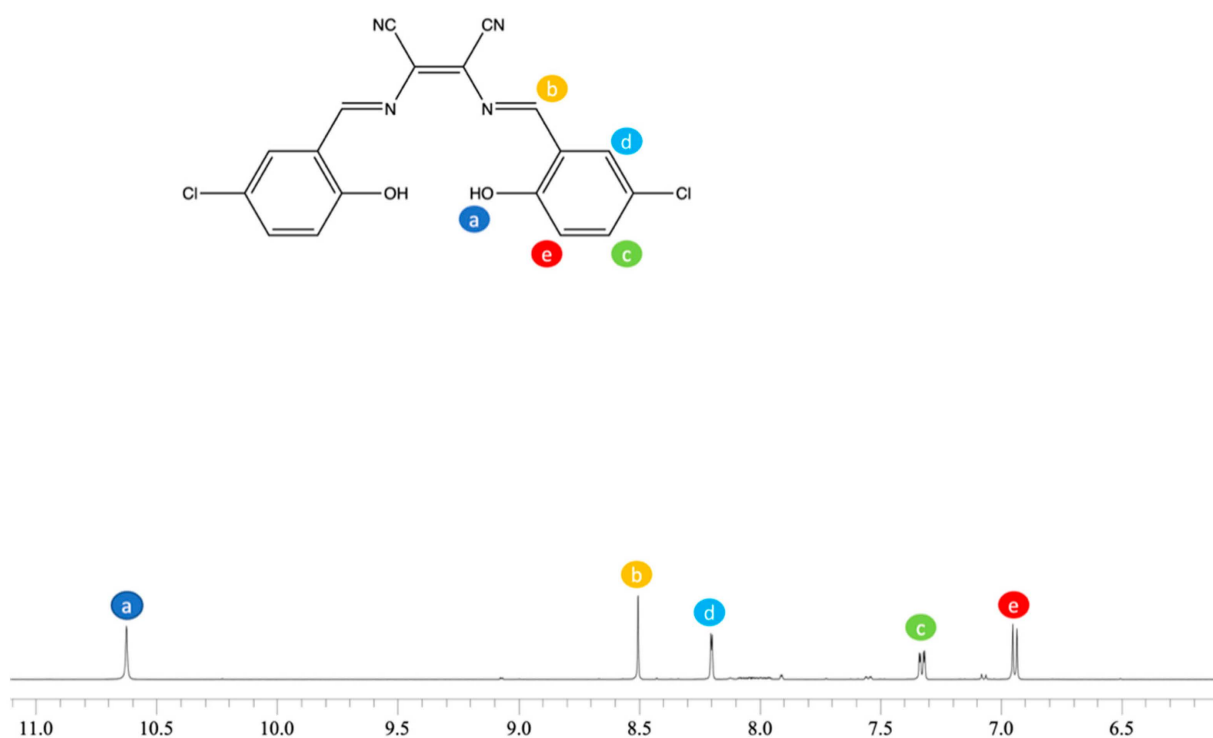
## 2. Results

Salen ligand **1** was obtained through the reaction of 5-chloro-salicylaldehyde and 2,3-diaminomaleonitrile in absolute ethanol (Scheme 2).



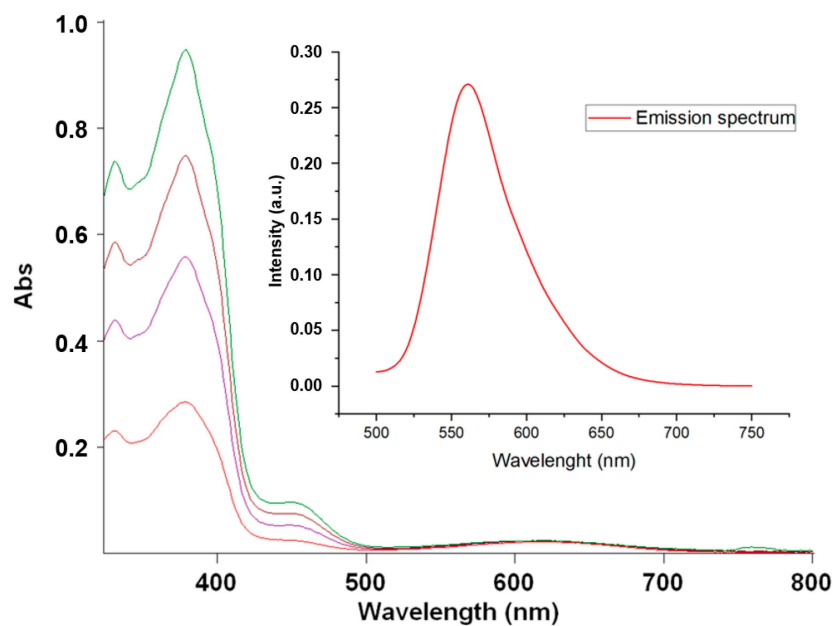
**Scheme 2.** Synthesis of the salen ligand **1**.

The reaction was performed overnight through reflux. The conversion of the starting aldehyde was monitored by TLC analysis. After the disappearance of the aldehyde, the precipitate was collected by vacuum filtration. The desired compound was characterized by  $^1\text{H}$  NMR,  $^{13}\text{C}$  NMR, ESI-MS and FT-IR analyses. In particular, the  $^1\text{H}$  NMR spectrum showed the presence of three signals at 8.20 and 6.94 ppm (doublets) and at 7.33 ppm (doublet of doublets) relative to the aromatic protons (Figure 2, light blue, green and red circles, respectively). In addition, the diagnostic signal due to the formation of the desired compound is at 8.50 ppm (singlet), and it is relative to the proton of the imine group (yellow circle in Figure 2). Finally, the singlet signal at 10.62 ppm is ascribed to the phenolic proton (blue circle in Figure 2).



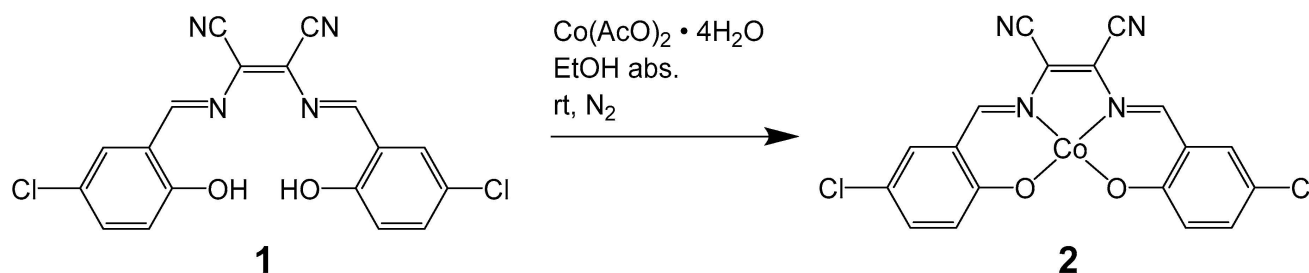
**Figure 2.**  $^1\text{H}$  NMR spectrum of **1** in  $\text{DMSO}-d_6$  and molecular structure.

The  $^{13}\text{C}$  NMR spectrum confirmed the structure of the molecule by the presence of nine different carbon signals (see Supplementary Materials). Moreover, the ESI-MS spectrum of **1** in methanol showed the presence of a signal at  $m/z$  408.1, relative to  $[\text{M}+\text{H}]^+$  (see Supplementary Materials). The UV-vis spectrum of **1** in  $\text{CH}_3\text{CN}$  showed a band centred at 379 nm, with  $\epsilon = 20,698$ , calculated using four solutions at four different concentrations ( $1 \times 10^{-5}$ ,  $2 \times 10^{-5}$ ,  $3 \times 10^{-5}$  and  $4 \times 10^{-5}$  mol/L, Figure 3). Upon excitation at 390 nm, an emission band with a maximum at 561 nm can be observed (Figure 3).



**Figure 3.** UV- vis spectrum in  $\text{CH}_3\text{CN}$  (red  $1 \times 10^{-5}$ , violet  $2 \times 10^{-5}$ , brown  $3 \times 10^{-5}$  and green  $4 \times 10^{-5}$  mol/L) and emission spectrum (red line,  $1 \times 10^{-5}$  M,  $\lambda_{\text{ex}}$  390 nm) in  $\text{CH}_3\text{CN}$  of **1**.

Salen ligand **1** was employed for the formation of a Co(II) complex **2** (Scheme 3). The reaction was performed at room temperature under a nitrogen atmosphere in the presence of Co(II) acetate until the formation of a precipitate. The conversion of the starting reagent was monitored by TLC analysis. The precipitate was collected by vacuum filtration. Due to the paramagnetic nature of Co(II), it is not possible to carry out NMR experiments [4,24,25]. The desired complex was characterized by ESI-MS analysis, showing a signal at  $m/z$  440.9, relative to  $[M]^-$  (see Supplementary Materials). Furthermore, FT-IR spectrum of **2** shows, in the region 3000–3500  $\text{cm}^{-1}$ , a broader band in respect to the ligand **1**, probably due to the absence of OH groups and the introduction of cobalt metal ion.



**Scheme 3.** Synthesis of Co(II)-salen complex **2**.

### 3. Materials and Methods

The NMR experiments were carried out at 27 °C on a Varian UNITY Inova 500 MHz spectrometer ( $^1\text{H}$  NMR at 499.88 MHz and  $^{13}\text{C}$  NMR at 125.7 MHz) equipped with a pulse-filed gradient module (Z axis) and a tunable 5 mm Varian inverse detection probe (ID-PFG). The ESI spectrum was acquired on an API 2000-ABSciex (positive and negative ion-mode for **1** and **2**, respectively). A JASCO V-560 UV-vis spectrophotometer, equipped with a 1 cm path-length cell, was used for UV-vis measurements (a resolution of 0.1 nm). Luminescence measurements were carried out using a Cary Eclipse fluorescence spectrophotometer at room temperature. The emission was recorded at 90° with respect to the exciting line beam, using 5:5 slit widths for all measurements. All chemicals were of reagent grade and were used without further purification.

#### 3.1. Synthesis of **1**

0.720 g ( $4.64 \times 10^{-3}$  mol) of 5-chloro-salicylaldehyde were transferred into a 250 mL flask and solubilized with 100 mL of absolute ethanol. Then, 0.250 g ( $2.32 \times 10^{-3}$  mol) of 2,3-diaminomaleonitrile were added to the solution. The reaction was stirred at reflux for 19 h. Conversion was monitored by TLC analysis (silica gel: *n*-hexane/EtOAc 8:2), and the disappearance of the starting reagent was observed. The precipitate was collected by vacuum filtration on Millipore, and it was washed with absolute ethanol. The product was dried on air (yield 45%).  $^1\text{H}$  NMR (500 MHz,  $\text{DMSO}-d_6$ ):  $\delta$  10.62 (s, 2H, OH), 8.50 (s, 2H, CH=N), 8.20 (d,  $J = 2.4$  Hz, 2H, Ar-H), 7.33 (dd,  $J = 3.0$  Hz,  $J = 9.1$  Hz, 2H, Ar-H), 6.94 (d,  $J = 8.5$  Hz, 2H, Ar-H) ppm.  $^{13}\text{C}$  NMR (125 MHz,  $\text{DMSO}-d_6$ )  $\delta$  103.46, 114.31, 118.64, 123.67, 124.08, 127.23, 132.82, 150.35, 157.16 ppm. ESI-MS:  $m/z$  408.1  $[\text{M}+\text{Na}]^+$ . FT-IR:  $\nu(\text{OH})$  3410  $\text{cm}^{-1}$ ;  $\nu(\text{Ar}-\text{C}-\text{H})$  3195  $\text{cm}^{-1}$ ;  $\nu(\text{C}\equiv\text{N})$  2247  $\text{cm}^{-1}$ ;  $\nu(\text{C}=\text{N})$  1637  $\text{cm}^{-1}$ ;  $\nu(\text{C}=\text{C})$  1553  $\text{cm}^{-1}$ . Anal. Calcd. For  $\text{C}_{18}\text{H}_{10}\text{Cl}_2\text{N}_4\text{O}_2$ : C, 56.13; H, 2.62; N, 14.55. Found: C, 56.09; H, 2.58; N, 14.53.

#### 3.2. Synthesis of **2**

A total of 0.150 g ( $3.9 \times 10^{-4}$  mol) of **1** were transferred into a 25 mL flask and solubilized with 2 mL of absolute ethanol. The reaction was stirred at reflux under  $\text{N}_2$  atmosphere. Then, 0.107 g ( $4.3 \times 10^{-4}$  mol) of Cobalt(II) acetate tetrahydrate were added to the solution. Once the precipitate was formed, the reaction was monitored by TLC analysis (silica gel: *n*-hexane/EtOAc 6:4). The precipitate was filtered under vacuum on Millipore and washed with 1 mL of absolute ethanol. The product was dried on air (yield

94%). ESI-MS:  $m/z$  440.9  $[M]^-$ . FT-IR:  $\nu(C\equiv N)$  2247  $cm^{-1}$ ;  $\nu(Ar-C-H)$  3424  $cm^{-1}$ ;  $\nu(C\equiv N)$  2247  $cm^{-1}$ ;  $\nu(C=N)$  1637  $cm^{-1}$ ;  $\nu(C=C)$  1553  $cm^{-1}$ ;  $g(Co-O)$  550  $cm^{-1}$ ;  $g(Co-N)$  494  $cm^{-1}$ . Anal. Calcd. For  $C_{18}H_8Cl_2CoN_4O_2$ : C, 48.90; H, 1.82; N, 12.67. Found: C, 48.85; H, 1.78; N, 12.62.

#### 4. Conclusions

Two new maleonitrile salen compounds, the salen ligand and its relative Co(II) complex, having chlorine atoms in 5-5' positions, have been synthesized and characterized. Further spectroscopic studies on the metal-salen complex **2** are in progress. These compounds can have applications in catalysis as well as sensing applications.

**Supplementary Materials:** The following supporting information can be downloaded online. Figure S1:  $^1H$  NMR spectrum of **1** in DMSO- $d_6$ ; Figure S2: APT spectrum of **1** in DMSO- $d_6$ ; Figure S3: ESI-MS spectrum of **1** in  $CH_3OH$ ; Figure S4: ESI-MS spectrum of **2** in  $CH_3OH$ .

**Author Contributions:** Methodology, A.C. and R.S.; formal analysis and data curation, A.P. and R.P.; conceptualization, G.T.S.; writing, review and editing, G.T.S. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by the University of Catania [“DetCWAs” (PIA.CE.RI 2020-2022-Linea Intervento 3)]. This work has been partially funded by the European Union (NextGeneration EU), through the MUR-PNRR project SAMOTHRACE (ECS00000022).

**Data Availability Statement:** Data are contained within the article. Compounds **1** and **2** can be provided by the authors.

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

#### References

- Holbach, M.; Zheng, X.; Burd, C.; Jones, W.; Weck, M. A Practical One-Pot Synthesis of Enantiopure Unsymmetrical Salen Ligands. *J. Org. Chem.* **2006**, *71*, 2903–2906. [[CrossRef](#)] [[PubMed](#)]
- Brancatelli, G.; Pappalardo, A.; Trusso Sfrazzetto, G.; Notti, A.; Geremia, S. Mono- and dinuclear uranyl(VI) complexes with chiral Schiff base ligand. *Inorg. Chim. Acta* **2013**, *369*, 25–29. [[CrossRef](#)]
- Lombardo, G.M.; Thompson, A.L.; Ballistreri, F.P.; Pappalardo, A.; Trusso Sfrazzetto, G.; Tomaselli, G.A.; Toscano, R.M.; Punzo, F. An integrated X-ray and molecular dynamics study of uranyl-salen structures and properties. *Dalton Trans.* **2012**, *41*, 1951–1960. [[CrossRef](#)] [[PubMed](#)]
- Patti, A.; Pedotti, S.; Ballistreri, F.P.; Trusso Sfrazzetto, G. Synthesis and characterization of some chiral metal-salen complexes bearing a ferrocenophane substituent. *Molecules* **2009**, *14*, 4312–4325. [[CrossRef](#)] [[PubMed](#)]
- Annis, D.A.; Jacobsen, E.N. Polymer-Supported Chiral Co(salen) Complexes: Synthetic Applications and Mechanistic Investigations in the Hydrolytic Kinetic Resolution of Terminal Epoxides. *J. Am. Chem. Soc.* **1999**, *121*, 4147–4154. [[CrossRef](#)]
- Breinauer, R.; Jacobsen, E.N. Cooperative Asymmetric Catalysis with Dendrimeric [Co(salen)] Complexes. *Angew. Chem. Int. Ed.* **2000**, *39*, 3604–3607. [[CrossRef](#)]
- D’Urso, A.; Tudisco, C.; Ballistreri, F.P.; Condorelli, G.G.; Randazzo, R.; Tomaselli, G.; Toscano, R.M.; Trusso Sfrazzetto, G.; Pappalardo, A. Enantioselective extraction mediated by a chiral cavitand-salen covalently assembled on a porous silicon surface. *Chem. Commun.* **2014**, *50*, 4993–4996. [[CrossRef](#)]
- Pappalardo, A.; Amato, M.E.; Ballistreri, F.P.; Tomaselli, G.A.; Toscano, R.M.; Trusso Sfrazzetto, G. Pair of diastereomeric uranyl salen cavitands displaying opposite enantiodiscrimination of  $\alpha$ -amino acid ammonium salts. *J. Org. Chem.* **2012**, *77*, 7684–7687. [[CrossRef](#)]
- Amato, M.E.; Ballistreri, F.P.; D’Agata, S.; Pappalardo, A.; Tomaselli, G.A.; Toscano, R.M.; Trusso Sfrazzetto, G. Enantioselective molecular recognition of chiral organic ammonium ions and amino acids using cavitand-salen-based receptors. *Eur. J. Org. Chem.* **2011**, *2011*, 5674–5780. [[CrossRef](#)]
- Tudisco, C.; Trusso Sfrazzetto, G.; Pappalardo, A.; Motta, A.; Tomaselli, G.; Fragalà, I.L.; Ballistreri, F.P.; Condorelli, G.G. Covalent functionalization of silicon surfaces with a cavitand-modified salen. *Eur. J. Org. Chem.* **2011**, *13*, 2124–2131. [[CrossRef](#)]
- Ballistreri, F.P.; Pappalardo, A.; Tomaselli, G.; Toscano, R.M.; Trusso Sfrazzetto, G. Heteroditopic chiral uranyl-salen receptor for molecular recognition of amino acid ammonium salts. *Eur. J. Org. Chem.* **2010**, *20*, 3806–3810. [[CrossRef](#)]
- Pappalardo, A.; Ballistreri, F.P.; Toscano, R.M.; Chiacchio, M.A.; Legnani, L.; Grazioso, G.; Veltri, L.; Trusso Sfrazzetto, G. Alkene epoxidations mediated by mn-salen macrocyclic catalysts. *Catalysts* **2021**, *11*, 465. [[CrossRef](#)]
- Zammataro, A.; Gangemi, C.M.A.; Pappalardo, A.; Toscano, R.M.; Puglisi, R.; Nicotra, G.; Fragalà, M.E.; Tuccitto, N.; Trusso Sfrazzetto, G. Covalently functionalized carbon nanoparticles with a chiral Mn-Salen: A new nanocatalyst for enantioselective epoxidation of alkenes. *Chem. Commun.* **2019**, *55*, 5255–5258. [[CrossRef](#)] [[PubMed](#)]

14. Ballistreri, F.P.; Toscano, R.M.; Amato, M.E.; Pappalardo, A.; Gangemi, C.M.A.; Spidalieri, S.; Puglisi, R.; Trusso Sfrazzetto, G. A new Mn-Salen micellar nanoreactor for enantioselective epoxidation of alkenes in water. *Catalysts* **2018**, *8*, 129. [[CrossRef](#)]
15. Ballistreri, F.P.; Gangemi, C.M.A.; Pappalardo, A.; Tomaselli, G.A.; Toscano, R.M.; Trusso Sfrazzetto, G. (Salen)Mn(III) catalyzed asymmetric epoxidation reactions by hydrogen peroxide in water: A green protocol. *Int. J. Mol. Sci.* **2016**, *17*, 1112. [[CrossRef](#)]
16. Trusso Sfrazzetto, G.; Millesi, S.; Pappalardo, A.; Toscano, R.M.; Ballistreri, F.P.; Tomaselli, G.A.; Gulino, A. Olefin epoxidation by a (salen)Mn(III) catalyst covalently grafted on glass beads. *Cat. Sci. Technol.* **2015**, *5*, 673–679. [[CrossRef](#)]
17. La Paglia Fragola, V.; Lupo, F.; Pappalardo, A.; Trusso Sfrazzetto, G.; Toscano, R.M.; Ballistreri, F.P.; Tomaselli, G.A.; Gulino, A. A surface-confined O=MnV(salen) oxene catalyst and high turnover values in asymmetric epoxidation of unfunctionalized olefins. *J. Mat. Chem.* **2012**, *22*, 20561–20565. [[CrossRef](#)]
18. Legnani, L.; Puglisi, R.; Pappalardo, A.; Chiacchio, M.A.; Trusso Sfrazzetto, G. Supramolecular recognition of phosphocholine by an enzyme-like cavitand receptor. *Chem. Commun.* **2020**, *56*, 539–542. [[CrossRef](#)]
19. Puglisi, R.; Mineo, P.G.; Pappalardo, A.; Gulino, A.; Trusso Sfrazzetto, G. Supramolecular detection of a nerve agent simulant by fluorescent Zn-Salen oligomer receptors. *Molecules* **2019**, *24*, 2160. [[CrossRef](#)]
20. Puglisi, R.; Pappalardo, A.; Gulino, A.; Trusso Sfrazzetto, G. Supramolecular recognition of a CWA simulant by metal-salen complexes: The first multi-topic approach. *Chem. Commun.* **2018**, *54*, 11156–11159. [[CrossRef](#)]
21. Trusso Sfrazzetto, G.; Millesi, S.; Pappalardo, A.; Tomaselli, G.; Ballistreri, F.P.; Toscano, R.M.; Fragalà, I.; Gulino, A. Nerve Gas Simulant Sensing by a Uranyl-Salen Monolayer Covalently Anchored on Quartz Substrates. *Chem. Eur. J.* **2017**, *23*, 1576–1583. [[CrossRef](#)] [[PubMed](#)]
22. Puglisi, R.; Ballistreri, F.P.; Gangemi, C.M.A.; Toscano, R.M.; Tomaselli, G.; Pappalardo, A.; Trusso Sfrazzetto, G. Chiral Zn-salen complexes: A new class of fluorescent receptors for enantiodiscrimination of chiral amines. *New J. Chem.* **2017**, *41*, 911–915. [[CrossRef](#)]
23. Xia, Q.; Shi, S.; Gao, P.; Lalancette, R.; Szostak, R.; Szostak, M. [(NHC)PdCl<sub>2</sub>(Aniline)] Complexes: Easily Synthesized, Highly Active Pd(II)-NHC Precatalysts for Cross-Coupling Reactions. *J. Org. Chem.* **2021**, *86*, 15650–15657. [[CrossRef](#)] [[PubMed](#)]
24. Tuccitto, N.; Amato, T.; Gangemi, C.M.A.; Trusso Sfrazzetto, G.; Puglisi, R.; Pappalardo, A.; Ballistreri, F.P.; Messina, G.M.L.; Li-Destri, G.; Marletta, G. Driving Coordination Polymer Monolayer Formation by Competitive Reactions at the Air/Water Interface. *Langmuir* **2018**, *34*, 11706–11713. [[CrossRef](#)]
25. Ishihara, K.; Hirota, S.; Fujino, A.; Ishihara, K.; Shioiri, T.; Matsugi, M. Asymmetric Henry reaction using a double fluorine-tagged Co-salen complex. *Tetrahedron Lett.* **2022**, *99*, 153833. [[CrossRef](#)]

**Disclaimer/Publisher's Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.