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Mini Review

Chemical Sensor Technology

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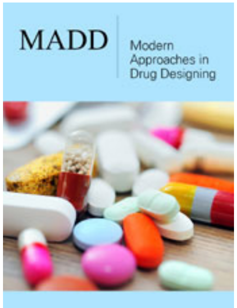

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Abstract

A sensor is a molecule that is designed to spectrally and electrochemically sense cations, anions and neutral molecules or other substrate molecules via non-covalent interactions, coulombic or a combination. These interactions involve hydrogen bonding, coulombic, coulombic in the presence of hydrogen bonding interactions. The design of a sensor is a thoughtful process, since the binding sites of the receptors must complement those of the substrates. It's important that the binding sites of chemical sensors be close to the redox active centre, so that any perturbation may be electrochemically sense. Electrochemically, binding can be reversible and irreversible. Over the years chemical sensors have been fabricated from several synthetic platforms which may or may not be redox active or endowed with a spectral chromophore. Amongst synthetic skeletons employed are: ferrocene, cobaltecenium, bipyridine, calixarene, porphyrins etc. These have been functionalized with amides and urea linkages. The complexity of the sensor may be increased via the presence of functionalities that may allow the sensor to self-assemble in solution. This presentation, outline the design, synthesis and spectral and electrochemical sensing of contemporary sensors in chemical sensor technology.

Keywords: Sensor; Hydrogen bonding interactions; Non-covalent interactions; Spectral and electrochemical

Introduction

A chemical sensor is a device that converts chemical data such as the concentration of a single sample component to complete composition analysis, into an analytically usable signal [1]. It consists basically of two components: a receptor which receive the signals and a physicochemical transducer. The receptors can take various form and range from activated or doped surfaces to complex macromolecules that are engaged with specific interactions with the analyte. Figure 1 shows a schematic representation of a chemical sensor.

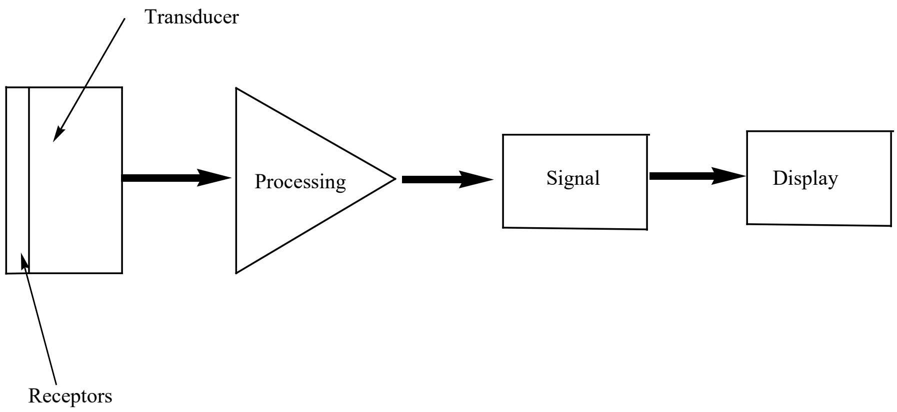

Figure 1: Schematic representation of a chemical sensor.

Requirements of sensors

A chemical sensor must maintain a high degree of specificity for the intended analyte in the presence of potentially interfering chemical species to avoid false positive outcomes. A chemical sensor must also have a transducer, responsible for converting the signal created by the receptor-analyte interactions in a readable and recognizable one. Another aspect is that sampling is often overlooked. An analyte cannot accurately be detected if it's not delivered to the transducer in a functional form. Fouling of a sensor by other macromolecular or reactive species can be an issue. An advantage of chemical sensing is that the sensor interface can be frequently refreshed or replaced. Monitoring of the recognition events can be performed via several methods, depending on the type of transducer utilized. These include optical, gravimetric or electrochemical [2].

Classification of chemical sensors

Chemical sensors can be classified into various types. These include:

A. Bio-sensors

B. Catalytic sensors

C. Electrochemical sensors

D. Nanosensors

This mini review will focus on Bio sensors and electrochemical sensors. It's beyond the scope of this review to address all.

Biosensors

A biosensor is one whose receptor is of biological origin. These receptors include DNA, antibodies and enzymes. A biosensor is composed of three major components:

a) Biocomponents or systems of biological detection. These include enzymes, antibodies, DNA probes, live cells and organelles.

b) Transducers: Converts signals generated by the analyte's interaction with the bio-component into a quantifiable electrical signal

c) A signal processing system: This converts the signal to a form that is accessible and readable

Biosensors are interesting candidates for environmental and biological operations because they possess the following advantages:

A. Quick data collection

B. Detection of the important substrate is accomplished without previous separation

C. Low sensitivity, ng/mL

D. Good selectivity and specificity

E. A high benefit/cost ratio and easy usage [3-5].

Biosensors are used in several bio/medical realms. These include:

a) Biomolecule Electrochemical Detection

b) Biosensors for Viral Infections

c) Enzyme-Based Electro sensor Application

d) Ion-Selective Electrodes (ISEs) in medicinal application

e) Biosensors for healthcare

Bio-sensing technology is a difficult task. First the design and then the construction. Biomolecules of a small size such as hormones, nuclei acids and enzymes are detected based on their physiological and biological roles. These include transferring, regulating biological activity, genetic information and catalysing cellular processes [6]. Biomolecular methods, such as Western blot, Polymerase Chain Reaction (PCR) and gel electrophoresis have been developed for the biosensing and analysis of biomolecules [7]. Enzyme sensing is in great demand. Many analytical techniques have been approved for measuring enzymatic activity. These include mass spectrometry, spectrophotometry, Raman spectroscopy and electrochemical techniques. Electrochemical procedures are favoured over other analytical techniques because of their cheap cost and speed [8]. Enzymatic sensors are created by immobilizing an enzyme on an electrode and then using it to determine the concentration of the matching substrate [9]. Biosensors are finding increasing application in the health sciences realm. One area it has addressed is the sensing of diabetes. Diabetes prevalence and diabetes patients use of biosensors are contributing significantly to worldwide business profitability. Biosensors for diabetes have made it possible to address the problem as soon as possible. Biosensors continuing developments have made it possible to detect blood glucose in the presence of various intervening substances within a wide range of temperatures. ZnO nanorods have been synthesized to detect glucose at a low cost, safe, accurate and rapid manner [10]. The sensitivity of biosensors for glucose in minute sample has been increasing due to advancement of chemical sensor technology. They are finding increasing application in the diabetes domain.

Electrochemical Sensors

Electrochemical sensors are those that possess a redox active centre close to the binding site of the sensor. Through its redox centre it can electrochemically sense the presence of neutral or cationic or anionic molecules. The binding can be reversible or irreversible and its facilitated via the presence of moieties such as hydroxyl, amino or other hydrogen bonding platform. Electrochemical sensors are the most frequently employed sensor, due to the fact of their advantages associated with low detection limits such as picomoles. In addition, their rapidness and the low cost of the equipment employed for their monitoring. Electrochemical sensors can be classified into several categories. These include amperometric, potentiometric, impedimetric, photoelectrochemical and electrogenerated chemiluminescence. Electrochemical sensors are in a variety of forms, ranging from the top-bench to the fully integrated wearable devices [11]. There are an increasing number of electrochemical sensors reported in the literature. For example, a novel 5,10,15,20 meso tetrakis (R -substituted) porphyrin receptor molecule (R= $C_6H_4NHC(O)C_5H_4C_oC_5H_5^+PF_6^-)_3$ was prepared and shown to spectrally and electrochemically sense halide, nitrate, hydrogen sulfate and dihydrogen phosphate guest anions [12], Figure 2.

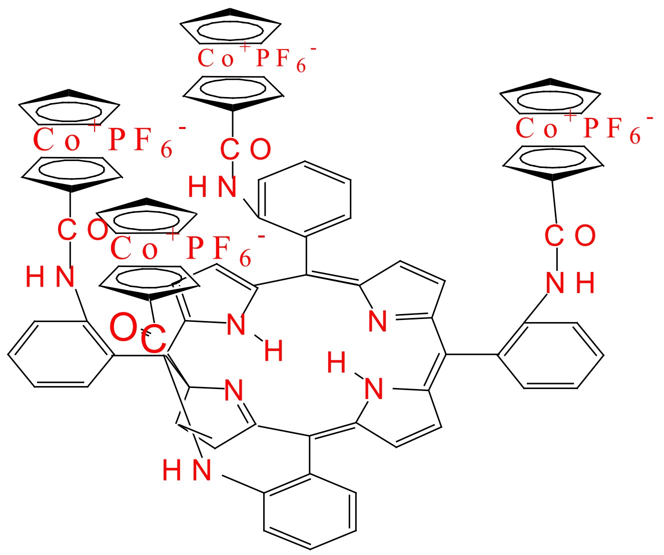

Figure2:

New free-base and zinc metalated 5,10,15,20-tetrakis(o-ferrocenylcarbonylaminophenyl-substituted) porphyrin atropisomers have been prepared. Proton NMR anion-binding investigations revealed the free base porphyrins to be poor complexing agents for anions. The corresponding zinc metalloporphyrin receptors strongly complex halide, nitrate and hydrogensulfate anions and stability constant evaluations showed marked selectivity trends dependent upon the particular atropisomer. Electrochemical studies showed that these zinc metalloporphyrins receptors electrochemically sense anions via significant cathode perturbations of the respective porphyrin oxidation and ferrocene redox couples [13]. A series of neutral, urea appended free base porphyrins and their Zn (II) complexes have been synthesized and characterized. The (α,α,α,α)-5-10,15,20-tetrakis (2-(arylurea)phenyl) porphyrins bind strongly (K(M-1) > 10^3-10^5) to chloride anion in DMSO-d6 and also in the more competitive solvent system DMSO-d_6/D_2O (88:12, v/v) and bromide anion in DMSO-d_6 as revealed by ^{1}HNMR titration studies. The porphyrin derivatives exhibited significant binding selectivity since they complexed with the spherical Cl^- and Br- to a much greater extent than with the tetrahedral H_2PO- and HSO_4- and the trigonal NO_3- anions in DMSO-d_6. The selectivity trend Cl- > Br- >H_2PO4- >HSO_4^- > NO_3^- is novel for any neutral urea-anion binding system [14]. An ion selective electrode for acetate based on (α,α,α,α)-5-10,15,20-tetrakis[2-(4-fluorophenylureylene)phenyl]-porphyrin as an ionophore that has no metal center and forms hydrogen bonds with the analyte has been reported. At a pH of 7.0 (0.1 M HEPES-NaOH buffer), the electrode based on this ionophore) responds to acetate in a linear range from $1.58x10^{-4}$ to 1.58x10-^{2}M with a slope of -51.8±0.8mV/decade and a detection limit of (3.06±1.15) x 10^{-5} M [15].

DNA and RNA electrochemical biosensors have been developed to diagnose viral illnesses such as hepatitis E, coronavirus, HIV, influenza virus, bacterium, malaria and Zika virus [16,17]. Electrochemical biosensors are robust, easy to use, portable and an inexpensive analytical system that can function in turbid media and they give highly sensitive readouts. Recently, electrochemical-sensor-based techniques have been used to detect SARS-CoV-2 virus, the agent responsible for COVID-19. These methods are fast, cheap, sensitive and specific. Both RT-PCR and electrochemical detection of SARS-CoV-2 by biosensors must be used together to identify SARS-CoV-2 virus and thus measures can then be taken to prevent COVID-19. RT-PCR test have been used as diagnostic tools to detect SARS-CoV-2 virus. However, these tests are time-consuming, needs highly skilled people. In addition, its expensive. Hence, they may not be good for monitoring many different samples at the same time. Thus, an alternative method in electrochemical biosensing must be used [18].

Conclusion

Chemical sensing is an important dimension in science and thus research has been ever increasing in this area. There are several technologies of detecting various substrates: neutral, cationic and anionic which has formed the basis for application environmentally, industrially, biologically and in the health care sector.

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