

CHAPTER I

INTRODUCTION

1.1 Supramolecular Chemistry

For many years, chemists have synthesized molecules and investigated their physical and chemical properties. The field of supramolecular chemistry has been defined as 'chemistry beyond the molecule' and involves new molecular system in which the most important feature is that the components are held together by intermolecular forces, not by covalent bonds.[1] Moreover, much recent work has focused on the development of self-assembling synthetic pathways towards large molecules or molecular arrays. These systems are often self-assemble using a variety of interactions such as hydrogen bonds, van der Waals and π - π interaction, etc.[2]

1.2 Molecular Recognition and Sensor

Considering a molecule (a 'host') binds another molecule (a 'guest') to produce a 'host-guest' complex or supramolecule. Normally, the host is defined as the molecular entity possessing convergent binding sites (e.g. Lewis basic donor atom) and The guest possesses divergent binding sites (e.g. Lewis acidic metal cation or hydrogen bond acceptor halide anion). The host-guest relationship involves a complementary stereo electronic arrangement of binding sites in host and guest. Depending on the size and nature of the cavities, these structures can act as a host for various types of guest molecules of different supramolecule with their arising luminescent or electronic properties can, thus, be exploited for sensing purpose.[3] The assembly of a specific receptor with a subunit is capable of signaling by the occurrence of receptor-substrate interaction, namely as a sensor. Sensor is related to a comparable extent

- 1) to the selectivity of the binding site.
- 2) to ease and implicitly of detecting and measuring the displayed signal.

The developments of chemical sensors have been of importances in:

- (a) industry (for monitoring chemical process, pollution, etc.);

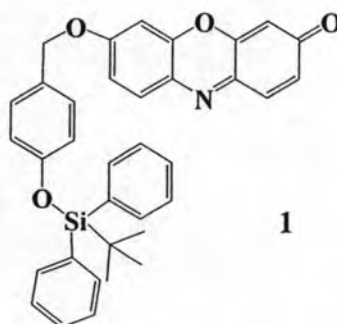
(b) diagnostic and therapeutic medicine (for electrolytes and as therapeutics in photo dynamic monitoring therapy, etc.);

(c) various kinds of environmental monitoring.

1.3 Anion sensor

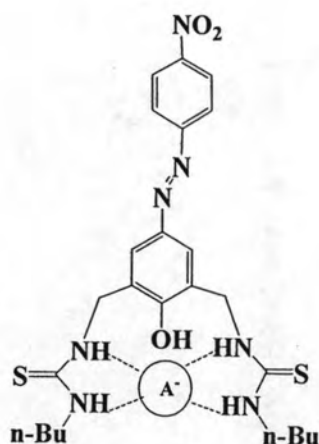
Anions are essential to life need, as many biological processes depending on the presence or transport of anions, or using anion to carry out chemical transformations. They are also important for many industrial processes and are often found as harmful pollutants.[4, 5] Anion sensing is a more challenging field due to the variable size, shape, and strong solvation of the species. Anion recognition chemistry of host-anion uses non-covalent interaction, which can be actually categorized into 4 types; hydrogen bonding, electrostatic interaction, metal or Lewis acid center (dipole-dipole interaction) or hydrophobic effects.[6]

Kim, S. Y. and coworkers[7] synthesized a dual chromogenic and fluorescent chemodosimeter **1**, which is selective for F⁻.



When fluoride selectively attacked silicon atom of the silyl ether group, it made the negative charge on the phenolate oxygen atom. Consequently, the resorufin was released through a fluoride-induced Si-O bond cleavage, resulting in dual spectroscopic changes.

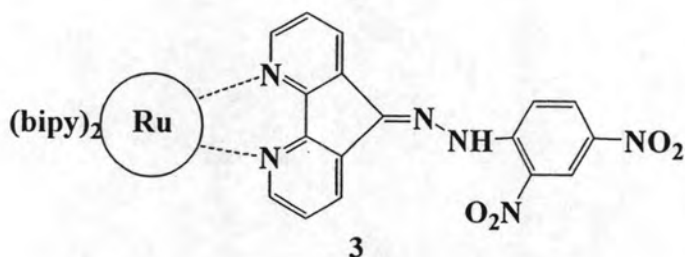
Lee, D.H. and coworkers[8] used a chromogenic azophenol-thiourea **2** to detect anions. It was found that four oxygens of H₂PO₄⁻ is favourable to form the strongest complex with **2** via multitopic hydrogen-bonding interaction.



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Furthermore, azophenol-based sensor **2** might cause colour changes, namely, for 'naked eye' because the electronic excitation occurs through a charge transfer from donor oxygen of the phenol to acceptor substituent (-NO₂) of the chromophore **2**. The selectivity trends of **2** were determined to be F⁻ > H₂PO₄⁻ > AcO⁻ > H₂SO₄⁻ > Cl⁻ > Br⁻ > I⁻. F⁻, H₂PO₄⁻ and AcO⁻ showed stronger complexes than other anion because of the basicity order of anions.[9, 10]

Lin, Z.H and coworker[11] designed the highly selective fluoride sensor **3** and constructed a test paper for detecting F⁻, at the low concentration limit to 1 ppm.



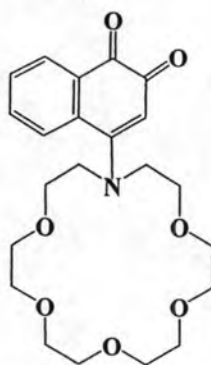
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The presence of 1 equivalent F⁻ in sensor **3** causes the different spectral change. Considering a stronger basicity of F⁻, it will not only induce a deprotonation process but also form a H-bonding complexed species. The colour changes from yellow to magenta. The colour changes of the test paper can be observed for the aqueous solution containing F⁻ which can be detected at the lowest concentration limit down to 1 ppm.

1.4 Cation sensor

Cations are important in many processes. One of them is used to transport organic substrates into cell. Additionally, metal cations play necessary roles in catalyst, enzymes and stabilizing the peptide structures. The last decade, many receptors were developed for detecting a toxic or a pollutant metal such as lead, cadmium, mercury or plutonium. Cation binding concentrated on synthetic receptors for cations via electrostatic ion-dipole interaction, and some case are used by hydrogen bonds. Therefore, the systems are designed to use in chelation therapy or to remove pollutant from environment.

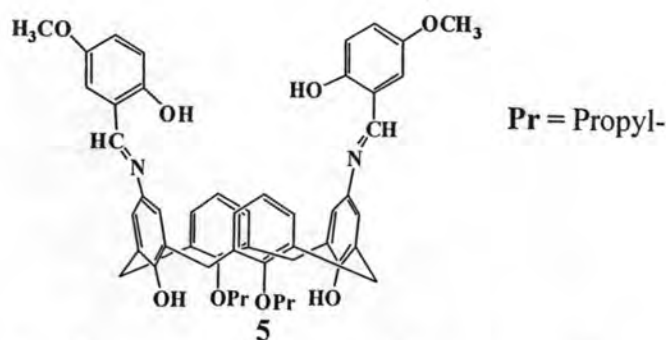
Ros,L and coworker[12] studied on the use of naphthoquinone derivative **4** as a receptor for the chromogenic sensing of Pb^{2+} and Ba^{2+} .



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From the UV-vis spectroscopy, spectrum of **4** in the presence of Pb^{2+} showed a complete deactivation of the charge transfer band and the case of Ba^{2+} receptor **4** is able to produce a partial decrease of the intensity of the band. This might be attributed to a strong covalent Pb^{2+} -N interaction due to a more efficient capture of the electron pair on the nitrogen atom.[13] In the case of Ba^{2+} with **4**, this is a strong electrostatic interaction among coordinating oxygen atoms and the partial interaction with the nitrogen atom from the macrocycle.

Liang, Z. and coworkers[14] incorporated imine group into the upper rim of calix[4]arene to obtain the schiff base-calix[4]arene **5**.



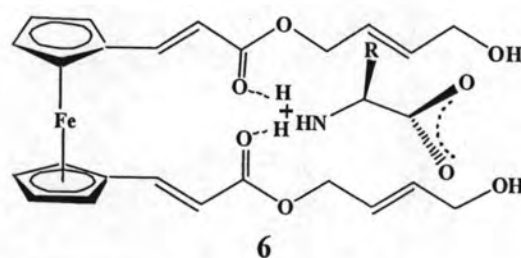
Ligand **5** is able to selectively recognize to lanthanide ion- Dy^{3+} and Er^{3+} observing from the solution colour changed from colourless to pink for Dy^{3+} and to pale yellow for Er^{3+} . The compound **5** might occur photo-induced electron transfer (PET) from imine group to methoxyl-phenol resulting in the fluorescence emission. The presence of Dy^{3+} and Er^{3+} , maximum fluorescent emission exhibited red shift and the lone pair electrons of nitrogen were donated to the empty orbital of the cations (Dy^{3+} and Er^{3+}) and a large chelation enhanced fluorescence (CHEF).[15]

1.5 Amino acids sensor

Amino acid is a molecule that contains both amine and carbonyl functional group. Amino acids play important role both as building blocks of proteins and as intermediates in metabolism[16]. The chemical properties of the amino acids of protein determine the biological activity of the protein. Several amino acids studies have been used as cancer makers[17-22] and, in relation to food quality and toxicity for human health[23], are currently being monitored in several food stuffs (fish, meat, cheese, wine) susceptible to microbial degradation during aging and storage.[24]

Debroy and coworkers[25] studied a ferrocene receptor **6** based on an open-arm framework and ene spacers. The hydrogen bonding will be versatile depending on the number of ene group and nature of binding chromophore. The receptor containing the α,β -unsaturated carbonyl residue near the Fc terminus, was designed to favorably bind with the $-\text{NH}_3^+$ end of the amino acid via $-\text{NH}^+\cdots\text{O}$ hydrogen bonding. The second design feature was invoked by two allylic alcohols at the termini of the receptor, with simultaneous interaction to a $-\text{COO}^-$ group of amino acid via hydrogen bonding. It was found that the binding constant values for various amino acids may be grouped into three

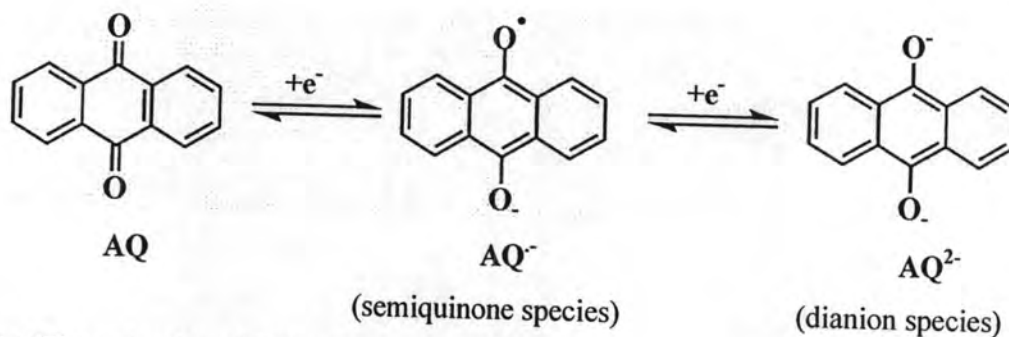
classes. They are (a) low K for the cationic amino acid guest (Lys), (b) intermediate K for zwitterionic guests (Gly, Gln), and (c) higher K for anionic amino acids (Glu, Asp).



1.6 Quinone Sensor

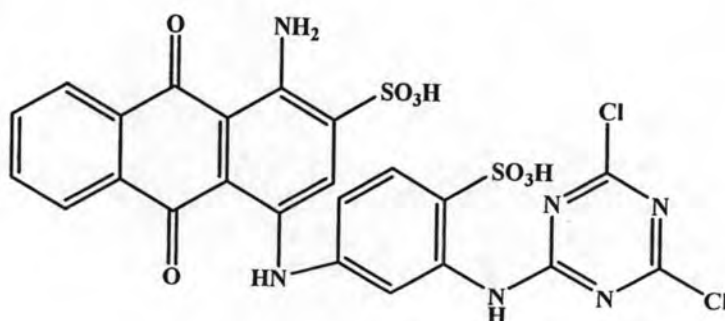
Quinone – hydroquinone couples have been studied over many decades as the prototypical examples of organic redox systems.[26, 27] In this regard, their electrochemical behavior, involving the kinetics and equilibria of coupled electron and electron transfer reactions, has given much information concerning the effect of molecular structure and environment on these basic processes.[28] In addition to their intrinsic chemical interest, these studies are particularly important in view of the key biological functions of quinone-based couples as electron-transfer agents in oxidative phosphorylation or photosynthesis.[29]

In well-buffered aqueous media (including mixture with ethanol, dioxane, etc.), quinone-hydroquinone couples provide familiar, reversible two-electron redox systems in which potentiometric or polarograph potentials vary with pH in a straightforward Nernstian manner.[28] This behaviour is conveniently summarized in E -pH diagrams, showing regions of existence of various redox and protonated species and their respective pK_a values.[27] In the strongly basic region ($pH > pK_a$ of QH^-) only the unprotonated forms, Q , $Q^{\cdot-}$, and Q^{2-} appear.[27]

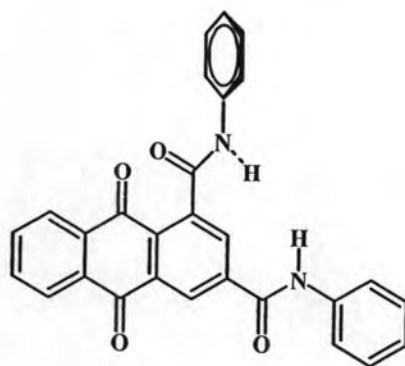


Scheme 1 The reduction of anthraquinone processes.

Carneiro, P. A. and coworker[30] investigated the electrochemical reduction of the (RB4) 7 in aqueous solution on a carbon electrode. It was found that at $\text{pH} < 8.0$ the anthraquinone group of the RB4 dye 7 are reduced in one cathodic step to hydroquinone after a reversible two-electron process involving a precedent two proton reaction. At $\text{pH} > 8.0$ the reduction process involves two reversible 2-electron step, which species are generated by a protonation equilibrium of anthraquinone group. The results showed that 60% of colour removal was obtained after 3 hours of RB4 dye 7 electrolysis at acidic and neutral conditions only 37% at alkaline condition.



Brooks, S., J. and coworker [31] synthesized the 1,3-diphenylcarboxamidoanthraquinone 8 and investigated that the hydrogen bonding with the anthraquinone occurred at through intra- or intermolecular interactions. Both semiquinone and dianion species was stabilized by these interactions. In the presence of a suitable competitive anion (specifically F^-), the hydrogen-bond donor groups bind to the anion rather than the quinone oxygen atoms. This removes the hydrogen bonding interaction to the redox0active quinone centre and hence dramatically changed the electrochemistry.



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1.7 Luminescent molecular logic gates

1.7.1 The design of PET sensor[32-35]

The PET mechanism is widely used in development of molecular sensing. This is in part due to the easy arrangement of the PET signaling switchable system which incorporates a receptor (donor moiety) coupled to a fluorophore (acceptor moiety) via σ -spacer. The presence of the spacer allows the fluorophore and receptor to be spatially distinct therefore minimizing any orbital interactions between these modules, while still allowing for long-range PET. The design of these systems follows the modular design shown schematically in Figure 1.1 where the fluorophore module is the site both excitation and emission while the receptor molecule is responsible for guest complexation and decomplexation.



Figure 1.1 Schematic representation displaying the PET system modular design.

PET is therefore a controllable process where fluorescence emission may be quenched, leading to the off state, as it depends on the redox potential which can be judge from the parent moiety of the system. The fluorophore and receptor are chosen so that an electron transfer can occur from the receptor to the fluorophore upon excitation. This

requires the excited state energy to be sufficient to oxidize the receptor (oxidation potential) and reduce the fluorophore (reduction potential).

The driving force for any PET mechanism is governed by ΔG_{ET} , the overall change in free energy for the electron transfer. ΔG_{ET} can be estimated using the Rehm Weller equation, (1.1).

$$\Delta G_{ET} = E_S - E_{Red.Fluorophore} + E_{Ox.Receptor} - e^2/(\epsilon r) \quad (1.1)$$

The equation as shown describes the fluorophore acting as an electron acceptor with the receptor as an electron donor. E_S is the singlet energy of the fluorophore, $E_{Red.Fluorophore}$ is the reduction potential of fluorophore, $E_{Ox.Receptor}$ is the oxidation potential of the receptor and the term $e^2/(\epsilon r)$ is the coulombic interaction between the fluorophore and receptor after the formation of radical ion pair. For highly polar solvents this latter term can be ignored for the purposes of our analysis.

The introduction of a guest can, when chosen correctly, alter the oxidation potential of the receptor, thus changing the thermodynamic driving force for PET. Figure 1.2 shows such a system, where PET occurs rapidly in the unbound case resulting in the formation of radical ion species with ΔG_{ET} negative and therefore thermodynamically favourable. However, in the case where the receptor (R) is bound to a guest (G) the oxidation potential of the receptor is raised (i.e. energy of its HOMO is lowered) and it is no longer thermodynamically favourable for the PET process to take place as ΔG_{ET} is now positive. The excited state energy of the fluorophore (E_s^*) can now be emitted via fluorescence as the deactivation pathway and the system is said to be switched on. This can be seen in Figure 1.3

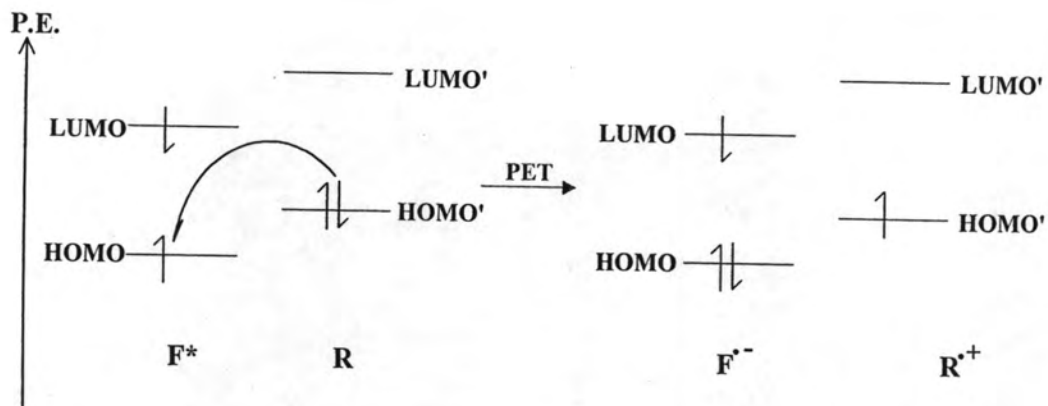


Figure 1.2 Frontier orbital diagram of the PET process which occurs in the guest free state. This is the off state.

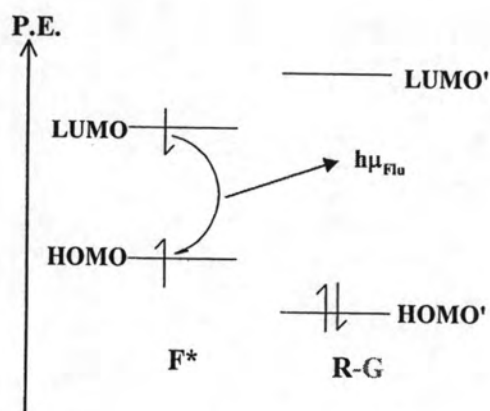


Figure 1.3 Frontier orbital diagram showing the effect of guest binding on the receptor's oxidation potential. This is the on state.

These processes can also be visualized with the use of modular diagrams, where it is possible to clearly see PET being retarded upon complexation of a guest species in a 'fluorophore-spacer-receptor' system. This can be seen in Figure 1.4.

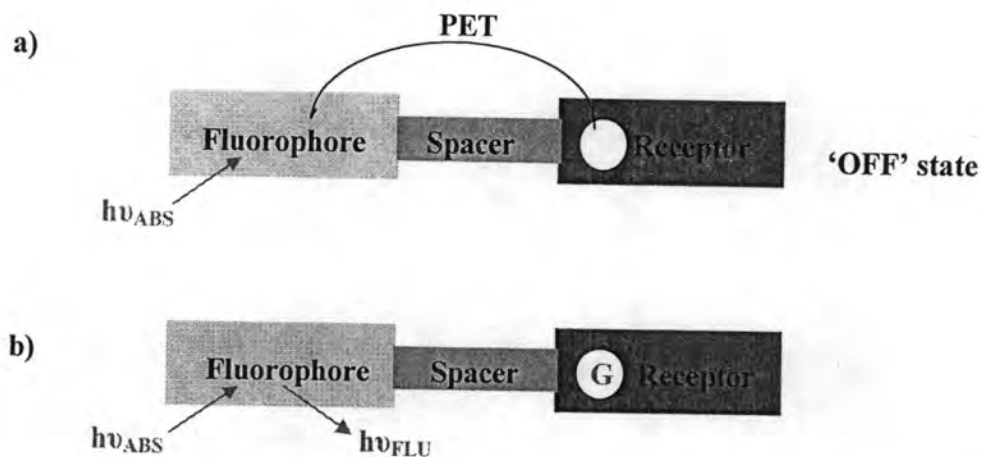


Figure 1.4 Modular diagrams showing (a) the off state and (b) the on state upon guest (G) binding.

1.7.2 Spectroscopic investigations

The fluorescence emission of a number of PET sensors shall be investigated upon the addition of a variety of salts to a number of solutions with differing polarities. The binding ability of the sensor towards the cation can be deduced from changes in the fluorescence spectrum upon varying ion concentration, showing the nature of the receptor both before and after complexation. By plotting the intensity of fluorescence at a specific wavelength (or the fluorescence quantum yield) against $-\log [M^+]$, i.e. pM, a sigmoidal plot of the type shown in figure 1.5 can be obtained, if the sensor is behaving correctly and complexing with the target cation.

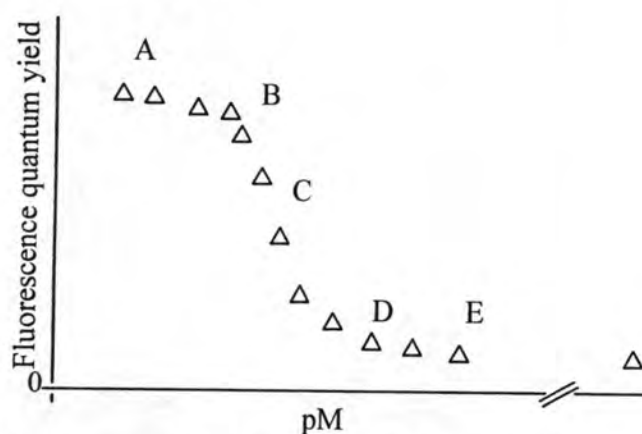


Figure 1.5 Sigmoidal plot for a sensor's fluorescence quantum yield (or intensity at a chosen wavelength) as a function of pM showing host:guest interaction.

This binding profile is an example of mass action and is general for all binding processes in the absence of second order effects, such as non-unity activity coefficients. Activity coefficients differ from unity when interactions of ionic species in low polarity solvents are involved. Labels on the curve correspond to differing ratios of bound and unbound receptor molecules. At point A, the sensor is completely bound while at B, only a few sensors remaining unbound. At D, the sensor molecule is only beginning to bind to the guest molecules whereas at E, the sensor is not binding at all. At point A, the sensor is said to be in the on state while at E, it is in the off state. Conventionally, switching take place over 2 pM units, between B and D, if 1:1 complexation is occurring.

From this graph, the relevant data can be taken and inserted into equation (2) in order to obtain the value of the binding constant, $\log \beta$.

$$\log [(\Phi F_{\max} - \Phi F) / (\Phi F - \Phi F_{\min})] = \log [X] - \log \beta \quad (1.2)$$

Where ΦF_{\max} = maximum fluorescence emission quantum yield

ΦF = fluorescence emission quantum yield at a given $\log [X]$ value

ΦF_{\min} = minimum fluorescence emission quantum yield

$[X]$ = concentration of metal ion

$\log \beta$ = binding constant in log units of sensor molecule

This equation can also be applied to absorbance, and can be rewritten to give equation (3), where A is the corresponding absorbance.

$$\log [(A_{\max} - A) / (A - A_{\min})] = \log [X] - \log \beta \quad (1.3)$$

1.7.3 Molecular logic gates [36, 37]

Presently, computers are based on silicon microchips which consist of millions of transistors, each acting as a logic gate performing binary arithmetic and logical operations. A most promising candidate is substituting standard silicon based logic gates with molecular logic gates (MLG's). Both classes operate under Boolean algebra with digitalised signals. Their distinction lies in the type of input and output signals; standard silicon logic gates avail of electronic input and output signals whilst MLG's can operate with either chemical or physical inputs and fluorescence or electronic outputs.

1.7.3.1 YES logic gates

It is the simplest and the most fundamental logic gate is the Yes logic gate. Boolean inputs representing true (1, high voltage) or false (0, low voltage) values and generate the appropriate Boolean output.²¹ When the applied input is low (0) the gate responds with a low output (0), while a high input (1) produces a high output (1). The truth table for the YES logic operation and its electronic representation can be seen in Figure 1.6

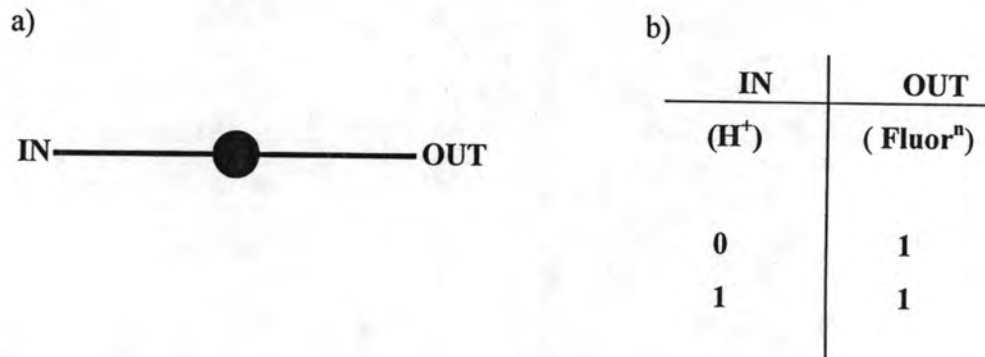


Figure 1.6 a) Electronic representation of YES logic,
b) Truth table for YES logic operation.

1.7.3.2 NOT logic gates

It is inverting to the Yes logic gates by showing the truth table and electronic representation in Figure 1.7.

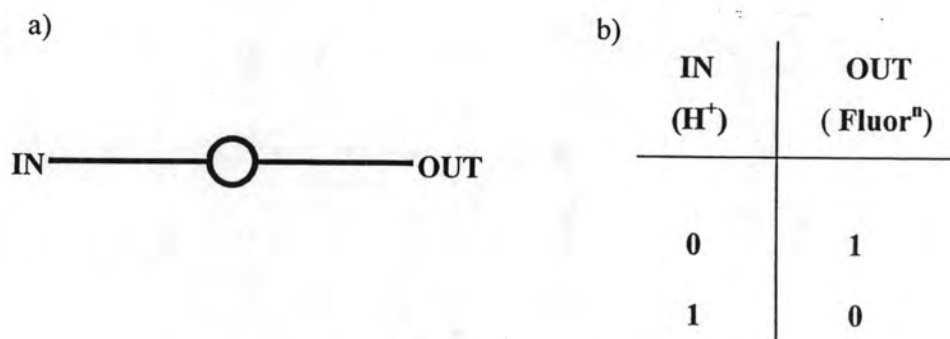


Figure 1.7 a) Electronic representation of NOT logic
b) Truth table for NOT logic operation.

1.7.3.4 AND logic gates

It is simple logic systems with two inputs. It is different from YES and NOT logic gates because it is more complex with two inputs and one output signal. This is apparent from the truth table and electronic symbol in Figure 1.8.

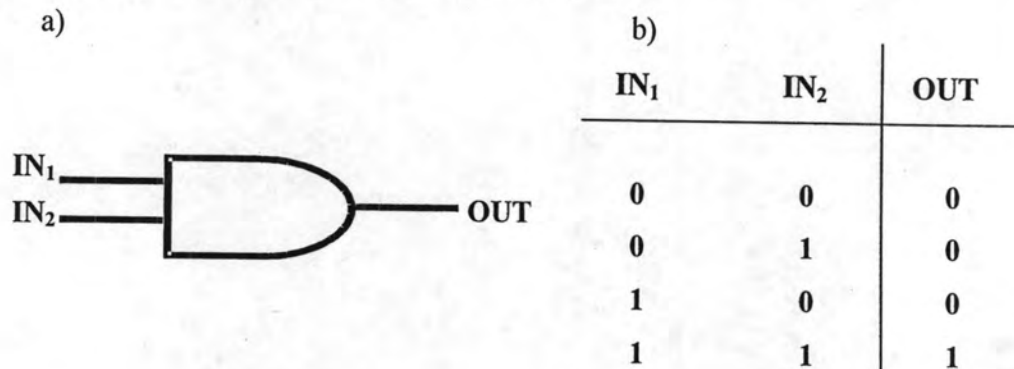


Figure 1.8 a) Electronic representation of AND logic

b) Truth table for AND logic operation

1.7.3.5 OR logic gates

OR logic gate is another two input logic. The high output is observed due to either a high input or both high input. It is showed the truth table and electronic symbol in Figure 1.9.

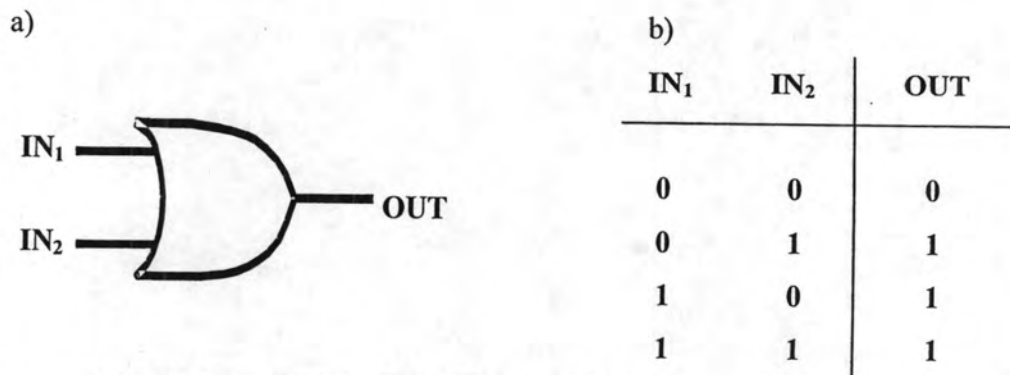


Figure 1.9 a) Electronic representation of OR logic

b) Truth table for OR logic operation

1.7.3.6 XOR logic gates

The XOR is frequently called an exclusive-OR logic gates. It is only either input is present, it is an output high signal as seen from the truth table in Figure 1.10.

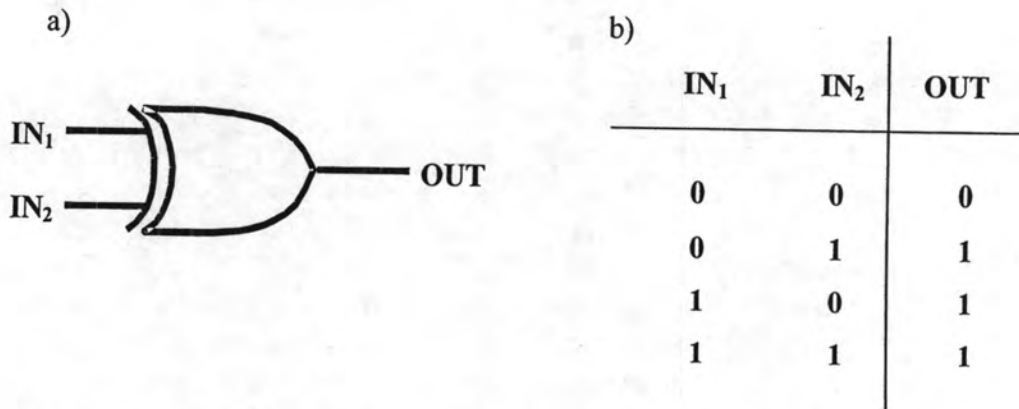


Figure 1.10 a) Electronic representation of XOR logic
b) Truth table for XOR logic operation

1.7.3.7 NOR logic gates

The NOR logic gate is operated by double inputs. NOR logic gate is combining of NOT and OR logic functions. It is showed the truth table and electronic symbol in Figure 1.11.

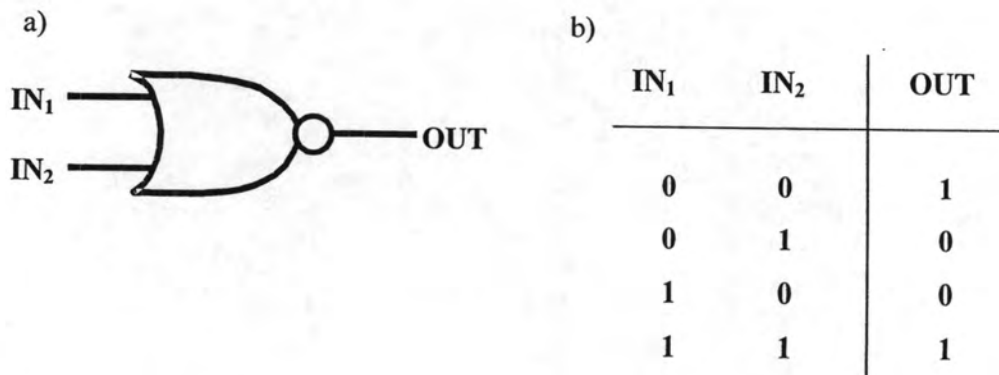


Figure 1.11 a) Electronic representation of NOR logic
b) Truth table for NOR logic operation

1.7.3.8 INHIBIT logic gates

INHIBIT is generated by combining of AND and NOT logic gates. It is showed the truth table and electronic symbol in Figure 1.12.

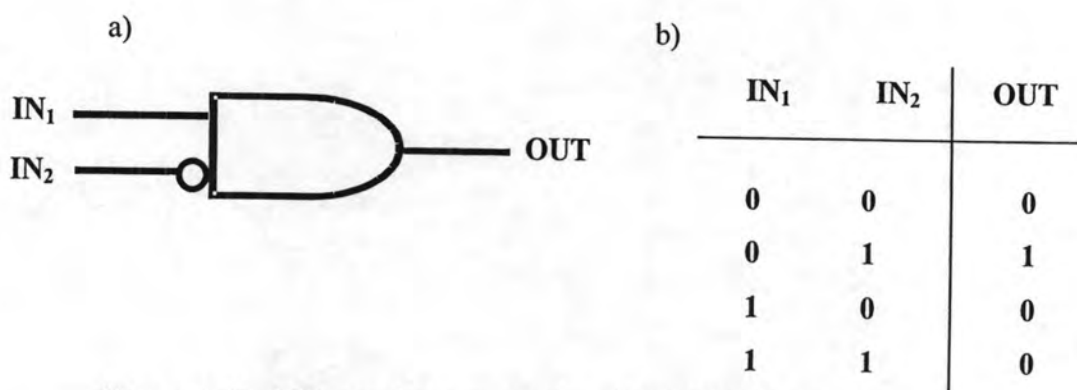


Figure 1.12 a) Electronic representation of INHIBIT logic

b) Truth table for INHIBIT logic operation

1.8 The objectives and scope of this research

The main goals of this research are;

(i) to synthesize benzimidazole bearing anthraquinone derivatives as the sensory unit L^1H , L^2H and L^3H and benzimidazole as well as amide group as the binding site. All of these compounds consist of $-C(2)H-$ and $NH-$ amide to serve as anion and amino acid receptors. The complexation studies of all derivatives with anions and amino acids were investigated by ^1H-NMR , $Uv-vis$ spectroscopy and cyclic voltammetry.

(ii) to synthesize receptor **8b** and **9b** using in the micelle for binding with Na^+ and Ca^{2+} . Moreover, receptors **12b**, **13b**, **15b**, **16b**, **18b** and **20b** were used for the effect of pH and temperature before attaching on beads. All of these compounds were investigated by fluorescence spectroscopy.

The target molecules were shown below.

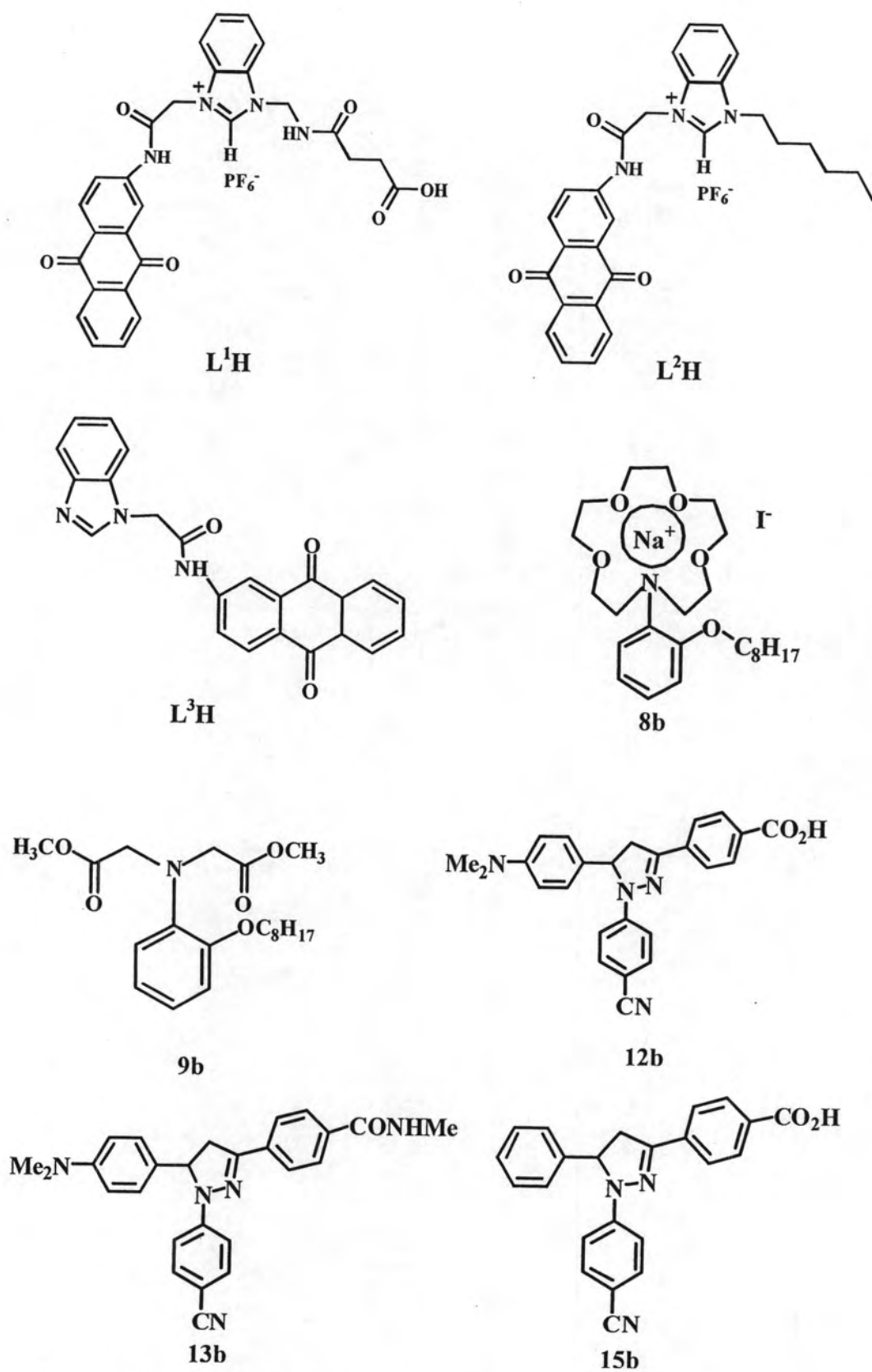


Figure 1.13 Target molecules.

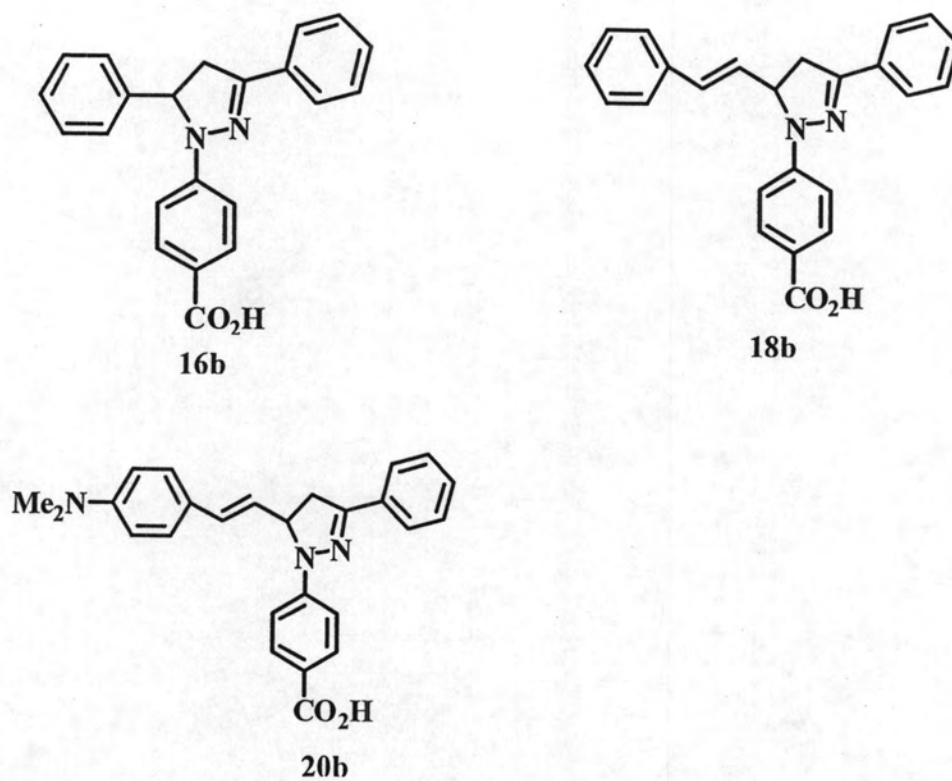


Figure 1.14 Target molecules continuous.