Non-covalent interactions play key role in specific recognition of substrates by enzymes, precise replication of DNA and folding of proteins into intricate three-dimensional forms. Supramolecular chemistry, based on non-covalent interactions becomes increasingly important relative to conventional molecular chemistry based on covalent bonds.\textsuperscript{1} Supramolecular chemistry produces an astonishing variety of new and very spectacular ‘host’ molecules, which form inclusion-type associations with appropriate ‘guest’ species (ions, radicals, molecules) called inclusion complexes, adducts, cryptands, etc. Among the macrocycles constituting the great class of ‘hosts’ in supramolecular chemistry, cyclodextrins (CDs) are the most attractive as they possess a unique molecular architecture, with a hydrophilic exterior and a hydrophobic interior.\textsuperscript{2} Though there are many cavitand host molecules such as calixaranes, crown ethers etc., CDs are very special as they can complex with a broad spectrum of guest molecules of appropriate size, shape and polarity. The physico-chemical characteristics of guest molecules are beneficially modified after inclusion into these elegant ‘organized’ assemblies.

The thesis comprises of six chapters. Chapters I and II discuss the introduction and experimental aspects of the work. In chapter III the synthesis, structural and complexation behavior of herbicide, isoproturon with native and hydroxypropylated $\beta$-cyclodextrin have been discussed. The modification of the binding behavior of 2,4,6-trinitrophenol upon inclusion into $\beta$-CD cavity has been discussed in Chapter IV. Chapter V elaborates on the characterization of CD complexes of bifenox which are of agricultural importance. Chapter VI explores the synthesis of $\beta$-CD-capped silver nanoparticles, their characterization by UV-vis, XRD and TEM analysis. It has been shown that $\beta$-CD
stabilizes silver nanoparticles which serve as a sensor for detecting bifenox in aqueous solution.

CHAPTER I
INTRODUCTION
The first chapter of this thesis gives a detailed account of the relevant background of this study including a brief account of the previous research done with cyclodextrins. Cyclodextrins form inclusion complexes with a wide variety of hydrophobic guest molecules. Their ability to alter the physical, chemical and biological properties of guest molecules has been used for the preparation of new formulations of pesticides. CD complexation technique that helps to improve solubility of some pesticides are reviewed. CDs have a specific cylindrical shape hydrophobic cavity of a specific size with a hydrophilic exterior. The solubility of some of the molecules increases when they bind with CD which are less soluble in water. Certain pertinent aspects of CDs and their inclusion complexes such as their physico-chemical properties and binding constants are discussed. A brief pesticide-CD complex review along with an outline of the aims and objectives of this thesis are also provided.

Expanding the lifespan of materials become highly desirable and self-healing and self-repairing materials may become valuable commodities. The formation of supramolecular materials through host-guest interactions is a powerful method to create non-conventional materials. In this work CD has been employed as a host molecule because of its environmentally benign and diverse applications. When starch is degraded by Bacillus macerans amylase, CDs are formed via transglycosidation. CDs are a group of cyclic oligosaccharides composing of six (α-CD) seven (β-CD) or eight (γ- CD), α (1,4)-linked glucopyranose units. The oligosaccharide forms a truncated cone in which the 1°-OH groups are directed to the narrow side (primary face) and the 2°-OH groups are on the
wide side of the torus (secondary face) (Scheme 1). While the -OH groups on both faces are capable of forming intramolecular H-bonding. The distortion of the glucopyranose units may disrupt the hydrogen bonding. As a result, more extensive H-bonds are formed on the primary face due to the flexibility of the 1°-OH groups as compared to the 2°-OH groups on the secondary face. The cavity, lined by the hydrogen atoms and the glycosidic oxygen bridges, acquires a hydrophobic character, which allows CDs to form inclusion complexes with small hydrophobic molecules that fit into the cavity. This host-guest interaction may be applied in drug delivery, chromatography, solubility enhancement and selective removal of undesired substances.

![Scheme 1. Structure of α-CD and schematic representations of hydrophilic and hydrophobic regions.](image)

As a consequence, CDs can include other hydrophobic molecules of appropriate dimensions inside their cavity, the magnitude of binding constants correlates with the fit of the guest in the CD cavity. Therefore, CDs can give beneficial modifications of guest molecules not otherwise achievable like solubility enhancement, stabilization of labile
guests, control of volatility, sublimation and physical isolation of incompatible compounds. Because they are practically nontoxic, they are added into pharmaceuticals and foods. Their attractive structural characteristics, i.e., small size, spherical shape, different ring size, high solubility in water, their environmental responsiveness render CDs as “smart probe molecules” in the field of supramolecular chemistry.⁴

Pesticides constitute a heterogeneous category of chemicals specifically designed for the control of pests, weeds and plant diseases. Some pesticides have been considered as potential chemical mutagens, due to their capacity to induce mutations, chromosomal alterations or DNA damage. Furthermore, earlier studies showed that only 0.1 % of the applied pesticide reaches the targeted area and that a great amount is wasted and polluted the surrounding areas and underground water.⁵ The fact associates to the low solubility of some pesticides, can lead to the bioaccumulation of this type of toxic organic compounds in soils, water and air. Hence, serious consequences to environment and human health are expected to occur.⁶

CDs have emerged as a new tool to improve pesticide photostabilization and solubility. Due to their hydrophobic internal cavity CDs can complex with molecules which have dimensions compatible with and thereby can change some of its physicochemical properties as water solubility, stability and bioavailability.⁷ In addition, being circular polymers of the sugar glucose, CD complexes can also contribute to the biodegradation of organic pollutants. By considering the host-guest complexation and guest selectivity of CDs, it is hoped that a better understanding of the factors influencing and optimizing these two properties have been obtained. To gain insight of reactivity and selectivity in organic reactions and also to understand the binding behavior of this unique host system, the present work is designed in to two parts: i) utilization of CDs as
‘microvessels’ to achieve selectivity and ii) physico-chemical characterization of CD complexes with various analytical techniques.

CHAPTER II

EXPERIMENTAL METHODS

In this chapter, a detailed account of various materials used, general experimental procedures for the preparation of CD complexes, characterization of the starting materials and products, spectroscopic methods and analytical techniques such as UV-visible, FT-IR, $^1$H NMR, XRD, TEM and DSC used in this study are described.

The formation of host-guest inclusion complex in solution phase is studied by UV-visible spectroscopy. The solid complexes are characterized by $^1$H NMR, FT-IR, XRD and DSC techniques. The morphology and size of the silver organosol are investigated by TEM measurements.

CHAPTER III

COMPLEXATION OF ISOPROTRURON WITH NATIVE AND HYDROXY PROPYLATED $\beta$-CYCLODEXTRIN

The widely used herbicide isoproturon (3-(4-isopropylphenyl)-1,1-dimethylurea) has setback in its poor solubility profile. Poor aqueous solubility and slow dissolution of isoproturon (IPU) result in poor bioavailability. The interaction of IPU with $\beta$-cyclodextrin ($\beta$-CD) and hydroxypropyl-$\beta$-cyclodextrin (HP-$\beta$-CD) is conducive to the formation of inclusion complexes in aqueous as well as in the solid state. Inclusion complex formation of IPU with $\beta$-CD and HP-$\beta$-CD is studied in stability and solubility enhancement of the herbicide. A comparative analysis is made on the binding behaviour of IPU with $\beta$-CD and HP-$\beta$-CD and the mode of inclusion of the guest molecule into the host cavities is also envisaged. Complexation is proved by UV-vis, FT-IR, $^1$H NMR, XRD and DSC studies. Binding constant values showed that IPU forms more stable complexes
with $\beta$-CD ($k_b = 2,000 \text{ M}^{-1}$) than HP-$\beta$-CD ($k_b = 714 \text{ M}^{-1}$) due to the availability of hydrophobic cavity without steric hindrance. FT-IR spectroscopy shows that the aminomethyl group and benzene ring can enter into the cavity of CDs, but the isopropyl group is excluded because it is less hydrophobic. It is established that the vibrations of the IPU molecule are restricted through encapsulation of IPU into the CD cavity. The same observations are also viewed from $^1$H NMR spectral studies. XRD analysis shows that the degree of crystallinity of supramolecular complex substantially decreases in comparison with $\beta$-CD, HP-$\beta$-CD and IPU. The overall crystallinity decreases thus the solubility is increased due to its amorphous nature. As IPU molecule is included in CD cavity their melting and sublimation points shift to different temperature. The difference in thermal behaviour between inclusion complex and hosts ($\beta$-CD and HP-$\beta$-CD) clearly reveals encapsulation of IPU in CD cavity. The mode of inclusion of IPU into CDs cavity can be explained with scheme 2. These results indicate that $\beta$-CD and HP-$\beta$-CD can be used as formulation additives to improve the solubility of IPU, to reduce its adsorption on soil and to increase the availability of IPU for weeds.

Scheme 2. A plausible structure for isoproturon and cyclodextrin complex.
CHAPTER IV

SPECTRAL STUDIES ON INCLUSION COMPLEX FORMED BETWEEN 2,4,6-TRINITROPHENOL AND β-CYCLODEXTRIN

The host-guest inclusion complex mechanism between 2,4,6-trinitrophenol (2,4,6-TNP) with nano-hydrophobic cavity of β-cyclodextrin (β-CD) in solution phase has been studied by UV-visible spectroscopy. The spectral behaviour of 2,4,6-TNP in different pH medium with β-CD is reported. The solid complexes in 1:1 molar ratios of guest and host are prepared and characterized by $^1$H NMR and FT-IR techniques.

At acidic conditions (pH 4.0), the absorption maximum of 2,4,6-TNP is blue shifted. The blue shift in the absorption spectrum at higher hydrogen ion concentration corresponds to the formation of the monocation by the protonation of hydroxyl group of 2,4,6-TNP. The blue shift is observed only in the lower pH values because protonation can occurs in acidic solution only. Further, a red shift (390 nm) is noted in the absorption spectrum of 2,4,6-TNP at pH 9.0 which indicates the formation of monoanion, phenoxide ion in the basic solution. The binding constant for the inclusion complexation of 2,4,6-TNP with β-CD at pH 4 is 8070 M$^{-1}$ which is higher than that at pH 9 (6850 M$^{-1}$). The higher binding constant at pH 4 may be attributed to its size/shape fit within the host β-CD cavity. The binding constants are sensitive to change of pH values, which supports the selective inclusion associated with the specific form of 2,4,6-TNP. Of the two species, it is noted that the β-CD can readily accept the cationic species than the anionic species, because the anionic species is more hydrophilic than the cationic species.

The FT-IR spectrum of the inclusion complex shows all the peaks corresponding to β-CD while only a few of the 2,4,6-TNP peaks are visible. As a consequence of complexation, all the β-CD related peaks are shifted to higher or lower frequencies, thus confirming the involvement of 2,4,6-TNP in the complex formation. In the FT-IR
spectrum of the complex, the characteristic peak of aromatic nitro group is found to change as a result of inclusion of nitro groups into the β-CD cavity. The inclusion of nitro group is also confirmed from the decrease in –C-N stretching intensity. Further, the characteristic stretching intensity of -C=C- bond is reduced and shifted from 1633 cm\(^{-1}\) to 1635 cm\(^{-1}\) due to the inclusion of benzene ring into the nano hydrophobic cavity of β-CD. The characteristic C-O stretching vibration is also shifted from 1151 cm\(^{-1}\) to 1155 cm\(^{-1}\) and its intensity is reduced. The significant upfield shift observed in H-3 and H-5 protons of β-CD located in the cavity suggest that the 2,4,6-TNP is completely entered into the hydrophobic cavity of β-CD. The π electrons of phenyl ring of 2,4,6-TNP is responsible for the observed upfield shift of β-CD protons especially in H-3 and H-5. The formation of inclusion complex of 2,4,6-TNP with β-CD is accompanied by a significant downfield shift of all protons of 2,4,6-TNP molecule. These results confirmed the inclusion of 2,4,6-TNP molecule into β-CD cavity. The significance of this work lies in the increase in bioavailability of 2,4,6-TNP by complexation with β-CD and hence is a good pathway to make it potentially useful for its application as anti-fungal and anti-microbial agent.

CHAPTER V

EFFECT OF CAVITY SIZE ON COMPLEXATION OF CYCLODEXTRINS WITH BIFENOX AND SPECTRAL CHARACTERIZATION

α-, β- and γ-CD inclusion complexes with bifenox (BX) are prepared. BX, the chlorophenoxy herbicide, (methyl-5-(2,4-dichlorophenoxy)-2nitrobenzoate) is widely used to control weeds but often shows a reduced biological activity against the target grasses due to its poor water solubility and slow translocation within plant tissues. Inclusion of BX into CD cavity protects the phenoxy moiety and hence CD can be used to protect the BX until it reaches its destination. The synthesized inclusion complexes are characterized by UV-visible spectroscopy, FT-IR and \(^1\)H NMR techniques.
The UV-vis spectrum of BX exhibited hyperchromic shift and shift to a longer wavelength upon the addition of increasing concentrations of CDs. These spectral changes may be interpreted as arising from environmental changes experienced in the BX. The calculated binding constant values of inclusion complexes of α-, β-, and γ-CDs with BX, indicates that BX readily forms inclusion complex with β-CD. The stoichiometry of each complex formed between BX and α-, β- and γ-CDs is found to be 1:1 by Job’s method. The characteristic stretching vibration of –C-Cl band is shifted to lower frequency for all inclusion complexes (from 1060 cm\(^{-1}\) to 1031 cm\(^{-1}\) for α-CD, 1029 cm\(^{-1}\) for β-CD and 1028 cm\(^{-1}\) for γ-CD). The insignificant change in the characteristic stretching vibrations of aromatic nitro group and carbonyl group indicated that the nitro and ester groups are projected above the CD rim. The shift of the band corresponding to the methyl stretching vibration in complexes at 1340 to 1342 cm\(^{-1}\) suggests the electronic change around the methyl group, likely due to the formation of new hydrogen bonding between the carbonyl of BX and the OH of CDs.

FT-IR studies clearly indicated that the dichlorophenoxy group ring is positioned inside the CD cavity while the methyl ester is exposed outward, away from the cavity. A strong evidence for the formation of an inclusion complex is obtained from the change in chemical shift values of H-3 and H-5 protons of CD.\(^{10}\) The downfield shift changes in the BX protons can be explained in term of ring current effect of aromatic ring entering the host cavity. The results clearly showed that only the chlorophenoxy ring of BX molecule enters into the nano cavity of CD while the hydrophilic group, such as ester group appears to remain exposed to the bulk solvent even after the inclusion of the hydrophobic segment. The existence of chlorophenoxy group within CD cavity is confirmed by changes in chemical shift of chlorophenoxy protons of BX.
Among the three native CDs, β-CD offered more stability to the guest. The formation of inclusion complexes between BX and CDs increases the aqueous solubility of this herbicide which could be an added advantageous property to improve its commercial usage and environmental protection.

CHAPTER VI
DETECTION OF BIFENOX USING β-CYCLODEXTRIN FUNCTIONALIZED SILVER NANOPARTICLES

The typical synthesis of AgNPs incorporates contaminants that could pose problems. This chapter deals with the cost effective and environment friendly green synthesis of silver nanoparticles (AgNPs) from AgNO$_3$ solution and β-CD. β-CD acts as reducing as well as capping agent. Thermal treatment has been used to intensify the reduction. The optimum condition for obtaining AgNPs is pH 11. The formation of AgNPs is confirmed by UV-visible spectroscopy, X-Ray diffraction (XRD) and Transmission Electron Microscopy (TEM) techniques. In recent years, gold nanoparticles (AuNPs) and AgNPs have been widely used as colorimetric probes for chemical sensing and biosensing for various substances. The synthesized AgNPs are found to be predominately spherical in shape and poly dispersed. The particles are found to be stable even for six months at a temperature of 25 °C.

AgNPs exhibit yellow colour in aqueous solution due to excitation of its surface plasmon vibrations. The solution turned yellowish brown after 20 minutes of incubation. The color and the intensity of the peaks are pH dependent. At pH 2.0 the solution is colourless while at pH 11 it is yellow in colour. A change in colour is associated with well-defined peaks characterized by maxima centered at 400 nm. The presence of an absorption peak at 400 nm is attributed to the formation of spherical AgNPs and corresponds to the surface plasmon resonance of these nanoparticles. The size of the
AgNPs is calculated from X-ray diffraction peak. Broadening is a measure of the smallest unfaulted regions or coherently scattering domains of the material. In fact, this is the size of regions bounded by defects, grain boundaries and separated from surrounding by a small misorientation, typically one or two degrees. Scherrer method is used to calculate crystalline size. The calculated particle size of AgNPs from Scherrer equation is 42 nm. The size and shape of the AgNPs are characterized by TEM. In the presence of β-CD, AgNPs are nearly spherical and their average size is about 50 nm. Yet there are few silver crystallites of size 100 nm and 200 nm visible in the sample. These images suggest that the particles are poly dispersed and are mostly spherical in shape. The experimental conditions (viz., pH, temperature and the concentration of Ag⁺ etc.) influence the dispersity and shape.

Bifenox is one of the most common herbicide which can be detected in mM levels using AgNPs. To examine the effect of BX concentration on the phase transfer of the AgNPs in aqueous solution, the AgNPs suspension is mixed with equal volumes of aqueous solutions of BX at different concentrations from $1 \times 10^{-3}$ M to $5 \times 10^{-3}$ M. Upon addition of BX, colour of the AgNPs is changed from yellow to pink and absorption maximum of AgNPs is shifted from 400 nm to 550 nm. This suggests that the inclusion complex formation between BX and CD is essential for the phase transfer of AgNPs to aqueous phase.¹¹ Bifenox forms inclusion complex with β-CD and the silver nanoparticles get aggregated, as a result the intensity of absorption maxima is decreased (Scheme 3). Thus, a simple, rapid and field-portable colorimetric method can be developed for the analysis of bifenox by naked eyes or by UV-vis spectroscopy. AgNPs display optical properties due to the presence of surface plasmon resonance (SPR) band. Small shifts in the SPR band occur perhaps due to the changes in the dielectric properties of the medium of AgNPs or due to the specific adsorption of materials on the surface of the silver
particle. At low concentrations of BX, only small portion of surface-bound CD molecules on the surfaces of AgNPs forms complexes with the BX, which is not sufficiently hydrophilic for the stabilization of nanoparticles in aqueous phase. However, at relatively high BX concentrations, substantial amounts of CD molecules can form host-guest complexes with BX, which lead to the increase of AgNPs in the hydrophilic media. These results confirm that β-CD capped AgNPs show high selectivity towards BX.

Scheme 3. Schematic representation of β-CD capped silver nanoparticle for the detection of bifenox.
References


