DESIGN AND SYNTHESIS OF NEW SERIES OF PODANDS AND THEIR USE IN EXTRACTION AND BULK LIQUID MEMBRANE TRANSPORT OF ALKALI AND ALKALINE EARTH METAL IONS

A Thesis

Submitted for the Award of Ph.D. Degree of

University of Kota, Kota

in Faculty of Science

By

Varsha Gautam

Under the

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2017

Certificate

We feel great pleasure in certifying that the thesis entitled ***"Design and Synthesis of New Series of Podands and Their Use in Extraction and Bulk Liquid Membrane Transport of Alkali and Alkaline Earth Metal Ions"*** *embodies a record of the results of investigations carried out by* ***Varsha Gautam*** *under our guidance. We are satisfied with the analysis of data, interpretation of results and conclusions drawn. She has completed the residential requirement as per rules (200 days).*

We recommend the submission of thesis.

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Declaration by the Candidate

*I declare that the thesis entitled "***Design and Synthesis of New Series of Podands and Their Use in Extraction and Bulk Liquid Membrane Transport of Alkali and Alkaline Earth Metal Ions"** *is my own work conducted under the supervision of Dr. (Mrs.) Loni Lokwani and co-supervision of Dr. Sharda Sharma, Department of Chemistry, Govt. College Kota and approved by Senior Research Committee. I have put in more than 200 days of attendance with the supervisors at the center.*

I further declare that to the best of my knowledge the thesis dose not contain any part of work which has been submitted for the award of any degree either in this university or in any other university.

Date: ***VARSHA GAUTAM***

Place:

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Kota

Date:

Varsha Gautam

Dedicated to my beloved parents,
guide, co-guide,
and
my husband

Abbreviations-

BLM = Bulk liquid membrane

D_M = Distribution ratio

J_M= Cation flux

Pic^- = picrate (2,4,6-trinitrophenolate)

Dnp^-= 2,4-dinitrophenolate

Onp^-= Orthonitrophenalote

MX_Z = Metal salt

M^{Z+} = Li^+, Na^+, K^+, Mg^{2+}, Ca^{2+}

X^- = Pic^-, Dnp^-, Onp^-

ppm = Parts per million

rpm = rotation per minute

A_1= (1-(4-Bromophenyl)-2-(2-{2-[2-(4-bromophenyl)-2-oxo-ethoxy]-ethoxy}-ethoxy)-ethanone)

A_2= 1-(4-Bromophenyl)-2-{2-[2-(2-butoxy-ethoxy)-ethoxy]-ethoxy}-ethanone

A_3 = 1-(4-Bromophenyl)-2-(2-{2-[2-(2-{2-(4-bromophenyl)-2-oxo-ethoxy}-ethoxy)-ethoxy]-ethoxy}-ethoxy)-ethanone

A_4 = 1-(4-Bromophenyl)-2-{2-[2-(2-butoxy-propoxy)-propoxy]-propoxy}ethanone

A_5 = ethyleneglycoldiacetate

A_6 = tripropyleneglycolmonobutylether

CONTENTS

CHAPTER –I

INTRODUCTION

Chapter 1

Introduction

According to **Jean-Marie Lehn**, “Supramolecular chemistry is the chemistry of the intermolecular bond, covering the structures and functions of the entities formed by the association of two or more chemical species.”

Fritz Votğle stated, “Supramolecular chemistry is based upon intermolecular interactions, i.e. on the association of two or more building blocks, which are held together by intermolecular bond.”

Supramolecular chemistry and molecular recognition

Supramolecular chemistry may also defined as “chemistry beyond the molecules” and focuses on the chemical systems made up of a discrete number of assembled molecular subunits or components (**Figure 1**). These supramolecular assemblies (**Figure 2**) are a multicomponent system of atoms, ions, and/or molecules which are held together by noncovalent interactions such as hydrogen bonds, van der Waals forces, π-π interactions and electrostatic effects.

The forces responsible for the spatial organization may vary from weak (intermolecular forces, electrostatic and hydrogen bonding) to strong (covalent bonding), provide the degree of electronic coupling between the molecular component remains small with respect to relevant energy parameters of the components.

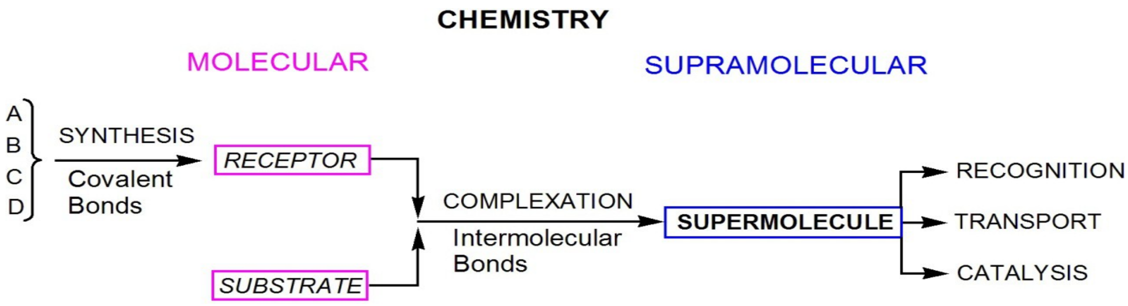


Figure 1: Assembly of molecular subunits to form a supramolecular device

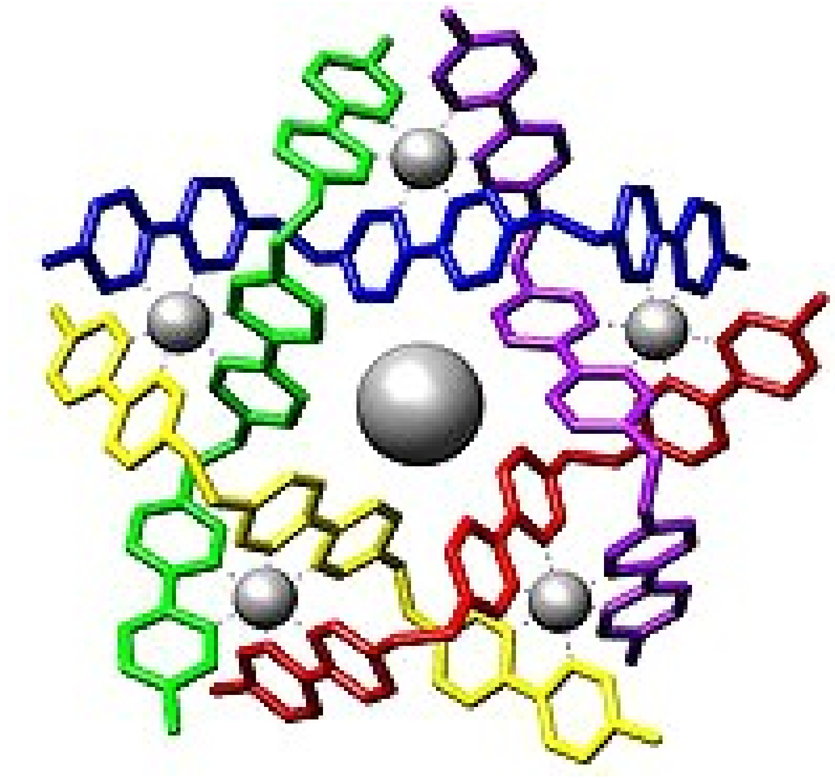


Figure 2: Supramolecular assembly

Molecular recognition and transport phenomena [1] are important subject, especially in host-guest and biomimetic systems [2]. This is selective binding of a substrate by a molecular receptor which is a continuing theme in supramolecular chemistry. Important concepts that have been demonstrated by supramolecular chemistry include molecular self assembly, folding, molecular recognition, host guest chemistry (**Figure 3 & 4**), mechanically- interlocked molecular architectures and dynamic covalent chemistry [3].

Separation phenomenon through molecular recognition of the host compound has widely been used by incorporation of ionophores into solvent extraction or liquid membranes.

Supramolecular Host Design

In order to design a host that will selectively bind a particular guest, use of the chelate and macrocyclic effects as well as the concept of complementary (matching of steric and electronic requirements of host and guest). The first step in host design [4] is a clear definition and careful consideration of the target. If cation is the guest, then host size (diameter), charge density and hardness are important.

Second step is the intellectual process of podand tailoring. Host-guest interaction occurs through binding site. The type and number of binding sites must be selected in a fashion that is most complementary to the characteristics of the binding sites of the guest. These binding sites must be arranged on an organic scaffold or frame work of suitable size to accommodate the guest. Binding sites should be spaced somewhat apart from one another to minimize repulsion between them but arranged in such a way that they can all interact simultaneously with the guest. The nature of the organic frame work of the host itself whether hydrophilic or lipophobic plays a fundamental role in host behaviour. This determines the solubility characteristics of host and its complexes. The thickness of the podand and the ease of access to the binding pockets, cavity or cleft affect both thermodynamic stability and binding.

This approach would also aid design of noval functional molecular system and biologically important chemical sensors based on ion selective electrodes.

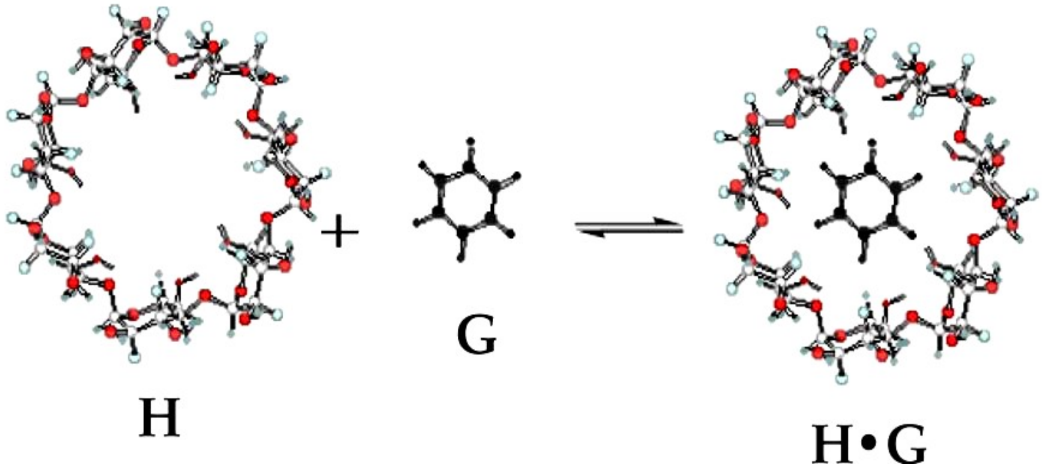
One of the major goals of supramolecular chemists is the synthesis of supramolecular assemblies, which have new functions that can not appear from a single molecule or ion. These functions are based on novel magnetic properties, light responsiveness, catalytic activity, florescence and redox properties of supramolecular systems. These useful properties may led to the application of these assemblies as high tech sensors for pollutants in air or water, compact information storage devices for next generation computers, as high performance catalysts in industrial processes or contrast agents for CAT scans.

There may be a modest correlation between the free energy of the complexation and the size match between the ion and ionophore. Thus, when the size matches closely, the metal ion is centered within the cavity or pocket and experiences the most symmetrical electrostatic interactions. As smaller ion will experience a proportionally smaller electrostatic interaction and thus will not be tightly bound, conversely an ion that is larger cannot fit within the pocket symmetry electrically and as consequences will not be benefited from cell of the electrostatic stabilizing interactions providing by the ionophores.

The design and synthesis of highly selective ionophores has received much attention because of the important role played by these sensors in many applications. The concept of this research involves host-guest supramolecular chemistry, where the ionophores serve as host for cation guest. The goal of supramolecular host design is the achievement of selectivity, discrimination between one guest and other.

Based on this, we have been successful in designing and synthesizing a new series of podands having p-bromophenacyl moiety. These podands show extremely high affinity and selectivity for cation through ion dipole interaction. In this case, charge – charge interaction and charge – dipole interactions both employed.

Host that binds guest less strongly, find applications as sensors and carriers in which event sequences such as ‘bind-detect-release’ or ‘bind- transport-release’ are needed [5].



Supramolecular cavity Guest molecule Complex formation

Figure 3: Host-guest molecule

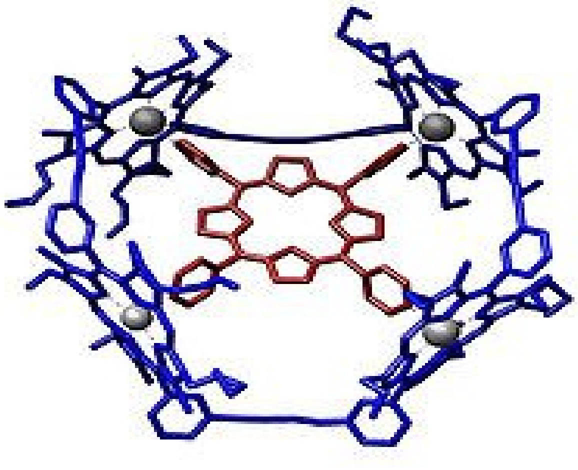


Figure 4: Host-guest chemistry

The major field of supramolecular chemistry where it has always been the focus is known as host-guest chemistry [6]. A host-guest relationship involves complementary stereoelectronic arrangements of binding site in host and guest molecules.

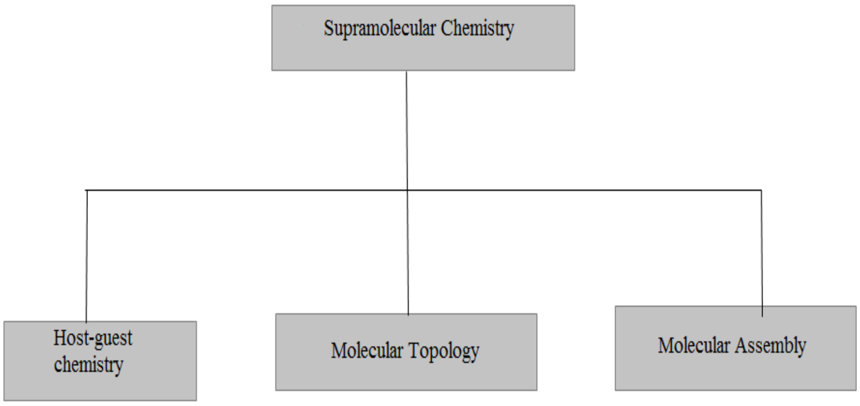


Figure 5: Components of supramolecular chemistry

Membrane

A membrane is termed a selectively semi permeable membrane, when it allow certain metal ions to pass through it across two phases by a concentration gradient. The membrane contains a suitable podand (noncyclic ionophore) to act as the metal ion transporter [7].

Membranes have gained an important place in chemical technology and are used in a broad range of applications. The key property that exploited is the ability of a membrane to control the permeation rate of a chemical species through the membrane. In controlled drug delivery, the goal is to moderate the permeation rate of a drug from a reservoir to the body.

Properties of membranes

The suitability of any given membrane for any particular operation is determined by a number of factors:

1. The membrane should be chemically stable when immersed in salt solutions of various pH and in salt solutions containing organic solvents or oxidizing agents and should never become folded by surface active agents or detergents likely to be present in solutions to be employed with membranes.
2. It should have sufficient mechanical strength.
3. Low electric resistance.

4. Good dimensional stability under different wetting conditions.
5. Sufficient membrane flexibility.
6. High ionic selectivity even in a high salt environment.
7. Low salt diffusion in a membrane concentration cell.
8. Low electro-osmotic transport.

Classification of membranes

(I) Natural membranes

Natural membranes exist in biological systems. A biomembrane (**Figure 6**) is an enclosing or separating membranes that acts as a selectively permeable barrier within living things.

These membranes consist of phospholipids bilayer (**Figure7**) with embedded, integral and peripheral proteins used in communication and transportation of chemicals and ions. The plasma membrane has membrane protein such as transporter that transports specific molecules to pass. Most solute can pass through the membrane only when transported by membrane proteins. In this case, passive transport (i.e. transport following the concentration gradient) occurs without relying on energy, whereas active transport (i.e. transport against the concentration gradient) requires energy. Active transport is performed by transporters. Na^+ is maintained at low concentrations inside the cell and K^+ is at higher concentrations. The reverse is the case on the outside of the cell. When a nerve message is propagated, the ions pass across the membrane, thus sending the message. After the message has passed, the ions must be actively transported back to their "starting positions" across the membrane.

To maintain these conditions, an Na^+/K^+ pump (**Figure 8**) transports Na^+ ions to the outside and K^+ ions to the inside of the cell against the concentration gradient using the energy generated when ATP hydrolyzed into ADP.

(II) Artificial membranes

An artificial membrane, or synthetic membrane, is a synthetically created membrane which is usually intended for separation purposes. Synthetic membranes have been successfully used for small and large-scale industrial processes since the middle of twentieth century. The chemical and physical properties of synthetic membranes and separated particles as well as a choice of driving force define a particular membrane separation processes. The most commonly use driving force of a membrane process in industry are pressure and concentration gradients.

The best known synthetic membrane separation processes include water purification, reverse osmosis, dehydrogenation of natural gases, removal of cell particles by microfiltration and ultrafiltration, removal of microorganisms from dairy products, and dialysis. Some examples of artificial membranes are $C_2H_4Cl_2$, CH_2Cl_2, $CHCl_3$, CCl_4, resin, $K_4[Fe(CN)_6]$, dioxane, cellulose-stileben, permaplex C-10, polyethylene and cellulose acetate membranes, hexanol, acetonitrile-butadiene-styrene membrane.

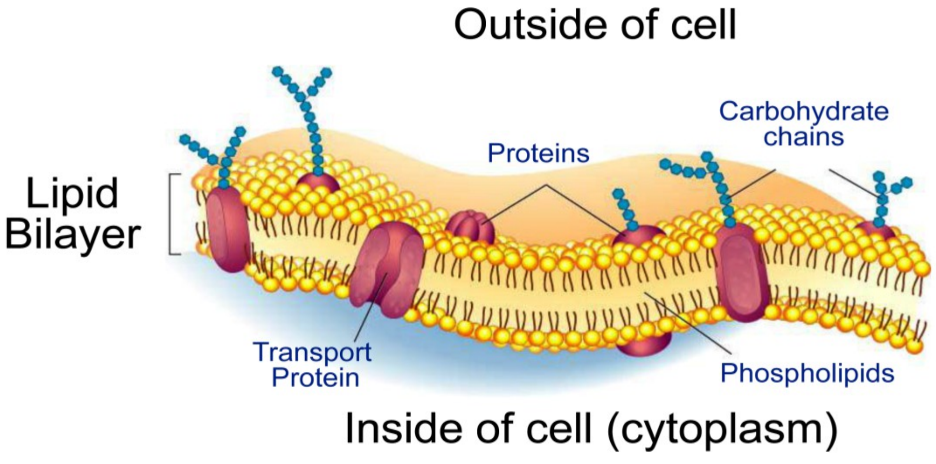


Figure 6: Structure of the cell membrane

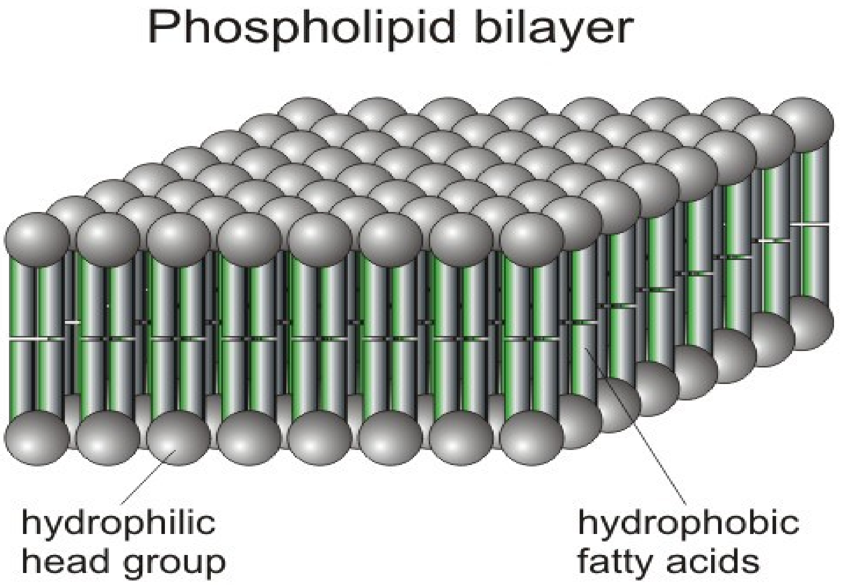


Figure 7: Structure of phospholipids bilayer

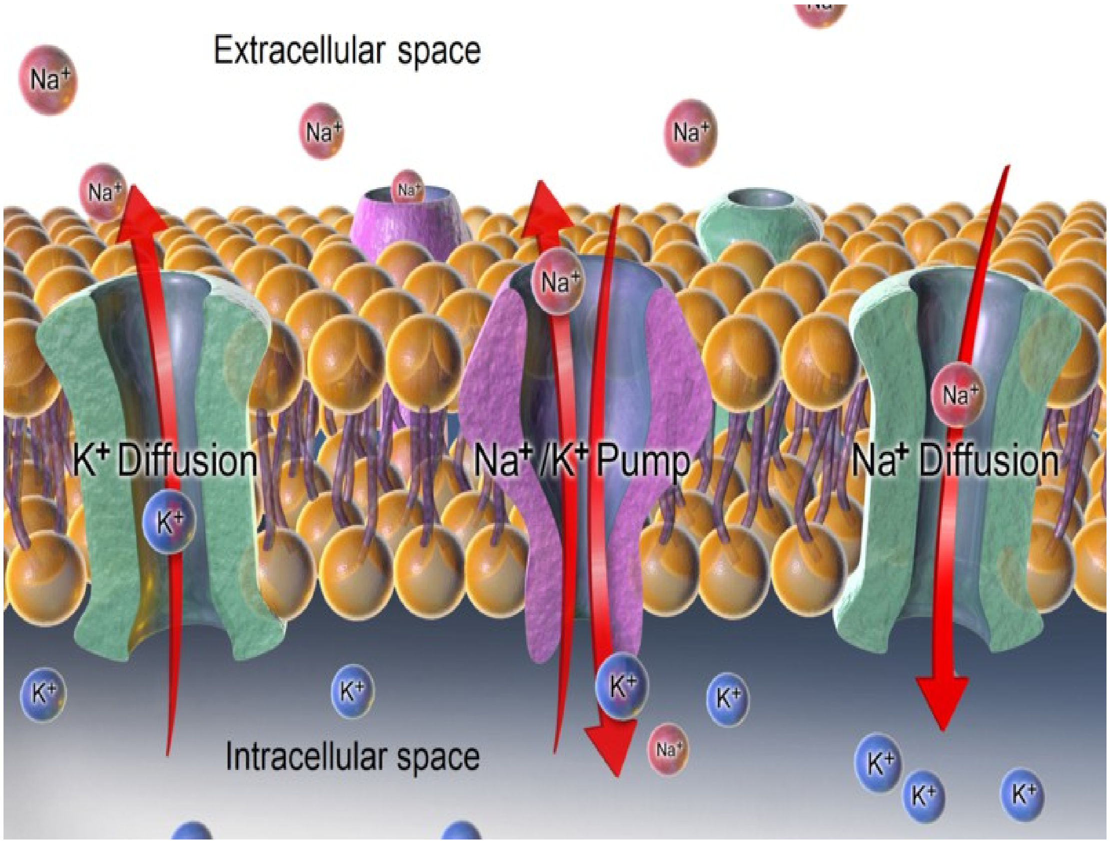
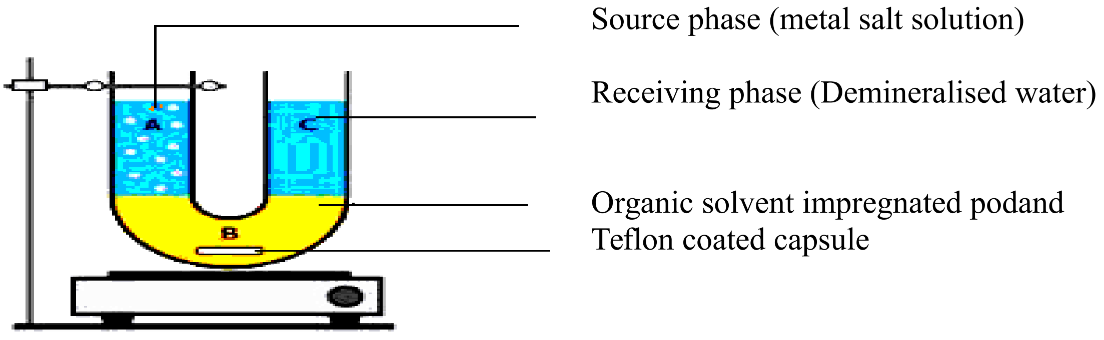


Figure 8: Sodium-potassium pump

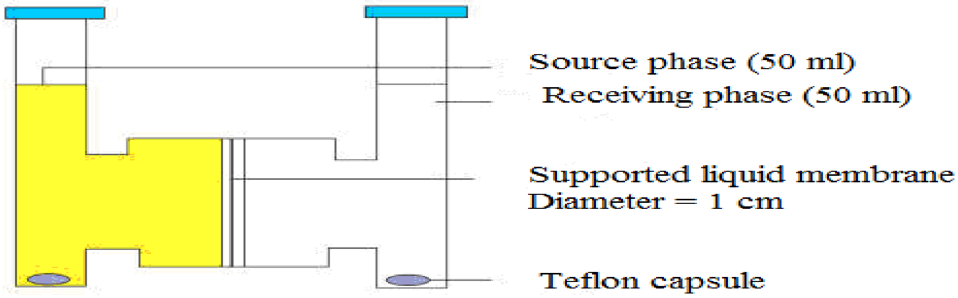
Types of artificial membranes

(i) Bulk Liquid Membrane System (BLM)

Transport experiments performed in a 'U' shape glass cell (**Figure 9**). 25 ml of the organic solution of podand placed at the bottom of the 'U' tube to serve as liquid membrane. 10 ml of aqueous solution of metal salt placed in one limb of the 'U' tube to serve as the source phase (SP) and 10 ml of demineralised water placed in the other limb of the 'U' tube to serve as the receiving phase (RP). The membrane phase stirred for 24 hours. Amount of cation transported was analysed after 24 hours.



[Figure 9]
Apparatus for bulk liquid membrane



[Figure 10]
Apparatus for supported liquid membrane

(ii) Supported Liquid Membranes (SLM)

In supported liquid membrane micro porous films are used as the solid support (**Figure 10**). SLM is a non dispersive type liquid membrane, whose membrane phase is immobilized in the pores of a porous polymer.

(iii) Emulsion Liquid Membrane (ELM)

This setup has a very thin membrane and a large surface area per unit source phase volume, which enhance the transport rate of this membrane (**Figure 11**). In biomedical applications, it has been used for oxygenation of blood and removal of toxins uremia from the gastrointestinal tract.

(iv) Thin Sheet Supported Liquid Membranes (TSSLM)

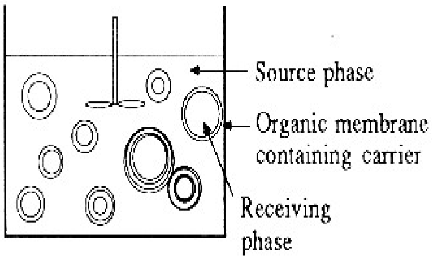
This is just a porous polymer membrane whose pores are filled with the organic liquid and carrier, set in between source phase and receiving phase, which are being gently stirred (**Figure 12**).

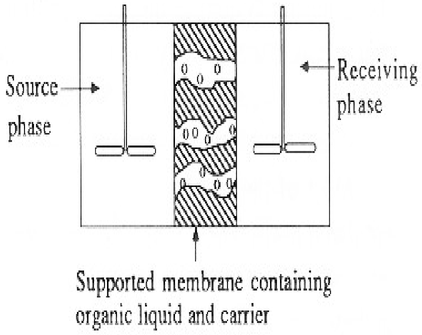
(v) Hollow Fiber Supported Liquid Membranes (HFSLM)

This system has the outer shell, which is a single nonporous material, through which the materials inside cannot be transported. Inside that shell, there are many fibers running the length of the shell. The source phase is piped through the system from top to bottom and the pores in the fibers themselves are filled with the organic phase (**Figure 13).**

(vi) Two Module Hollow Fiber Supported Liquid Membranes (TMHFSLM)

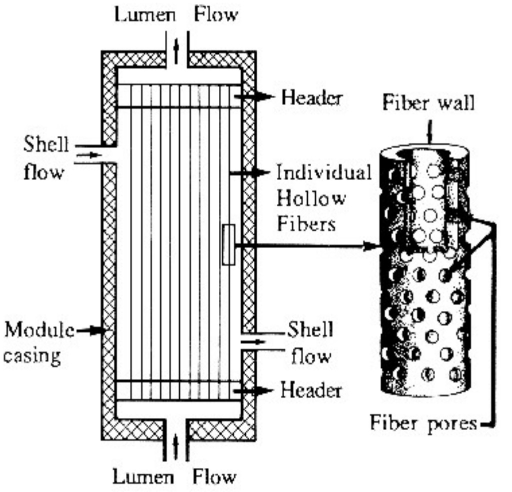
In this system the source phase is piped in through one channel of hollow fibers, and the receiving phase in and out through another, with a stirred membrane phase in contact with both phases (**Figure 14**).

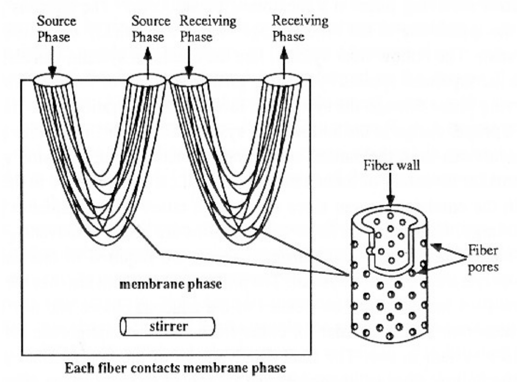




[Figure 11]
Emulsion liquid membrane

[Figure 12]
Thin sheet supported liquid membrane





[Figure 13]
Hollow fiber supported liquid membrane

[Figure 14]
Two module hollow fiber supported liquid membrane

Theory of membrane transport

A membrane process is a separation process that covers a broad range of problems from particles to molecules and a wide variety of membranes are available to design a process. In this process, the podand at one membrane solution interface envelops an ion so as to form an uncharged neutral complex with all polar or hydrophilic moieties of the carrier and ion “hidden” on the inside of the complex, so that the exterior of the complex is lipophilic.

The design and synthesis of podands binding selectively organic and inorganic substrate has made available a range of compounds. Thus, transport represents one of the basic functional features of supramolecular species together with recognition and catalysis.

Transport studies in membrane science can be planned under following headings:

(i)***Extraction***

Transfer of salt dissolved in water into the immiscible organic phase which contains the podand as a phase transfer agent (two phase transfer) is termed extraction.

The extraction is one of the most important technique in analytical chemistry. It is based on the transfer of a solute from one immiscible solvent into another. The substance usually extracted either as uncharged molecules or expressed in terms of the distribution coefficient between the aqueous phase and the immiscible organic phase.

This provided a powerful tool to explore molecular recognition skill of the podands to effective membrane separation via liquid membranes by process of solvent extraction. Among the various extracting systems, liquid membrane technology for the separation process is increasingly being intensified which restricts lengthy extraction times, automation challenges and use of large organic solvents used in the traditional liquid-liquid extraction techniques.

Mechanism of complexation-

The complex formation usually proceeds by binding of cation caused by electrostatic ion-dipole interaction between cation and negatively charged oxygen donor atom arranged in the polyether ring. The stability of such complexes affected by various factors such as size of cavity and cation, number of oxygen atoms in podand, structure, basicity of donor atoms, steric hindrance and electrical charge of the cation. It has been observed from earlier studies [8] that the complex formed will be more stable if-

- The size of cation and cavity of podand matched with each other.
- The podand is planner.
- The donor atoms are more basic in podand.
- There is less steric hindrance in the podand.

(ii) Transport

Transfer of salt from one aqueous to another aqueous phase across a layer of water immiscible organic phase (three phase extraction) is called transport. The current work on carrier facilitated membrane transport is focused upon the coupled process in which the carrier agent couples the flow of two or more species.

During membrane transport the overall driving force depended solely on the cation and proton concentration in the two aqueous phases. In any direction transport could take place until a balance was attained between cation and proton gradients were equal.

The natural as well as synthetic ionophores have a macromolecular structure and the effect of their complexes on various phenomenons depends markedly on the type of the bound cation. This property is termed ion selectivity. Such type of transport can take place in the direction of the concentration gradient (passive transport) and against it (active transport).

Transport process and carrier design-

The organic chemistry of membrane transport process and carrier molecules has been developed, considering that their physiochemical features and biological importance have been recognized. The designed and synthesized podands bind selectively organic and inorganic substrate and become carrier molecules and induce selective transport through membranes. Thus, transport represents one of the basic functional features of supramolecular species together with recognition and catalysis.

Carrier mediated transport consists of transfer of a substrate across a membrane, facilitated by carrier molecule located in the membrane. It is a cyclic process comprising following steps:

- Formation of the carrier substrate complex at one interface.
- Diffusion of the complex through the membrane phase.
- Release of the substrate at the other interface.
- Back diffusion of the free carrier.

Carrier mediated transport can be classified into three main types:

(A) Passive transport- The type of passive transport mechanism that permits substances to pass across membranes in order to reach states of chemical or electrochemical equilibrium is called “passive transport” (**Figure 15**).

(B) Active transport- If ions or molecules move across cell membranes against an obvious concentration gradient in solution on both side of membrane, it is called “active transport”. Such process requires a source of energy (**Figure 16**).

(C) Coupled transport- There are many instances in which the uphill transport of one substance, usually an inorganic ion drives the uphill or even downhill transport of another substance either in the opposite or in the same directions (**Figure 17**).

Supramolecular interactions –

Supramolecular chemistry concerns non-covalent bonding interactions. These interactions are considerably weaker than covalent interactions. When these interactions are used in a co-operative manner a stable supramolecular complex can exist. When considering a supramolecular system, it is vital to consider the interplay of all of these interactions and effects relating both to the host and guest as well as their surroundings (e.g. solvation, ion pairing, crystal lattice, gas phase etc.) [9].

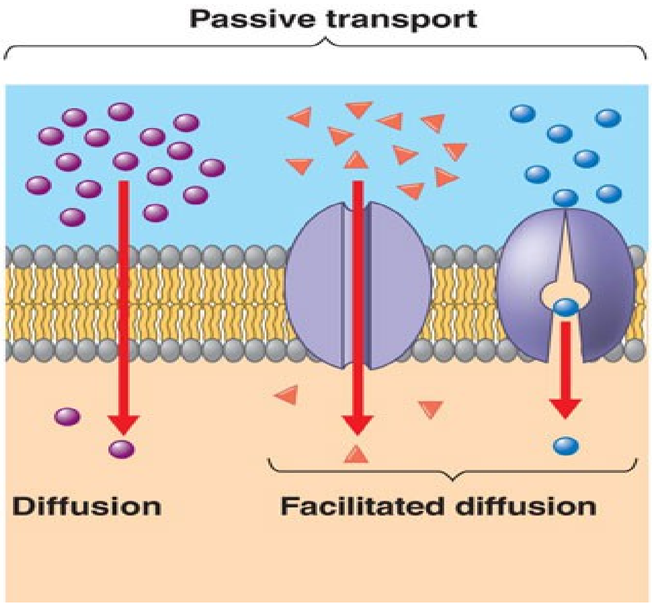


Figure 15: Passive transport

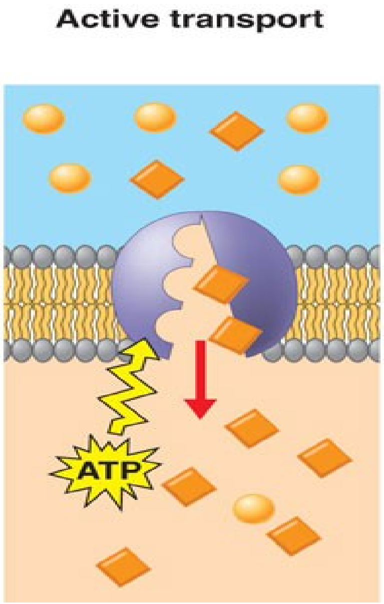


Figure 16: Active transport

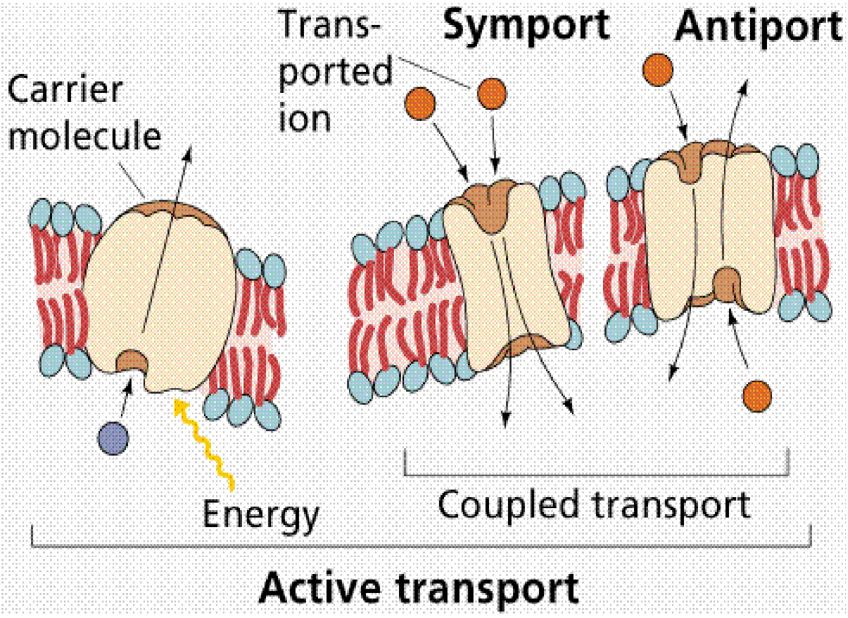


Figure 17: Coupled transport

Non covalent interactions are weak interactions that bind together different kinds of building blocks into supramolecular entities. Covalent bonds are generally shorter than 2 Å, while noncovalent interactions function within range of several angstroms

(Å). The formation of a covalent bond requires overlapping of partially occupied orbital of interacting atoms, which share a pair of electrons. In noncovalent interactions, in turn, no overlapping is necessary because the attraction comes from the electrical properties of the building blocks.

1. Ion and dipolar interactions-

Non covalent interactions, such as hydrogen bonding and metal coordination represents the basic set of tools for the constructions of elaborate architectures in the supramolecular chemistry of organic or metal organic compounds [10].

Ion-ion interactions are stronger (100-350 KJ/mol) and non directional in nature. Ion-dipole (**Figure 18**) interactions are moderately stronger (50-200 KJ/mol) and dipole-dipole interactions are relatively weak (5-50 KJ/mol). Both these interactions are directional in nature.

These interaction play an important role in understand the factors that influences high binding affinities, particularly, in biological systems in which there is a large number of recognition processes that involve charge-charge interactions; indeed these are often the first interactions between a substrate and an enzyme [11].

2. Hydrogen bonding-

Hydrogen bonding (**Figure 19**) is a relatively strong and probably the most important noncovalent interaction [12]. A hydrogen bonding may be regarded as a particular kind of dipole-dipole interactions in which a hydrogen atom attached to an electronegative atom (or electron withdrawing group) is attached to a neighboring dipole on an adjacent molecule or functional group. In particular, hydrogen bonds are responsible for the overall shape of many proteins, recognition of substrate by numerous enzymes and (along with π-π stacking interactions) for the double helix structure of DNA.

3. π-interactions-

(A) Cation-π interactions-

These interactions of alkali and alkaline earth metal cations with C=C double bonds is however, a much more non-covalent 'weak' interactions and is suggested to play an important role in biological systems [13] e.g. cation – π interactions are well described by a schematic drawing such as showing a K^+ ion interacting with the negatively charged π-electron cloud of benzene. (**Figure 20**).

(B) Anion- π interactions-

The interaction of an anion with π-electron density seems like it should be repulsive and indeed the affinity of the aromatic ring. Work by Kochi [14] has shown that anion forms stable charge transfer complexes with a variety of electron deficient aromatic compounds.

Anion π-interaction has also been implicated as controlling elements in self-assembly reaction of complexes with π-acidic aromatic rings.

(C) π-π interactions-

Aromatic π-π interactions (sometimes called π-π stacking interactions) occurs between aromatic moieties [15] , often in situations where one is relatively electron rich and one is electron deficient (**Figure 21**). These are responsible for the packing of a range of small aromatic hydrocarbons including benzene in crystal structure [16].

4. van der Waals interactions-

In supramolecular chemistry, these are most important in formation of 'inclusion' compounds in which small, typically organic molecules are loosely incorporated with in crystalline lattice or molecular cavities, van der Waals interactions (**Figure 22**) may be divided into dispersion (london) and exchange-repulsion terms. The dispersion interaction is attraction between fluctuating poles of adjacent molecules.

The exchange repulsion defines molecular shape and balances dispersion at start range, decreasing with the twelth power of inter atomic separation [17].

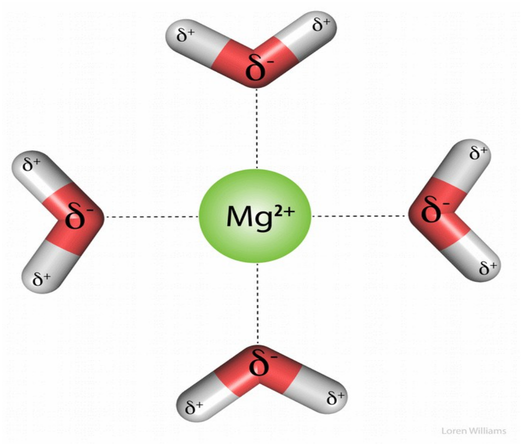


Figure 18: Ion-dipole interaction

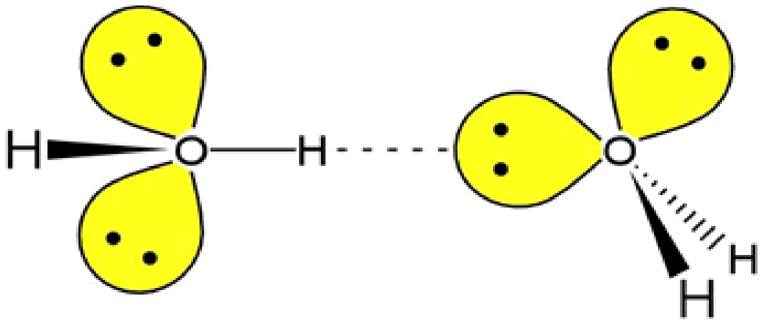


Figure 19: Hydrogen bonding between two water molecules

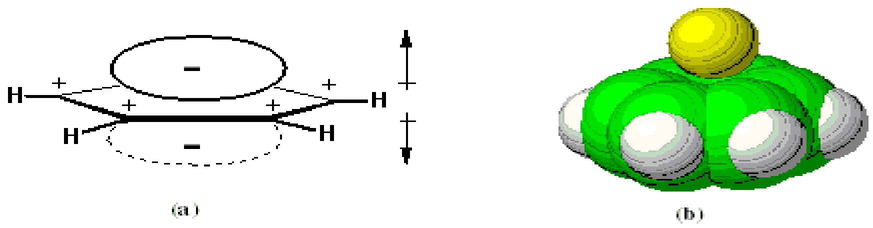


Figure 20: Interaction of potassium ion with benzene

5. Hydrophobic effects-

Hydrophobic effects generally relate to the exclusion from polar solvents, particularly water, of large particles or those that are weakly solvated (e.g. via hydrogen bonds or dipolar interactions). This can produce effects resembling attraction between one organic molecule and another, although there are in addition van der Waals and π-π stacking attractions between the organic molecules themselves.

The hydrophobic effects are very important in biological system in the creation and maintenance of protein and polynucleotide structure and in the maintenance of phospholipid bilayer cell walls.

Hydrophobic effects (**Figure 23**) are of crucial importance in the binding of organic guests by cyclodextrins and cyclophane hosts in water and may be divided into two energetic components 'enthalpy and entropy'.

The enthalpic hydrophobic effects involve the stabilization of water molecules that are driven from a host cavity upon guest binding, because host cavities are often hydrophobic, intracavity water does not interact strongly with the host walls and is therefore of high energy. Upon release into the bulk solvent, it is stabilized by interactions with other water molecules. The entropic hydrophobic effects arise from the fact that the presence of two (often organic) molecules in solution (host and guest) creates two 'holes' in the structure of bulk water. Combining host and guest form a complex results in less disruption to the solvent structure and hence an entropic gain (resulting in a lowering of overall free energy) [18].

6. Solvation effect-

The importance of solvent in supramolecular chemistry can hardly be over stated. In solution, all complexation phenomena are in competition with solvation interactions and the solvent is almost invariably in a huge molar excess. Polar solvents, particularly water, compete very affectively for binding sites, particularly hydrogen bonding functionality, making hydrophobic (or solvophobic) effects of paramount importance. In non polar solvents and in the gas phase specific host-guest dipolar and hydrogen bonding interactions are much more significant (**Figure 24**).

So, the host-guest binding process is the interaction of a more or less preorganised host with a necked guest. In reality, both host and guest are highly solvated in solution and the solvation stabilization of the free host may well be significantly different from its interaction to solvent in the complexed state, particularly if there is a significant conformational change (induced fit) on binding.

7. Charge transfer complex-

These interactions play an important role in host-guest equilibrium. These interactions involves electron transfer from higher energy occupied molecular orbital (HOMO) of electron rich compound or donors into low lying unoccupied orbital of electron deficient system or acceptor.

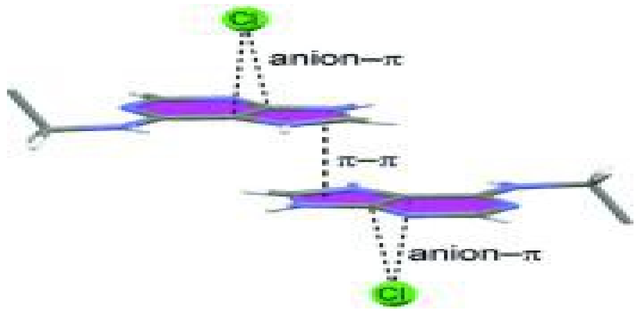


Figure 21: π-π Interaction and anion π-interaction

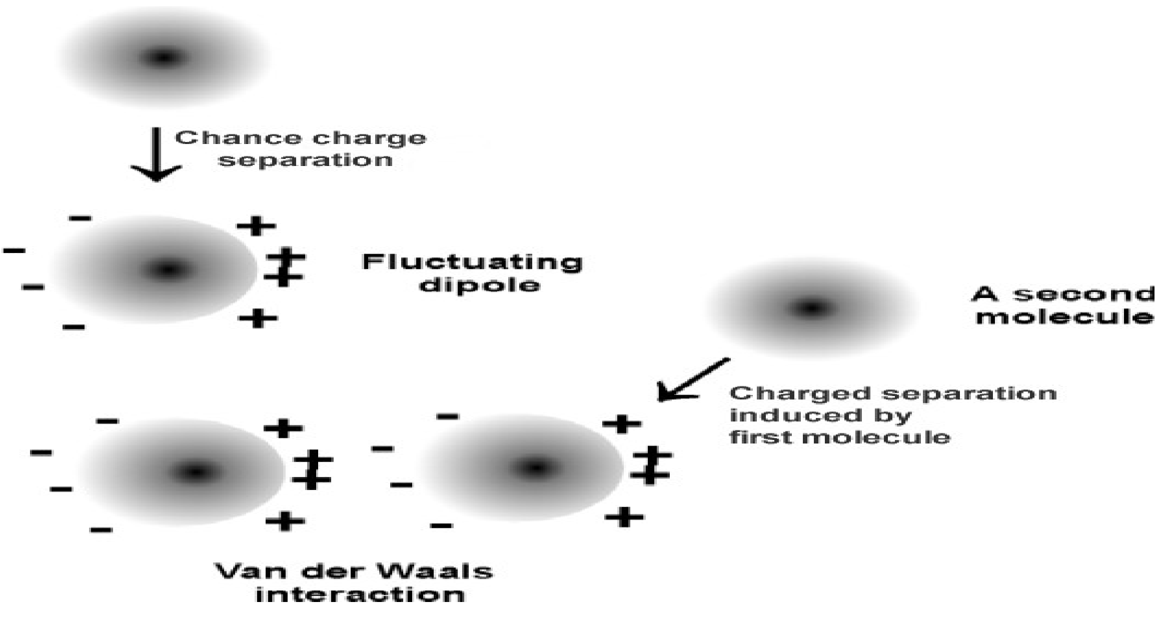


Figure 22: van der Waal forces

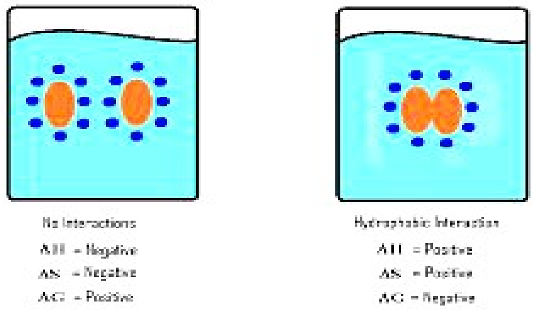


Figure 23: Hydrophobic effect

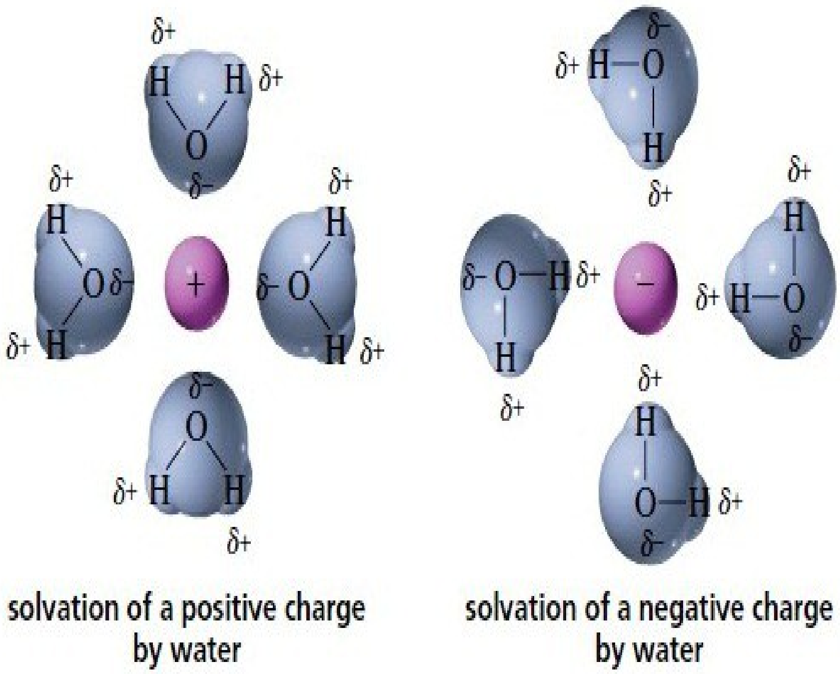


Figure 24: Solvation effects

Ionophores-

Ionophores are organic molecules that form specific complexes with metal cations and certain hydrophilic organic cations, rendering them lipophilic and providing a means for their transport across a polar barrier.

or

An ionophore is a lipid soluble molecule usually synthesized by microorganisms to transport ions across the lipid bilayer of the cell membrane. In laboratory research, ionophores are used to increase the permeability of biological membrane to certain ions.

Basically, the ionophores are carrier for metal ions. These carriers form a liposoluble complex with the cation, which is able to cross the membrane. The ionophores may be negatively charged and so give a neutral complex, or it may be a neutral species and so form a charged complex.

Ion selectivity of ionophore-

The presence of selective ionophore in the membrane leads to decreases the total free energy required for the transfer of the ionophore-ion complex into the organic phase. So, the binding of ionophore to an ion will be affecting the phase transfer equilibrium of the ions [19].

The complexation of ionophore must also be kinetically fast [20,21], which lowers the free energy barrier for the free and complexed states and leads to a facile complexation, the ion carrier must be preorganised and flexible to some extent.

The carrier molecule situated at the interface of aqueous solution and the membrane metal complex diffused through the membrane to other side where the cation was set free in the water solution. The cycle was completed by reverse diffusion of the free carrier. This process was called “carrier relay mechanism”.

The selectivity of the ionophore and host-guest interactions depends on following factors-

(1) The nature and number of binding sites in ionophore, their shape, size, arrangement and reactivity should be match with the geometric shape of the ion, its charge density and its size (ionic radius).

(2) The number of donor sites should be sufficient to match the coordination number of the guest species.

(3) The flexibility of holding of donor atoms by the host backbone must be limited, so that their positions are suitable to match the shape of the coordination sphere of the guest.

(4) Branched groups can be attached to proper sites of the host for high hydrophobicites and avoiding crystallized membrane phases.

The requirements for a podand that behaves as an ionophore-

(1) The carrier must be able to assume a stable conformation, which directs the polar liganding moieties into a central cavity suitable for encaging a cation.

(2) High ion complexation selectivity is achieved by lacking the coordination sites into a rigid arrangement around the cavity.

(3) The carrier must possess both polar and non-polar groups. The polar group functions as ligand, which replaces the solvent molecules in the primary solvation sphere of the complex-ions.

(4) Ion complexation-decomplexation reactions must proceed at a sufficient rapid rate in order for the ionophore to function as an efficient carrier. This is possible only when the ionophore is flexible enough to allow a stepwise rather than a concerted substitution of liganding moieties solvent molecules.

Structural features of ionophores-

The structure of the ionophore and their geometric factors play an important role in determining the ion selectivity. The ionophores have a large hydrocarbon backbone incorporating oxygen containing moieties which are electron donating species. The flexibility of this backbone makes it suitable to match the shape of the coordination sphere of the target species. The electron donating atoms complex with cations through ion-dipole interaction, results a perturbation in the conformation of ionophore. The cation is centrally located in the cavity and the polar nucleophilic moieties are oriented towards the interior of the resulting complex. The backbone of the hydrocarbon is exposed to the exterior.

Classification of ionophores-

1. On the basis of structural features-

(A) Neutral ionophores-

These ionophores forms complexes with metal ions from ion-dipole interactions, when the complex encounters a hydrophilic environment during transport, decomplexation occurs as the reverse reaction of complexation. E.g. Valinomycin (**Figure 25**) [22].

(B) Charged ionophores-

These are open chain compounds with oxygen containing heterocyclic aromatic rings incorporated in their structure. These ionophores have a charged group and a tail capable of participating in hydrogen bonding (a hydroxyl group or an amino group). These ionophores may be positively or negatively charged. e.g. The transport of anionic cadmium complexes from iodide solutions through bulk liquid membrane containing rhodamine B (positively charged ionophore) as a carrier (**Figure 26**) [23].

(C) Channel forming ionophores-

These ionophores form complexes with metal ion in the presence of membrane. These molecules dimerize in the lipid membrane to form channels 25-30 Å long and about 4 Å in diameter, which act as ion conducting channels through the membrane. The internal part of these channels (**Figure 27**) is lined with oxygen atoms that create an electron rich field which stabilizes cations.

2. On the basis of occurrence-

(A) Naturally occurring ionophores-

These are lipid soluble natural products. These were extracted from naturally occurring antibiotics eg. Valinomycin, Enniatin, Beauvaricin, Monensin (**Figure 28**), Nigericin and Gramicidins etc.

- ***Valinomycin***- Valinomycin was isolated from Streptomyces Fulvissimus. It was isolated and characterized [24] by Brockman and it was synthesized and identified by Shemyakin & coworkers [25]. Valinomycin is a macrocyclic dodecapsipeptide with 12 subunits amino and hydroxyl carboxylic acids which are connected by alternate peptide and ester bonds. Because of the high selectivity displayed for K^+/Na^+ this antibiotic is unequalled by any other ionophore which led to its designation as a “Prime ionophore” [26].

- ***Enniatin and Beauvericin***- The enniatins are cyclic hexadepsipeptide i.e. 18-membered macrocycles which exhibit considerable lower cation selectivity than the valinomycin. Beauvericin is produced by the fungus beauveria bassiana [27] where as the enniatins can be isolated from various Fusarium Culture [28].
- ***Polyether Antibiotics- pseudocavities-*** These types of ionophores are referred to as nigericin antibiotics because nigericin was the first compound of this family.

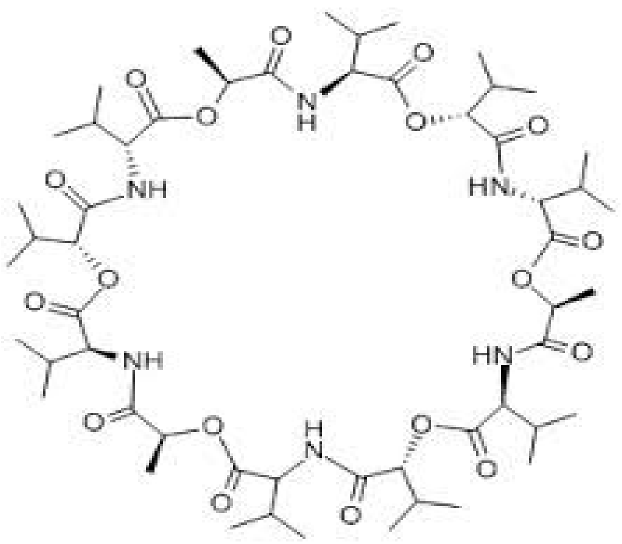


Figure 25: Valinomycin

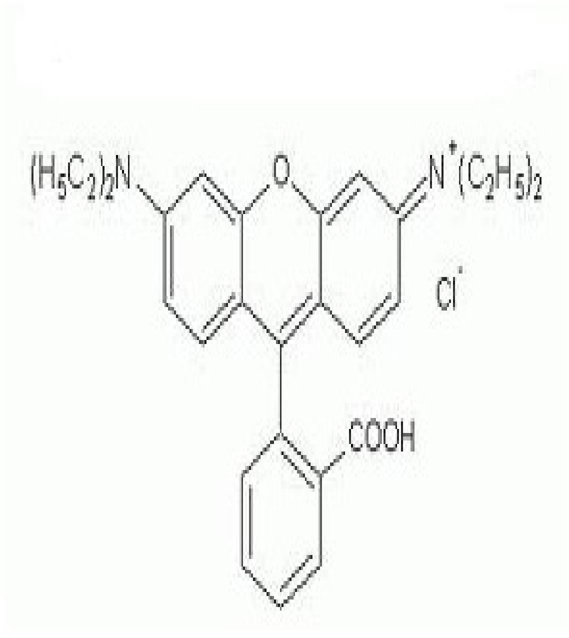


Figure 26: Rhodamine B

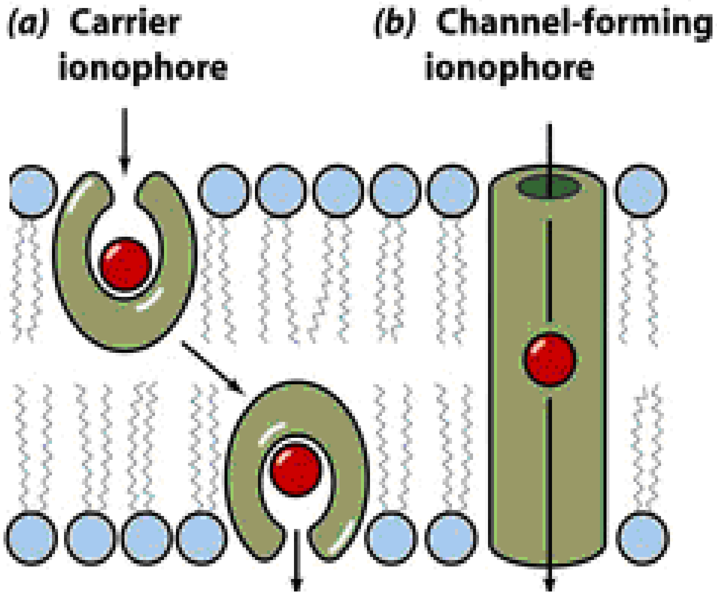


Figure 27: Channel formation

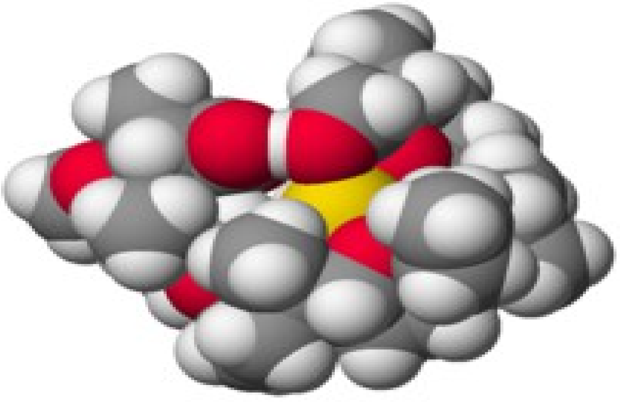


Figure 28: Structure of sodium (Na^+) complex with monensin

(B) Synthetic ionophores-

Extensive work is being carried out on alkali and alkaline earth metal ions with natural antibiotics and synthetic tri, bi and monocyclic macromolecules [29]. However more systematic investigations on the relationship between host cavity size and guest ion radius could only be carried out using simpler synthetic ligands as models. In 1967, Pedersen reported the synthetic and complexing properties of a new class of compounds named “Crown ethers” [30] which are able to mimic effectively their natural counter pieces. Many synthetic ionophores are based on crown ethers, cryptands and calixarenes. These synthetic species are often macrocyclic. Even simple organic compounds such as phenols exhibit ionophoric properties.

Some new ionophores were synthesized by the composition of glycol chain and naphthalene and anthraquinone moiety (31,32).

Carrier facilitated transport of urea by synthetic non cyclic receptors and new ionophores were synthesized by insertion of napthaquinone and anthraquinone moiety [33-35].

Crown Ethers-

These are macrocyclic close ring polyethers (**Figure 29**) in which donor oxygen atoms are arranged in a ring. These oxygen atoms separated from each other by two carbon atoms $-CH_2$-CH_2-. The rings are of different sizes with or without aromatic nuclei. The complexation of metal ions by macrocyclic polyethers or crown ethers well documented.

A large number of crown ethers have been synthesized and used as ligands for M^{Z+}. The example of cyclic form are 18-crown-6, dibenzo 18-crown-6, 15-crown-5 etc. The nomenclature of crown ethers was proposed by Pedersen. A large number of crown ethers and related macrocycles have been designed with bis(methylene) aromatic or hetero aromatic moieties as the main building blocks.

Podands-

The term “podands” appeared in the chemical literature comparatively recently towards the end of 1970’s [36,37]. General information on this class of compounds can be formed in recent review by Vogtle and Weber [38].

These workers have also suggested the name “podands” to indicate an open chain equivalent of crown ethers or cryptands comounds. The metal ion complexing behavior of both naturally occurring and synthetic acyclic ionophores (podands) has been investigated in recent years in an attempt to access the factors that affect metal ion complexation behaviour. Several studies have focused on determination of the selectivity and efficiency of podands mediated extraction of metal ions from an aqueous source phase in to an organic medium or the podand mediated transport of metal ion through the organic media into an aqueous receiving phase.

Podands are major class of supramolecular hosts having the possibility to form interesting complexes by forming pseudocyclic cavity exhibiting extractability and selectivity by trapping the metal ion [39].

Classification of podands-

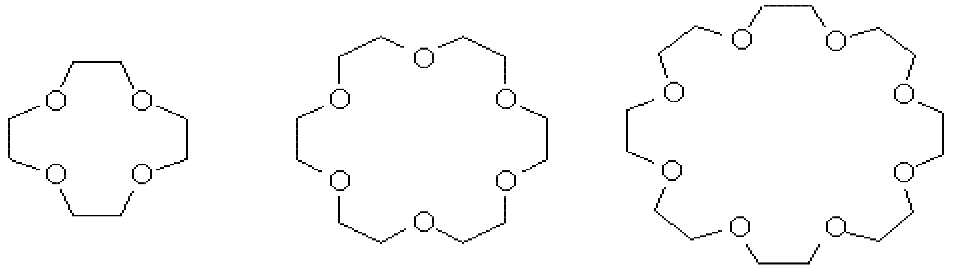
(I) Podands with aromatic donor end groups-

The podands with aromatic donor end groups form more stable complexes. These podands have electron donating end groups with oxyethylene chain (**Figure 30).** The work on these type of ionophores have been done in bulk. Many more types of podands with donor end groups have been also synthesized and used in extraction and transport of alkali and alkaline earth metal ions. Some pseudocyclic ionophores of oligoethylene glycols were synthesized by the insertion of quinolinyoxy group at the end of chain. These types of ionophores were used for the complexation of alkali metal ions [40].

Synthesis of diionozable polyethers and tetrahydrofurane composed noncyclic ionophores were synthesized to use separation of alkali and alkaline earth metal ions through bulk liquid membrane [41-43].

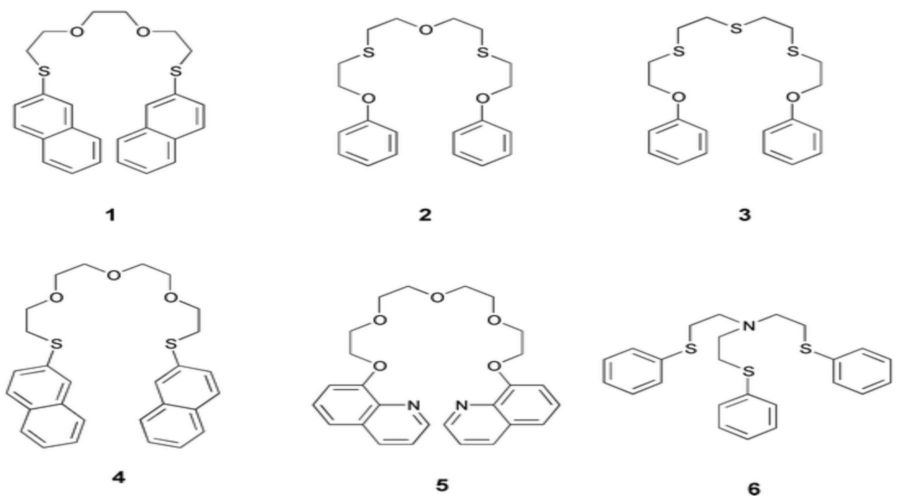
(II) Podands without donor end groups-

Work on podand without donor end groups also has been done. These are very simple glymes (glycoldimethylethers). They form less stable complexes than podands containing aromatic end groups but exhibit considerably enhanced selectivity (**Figure 31**) [44]. Oligoethylene and polyethylene (ethylene glycols) and glymes began to be regarded as open chain analogues of crown ethers. Polydentate acyclic complex forming agents of a new type were created on their basis and found extensive applications as solvents. The specific solvation of alkali and alkaline earth metal cations by ethylene glycol ethers and their oligomers (glymes) is well known [45,46]. The use of these compounds as solvents for organic anionic reactions is in fact based on this phenomenon.



[12]-crown-4 [18]-crown-6 [24]-crown-8

Figure 29: Crown ethers



1 2 3 4 5 6

Figure 30: Podands with aromatic donor end groups

14-Hydroxy-3,6,9,12-tetraoxatetradecanoic acid

Diethyleneglycolmonomethylether

Diethyleneglycoldimethylether

Tetraethyleneglycoldiacrylate

Triethyleneglycolmonomethylether

Dipropyleneglycoldiacrylate

Figure 31: Podands without aromatic donor end groups

Life requires a continuous material exchange which includes all chemical elements. The occurrence of these elements in organisms depends on external and endogenous conditions.

Bioinorganic chemistry can be broadly defined as study in which chemical reactivity of metal ions in biological environment is undertaken. The chemistry of biomolecules including metallobiomolecules is the same as those of that define the chemical and physical properties of typical organic, inorganic and complex molecules. It is the branch of chemistry, acts as a bridge between inorganic chemistry and biochemistry and tries to explain the role of inorganic constituents in biochemical processes.

Some biological important elements can be classified as follows:

1. **Organic constituents**: these are main constituent of living system which are derived from inorganic elements like C,H,O,N. here are 90% of solid materials e.g. proteins, carbohydrates, fats etc.
2. **Inorganic constituents**: these are important for maintaining vital activities of a living system. It is possible to divide the 30 elements into two main groups:

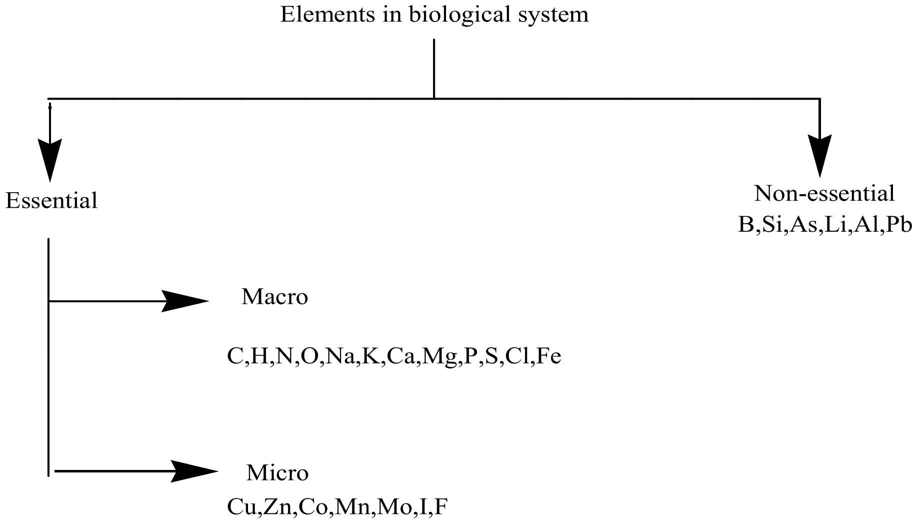
A. ***Essential elements-*** these elements play a role in maintenance of normal living state of a tissue or whole of the body. these are further divided into two sub-groups:

   i. *Macronutrients:* these elements form nearly 60-80% of all inorganic material in the body. These includes twelve elemens such as C,H,O,Na,K,Ca,Mg,Fe,P,S and Cl.

   ii. *Micronutrients:* these are needed by the body in very small amounts almost in miocrograms and nanogarms e.g. Cu,Zn,Co,Mn,Mo,I,F etc.

B. ***Non-essential elements***: These includes ten elements e.g. B,Si,As,Ni,Al,Pb etc. given in table 1.

Table 1
Elements in biological system



LITHIUM-

Lithium is a very reactive metal and is found naturally as lithium salt. It has been reported that lithium, at low dosage levels, has a generally beneficial effect on human behaviour.

Design and synthesis of molecules, which display a high affinity and selectivity for Li^+ is, a challenging task [47]. Although considerable progress has been made in this field, synthesis of such ionophores often requires substantial synthetic efforts.

- Lithium can control the mood extremes of bipolar disorder.
- It protects our brain from damage due to Alzheimer’s (neurodegenerative diseases), which causes of death of brain neurons and lithium reduces the area of cell death.
- It increases production of a major brain protective protein called “bcl-2” in both human and animal brain cells.
- Lithium gamma-linoleic acid is in clinical studies for the treatment of certain type of cancer.
- Lithium succinate is used in treatment for seborrheic dermatitis.

- $LiCO_3$ can be used in treatment of manic depressive illness.

SODIUM-

Sodium is essential for animals but less important for plants and indeed these generally contain relatively little amount of sodium. It is the major component of the cations and the extracellular fluid. It mainly exists as chloride and bicarbonate.

- Blood needs a lot of sodium to regulate osmotic pressure and blood pressure as well as to help solublize proteins and organic acids.
- Sodium's most important function is the movement of electrical impulses along nerve fibers in conjunction with potassium and chloride, which maintain water balance and distribution, kidney and adrenal function, acid-base balance, muscle and nerve cell function and heart function.
- Most of the sodium in the body is located outside the cells in the blood and other fluids. Cells pump sodium out and potassium in via the "sodium-potassium pump" (**Figure 32**). This pump is found in the membranes of all cells in the body. It prevents the swelling of cells. If sodium is not pumped out, water accumulates within the cell causing it to swell, and ultimately burst.
- Low potassium, high sodium diet plays a major role in the development of cancer and cardiovascular disease.
- Sodium deficiency may results from extreme excretion of sodium ion by sweating and other loss of body fluids. It is evidenced by thirst, anorexia and nausea. Other results of severe sodium loss are muscle cramps and mental disturbances.

POTASSIUM-

Red blood cells have most potassium, followed by muscles and brain tissues. Potassium is extremely important to cells such as brain cells, skin cells, liver cells, nerve cells and without it, we could not survive.

- Potassium which is in the plasma acts as an electrolyte, helping maintain plasma viscosity and osmotic pressure.

- Potassium has many functions, the more important of which are regulating intracellular fluids, solubilizing proteins, operating nerve impulses and contracting intracellular muscles.
- It is the cofactor for some internal enzymes which stabilizing internal structures.
- Glycolysis requires a high concentration of K^+ and is inhibited by Ca^{2+} and Na^+.
- It is essential for the conversion of blood sugar into glycogen, which is the storage form of blood sugar found in the muscles and liver.
- If there is a deficiency, then the person experiences muscular weakness, which can affect the heart muscle, causing irregular beating and even cardiac arrest.

MAGNESSIUM-

Magnesium is an essential element for almost all living things, excepts some insects. It is certainly essential for all green plants because it is at heart of the chlorophyll molecule, which plants use to capture the energy of the sun in order to convert CO_2 and water into glucose.

- Inside the cell Mg^{2+} exists as complexes with nucleotides, since Mg^{2+} binds preferentially to phosphates, So Mg^{2+} is necessary for DNA replication and protein biosynthesis.
- It protects from some heart disorders and high blood pressure.
- It helps to absorb calcium and potassium, normal functioning of the brain, to prevent depression, heart disease and kidney stones.
- It is essential in allowing our body to control insulin levels in the blood.
- If there is a deficiency mental confusion, irritability, weakness, heart disturbances, problem in nerve conduction, muscle contraction, muscle cramps, headaches, loss of appetite, insomnia, predisposition to stress, high blood pressure, kidney stones, cancer and menstrual cramps.

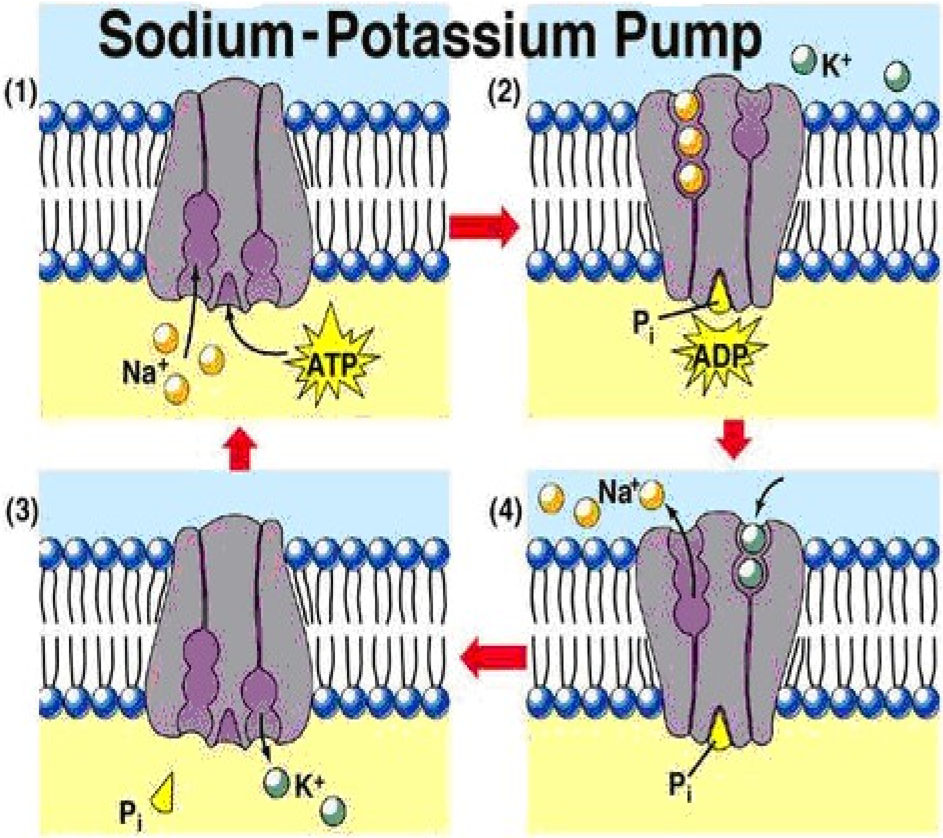


Figure 32: Sodium-potassium pump

CALCIUM-

Calcium is essential to practically all-living [48] things, except a few insects and bacteria. In higher animals calcium is located in the bones and teeth as apatite. Calcium is distributed throughout all tissues where it has special roles to control nerve impulse transmission, muscle action, blood clotting and cell permeability. Calcium is important for following functions:

- It regulates activity at membranes, e.g. it cements cell together.
- For muscle growth and the electrical impulses in the brain.
- For maintain blood pressure.
- For controlling cell division.
- It triggers hormone release.
- For making blood clot when get cut.
- For treatment of arthritis.
- During the periods of growth, pregnancy and lactation.

$CaCl_2$ in small doses acts as a diuretic and it may be included in a saline drip and calcium sulfate is used to make plaster casts.

Liquid membrane transport of metal ion relevant to biological processes is an interesting and important subject from a viewpoint of both the stimulation of a biological system and the development of novel separation techniques for such ions.

Table 2
Biologically important human elements

Metal ions in the human body	Blood	Bone	Tissue	Total amount in body
Lithium	4 ppb	1.3 ppm	Approx. 24 ppb	7 miligrams
Sodium	Plasma 3500 ppm (0.35%), red cells, 250 ppm	10000 ppm (1%)	Varies between 2000 and 8000 ppm	100 gm
Potassium	Plasma 400 ppm, red blood cells, 4000 ppm (0.4 %)	2100 ppm (0.21 %)	16000 ppm (1.6%)	Varies within range 110-140 depending on the weight of muscle in the body
Calcium	61 ppm. With the pasma having 80 ppm and red blood cells only 4 ppb	3-17%	Approx. 120 ppm	1.2 Kg
Magnessium	38 ppm	Varies between 700 and 1800 ppm	Approx. 900 ppm	25 gm

Table 3
Division of metals in biology

Group IA	Group IIA	Group II	Transition metals
Na^+,K^+	**Mg^{2+},Ca^{2+}**	**Zn^{2+}, Ni^{2+}**	**Mn,Fe,Co,Lu,Mo**
Osmotoic can for all elecrolytes ion currents	Triggers and conformational control	Acid catalysis	Redox catalysis

Applications of supramolecular chemistry-

(I) Materials technology-

(A) *Nanotechnology-*

Most of the bottom-up approaches to nanotechnology are based on supramolecular chemistry. Nanotechnology seeks the ability to make most structures with more attractive approach as a target for near term experimental effort in the use of molecular building blocks.

(B) *DNA as a material for nanotechnology-*

Present photolithographic technique to form structures of less than 100 nm size is highly uneconomical, therefore it was required to explore for new methods, which could utilize assembly of even smaller molecules building to form larger devices. DNA molecules with the conventional nucleotide help create specific topologies, shapes and arrangements of secondary and tertiary structures.

(C) *Nanofiber-*

The molecular structure of a nanofiber can be characterized by Fourier Transform Infra Red (FTIR) and Nuclear Magnetic Resonance (NMR) techniques. If two materials were blended together for nanofiber fabrication, not only the structure of the two materials can be detected but also the inter-molecular reaction can be tested [49].

(II) Catalysis-

A major application of supramolecular chemistry is the design and understanding of catalysis and catalyst. Noncovalent interactions are extremely important in catalysis, binding reactants into conformations suitable for reaction and lowering the transition state energy of reaction. Template-directed synthesis is a special case of supramolecular catalysis.

(III) Sensors-

Chemical/ biosensors [50] are a device which respond to a particular analyte in a selective way through a chemical or biochemical reactions and can be used for the qualitative or quantitative determination of the analyte.

(IV) Biological detection and imaging using quantum dots-

Quantum dots are nano-scale crystalline structures which can transform the colour of light. The quantum dot is considered to have greater flexibility than other fluorescent materials, which makes it suited to use in building nano-scale computing applications where light is used to process information.

(V) Medicines-

Supramolecular chemistry is also important to the development of new pharmaceutical therapies by understanding the interactions at a drug binding site. The area of drug delivery (**Figure 33**) has also made critical advances as a result of supramolecular chemistry providing encapsulation and targeted release mechanisms. In addition, supramolecular systems have been designed to disrupt protein-protein interactions that are important to cellular function.

(VI) Data storage and processing-

Supramolecular chemistry has been used to demonstrate computation function on a molecular scale. In many cases, photonic or chemical signals have been used in these components, but electrical interfacing of these units has also been shown by supramolecular signal transduction devices.

Data storage has been accomplished by the use of molecular switches withphotochromic and photoisomarizable units, by electrochromic and redox-switchable units, and even by molecular motion.

(VII) Supramolecular radio fullerenes-

Exohedral modification of fullerene in three dimensions by addition reaction and development of preparative fullerene chemistry are particularly attractive to physicist, chemist and material scientists. Supramolecular fullerenes can be applied in biochemical and toxicological applications.

(VIII) Green chemistry-

Research in supramolecular chemistry also has application in green chemistry where reactions have been developed which proceeds in the solid state directed by non-covalent bonding. Such procedures are highly desirable since they reduce the need for solvents during the production of chemicals.

Supramolecular chemistry is often pursued to develop new functions that cannot appear from a signal molecule. These functions also include magnetic properties, light responsiveness, self-healing polymers, molecular sensors etc. Supramolecular research has been applied to develop high-tech sensors, processes to treat radioactive waste and contrast agents for CAT scans.

A computational neutral network method [51] was used for the prediction of stability constants of simple crown ether complexes. The essence of the method lies in the ability of a computer neutral network to recognize the structure-property relationship in these host-guest systems.

With this introductory base, we have surveyed the literature on the same lines, as is presented in the next chapter.

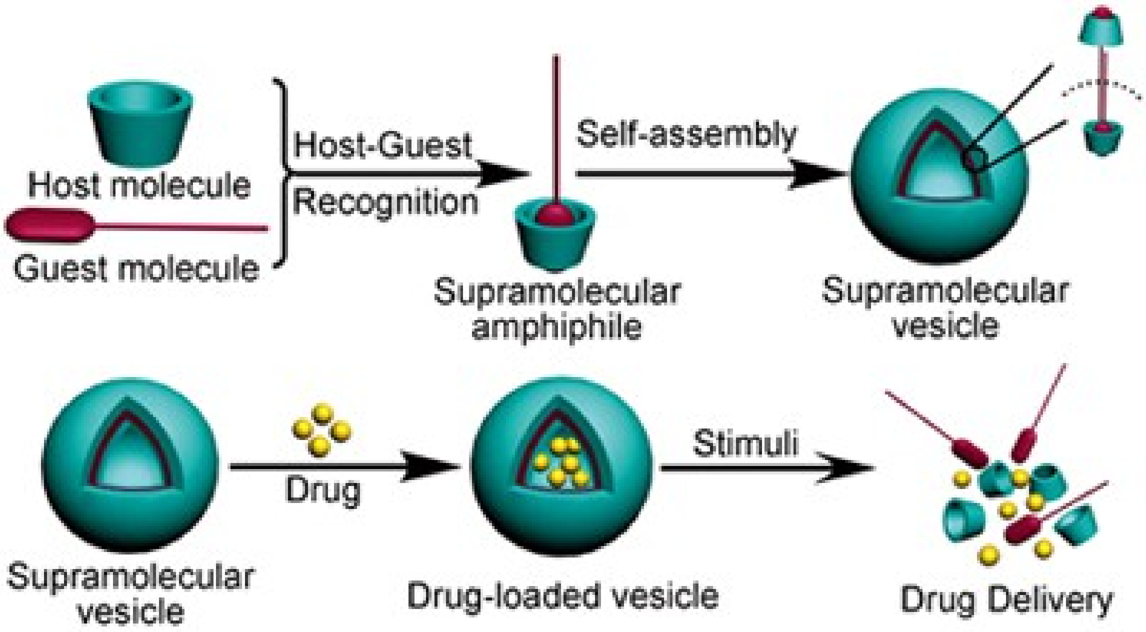


Figure 33: Role of host-guest complexes for site specific drug delivery in animals

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CHAPTER –II

LITERATURE SURVEY, AIM & SCOPE

Chapter 2

Literature Survey, Aim and Scope

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Literature survey is very important tool for the investigation of any work. It provides detailed information about the work have been done. It gives us useful insight of the invitro work that has been done on natural and synthetic ionophores for biologically important alkali and alkaline earth metal ions (Li^+, Na^+, K^+, Mg^{2+} and Ca^{2+}) by membrane integrated process of living cells.

Supramolecular chemistry is a relatively new field of chemistry which focuses quite literally ongoing "beyond" molecular chemistry. It can be described as the study of systems which contain more than one molecule, and it aims to understand the structure, function and properties of these assemblies.

Supramolecular chemistry involves investigating molecular systems in which the most important feature is that components are held together by intermolecular forces, not by covalent bonds. Supramolecular chemistry has emerged from the developments in macrocyclic chemistry in 1960's. These synthetic systems have been developed from natural macrocycles such as ionophore, hemes, pthalocyanines etc.

The existence of intermolecular forces was first postulated by Johannes Diderik van der Waals in 1873. However, it is with Nobel Laureate Hermann Emil Fischer that supramolecular chemistry has its philosophical roots. In 1890, Fischer suggested that enzyme-substrate interactions take the form of a "lock and key", prompting the concepts of molecular recognition and host guest chemistry. The antibiotics nigericin and lasalocid were first representative of the naturally occurring ionophores and isolated in 1951 from streptomycin culture [1] and their membrane affecting properties related to the host guest chemistry started in the late 1960's.

The real advancement in the subject took place in 1967 when Pedersen reported the synthesis and complexation properties of a new class of compounds named crown-ethers [2]. Lehn and co-workers (1969) [3] in France produced bicyclic macromolecules, which possess the ability of dissolving salt like $BaSO_4$. The term "Podands" appeared in the chemical literature comparatively recently towards the end of 1970's [4].

In 1976, Kobuke and co-workers [5] reported the synthesis of macrocyclic ligands containing tetrahydrofurane units and selective transport of monovalent cations using these synthesized ligands as carriers through liquid membranes. Vogtle prepared noncyclic ionophores in 1977 and these noncyclic ionophores have been found to be capable of complex formation with M^{Z+}, like macrocyclic polyethers [6-8]. The discovery of crown ethers by Pederson gave the shape of recent developments. The term "supramolecular chemistry" was introduced by Lehn in 1978 and defined as the "chemistry of molecular assemblies and of the intermolecular bonds".

In 1987, Lehn, Pederson and Cram were awarded **Nobel Prize** for their work in supramolecular chemistry.

The noncyclic ionophores were found selective for cation transport [9] and they have been used in biomimmetic chemistry [10]. Studies on the macrocyclic mediated transport [11] and on synthetic noncyclic ionophores [12] have been carried out. Work on noncyclic ligands composed of tetrahydrofurane for transport of alkali metal cations through liquid membranes have been studied [13]. In recent years, open chain analogues [14] of crown ethers have attracted increasing attention.

In the year 1990, Nonaka and coworkers reported the transport of alkali and alkaline earth metal ions against their concentration gradient [15]. Ca^{2+} and Na^{+} ions were selectively transported by dicarboxylic ligands [16].

In 1993, lithium ion selective ionophores were designed and synthesized for use as an ion selective electrode [17]. Supramolecular complexes of alkali metal ions were prepared and the transport of alkali and alkaline earth metal ions through chloroform membranes containing synthetic noncyclic ionophores have been carried out [18-20].

In 1996, Kroto, Smally and Curl were also awarded **Nobel Prize** for their work on supramolecular fullerenes. Early work in supramolecular chemistry [21] is focused on molecular recognition, i.e., on the selective recognition of substrate molecules (guest) by synthetic ionophores (host).

Isolation of alkali and alkaline earth metal complexes by diethyleneglycoldibenzoate has been studied [22]. New lipophilic acyclic polyethers were synthesized and used in transport of alkaline earth metal ions [23] and the effect of picrate salt was studied in 1996 [24]. The field of supramolecular chemistry has reached such a level that it can control the K^+/Na^+ selectivity of the antibiotics valinomycin [25] and synthetic anion receptors.

Carrier mediated transport of some main group metal ions [26], transition and post-transition metal ions using oxygen-nitrogen donor macrocycles as ionophores have been carried out [27]. The calcium ionophore ETH-129 has been used in transport studies [28]. Calixarene derivatives [29], new synthetic noncyclic ionophores [30,31] and triethyleneglycolmonomethylether [32] were used for membrane transport studies and the effect of end group of ionophores was also studied.

Stoichiometric complexes of some main group metal ions (Li^+ ,Na^+, K^+, Ca^{2+}) with redox switched lariat ethers have been studied [33,34]. Extractability and selectivity of synthetic ionophores [35] and newly designed and synthesized anthraquinone derived ionophores [36] have been studied.

Applications of membrane based separation in environmental remediation have been reported [37]. Extraction and transport of alkali and alkaline earth metal ions have been carried out with anthraquinone derived redox switchable ionophores [38] and with noncyclic ionophores composed of furan units [39]. N-(diethylthiophosphoryl)-aza-[18]-crown-[6] have been synthesized and used to examine its carrier ability towards heavy metal ions lead (II), zinc (II) and cadmium (II) [40].

The interaction of napthaquinone derived ionophores with biologically important metal ions has been studied [41]. The carrier facilitated transport of urea using synthetic noncyclic receptors through supported and bulk liquid membrane system have been carried out [42].

The study on acetic acid extraction from aqueous solution and separation of dimethyl disulfide from liquified petroleum gas has been carried out [43, 44]. The transport of mercury ion through a bulk liquid membrane by 18-crown-6 and 2-(4-chlorophenyl)-2,3-dihydroquinazoline (1H)-4-one(CPHQO) as counter ion have been studied [45]. The selective separation of silver (I) ion through bulk liquid membrane containing 1,1'-(1,3-phenylene) bis (3-allylthiourea) as carrier have been carried out [46].

Recently, a new family of ionophores was synthesized based on aluminum dipyrrin complexes and they were used for recognition of alkaline earth metal ions [47]. The design and synthesis of molecular containers [48] is playing an increasing role in the selective removal and detection of species within the solution.

Noble prize 2016 has been awarded to scientists Jean-Pierre Sauvage (Strasbourg University, France), Sir Fraser Stoddart (Northwestern University, Illinois, US) and Bernard Feringa (University of Groningen, Netherland) for the discovery of the world's smallest machine which is also a supramolecular device. This device could slip inside the human body for applying pharmaceuticals directly to the cancer cells.

In our laboratory earlier studies were carried out with dipropyleneglycoldibenzoate [49,50], triethyleneglycol bis(2-ethylhexanoate) [51], dipropyleneglycolmonomethyl-ether [52], ethyleneglycoldiacetate [53] and tripropyleneglycolmonobutylether [54,55]. Dipropyleneglycolmonomethylether bis(acetoacetate) was also synthesized and used as carrier for extraction and transport studies.

From the literature survey, it was observed that most of the work done has been on the natural as well as synthetic macrocyclic ionophores and some on noncyclic ionophores.

In the present study we have synthesized a new series of podands containing one and two p- bromo phenacyl moieties for in-vitro extraction and transport studies of Li^+, Na^+, K^+, Ca^{2+} and Mg^{2+} ions [56].

Aim and scope of the work

Supramolecular chemistry has vast applications in recent time and molecular devices, photochemistry, electronic switches as well as dendrimers are the major area where it being applied. Designing of molecules with specific functions, molecules for self assembly into supramolecular structures and making carbon nano tubes are the major applications of supramolecular chemistry.

Liquid membranes are well known as one of the most powerful tools for separation and enrichment purposes. Carrier mediated transport through liquid membranes is not only an interning technique for concentration, separation and recovery, but is also of fundamental importance from the biological point of view.

This technique provides a powerful tool to explore molecular recognition skill of the crown ether to affect separation via liquid membranes by process of solvent extraction. The process was very rapid with neutral carriers which extracted cation and accompanying anion in order to maintain electro neutrality. The membrane system based consisted of bulk liquid membrane. The ion solvation pairing of ions in source phase and use of proton ionisable macrocycle played a significant role in transportation.

Membranes and membrane processes are used to produce potable water from the sea, to clean industrial effluents and recover valuable constituents, to concentrate, purify or fractionate macromolecular mixtures in the food and drug industries, and to separate gases and vapors. They are also key components in energy conversion systems, and in artificial organ and drug delivery devices.

Moore and pressman [57] discovered the use of biological membranes for the transport of antibiotic valinomycin for potassium in mitochondria.

Membrane operations in the last years have shown their potentialities in the rationalization of production systems. Their intrinsic characteristics of efficiency, operational simplicity and flexibility, relatively high selectivity and permeability for the transport of specific components, low energy requirements, good stability under a wide spectrum of operating conditions, environment capability, easy control and scale-up have been confirmed in a large variety of applications and operations, as molecular separation, fractionation, concentrations, purifications, clarifications, emulsifications, crystallization etc. in both liquid and gas phases and in a wide spectrum of operating parameters such as pH, temperature, pressure etc.

The study gives us an idea about the various factors and individual structural units of carriers that affects transport and this enables us to design and construct ligands capable of mimicking the transport properties of complex ionophores and also to set conditions to ensure maximum transport of desired species. The liquid membrane separation has attracted large industrial applications.

There are various analytical applications of membrane transport with crown ethers. The increasing concentration of lipophilic crown ethers in oil water emulsion droplets offered satisfactory separation for potassium [58]. During the separation of alkaline earths like Ca, Sr and Ba, the presence of anion like picrate in dichloromethane promoted transport of interfering alkali ions in opposite direction for basic phase [59]. Ba has been successfully separated from industrial effluents on dibenzo [18]-crown-[6] on octadecylsilica membrane disk but best results were achieved with the use of bis (crown ether carboxylate) derivatives [60].

The alkali and alkaline earth metal ions play vital role in biological system as charge carrier in nerve impulses. The continuous monitoring of Na^+, K^+ and Ca^{2+} activities in blood (eg. during open heart surgery) and of Na^+, K^+ activities in undiluted urine has become possible by ion selective electrode.

Among transition elements lanthanides, cobalt, silver cadmium and from main group elements lead were separated by membrane transport. The aza crown ethers gave best separation of silver from divalent cations like cobalt, zinc, copper, cadmium and lead.

The membrane transport phenomenon was offshoot development in the field of ion selective electrodes. In fact because of its excellent use in biological analysis solvent extraction as a matter of fact gave great boost to use of liquid membrane in metal separation.

The electrically neutral ionophores or ion carriers were used as the basic components of ion selective electrodes. These electrodes are useful in membrane potential, electrode selectivity, electrode fabrication and measurement of the potential of the system during quantitative analysis. Research has begun to focus on optical techniques of detection with a view to reduce overall complexity due to the fact that optically based system does not require external reference electrodes and expensive electronic potentiostate equipment. In order to reach the goal of optically based clinical diagnostic system, new sensors are needed that own their response to photonic energy rather than electrical differences.

Since, organic electronics has added a new dimension to conventional supramolecular chemistry. Huge advancement have been made with regard to its theoritical and functional understanding over the past few decades. Take a critical look at supramolecular aspects of domain control, monodispersity and control of dynamics of π-conjugated molecule assemblies [61].

The liquid membrane systems have much importance as model for cation transport across biomembranes. The anion effect may be turned on or off simply by alternating the anion present in the source solution. The same anion effect might be useful in separating and detecting anions themselves.

Now we can focus on the recent developments of arene ruthinium complexes towards both supramolecular chemistry and biology. Arene ruthinium complexes can form various supramolecular structures with applications as chemical/photochemical sensors, in medicine and for drug transport inside the cell [62]. Recent developments in supramolecular chemistry will give access to a variety of metal based drug/sensors within the next few years.

Supramolecular photonic device “Rhodopsin” is also an example of supramolecular alkali metal cation transport system such as stimulation by visible light of rod and cone cells in the retina of the eye. The rod cells are excellent functional supramolecular devices.

The design of ligands for the complexation of ions has become a major research area in recent years as reflected in the numerous reviews that have been written on the subject [63-72]. This interest is due to the fact that ion complexation ligands have applicability in the wide range of field. For example ion complexation ligands have spurred the development of new catalyst [63], antibiotics [65], artificial sensory system [64] and therapeutic agents in chelating therapy [68, 71]. One of the major driving force in the research of new ligands or ionophores, is sensory development, particularly for clinical diagnostic purpose and attention has focused on attaining high selectivity and sensitivity to specific ions [68, 71]. In particular due to their significant importance in the clinical diagnosis of diseases, research has centered on complexation of alkali and alkaline earth metal ions.

The nanomachine invented in 2016 is also a suparmolecular device which is thousand times thinner than strand of hair. This is very useful for direct drug delivery to the cancer cells. This field of nanotechnology could also yield applications in the design of smart materials.

Applications of liquid membrane technology-

(1) Industrial applications-

(A) Waste water treatment-

Bulk liquid membranes are used on lab scale to evaluate the carrier activity of different organic carriers and have also been used for preconcentration of uranium from seawater sample prior to analysis [73,74].

The removal of toxic heavy metal ions from wastewater was also studied. The results showed that liquid membranes are capable of reducing the levels of these heavy metal ions from several hundred ppm to less than 1 ppm under batch or continuous conditions.

(B) Separation of isomer-

Over the years, the separation of isomers using liquid membrane by carrier-facilitated transport has been done. e.g. extractive resolution of racemic mandelic acid through a bulk liquid membrane containing binary chiral carrier [75]. Liquid membrane technology provides applications in organic synthesis, photochemical energy conversion, isotope and isomer separation techniques.

(C) Extraction of metal ions-

In recent years liquid membranes have gained considerable interest in recovery of metal ions as well as removal of toxic metals which requires coupled transport with organic carriers in the membrane phase [76]. Separation of heavy metal ions like silver (I) and mercury, lead etc. have been done by use of ionophores in bulk liquid membrane technology.

(2) Biomedical and biochemical applications-

(A) Blood oxygenation-

Liquid membranes can be used for the diffusion of oxygen from the membrane into the blood while CO_2 diffuses in the opposite direction and is swept out.

(B) Removal of toxins from the blood-

Liquid membrane systems can also be used to remove phenolic toxins from blood during liver failure in which the internal trapping consists of an aqueous solution of the enzymes UDAPGA and UDPCT.

The membrane separation process, dialysis, is not used industrially but is used on a large scale in medicine to remove toxic metabolites from blood in patients suffering from kidney failure [77].

(C) Slow release of enzymes and drugs-

In the development of artificial kidney system, liquid membrane encapsulates urease, which is slowly released in to the gastrointestinal tract. It requires supplementing the naturally occurring urease in the tract in order to get rapid conversion of urea to ammonia. The ammonia is removes by a separate liquid membrane system.

Liquid membrane technology provides potential applications for small and large separation, drug delivery and fabrication of ion selective electrodes and sensing etc. Techniques.

(3) Liquid membranes as chemical reactors-

Liquid membranes can also be used as chemical reactors for the reaction between two gases in a heterogeneous catalytic system. As the gases diffuse through the membrane, the reaction occurs and the products diffuse out into the external receiving solvent. E.g. catalytic oxidation of ethylene to acetaldehyde, propylene to acetone, acetaldehyde to acetic acid etc.

After reviewing the different aspects of carrier mediated transport through artificial membrane, are approached towards studies in this field is to synthesize different podands and to study the transport of alkali and alkaline earth metal ions using different artificial membranes.

Present work deals with in-vitro studies of extraction, transport and isolation of alkali and alkaline earth metal ions by podands containing p-bromophenacyl moieties. We have studied the various factors that affect ionic transport by changing the experimental conditions in setup. We have also attempted to correlate the factors of ionic transport, ion-extractability and complexation behavior of ions using synthesized ligands in solid as well as in solution studies.

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CHAPTER –III

EXPERIMENTAL SECTION

Chapter 3

Experimental Section

Separation of various species is very important in the laboratory and industrial scale and usually the properties of solutes play an important role in the separation process [1]. Many processes like distillation, crystallization, centrifugal and gas absorption, the difference in the physical properties of the solutes are considered, but such process are less selective and feasible only when there is a great difference in the physical properties of the solutes from another components in the mixture [2].

Membrane separation process finds relevance in different industries due to benefits like cost being lucrative, ease of operation, high preconcentration factor with a high degree of selectivity and can be used for solutes at very low concentration level [3].

The experimental studies have been divided into four sections:

1. *Synthesis of podands*
2. *Extraction studies*
3. *Bulk liquid membrane transport studies*
4. *Isolation studies*

1. Synthesis of podands-

Supramolecular chemistry is intrinsically a dynamic chemistry in view of the liability of the interactions connecting the molecular components of a supramolecular entity and the resulting ability of supramolecular species to exchange their constituents. The same holds for molecular chemistry, when a molecular entity contains covalent bonds that may form and break reversibly. So as to make possible a continuous change in constitution and structure by recognition and exchange of building blocks.

This behaviour defines a constitutional dynamic chemistry that allows self organization by selection as well as by design at both the molecular and supramolecular level [4].

In chemistry, noncovalent interactions are now exploited for the synthesis of large supramolecular aggregates. The aim of this synthesis is not only the creation of particular structure, but also the introduction of specific chemical functions in these supermolecules [5].

In the late 1960's, Pedersen [6], Lehn [7], Cram [8] and co-workers published the synthesis of macrocyclic molecules (crown ethers, cryptands, spherands etc.) which can also selectively bind ions and small organic molecules via noncovalent interactions.

In last 20 years a huge number of different supramolecules with high affinity and selectivity for various anionic and cationic species have been synthesized and developed in the field of biomimetic chemistry, ion selective electrodes [9], chemical sensors [10] and bio sensors [11].

Our interest in this area was stimulated by the possibilities for the design and synthesis of other podands which could mediate the counter transport of protons and alkali metal ions [12].

The examination of carriers based upon noncyclic polyether's frame work. This type of compounds form complexes with metal ions. A large number of these compounds have been prepared [13-15] and many of the structural factors which influence complex structure, stability and selectivity have been investigated [16-18].

A source of inspiration for studying the open chain equivalents of crown ethers was the observations that a number of naturally occurring antibiotics enhance cation transport and bear a structural similarity to open chain crown ethers.

A considerable number of model compounds were synthesized which mimick the biological carriers. These synthetic macrocyclic polyethers are characterized by a hydrophilic cavity interior and hydrophobic exterior and complex with metal cations according to the ion cavity fit concept and to go through lipophilic biological membranes.

Using these approaches, we have designed and synthesized a new series of podands containing p-bromophenacylbromide moities. These ionophores have been used in extraction and bulk liquid membrane transport of alkali and alkaline earth metal ions.

In designing a suitable host, parameters like cavity size, charge, character of the donor atoms etc. should be in accordance to the properties of the target molecules. The route of synthesis of noncyclic ionophores is shown in different schemes.

To this end, it is the goal of this work to design noval ionophores for the complexation of monovalent cations such as Li^+, Na^+, K^+ and divalent cations such as Mg^{2+} and Ca^{2+} based upon the fundamental requirement for stable and selective host-guest interactions. A further goal is to corroborate these requirements with modern molecular modeling technology and thus provide a rational approach to the development of new ionophores.

[I] Reagents and Instruments-

[I.I] *Chemicals and Reagents*

The reagents used for the synthesis of podands are diethyleneglycol, triethyleneglycolmonobutylether, tetraethyleneglycol, tripropyleneglycolmonobutyl-ether which were purchased from Aldrich, p-bromoacetophenone, bromine, glacial acetic acid from merck and sodium hydroxide, potassium hydroxide, and magnesium sulphate from Qualigens.

The solvents dichloromethane, 1,2-dichloroethane, chloroform, methanol, ethylacetate were obtained from Loba and Merck.

For the preparation of metal salts Li_2CO_3, Na_2CO_3, KCl, $MgCO_3$, $CaCO_3$, C_2H_5OH were obtained from Rankem, Picric acid, dinitrophenol and orthonitrophenol were obtained from Qualigens and Merck (Mumbai). All reagents were used without further purification.

New type of podand ethyleneglycoldiacetate (A_5, **Figure 1**) and podand tripropyleneglycol-monobutylether (A_6, **Figure 2**) were purchased from Aldrich.

[I.II] *Instruments-*

Melting points of complexes were obtained using melting point apparatus (Remi). IR spectrum was recorded on FTIR spectrophotometer (Perkin Elmer 70836) at School of Studies in Chemistry & Biochemistry, Vikram University, Ujjain (M.P.), on FTIR spectrophotometer (Shimadzu) at Rajasthan University (Jaipur) and on FTIR spectrophotometer (Perkin Elmer) at Sophisticated Analytical Instrumental Facility, Punjab University, Chandigarh.

^1H NMR spectrum was obtained in $CDCl_3$ using TMS as an internal reference on NMR spectrophotometer (Bruckner Avance II 400) and elemental analysis through elemental analyzer (Thermo Scientific) at Sophisticated Analytical Instrumental Facility, Punjab University, Chandigarh.

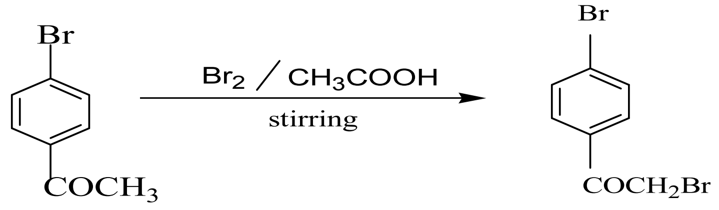
Metal estimation was carried out by digital flame photometer (Systronics-128) (**Figure 15**) and atomic absorption spectrophotometer (Shimadzu 6300) **(Figure 16)**. We used D_M water for whole practical work, which was obtained from Milipore water purifier (Elix UV_3, **Figure 17**) available at DST-FIST laboratory, Department of Chemistry, Government College Kota, Kota (Rajasthan). U-shaped glass tubes were used for transport studies. All borosilicate glassware were used.

We have synthesized a new series of podands by the addition of p-bromophenacyl bromide with different types of glycols. The design and synthesis of podands divided into two sections:

(A) Synthesis of p-bromophenacylbromide

(B) Synthesis of podands

(A) Synthesis of p-bromophenacylbromide-



P-bromoacetophenone p-bromophenacylbromide

For the synthesis of p-bromophenacylbromide, 0.25 mol (49.75 gm.) of p-bromoacetophenone was mixed with 100 ml. of glacial acetic acid in a 500 ml. flask. Then bromination was carried out by addition of 0.25 mol (12.9 ml.) of bromine in a period of about 30 minutes by dropping funnel. The mixture was stirred during the addition and the temperature was kept below 20ºC. P-bromophenacylbromide commences to separate as needle shape crystals after about half of bromine was introduced. When the addition was completed, the mixture was cooled in ice water. The crude product was filtered and washed with 50% alcohol until it becomes colorless (100 ml.). Then the filtered product was recrystallized from rectified spirit (400 ml.). The yield of pure p-bromophenacylbromide is 65 gm. (72%).

(B) Synthesis of podands-

(I) Synthesis of 1-(4-Bromophenyl)-2-(2-{2-[2-(4-bromophenyl)-2-oxo-ethoxy]-ethoxy}-ethoxy)-ethanone (podand A_1) –

In a round bottom flask 0.0155 mol (1.46 ml.) of diethyleneglycol and 0.031 mol (1.736 gm.) of KOH were dissolved in 100 ml. of ethanol. The mixture was refluxed for 1 hour and then 0.031 mol (8.618 gm.) of p-bromophenacylbromide was added over a period of 50 minutes. The mixture was stirred for another 3 hours. After cooling to room temperature the mixture was filtered and evaporated. The residue was dissolved in 150 ml. of $CHCl_3$ and washed with aqueous NaOH and then water. The organic layer was dried over $MgSO_4$ and purified by column chromatography over alumina. The synthesis of podand was carried out by **scheme 1** and confirmed by IR (**Figure 3**), ^{1}H NMR (**Figure 4**) and elemental analysis.

Yield: 4.80 gm. (50%), Molecular formula $C_{20}H_{20}O_5Br_2$, Molecular weight: 500.

Scheme 1

IR Peaks - 3401 cm^{-1} (enol-H strt.), 2956 cm^{-1} (C-H strt.), 1683.67 cm^{-1} (C=O strt.), 1590 cm^{-1} (Ar-C=C strt.), 1071 cm^{-1} (C-O strt.), 829 cm^{-1} (p-substituted Ar.)

^{1}H NMR Peaks (δ ppm**)** –3.5 (-CH$_2$-C**H**$_2$-O-,t), 4.63 (-C**H**$_2$-CO-,s), 7.5-7.7 (Ar-**H,**m)

Elemental analysis C & H – Calculated value (founded value)

C% - 48 (48.05) **H% -** 4 (3.56)

(II) Synthesis of 1-(4-Bromophenyl)-2-{2-[2-(2-butoxy-ethoxy)-ethoxy]-ethoxy}-ethanone (podand A$_2$) –

In a round bottom flask 0.0155 mol (3.20 ml.) of triethyleneglycolmonobutylether and 0.0155 mol (0.868 gm.) of KOH were dissolved in 100 ml. of ethanol. The mixture was refluxed for 1 hour and then 0.0155 mol (4.309 gm.) of p-bromophenacylbromide was added over a period of 50 minutes. The mixture was stirred for another 3 hours. After cooling to room temperature the mixture was filtered and evaporated. The residue was dissolved in 150 ml. of $CHCl_3$ and washed with aqueous NaOH and then water. The organic layer was dried over $MgSO_4$ and purified by column chromatography over alumina. The synthesis of podand was carried out by **scheme 2** and confirmed by IR (**Figure 5**), ^{1}H NMR (**Figure 6**) and elemental analysis.

Yield: 5.95 gm. (70%), Molecular formula $C_{18}H_{27}O_5Br$, Molecular weight: 403.

Scheme 2:

IR Peaks - 3401 cm^{-1} (enol H-stret.), 2956 cm^{-1} (C-H stret.), 1705 cm^{-1} (C=O stret.), 1587 cm^{-1} (Ar-C=C stret.), 1071 cm^{-1} (C-O stret.), 829 cm^{-1} (p-substituted- Ar).

^{1}H NMR Peaks (δ ppm**)-**3.5 (-CH$_2$-C**H**$_2$-O-, t), 3.3 (but.-O-C**H**$_2$-, t), 1.4 (but.-CH$_2$-C**H**$_2$-CH$_2$-, m), 1.3 (but. -C**H**$_2$-CH$_3$,m), 4.6 (-O-C**H**$_2$-, s), 7.5-7.7 (Ar-**H,** m), 0.96 (but. -C**H**$_3$-,t)

Elemental analysis C & H - Calculated value (founded value)

C% - 53.59 (52.24) **H% -** 6.69 (6.59)

(III) Synthesis of 1-(4-Bromophenyl)-2-(2-{2-[2-(2-{2-(4-bromophenyl)-2-oxo-ethoxy}-ethoxy)-ethoxy]-ethoxy}-ethoxy)-ethanone (podand A_3) –

In a round bottom flask 0.0155 mol. (2.6 ml) of tetraethyleneglycol and 0.031 mol. (1.736 gm) of KOH were dissolved in 100 ml. of ethanol. The mixture was refluxed for 1 hour and then 0.031 mol. (8.618 gm) of p-bromophenacylbromide was added over a period of 50 minutes. The mixture was stirred for another 3 hours. After cooling to room temperature the mixture was filtered and evaporated. The residue was dissolved in 150 ml. of $CHCl_3$ and washed with aqueous NaOH and then water. The organic layer was dried over $MgSO_4$ and purified by column chromatography over alumina. The synthesis of podand was carried out by **scheme 3** and confirmed by IR (**Figure 7**), ^{1}H NMR (**Figure 8**) and elemental analysis.

Yield: 11.80 gm (90%), Molecular formula $C_{24}H_{28}O_7Br_2$, Molecular weight: 588.

Scheme 3:

IR Peaks - 3478 cm^{-1} (enol H-stret.), 2930 cm^{-1} (C-H stret.), 1701 cm^{-1} (C=O stret.), 1587 cm^{-1} (Ar-C=C stret.), 1071 cm^{-1} (C-O stret.), 825 cm^{-1} (p-substituted Ar).

^{1}H NMR Peaks (δ ppm) - 3.5 (-CH_2-C**H_2**-O-,t), 4.5 (-O-C**H_2**-,s), 7.5-7.7 (Ar-**H,**m)

Elemental analysis C & H - Calculated value (founded value)

C% - 48.97 (49.73) **H% -** 4.76 (5.02)

(IV) Synthesis of 1-(4-Bromophenyl)-2-{2-[2-(2-butoxy-propoxy)-propoxy]-propoxy}-ethanone (Podand A_4) –

In a round bottom flask 0.0155 mol. (4.12 ml) of tripropyleneglycolmonobutylether and 0.0155 mol. (0.868 gm) of KOH were dissolved in 100 ml. of ethanol. The mixture was refluxed for 1 hour and then 0.0155 mol. (4.309 gm) of p-bromophenacylbromide was added over a period of 50 minutes. The mixture was stirred for another 3 hours. After cooling to room temperature the mixture was filtered and evaporated. The residue was dissolved in 150 ml. of $CHCl_3$ and washed with aqueous NaOH and then water. The organic layer was dried over $MgSO_4$ and purified by column chromatography over alumina. The synthesis of podand was carried out by **scheme 4** and confirmed by IR (**Figure 9**), ^{1}H NMR (**Figure 10**) and elemental analysis.

Yield: 8.09 gm (90%), Molecular formula $C_{21}H_{33}O_5Br$, Molecular weight: 445.

Scheme 4:

IR Peaks - 3448 cm^{-1} (enol-H stert.), 2932 cm^{-1} (C-H stret.), 1705 cm^{-1} (C=O stret.), 1587 cm^{-1} (Ar-C=C str.), 826 cm^{-1} (p-substituted-Ar).

NMR Peaks (δ ppm) **-** 3.5 (-O-C**H**$_2$-CH-, d), 4.6 (-O-C**H**$_2$-, s), 7.5-7.7 (Ar-**H,** m), 1.4 (but. -CH$_2$-C**H**$_2$-CH$_2$-, m), 1.2 (-CH-C**H**$_3$,d), 1.3 (but. -CH$_2$-C**H**$_2$-CH$_3$,m)

Elemental analysis C & H - Calculated value (founded value)

C% - 56.62 (55.97) **H% -** 7.41 (6.02).

Podands ethyleneglycoldiacetate (**A_5, Figure 1**) and tripropyleneglycolmonobutyl-ether (**A_6, Figure 2**) were purchased from Aldrich.

A_5 (Ethyleneglycoldiacetate)

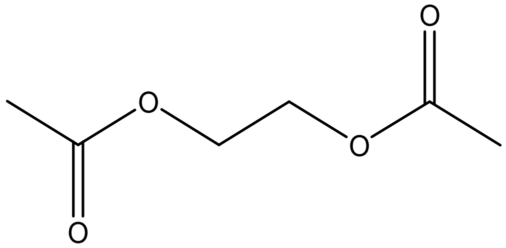


Figure 1: Ethyleneglycoldiacetate

Molecular formula: $C_6H_{10}O_4$, molecular weight: 146

IR Peaks: 2962 (C-H Stret.), 1743 (C=O Stret.), 1052 (C-O-C Stret.) (**Figure 11**)

A_6 (Tripropyleneglycolmonobutylether)

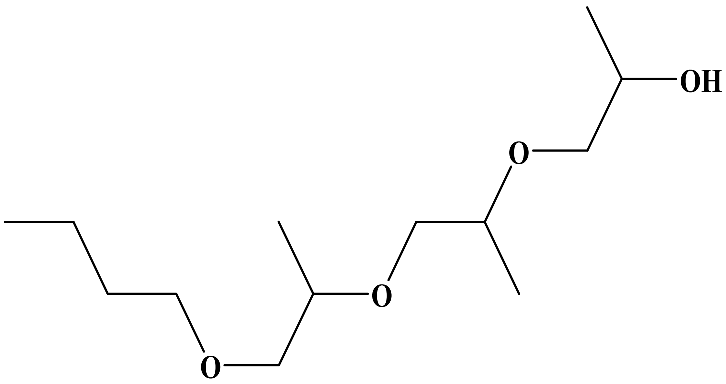
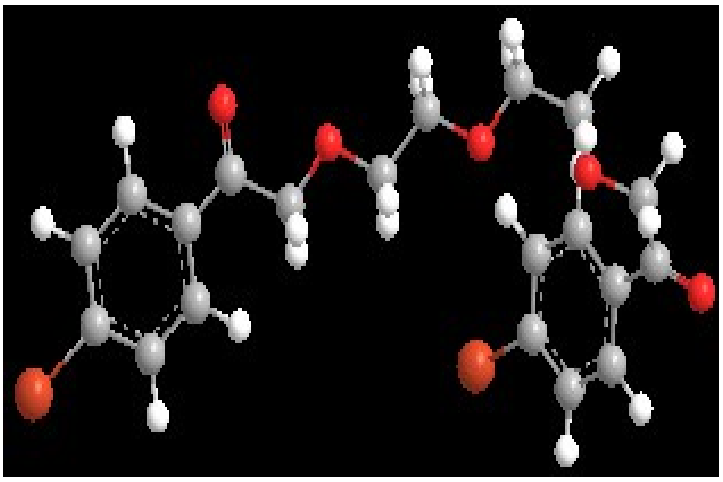


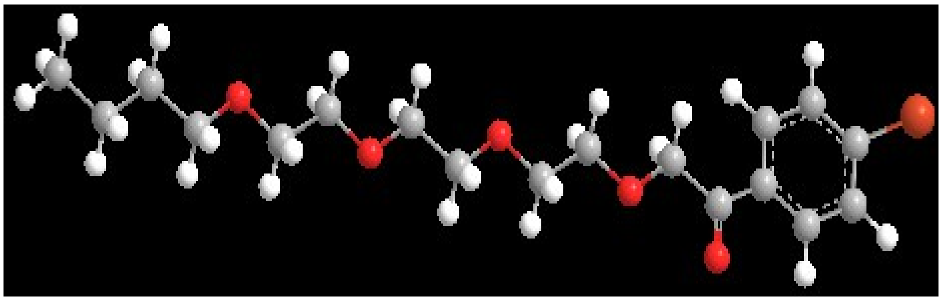
Figure 2: Tripropyleneglycolmonobutylether

Molecular formula: $C_{13}H_{28}O_4$, molecular weight: 248

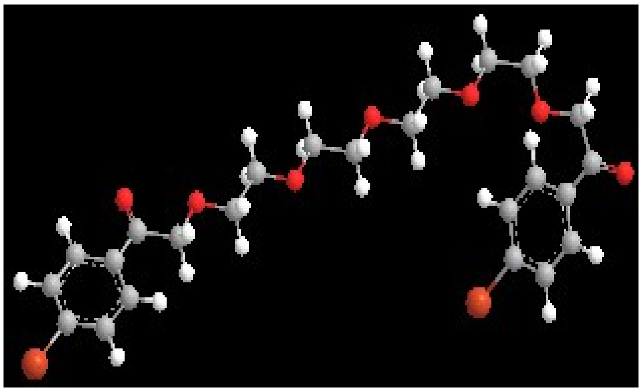
IR Peaks: 3454 (O-H Stret.), 2967 (C-H Stret.), 1114 (C-O-C Stret.) (**Figure 12**)



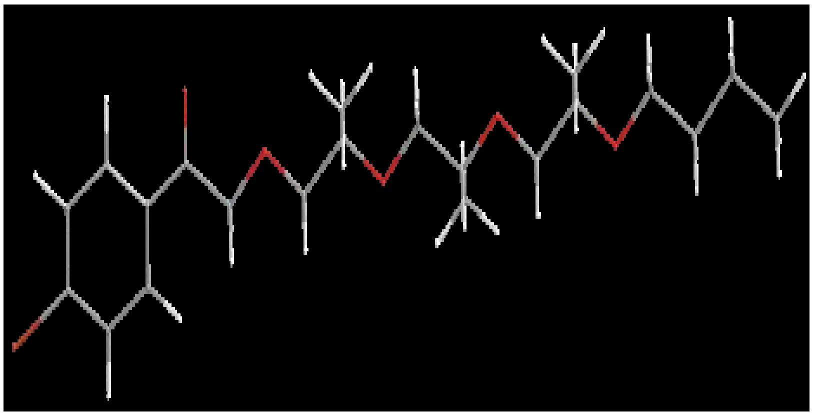
3-D ball & stick model of podand A_1



3-D ball & stick model of podand A_2



3-D ball & stick model of podand A_3

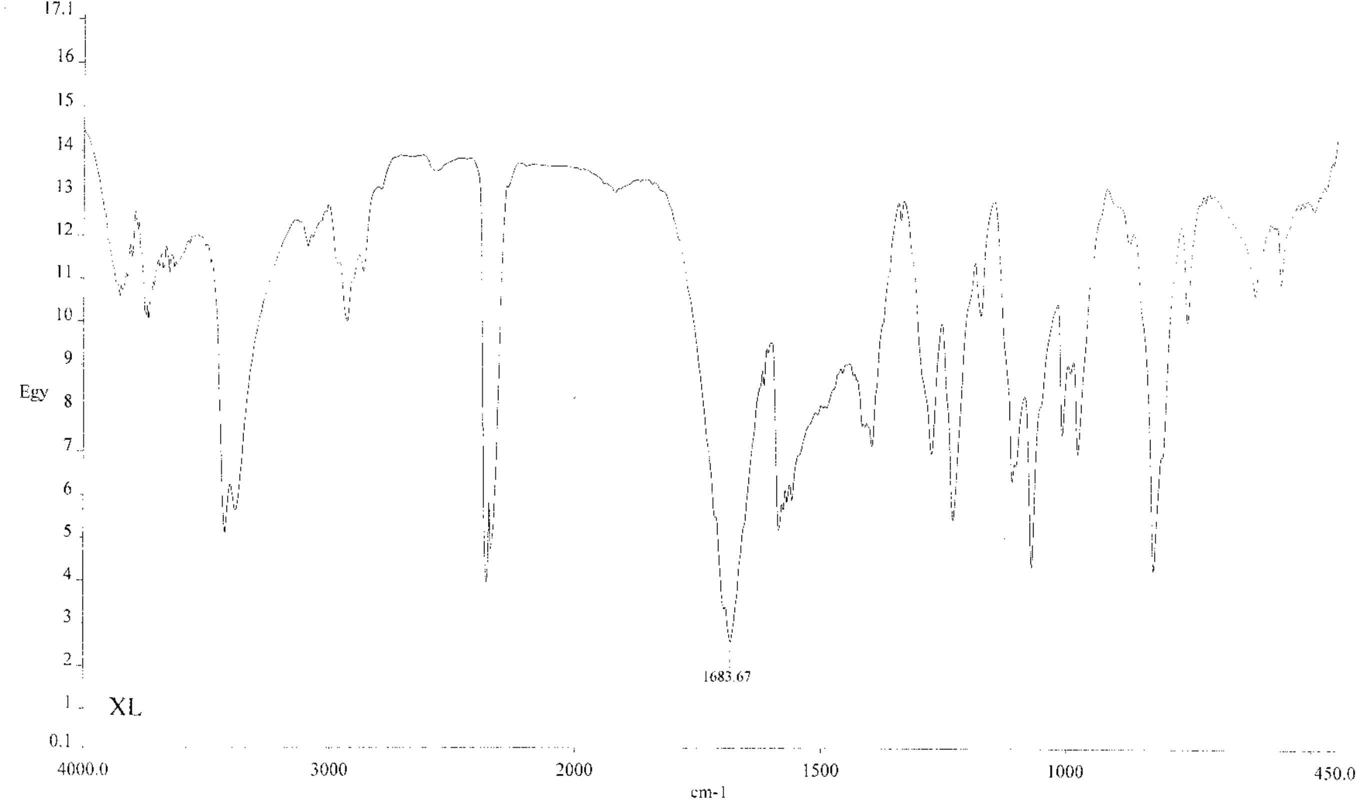


3-D stick model of podand A_4

School of Studies in Chemistry & Biochemistry

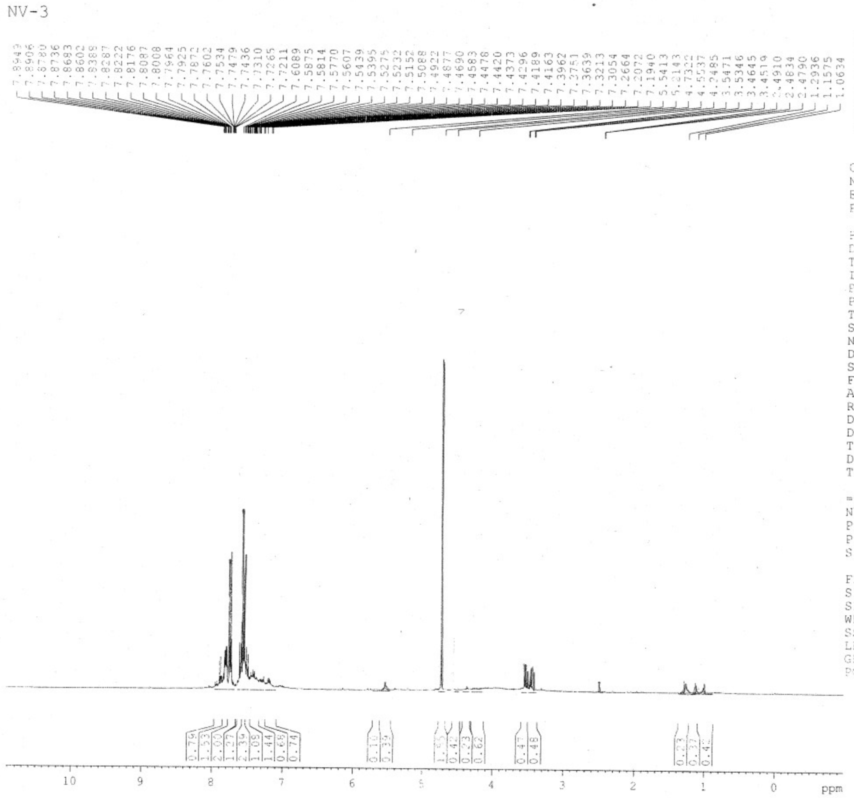
Vikram University, Ujjain

Date: 3/10/2004



Instrument Model: Spectrum BX Series

Fig.: 3 IR Spectrum of Podand A_1



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BRUKER
AVANCE II 400 NMR
Spectrometer
SAIF
Panjab University
Chandigarh

Current Data Parameters
NAME          Sep20-2012
EXPNO                 40
PROCNO                 1

F2 - Acquisition Parameters
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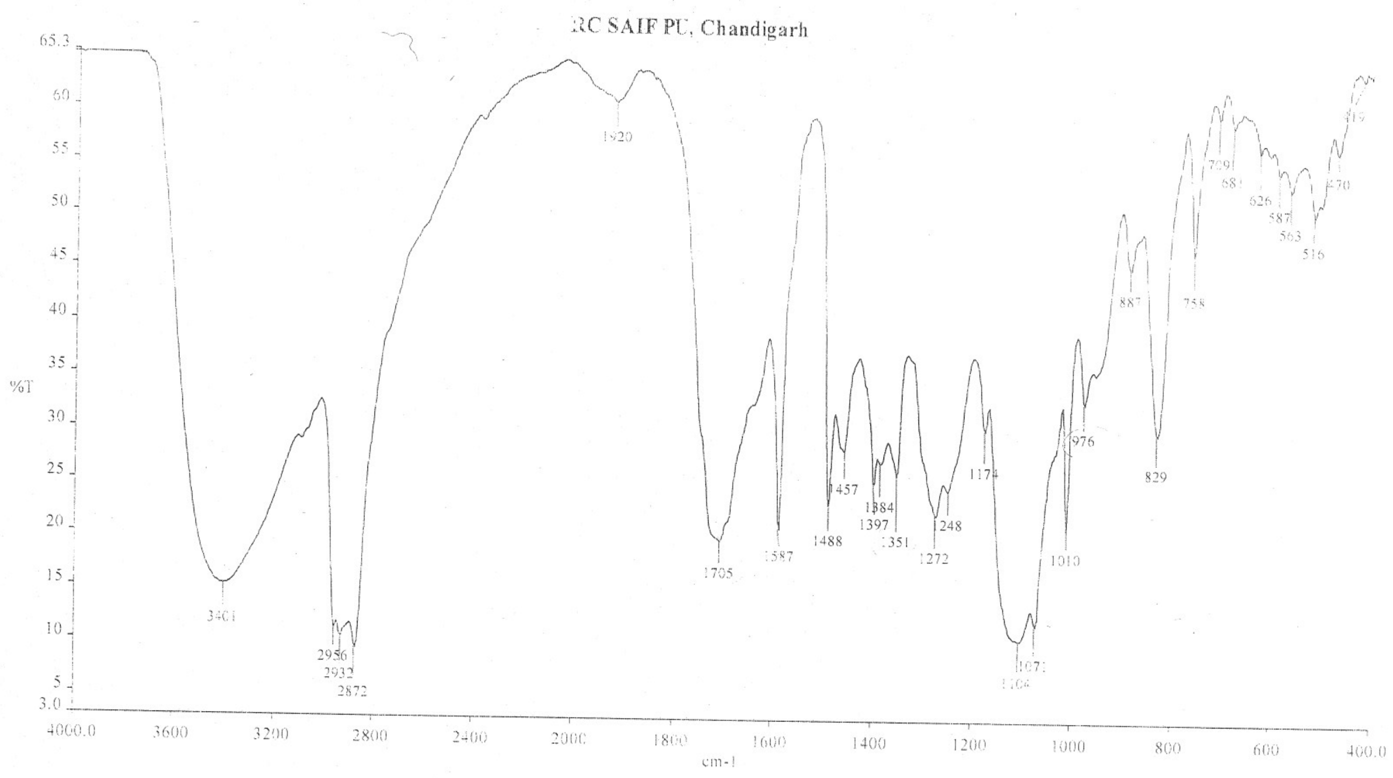
PULPROG             zg30
TD                 65536
SOLVENT             DMSO
NS                     8
DS                     2
SWH            12019.230 Hz
FIDRES          0.183399 Hz
AQ             2.7263477 sec
RG                  90.5
DW                41.600 usec
DE                  6.00 usec
TE                 294.9 K
D1            1.00000000 sec
TD0                    1

======== CHANNEL f1 ========
NUC1                  1H
P1                 10.90 usec
PL1                -3.00 dB
SFO1         400.1324710 MHz

F2 - Processing parameters
SI                 32768
SF           400.1300107 MHz
WDW                   EM
SSB                    0
LB                  0.30 Hz
GB                     0
PC                  1.00
```

avtar_saifpu@yahoo.co.in

Fig. 4 ^{1}H NMR Spectrum of Podand A_1



Spectrum Name: Varsha Gautam-3.sp

Description: S-C

Fig. 5 IR Spectrum of Podand A_2

Date Created: fri jul 13 15:05:05 2012 India Standard Time (GMT+5:30)

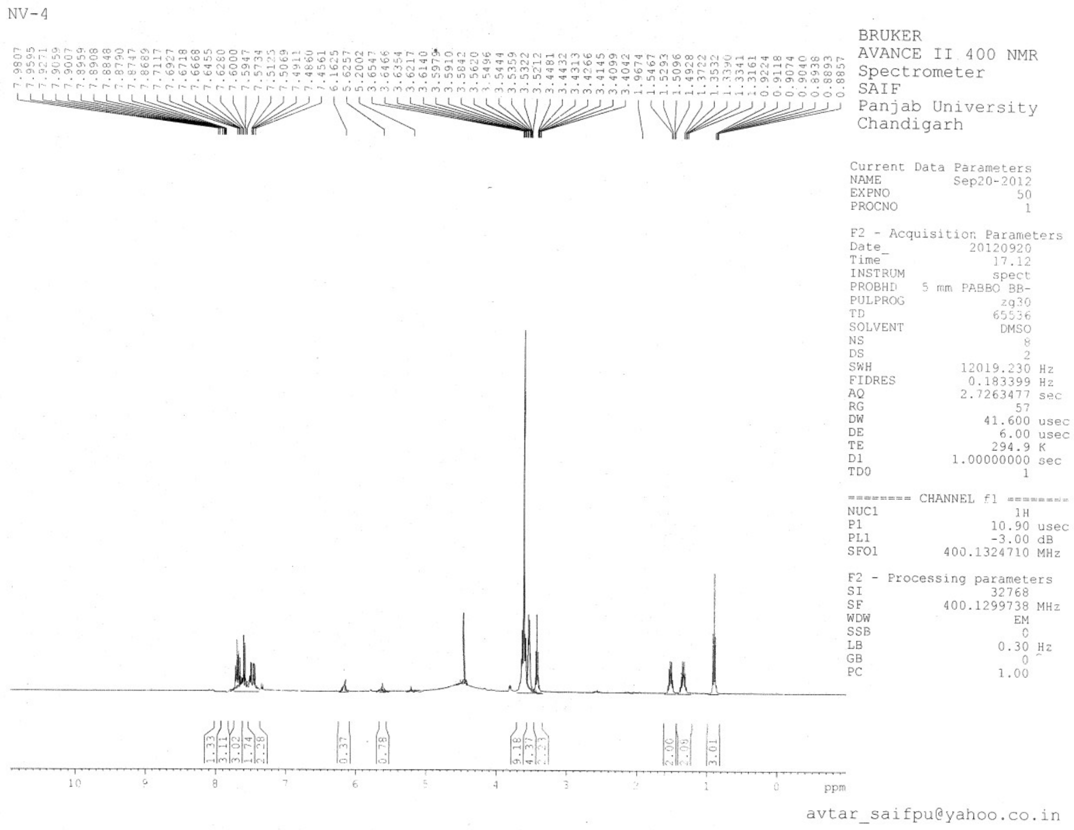
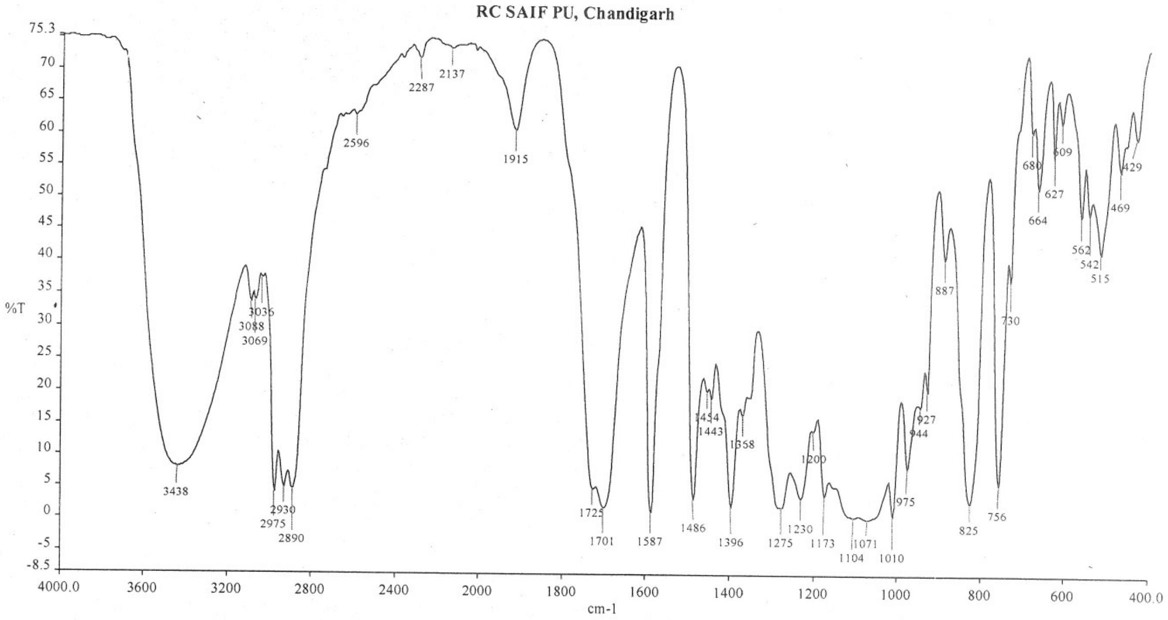


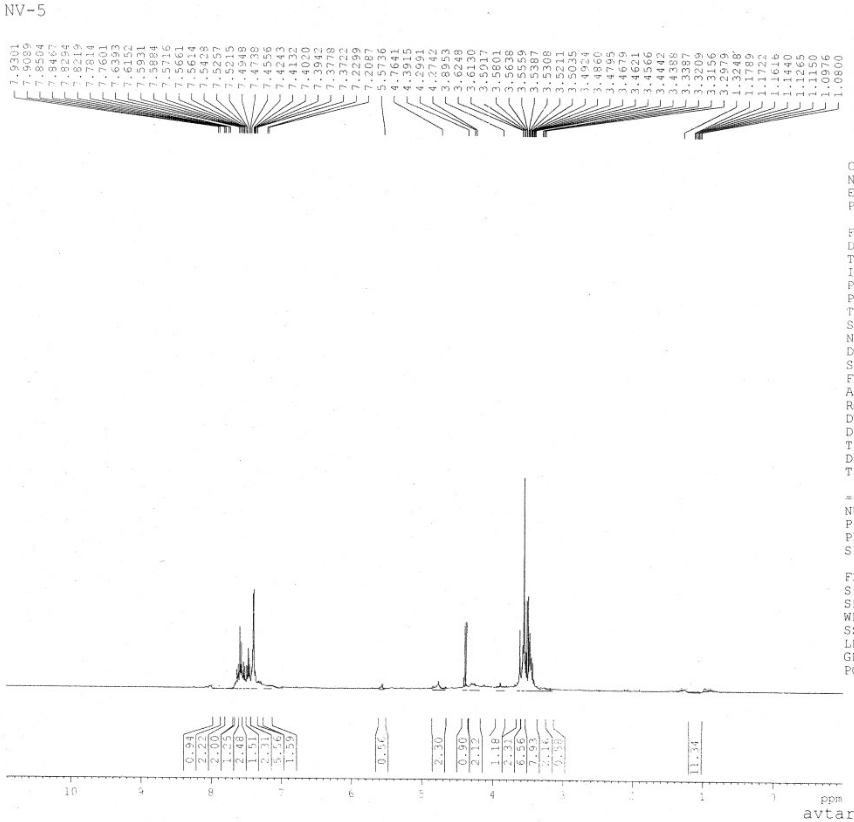
Fig. 6 ^{1}H NMR Spectrum of Podand A$_2$



Spectrum Name: Varsha Gautam-4.sp

Fig. 7 IR Spectrum of Podand A_3

Date Created: fri sep 21 14:32:43 2012 India Standard Time (GMT+5:30)



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BRUKER
AVANCE II 400 NMR
Spectrometer
SAIF
Panjab University
Chandigarh

Current Data Parameters
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PROCNO                    1

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PULPROG                zg30
TD                    65536
SOLVENT                DMSO
NS                        8
DS                        2
SWH              12019.230 Hz
FIDRES            0.183399 Hz
AQ               2.7263477 sec
RG                     45.2
DW                   41.600 usec
DE                     6.00 usec
TE                    294.9 K
D1               1.00000000 sec
TD0                       1

======== CHANNEL f1 ========
NUC1                     1H
P1                    10.90 usec
PL1                   -3.00 dB
SFO1            400.1324710 MHz

F2 - Processing parameters
SI                    32768
SF              400.1300000 MHz
WDW                      EM
SSB                       0
LB                     0.30 Hz
GB                        0
PC                     1.00
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Fig. 8 ^{1}H NMR Spectrum of Podand A_3

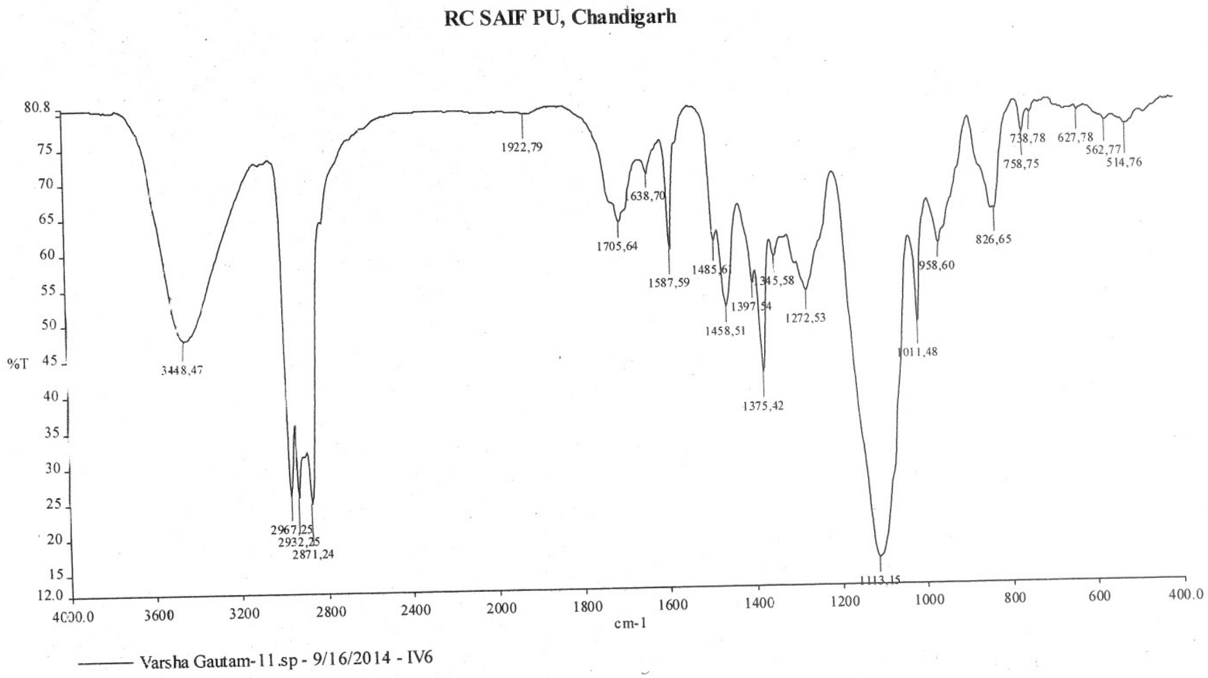
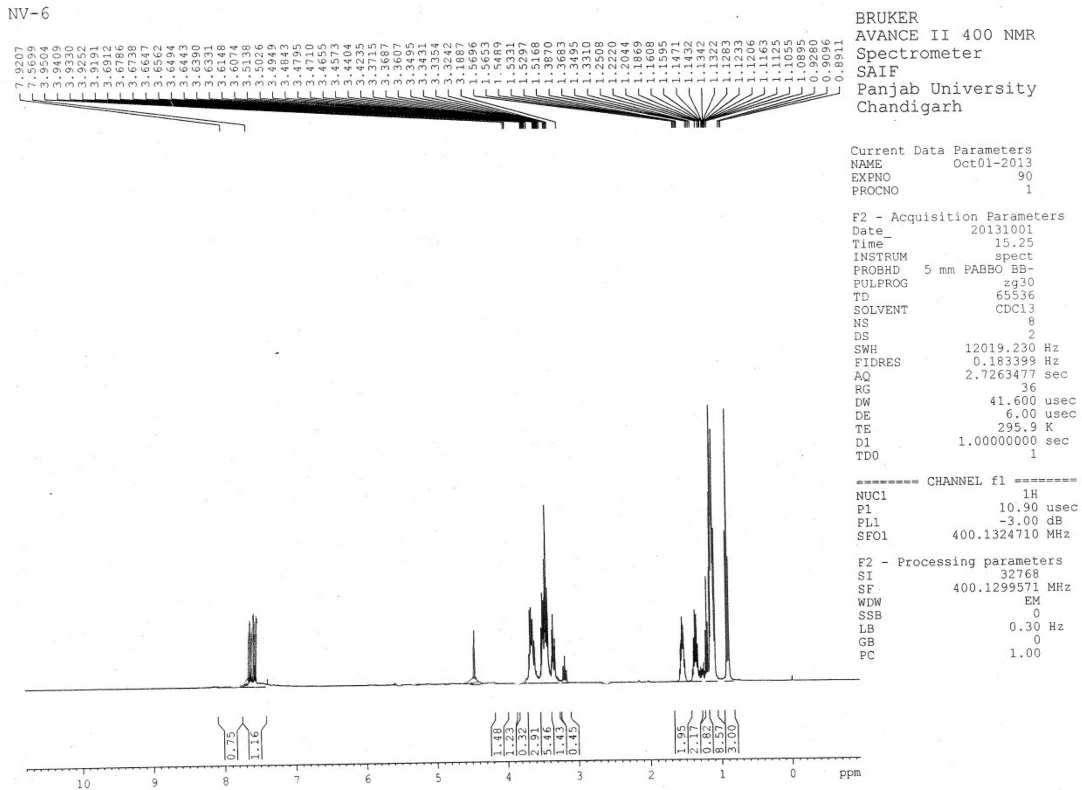


Fig 6 IR Spectrum of Podand A_4



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AVANCE II 400 NMR
Spectrometer
SAIF
Panjab University
Chandigarh

Current Data Parameters
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PROCNO                 1

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PULPROG             zg30
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FIDRES          0.183399 Hz
AQ             2.7263477 sec
RG                    36
DW                41.600 usec
DE                  6.00 usec
TE                 295.9 K
D1            1.00000000 sec
TD0                    1

======== CHANNEL f1 ========
NUC1                  1H
P1                 10.90 usec
PL1                -3.00 dB
SFO1         400.1324710 MHz

F2 - Processing parameters
SI                 32768
SF           400.1299571 MHz
WDW                   EM
SSB                    0
LB                  0.30 Hz
GB                     0
PC                  1.00
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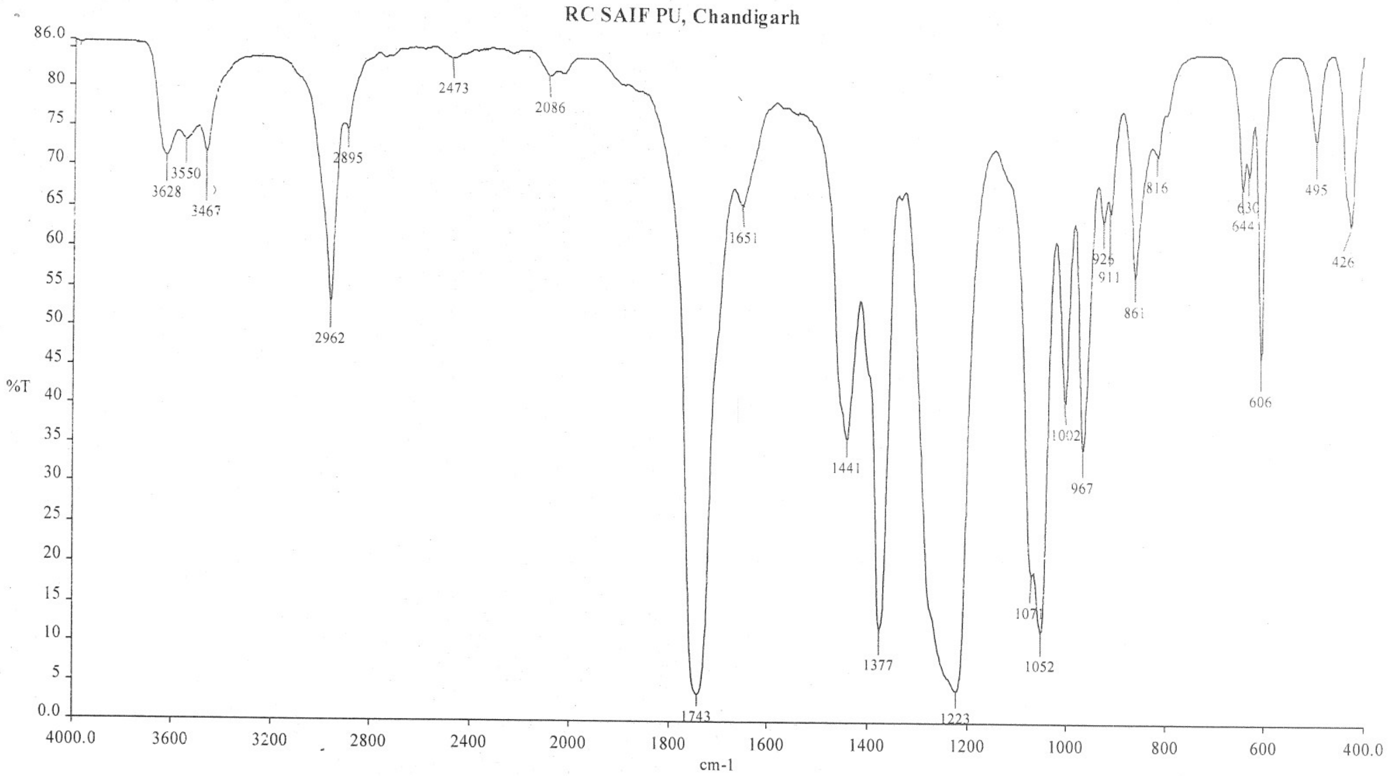
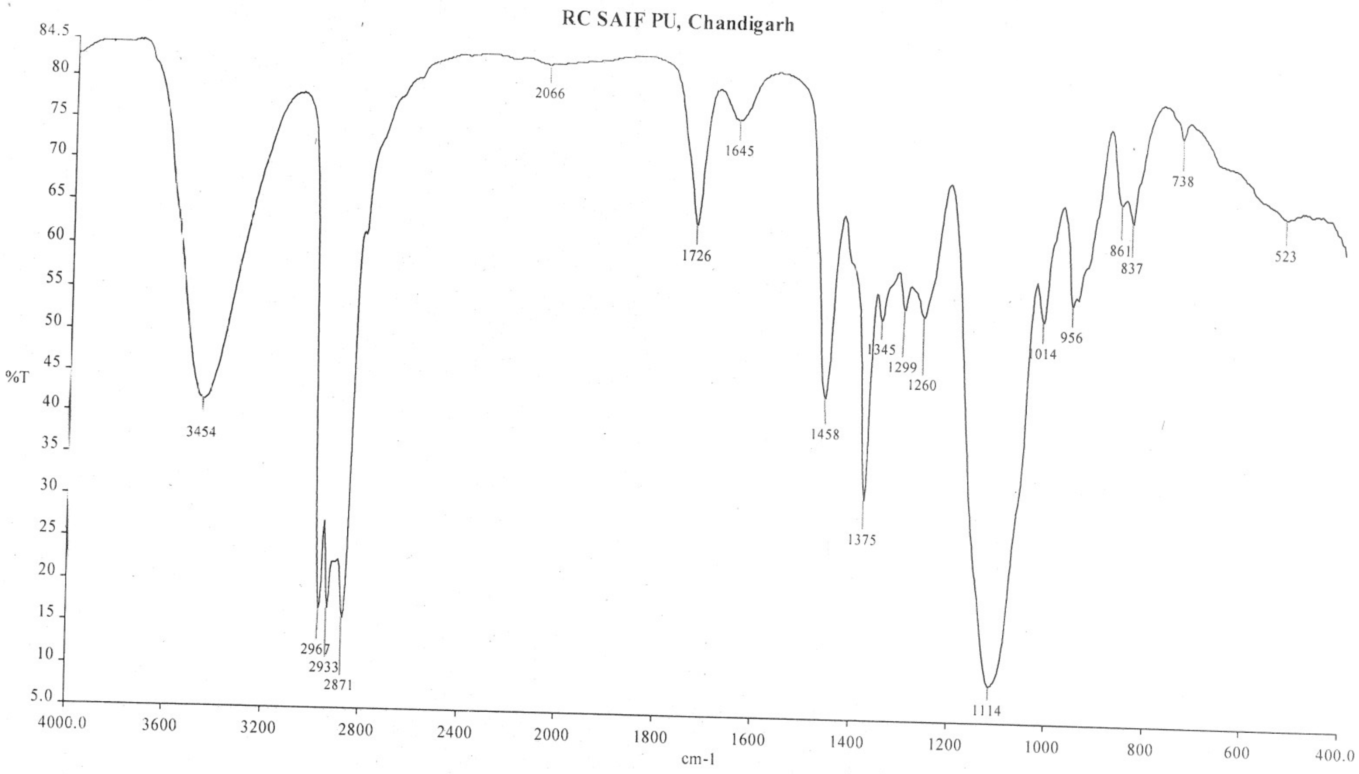
Fig 10 ^{1}H NMR Spectrum of Podand A$_4$



Spectrum Name: Varsha Gautam-1.sp

Fig 11 IR Spectrum of Podand A_5

Date Created: fri jul 13 14:58:40 2012 India Standard Time (GMT+5:30)



Spectrum Name: Varsha Gautam-2.sp

Fig 12 IR Spectrum of Podand A_6

Date Created: fri jul 13 15:00:57 2012 India Standard Time (GMT+5:30)

[I.III] ***Preparation of metal salts-***

Lithium, sodium and potassium picrate were prepared [19] by mixing a warm solution of picric acid in ethanol and warm aqueous solution of Li_2CO_3, Na_2CO_3 and KCl in 1:1 molar ratio with constant stirring. The solution was reduced on a water bath and hot filtered. The filtrate on cooling gave yellow crystals of the picrates, which were filtered on a vacuum pump and recrystalised from ethanol and dried in vacuum desiccator.

The dinitrophenol (Dnp) and orthonitrophenol (Onp) of lithium, sodium and potassium were prepared in the same manner using dinitrophenol (DnpH) and orthonitrophenol (OnpH) respectively.

Calcium and magnesium picrate, dinitrophenolates and orthonitrophenolates were prepared by the same procedure as mentioned for alkali metal picrates using $CaCO_3$/ $MgCO_3$ and PicH, DnpH and OnpH in 1:2 molar ratio. All the metal salts were characterized by their melting point and confirmed by IR spectral analysis.

Methodology-

1. Extraction studies

Extraction studies [20] were conducted to ascertain the occurrence of complexation between metal salts and podands in solution state. This study depends on the complexation of metal ions into the pseudocyclic cavity of noncyclic ionophores.

For liquid-liquid extraction [**Figure 13**] studies [21], 10 ml of 1.0 X 10^{-3} M aqueous metal salt [MX_Z (M^{Z+} = Li^+, Na^+, K^+, Mg^{2+}, Ca^{2+}, X^- = Pic^-, Dnp^-, Onp^-)] solution was vigorously stirred with 10 ml of 1.0 X 10^{-3} M podand solution in CH_2Cl_2, $C_2H_4Cl_2$ and $CHCl_3$ in a small beaker using a magnetic stirrer (200 rpm). The beaker was covered and kept in a thermostatic incubator (25±1ºC).

The amount of cation in aqueous phase was initially determined before extraction was conducted using digital flame photometer (Li^+, Na^+, K^+ and Ca^{2+}) and atomic absorption spectrophotometer for Mg^{2+} Ions. After 4 hours of stirring the mixture was allowed to stand for 5 minutes for separation of two phases.

The depleted aqueous phase was removed and analyzed for residual concentration of metal ions using digital flame photometer and atomic absorption spectrophotometer. The amount of cation extracted by the podand was found by determining its difference in aqueous phase before and after extraction. A blank experiment was also performed simultaneously with the same aqueous solution to determine the leakage of metal ion from aqueous to organic phase in absence of podand. All measurements were performed in duplicate to check the reproducibility. The equilibrium of metal-podand in aqueous and organic phases [22] is shown by the following equation:

$$M^{+} + L_{org} + X^{-} \rightleftharpoons (MLX)_{org}$$

$$K_{eq} = \frac{[MLX]_{org}}{[M^{+}]\,[L]_{org}[X^{-}]}$$

Values of distribution ratio (D_M) were calculated as follows:

$$D_M = \frac{\text{Total concentration of metal ion in organic phase}}{\text{Total concentration of metal ion in aqueous phase}}$$

2. Bulk liquid membrane transport studies

The liquid membrane system used for transport was adopted from the work of Kobuke and co-workers [23] and is similar in principle to Schulman bridge as used by Reusch and Cussler [24].

Bulk liquid membrane transport (water/organic phase/water) experiments [25] employed a 'U' tube cell [**Figure 14**] in which the aqueous source phase (10 ml) and receiving phase (10 ml) were separated by an organic phase (25 ml). The U tube was covered at both ends and kept on magnetic stirrer. In each case the aqueous source phase contained alkali and alkaline earth metal salt at concentration of 1.0 X 10^{-3} M. The organic phase was contained the ionophore at concentration 1.0 X 10^{-3} M. The samples were withdrawn from receiving phase after 24 hours and analyzed for cation transport using digital flame photometer and atomic absorption spectrophotometer. Competitive transport of sodium/potassium and magnesium/calcium was also carried out.

Cation flux (J_M) values were calculated using the relation:

$$J_M = \frac{C_{(receiving)} \text{ X } V}{A \text{ X } t}$$

Where C (receiving) is the concentration of cation in receiving phase (mol/dm^3), V is the volume of receiving phase (dm^3), A is the effective area of membrane (m^2) and t is time (sec.)

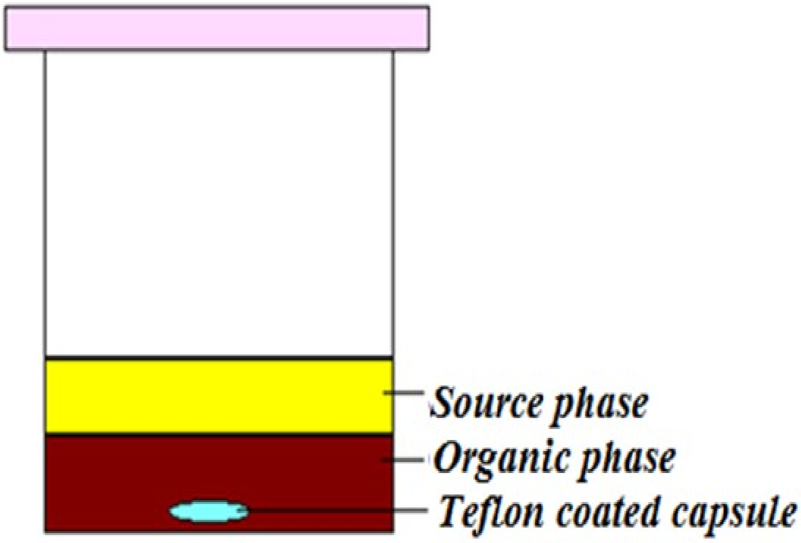


Figure 13: Extraction studies

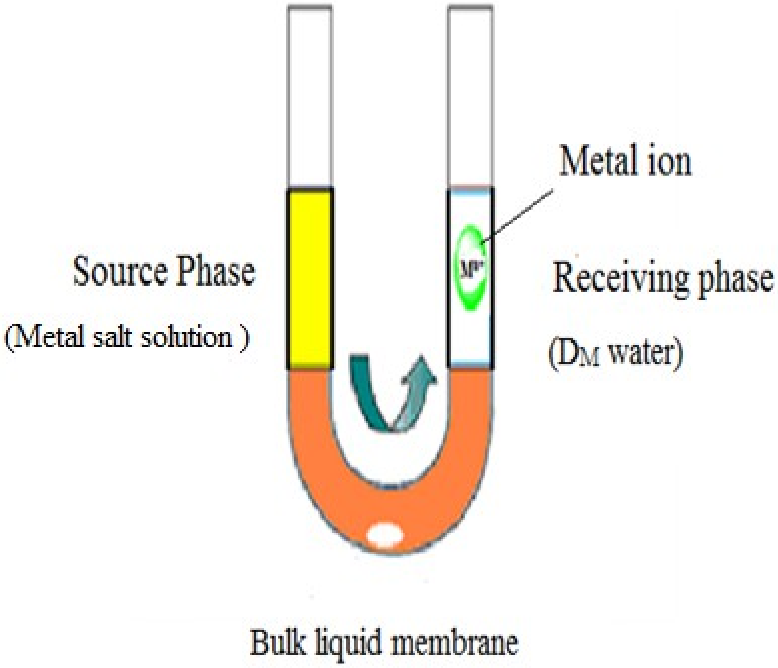


Figure 14: Transport studies

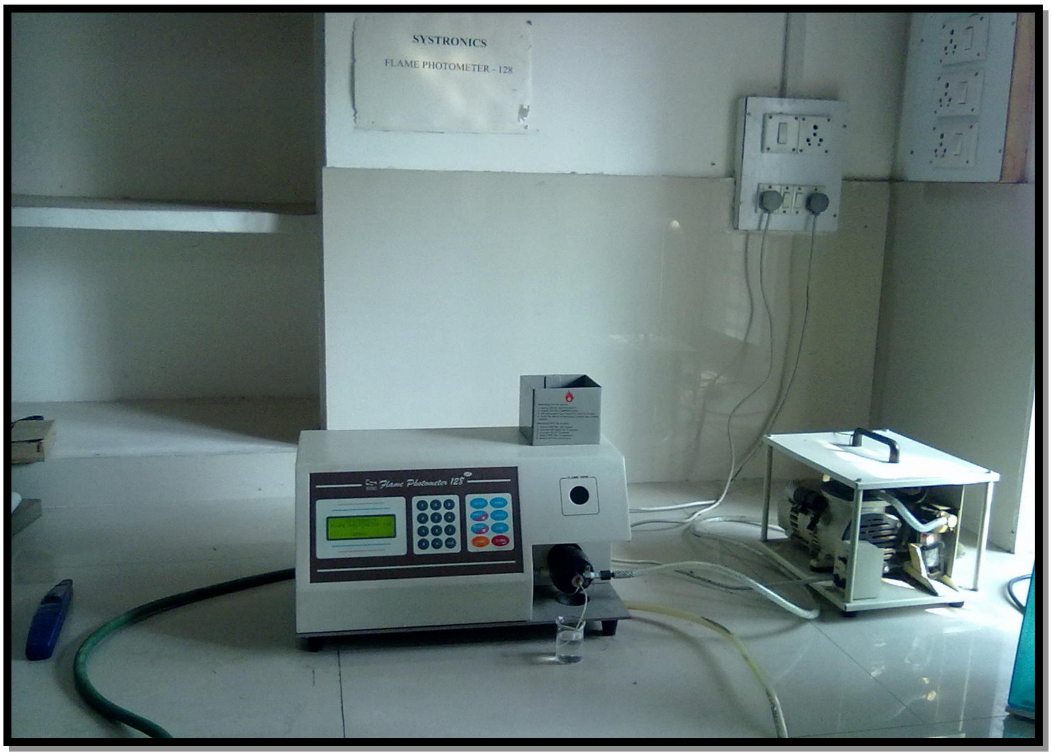


Figure 15: Flame Photometer-128

Figure 16: Atomic Absorption Spectrophotometer – Shimadzu-6300

Figure 17: Ultra Pure Water Purification System (Elix UV3)

3. Isolation studies-

Supramolecular chemistry referred as chemical information science or molecular informatics concerned with the molecular storage and the supramolecular reading and processing of information via structural features of supermolecules. A supramolecular assembly is a multi-component system of atoms, ions and/or molecules which are held together by noncovalent interactions.

The host guest systems mimic [26] the organizational ability of membranes and enzymes by bringing reactants together in highly structured specific microenvironments.

Variation in structures, end groups, donor group's arrangement leads to variation in cation binding strengths and selectivity. Such systems exhibit enhanced cation complexation and generally high complexation dynamics. Noncyclic ionophores (podands) having one or more side arms that contain donor atoms and can interact with alkali and alkaline earth metal cations.

In this chapter, we have reported a systematic study of isolation of alkali and alkaline earth metal salts (MX, $M^+= Li^+$, Na^+, K^+, Mg^{2+} and Ca^{2+}, $X^- = Pic^-$, Dnp^- and Onp^-) with podands (A_1-A_6).

Isolation studies are focused on the structural analysis of the complexes in order to ascertain the occurrence of complexation between metal salts and ionophores in solid phase.

Complexation of alkali and alkaline earth metal salts with podands-

Isolation studies has focused on structural analysis of complexes especially in terms of the stoichiometry, presence of anion and conformational changes in the podands. The complexes [27-29] were prepared by mixing in different proportion of metal ions (Li^+, Na^+, K^+, Mg^{2+} and Ca^{2+}) with podands (A_1-A_6) in different solvents like methanol, methanol+ethylacetate, acetonitrile, ethylacetate etc.

The mixture was then heated on water bath and allowed for crystallization at room temperature. Crystallization generally occurs within two or three days. The shiny crystals were obtained. The crystals were vacuum filtered and recrystalised from the same solvent from which they were isolated and dried in vacuum desiccator.

In some cases reactants disappear into gum or undefined products and sometimes no reaction observed when metal salt reappear from the reaction mixture. The podand in the complex was considered complexed, when it melted at a temperature significantly lower than that of the MX salts [30].

The characterization of isolated complexes was carried out by melting point determination and confirmed by elemental and spectral analysis (C, H, N analysis, IR, ^{1}H NMR). The stoichiometry of the complexes was determined by metal estimation on digital flame photometer (systronics-128) and atomic absorption spectrophotometer (Shimadzu 6300).

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CHAPTER –IV

RESULTS

&

DISSCUSSION

In this chapter we have investigates the results of extraction, transport and isolation studies of alkali and alkaline earth metal ions (Li^+, Na^+, K^+, Mg^{2+} and Ca^{2+}) with new series of podands (1-(4-Bromophenyl)-2-(2-{2-[2-(4-bromophenyl)-2-oxo-ethoxy]-ethoxy}-ethoxy)-ethanone) **(A_1),** 1-(4-Bromophenyl)-2-{2-[2-(2-butoxy-ethoxy)-ethoxy]-ethoxy}-ethanone **(A_2),** 1-(4-Bromophenyl)-2-(2-{2-[2-(2-{2-(4-bromophenyl)-2-oxo-ethoxy}-ethoxy)-ethoxy]-ethoxy}-ethoxy)-ethanone **(A_3)**, 1-(4-Bromophenyl)-2-{2-[2-(2-butoxy-propoxy)-propoxy]-propoxy}ethanone **(A_4),** ethyleneglycoldiacetate **(A_5)** and tripropyleneglycolmonobutylether **(A_6).**

Extraction studies-

Extraction studies were conducted to ascertain the occurrence of complexation between MX salts and the podands in solution state. The studies were focused on the capacity of various podands to extract metal cations from an aqueous phase into an organic phase by complexation.

This provided a powerful tool to explore molecular recognition skill of the podands to effect separaion via liquid membranes by process of solvent extraction. Among the various extracting system liquid membrane technique for the separation process is increasingly being intensified which restricts lengthy extraction times, automation challenges and role of large organic solvents used in the traditional liquid-liquid extraction.

In earlier studies, the podands were based upon cyclic and noncyclic polyethers frame work which forms complexes with metal cations by non covalent interaction. We have used the synthesized podands for the extraction of M^{Z+} cation.

The extraction studies of alkali and alkaline earth metal cations have been carried out using new series of podands (A_1-A_6). The synthesized podands A_1-A_4 having p-bromophenacyl moiety as end group and podands A_5 and A_6 are having simple oligoethylene glycol chains. The results of extraction studies are summarized in **Table 2-7** and **Figure 2-13**.

Back extraction studies were also carried out but no metal cation was detected in aqueous phase after back extraction, which represents that podands do not show back extraction with metal ions.

Metal concentration-

The metal salt concentration varied from $1.0X10^{-2}$ M to $1.0X10^{-4}$ M. But the optimum concentration of metal salts for extraction studies with noncyclic ionophores was found $1.0 X 10^{-3}$ M. The amount of cation extracted at optimum concentration and distribution ratio between organic and aqueous phase are recorded in **Table 2-7**. The results of extraction studies have been discussed under following headings:

Nature of ionophore-

The structure of podand plays an important role in extraction and transport processes [1]. The end group and chain length of ionophore affects the amount of cation extracted, transported and the selectivity of the metal ions [2]. Numerous podands are responsible for the molecular recognition in the biomembranes [3]. Oligoethylene glycol derivatives with aromatic donor groups at the end of chain are considered to have intermediate properties between crown ethers and common glymes.

An increasing attention has been recently focused on the studies that treat ‘structural effect’ of semi rigid host compounds which incorporates a π-stacking component (aromatic moiety) [4]. The podands with aromatic end group showed higher extraction efficiency rather than common glymes. The amount of cation extracted and transported mainly depends upon the structure of the ionophore, end group, number of donor sites, flexibility of chain length, ionophore concentration etc.

The observed trend for different podands towards M^{z+} extraction is: $A_3>A_1>A_2>A_6>A_4>A_5$ [**Fig. 8-10**].

From the results, it is observed that all six podands are effective extractants for alkali and alkaline earth metal ions and exhibit extraction selectivity for K^+ and Ca^{2+} ions.

Focusing on the difference in the amount of cation extracted by noncyclic ionophores it has been observed that podands A_1 and A_3 extracts K^+ ions to a greater extent in comparison to A_2, A_4, A_5 and A_6 ionophores with all three bulk liquid membranes dichloromethane, 1,2-dichloroethane and chloroform.

Podands A_1 and A_3 possessing short chain length (diethylene and tetraethylene glycol) with double aromatic moieties as end groups which form highly stable complex with metal ion by cation-π interaction.

The maximum extraction was observed when A_3 was impregnated in the organic phase which indicates that the podand A_3 form stable complex with metal ions through ion-dipole interaction. These interactions enhance the selection of cation in pseudocyclic cavity of the ligand. The noncyclic ionophore bind cation tightly in their cavity then the stable complex will be formed and the formation constant will also be very high.

It has been found that there was a relation between binding power of podand and the number of podand binding sites for maximum complex formation. Many podands have been synthesized with more complex structure for their role as specific complexing and extracting agents to enhance complexation [5].

If polyether is more soluble in water it exhibit higher extractability for metal ion. If thus polyether itself was soluble in water, it was reflected in the extractability of the complex. If molar volume of chemical species was large then complex was more extractable. This distribution of podand between water and organic solvents was of great important in deciding extractability.

Podands A_2 and A_4 have long oxyethylene chains (triethyleneglycolmonobutylether and tripropyleneglycolmonobutylether chain respectively) with single aromatic moiety as end group also shows extraction for K^+ ions but in less amount.

The podands A_2, A_4 and A_6 shows good extraction towards K^+ and Ca^{2+} ions but in less amount in comparison to A_1 and A_3 due to less number of aromatic moiety and long oxyethylene chain.

It was found that podand A_5 is selective only for Li^+ ions because the ionic diameter of Li^+ ion is 1.20 Å which is suitable to fit in the cavity of A_5 which has shortest oxyethylene chain and methyl groups. While podand A_1 and A_2 totally fails to extract Li^+ ions and A_4 and A_6 totally fails to extract Mg^{2+} ions.

High flexibility gave better adoption for conformation in which donor atoms were rotated outwards to allow H-bond formation with water molecules. Thus, the hydrophobic groups were exposed to the solvent enhancing extraction by transferring the podand and complex. The high solubility was not always favorable for extraction but high degree of substitution in polar solvents was favorable for extraction.

In non cyclic ionophores, there is minimum lone pair-lone pair repulsive interactions between lone pair of oxygen atoms in comparison to cyclic ionophores (**Figure 1**) due to which linear polyethers are favourable for the formation of stable complexes with metal ions.

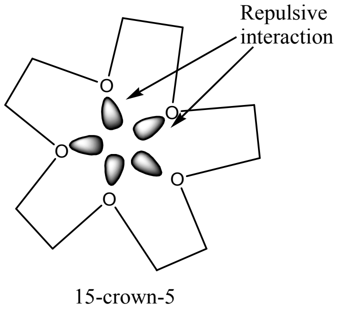


Figure 1: Repulsive interaction in cyclic and linear polyethers

The podand A_4 has been found more selective for K^+ and Ca^{2+} ions in comparison to A_6. The podand A_4 was derived from A_6 by the insertion of aromatic moiety which reduces the flexibility of the ionophore and hence the selectivity enhanced towards K^+ and Ca^{2+} ions.

The extraction of analyte through podands can be controlled [6] by the complex formation and their stability for the particular set of experimental conditions. The use of noncyclic polyethers can permit effective conformational changes in the binding of particular ion.

Binding and selectivity of podands towards metal cation and their enhanced complexation can be achieved by the addition of aromatic end group to simple glycols [7]. It has been observed from earlier studies that tetraethyleneglycol type ionophores seemed to be considered as the most efficient podand which consists of two aromatic moieties [8].

It is interesting that synthesized podands seem to perform as good ionophores while they are able to keep their conformations on a pseudocyclic structure. The overall observations indicate that the presence of aromatic end groups in podands (A_1-A_4) prefer the better extraction of metal ions in comparison to noncyclic ionophores without aromatic end group (A_5 & A_6). Hence, we can say that the presence of p-bromophenacyl moiety as aromatic end group in podands, enhance the extraction efficiency of podands.

Additional bromine atom can act as a weak σ – donor. In our podands containing p-bromophenacyl moiety have two different coordination modes and bidentate towards metal ion by means of the oxygen as well as the bromine atom [9].

For the molecular design of effective synthetic ionophores, introduction of aromatic moieties to the structure is more convenient.

Effect of cation-

The complexation depends upon the diameter of metal cations as well as the diameter of pseudocyclic cavity of ionophore and on ion-dipole interaction [10]. As reported by Kobuke & his co-workers [11], the extraction studies with macro heterocycles, the ionic diameter of metal cation and hole size of macroheterocycles are closely related and responsible for selective extraction while our results show that in case of noncyclic ionophores, this specificity and selectivity is not depend on hole size but on the preferred pseudocyclic conformation of noncyclic ionophore, chain length, end group and number of donor sites.

From the reported results [**Table 2-7 & Fig. 2-7**], it was observed that podands A_1 - A_4 and A_6 extracts monovalent cations in good amount in comparison to bivalent cations. While, podand A_5 is suitable only for Li^+ ions.

The observed trend for extraction of alkali metal ions with A_1 to A_4 and A_6 is : $K^+ > Na^+ > Li^+$ while it is just reversed with podand A_5 is: $Li^+ > Na^+ > K^+$. These results show that there is a relation between size of pseudocyclic cavity and diameter of metal cation. The trend for alkaline earth metal cations with podands A_1-A_6 is $Ca^{2+} >> Mg^{2+}$ while podand A_5 is not selective for both Ca^{2+} and Mg^{2+} cations.

The overall trend for extraction of alkali and alkaline earth metal ions for podand A_1 is: $K^+>>Ca^{2+}>Na^+>Mg^{2+}>>Li^+$ and A_2 is: $K^+>Na^+>Ca^{2+}>Mg^{2+}>>Li^+$, for podand A_3 and A_4 is: $K^+>Ca^{2+}>Na^+>Li^+>>Mg^{2+}$, for A_6 is: $K^+>Na^+>Li^+\geq Ca^{2+}$, while A_5 is only selective for Li^+ ions.

The peak selectivity of K^+ [**Fig. 8-10**] ions can be explained on the basis of charge density and diameter of metal ions. The diameter of K^+ (2.66 Å), Na^+ (1.90 Å) and Li^+ (1.20 Å) are in decreasing order which is related with their extracted amount with all podands. Such complexation depends upon the relative size of the diameter of pseudocyclic cavity of noncyclic ionophores as well as the diameter of cation [12].

It can be assumed that these podands show the selectivity for K^+ ions because the cavity size of podand matches with the diameter of K^+ (2.66 Å) ion. The podands show less selectivity for Na^+ and Ca^{2+} ions because their cavity size is not suitable to fit Na^+ (1.80 Å) and Ca^{2+} (1.98 Å) ions or they form less stable complexes with these ions.The overall selectivity of podands is for K^+ because Li^+ and Na^+ are more solvated in polar medium than K^+, so both have the tendency to remain in aqueous phase [13].

Since, ionic potential is minimum for K^+, so ion-dipole interaction in between metal ion and donor oxygen atoms of the podand is more. Thus, the complexation is more favorable for K^+ rather than Na^+ and Li^+.

In alkaline earth metal ions Ca^{2+} (1.98 Å) has large diameter than Mg^{2+} (1.38 Å) due to which it is extracted in excess amount than Mg^{2+} ions. The more extraction of Ca^{2+} (1.98 Å) than Mg^{2+} (1.38 Å) is due to size and ion-dipole interaction. It may be assumed that due to the smallest size of Li^+ and Mg^{2+}, charge density allows the solvation to a greater extent in aqueous phase and hence, pseudocyclic cavity of podand become improper towards its complexation of Li^+ and Mg^{2+} ions. Hence, Li^+ and Mg^{2+} both show minimum extraction. The minimum extraction of Mg^{2+} ion is also due to its highest heat of hydration [14].

The overall results indicate that the binding of small ions (Li^+ and Mg^{2+}) leads to an unfavourable conformation of the ionophore characterized by inter binding site repulsion and deformation of the molecular frame, hence poor and least extraction of Li^+ and Mg^{2+} ions is observed.

Effect of anion-

The extraction and transport of metal ions through membranes is depending on the nature of anion. The mobility of cation-carrier-anion complex depends on the characteristics of the anion and the extraction efficiency depends on the number of nitro group in anion. The extraction ability of podands must be carefully controlled with the companion anion [15].

The amount of alkali and alkaline earth metal cations extracted in 4 hours is reported in **Table 2-7**.

The trend of anion for extraction of alkali metal ions with podands A_1, A_3, A_4, and A_6 is: $Pic^- > Dnp^- > Onp^-$, for ionophore A_2 is: $Onp^- > Dnp^- > Pic^-$ and for A_6 is different for different metal ions which is $Dnp^- > Pic^- > Onp^-$ for Li^+ ions, $Onp^- > Dnp^- > Pic^-$ for Na^+ ions, $Pic^- > Onp^- > Dnp^-$ for K^+ ions and $Pic^- > Dnp^- > Onp^-$ for Ca^{2+} ions [**Figure 11-13**].

High extraction of metal ions from picrate salt with A_1, A_3, A_4 and A_6 is due to high delocalization of negative charge in picrate ring than dinitrophenolate and orthonitrophenolate ring [16].

This delocalization of negative charge density explains the existence and stability of the picrate complexes in which the picrate is completely excluded from the cation coordination sphere [17].

Extractability of A_2 and A_6 with onp^- is more due to more hydrophobicity of the anion but selectivity decreases. Since, onp^- is soft and polarizable anion. Therefore, it facilitates extraction of metal ions.

All anions were attracted to host on an electrostatic basis, forming a solvated ion pair in solution. This affinity would be expected to increase with anion net charge. These anions are highly polarizable so van der Waals interactions will be significant.

The preferred binding site is the phenolic oxygen due to ion-ion interaction. The second binding site is oxygen of the o-nitro group. In all cases where picrate is bidentate ligand the interaction with the cation is via the phenolic and o-nitro oxygen. The short distance of ~3.5 Å between the phenolic and o-nitro oxygen provide an effective bidentate ligand with both charge and dipole binding ability. When additional binding sites are needed the picrate becomes tridentate ligand via o- and p-nitro oxygen involved in the coordination of the cation [18,19]. Therefore, picrate is a versatile mono/bi/tri dentate ligand.

It has been reported that the extractability do not depend on change in concentation of an anion. The extent of extraction of complex depended upon the nature of counter anion used. Transfer of free energies of the anion from water to organic phase, picrate was 70 times more effective than 2,4-dinitrophenolate in extraction [20].

It is an integral part of complexes of alkali and alkaline earth metal cations with natural and synthetic ionophores. Cation extraction can be altered by order of magnitude by proper anion selection.

Effect of solvent-

The extraction was carried out with different solvents viz. dichloromethane, 1,2-dichloroethane and chloroform. The results of extraction studies using different solvents are given in **table 2-7**.

The extraction and selectivity of metal ions is greatly influenced by the properties of solvents [21] used. Literature values for selected physical properties [22] of the organic solvents used in the study are listed in **Table 1**.

The o-nitro phenolate and its p-nitro derivative are soft and polarizable anions. Such characteristic of the anions are often used to facilitate and increase the extraction and transport of alkali metal cations through solvents of low polarity [23]. Hence, picrate anion shows better complex ability in solvent of high polarity which is dichloromethane.

Dichloromethane and 1,2-dichloroethane were appropriate solvents for the extraction of metal ions. The trend for extraction of metal salts by podands A_1, A_2, A_3, A_4, A_5 and A_6 in various organic solvents is follows [**Figure 2-7].**

Dichloromethane > 1,2-dichloroethane > Chloroform.

It can be assumed that highly polar solvent have high dielectric constant, which favour the complexation of metal ions in pseudocyclic cavity of ionophore.

There is a competition between the solvent and the podand for the cation in complexation, in which the energy loss occurs in disruption of the cation-solvent interaction. The selectivity of the podand will depend on energy difference change between these two interactions. An increase in lipophilicity of the ionophore influences the efficiency of uptake of a metal salt from aqueous source phase i.e. extraction efficiency [24].

It was found that dichloromethane membrane provides better medium for extraction of metal ions by the ionophore. This is due to its high dipole moment and low viscosity of dichloromethane solvent among all three solvents [25].

It has been reported that the solvent with lower density is best for extraction because the solvent with high density has relatively thick water free boundary layer that resist the flux of both ions and ionophore for complexation [26].

Effect of time-

We have estimated the concentration of metal ion extraction with A_1-A_6 podands with each hour up to four hours. The best extraction of cations was observed for four hours and no considerable change could be seen in hourly estimation.

Effect of stirring rate-

The experiments were performed at several different speeds. The convenient extraction of metal ions was happened at 200 rpm. At higher speed the reduction in extracted amount was observed which may be due to the decomplexation.

Competitive extraction-

Competitive extraction studies were carried out of binary mixtures of Na^+-K^+ and Ca^{2+}-Mg^{2+} salts with all A_1-A_6 podands through all three bulk liquid membranes. These results are summarized in **table 8-13** and **figure 14-15**.

The binary mixtures of metal salts were used to study the competition for extraction between metal ions. From the results, it was observed that the extraction of metal ions from binary mixture is similar to single metal ion extraction, but less selectivity has been observed in coexisting metal salts than single metal salts.

All podands were found better extractant for K^+ and Ca^{2+} ions rather than Na^+ and Mg^{2+} ions respectively. It may be due to the competition between both cations towards complexation in pseudocyclic cavity of the podand.

It may be assumed that there is a relation between diameter of metal ions and pseudocyclic cavity of ionophores which preferred the selectivity towards K^+ and Ca^{2+} ions in both single metal ion and coexisting metal ion in extraction studies.

Table 1

Literature values for selected physical properties of the organic solvents

Solvent	Density (gm/cm3)	Surface tension (dyne/cm)	Viscosity (cP)	Solubility in water (% by Wt.)	Dielectric constant	Dipole moment (debye)
CH_2Cl_2	1.325	28.12	0.413	1.60	8.93	1.60
$C_2H_4Cl_2$	1.2521	32.20	0.887	0.81	10.36	1.20
$CHCl_3$	1.4891	26.70	0.596	0.81	4.81	1.01

Table 2

Amount of cation extracted into dichloromethane, 1,2-dichloroethane and chloroform membranes by podand A_1 in 4h.

Metal salt concentration = $1X10^{-3}$ M; Podand concentration = $1X10^{-3}$ M

Metal salts	Dichloromethane		1,2-dichloroethane		Chloroform	
	Amount of cation extracted (ppm)	D_M	Amount of cation extracted (ppm)	D_M	Amount of cation extracted (ppm)	D_M
Li.Pic	-	-	-	-	-	-
Li.Dnp	-	-	-	-	-	-
Li.Onp	-	-	-	-	0.51	-
Na.Pic	2.83	1.26	2.01	0.65	2.00	0.65
Na.Dnp	2.60	1.39	2.00	1.23	2.00	1.23
Na.Onp	2.00	0.49	1.89	0.45	1.88	0.45
K.Pic	33.12	15.69	32.12	10.32	32.00	10.01
K.Dnp	19.01	2.71	18.57	2.49	18.43	2.43
K.Onp	17.17	9.86	16.01	5.52	15.93	5.34
$Mg.Pic_2$	5.02	2.9	4.93	2.8	3.26	1.87
$Mg.Dnp_2$	1.37	1.07	1.15	1.0	0.97	0.70
$Mg.Onp_2$	0.44	0.51	-	-	-	-
$Ca.Pic_2$	4.26	2.50	3.16	1.12	3.00	1.01
$Ca.Dnp_2$	3.16	0.92	3.01	0.84	2.99	0.58
$Ca.Onp_2$	2.01	1.00	1.88	0.88	1.05	0.35

D_M = Distribution ratio

Table 3

Amount of cation extracted into dichloromethane, 1,2-dichloroethane and chloroform membranes by podand A_2 in 4h.

Metal salt concentration = 1X10^{-3} M; Podand concentration = 1X10^{-3} M

Metal salts	Dichloromethane		1,2-dichloroethane		Chloroform	
	Amount of cation extracted (ppm)	D_M	Amount of cation extracted (ppm)	D_M	Amount of cation extracted (ppm)	D_M
Li.Pic	-	-	-	-	-	-
Li.Dnp	-	-	-	-	-	-
Li.Onp	-	-	-	-	-	-
Na.Pic	4.48	0.2	3.85	0.16	1.65	0.06
Na.Dnp	6.03	0.31	5.7	0.28	-	-
Na.Onp	7.46	0.41	6.91	0.37	4.77	0.23
K.Pic	11.54	1.48	10.66	1.23	9.9	0.78
K.Dnp	18.07	1.53	17.56	1.43	13.11	1.05
K.Onp	20.89	1.72	20.14	1.56	19.03	1.36
Mg.Pic$_2$	0.44	1.07	-	-	-	-
Mg.Dnp$_2$	1.37	1.57	1.15	0.77	0.47	0.58
Mg.Onp$_2$	2.29	9.54	2.25	8.03	-	-
Ca.Pic$_2$	3.25	1.3	2.62	0.89	1.27	0.30
Ca.Dnp$_2$	5.0	2.5	4.93	3.94	3.26	1.11
Ca.Onp$_2$	5.02	4.32	5.23	4.76	4.66	6.29

D_M = Distribution ratio

Table 4

Amount of cation extracted into dichloromethane, 1,2-dichloroethane and chloroform membranes by podand A_3 in 4h.

Metal salt concentration = $1X10^{-3}$ M; Podand concentration = $1X10^{-3}$ M

Metal salts	Dichloromethane		1,2-dichloroethane		Chloroform	
	Amount of cation extracted (ppm)	D_M	Amount of cation extracted (ppm)	D_M	Amount of cation extracted (ppm)	D_M
Li.Pic	1.21	1.65	1.11	1.33	0.98	1.02
Li.Dnp	1.82	1.21	1.05	0.46	0.91	0.37
Li.Onp	1.18	2.26	0.89	1.09	0.23	0.15
Na.Pic	3.37	0.27	2.07	0.15	1.15	0.08
Na.Dnp	3.24	0.25	1.85	0.13	0.51	0.03
Na.Onp	2	0.14	0.84	0.05	0.46	0.03
K.Pic	33.07	2.87	29.5	1.89	25.35	1.29
K.Dnp	32.78	2.84	28.64	1.91	7.14	0.28
K.Onp	18.32	2.51	17.92	1.61	5.46	0.25
$Mg.Pic_2$	3.17	3.72	3.17	3.72	3.76	4.46
$Mg.Dnp_2$	0.35	0.26	0.4	0.31	0.46	0.38
$Mg.Onp_2$	0.11	0.10	0.20	0.20	0.55	1.37
$Ca.Pic_2$	13.85	1.16	7.33	0.39	5	0.24
$Ca.Dnp_2$	6.11	3.25	2.05	0.37	0.86	0.12
$Ca.Onp_2$	4.47	0.69	-	-	0.45	0.04

D_M = Distribution ratio

Table 5

Amount of cation extracted into dichloromethane, 1,2-dichloroethane and chloroform membranes by podand A_4 in 4h.

Metal salt concentration = $1X10^{-3}$ M; Podand concentration = $1X10^{-3}$ M

Metal salts	Dichloromethane		1,2-dichloroethane		Chloroform	
	Amount of cation extracted (ppm)	D_M	Amount of cation extracted (ppm)	D_M	Amount of cation extracted (ppm)	D_M
Li.Pic	0.23	0.01	-	-	1.72	0.09
Li.Dnp	-	-	0.8	0.04	-	-
Li.Onp	-	-	-	-	0.51	0.01
Na.Pic	10.24	3.09	10.12	2.95	1.64	0.13
Na.Dnp	0.91	0.26	0.91	0.26	-	-
Na.Onp	0.59	0.02	0.11	-	-	-
K.Pic	16.01	11.35	15.46	7.88	11.14	1.77
K.Dnp	13.01	4.33	12.96	4.24	12.00	2.99
K.Onp	10.41	2.06	10.09	1.87	10.01	1.83
$Mg.Pic_2$	-	-	-	-	-	-
$Mg.Dnp_2$	-	-	-	-	-	-
$Mg.Onp_2$	-	-	-	-	-	-
$Ca.Pic_2$	14.01	4.76	13.96	4.65	13	3.3
$Ca.Dnp_2$	12.91	5.06	12.38	4.01	12.01	3.48
$Ca.Onp_2$	11.14	12.8	10.91	9.91	10.01	5.0

D_M = Distribution ratio

Table 6

Amount of cation extracted into dichloromethane, 1,2-dichloroethane and chloroform membranes by podand A_5 in 4h.

Metal salt concentration = $1X10^{-3}$ M; Podand concentration = $1X10^{-3}$ M

Metal salts	Dichloromethane		1,2-dichloroethane		Chloroform	
	Amount of cation extracted (ppm)	D_M	Amount of cation extracted (ppm)	D_M	Amount of cation extracted (ppm)	D_M
Li.Pic	0.07	0.07	0.04	0.04	0.03	0.03
Li.Dnp	0.04	0.04	0.03	0.03	0.07	0.07
Li.Onp	0.17	0.15	0.10	0.08	0.12	0.10
Na.Pic	4.79	0.25	2.53	0.11	2.67	0.12
Na.Dnp	-	-	-	-	-	-
Na.Onp	2.07	0.06	0.39	0.01	7.83	0.31
K.Pic	-	-	-	-	0.31	0.06
K.Dnp	-	-	-	-	-	-
K.Onp	5.56	0.33	-	-	-	-
$Mg.Pic_2$	-	-	-	-	-	-
$Mg.Dnp_2$	-	-	-	-	-	-
$Mg.Onp_2$	-	-	-	-	-	-
$Ca.Pic_2$	0.54	0.54	-	-	-	-

Ca.Dnp$_2$	-	-	-	-	-	-
Ca.Onp$_2$	-	-	-	-	-	-

D_M = Distribution ratio

Table 7

Amount of cation extracted into dichloromethane, 1,2-dichloroethane and chloroform membranes by podand A_6 in 4h.

Metal salt concentration = $1X10^{-3}$ M; Podand concentration = $1X10^{-3}$ M

Metal salts	Dichloromethane		1,2-dichloroethane		Chloroform	
	Amount of cation extracted (ppm)	D_M	Amount of cation extracted (ppm)	D_M	Amount of cation extracted (ppm)	D_M
Li.Pic	0.32	0.19	0.21	0.11	0.20	0.11
Li.Dnp	2.83	1.27	2.19	0.76	2.03	0.67
Li.Onp	0.24	0.13	0.34	0.19	0.34	0.19
Na.Pic	3.84	0.18	1.16	0.05	0.74	0.03
Na.Dnp	8.23	0.46	6.14	0.31	2.58	0.11
Na.Onp	14	0.94	8.69	0.43	5.88	0.25
K.Pic	20.17	2.38	17.25	1.51	12	0.72
K.Dnp	11.12	3.07	8.24	1.26	5.98	0.68
K.Onp	19.68	1.17	17.72	0.94	8.86	0.32
Mg.Pic$_2$	-	-	-	-	-	-
Mg.Dnp$_2$	-	-	-	-	-	-
Mg.Onp$_2$	-	-	-	-	-	-
Ca.Pic$_2$	2.71	0.16	2.4	0.14	2.44	0.14

Ca.Dnp_2	0.48	0.02	0.33	0.01	0.24	0.01
Ca.Onp_2	0.19	0.01	0.07	-	0.01	-

DM = Distribution ratio

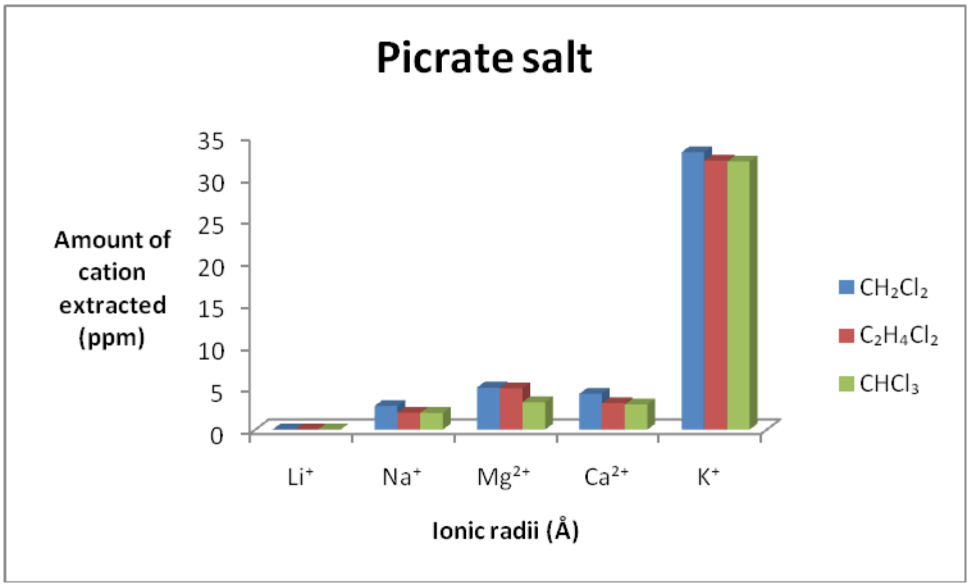


Fig. 2 : Effect of different bulk liquid membranes on amount of cation extracted by podand A_1 using picrate salt

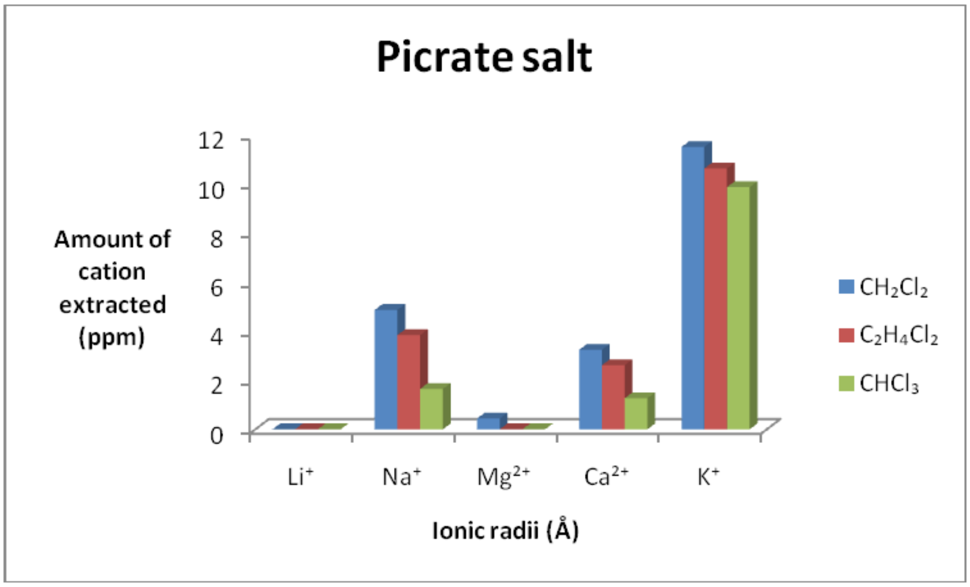


Fig. 3: Effect of different bulk liquid membranes on amount of cation extracted by podand A_2 using picrate salt

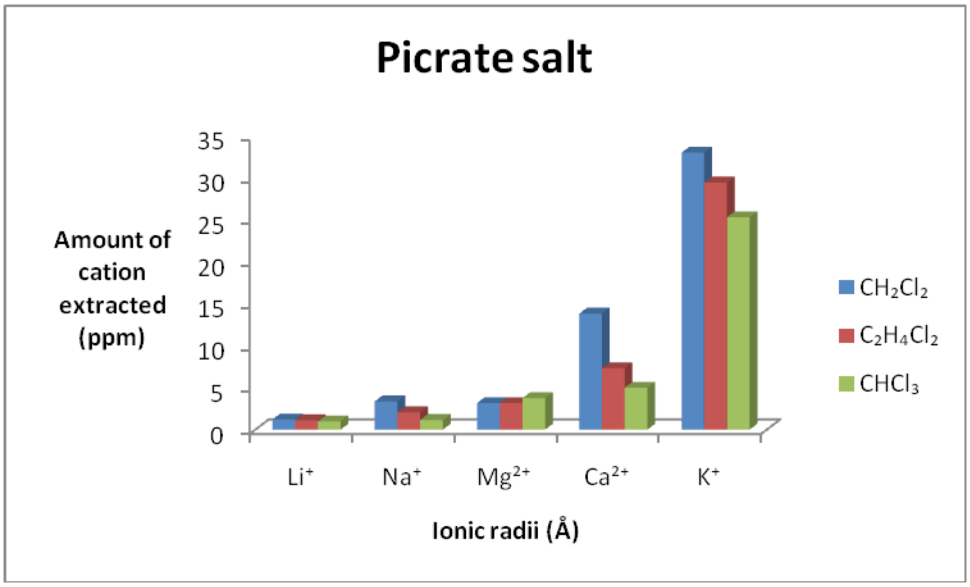


Fig. 4: Effect of different bulk liquid membranes on amount of cation extracted by podand A_3 using picrate salt

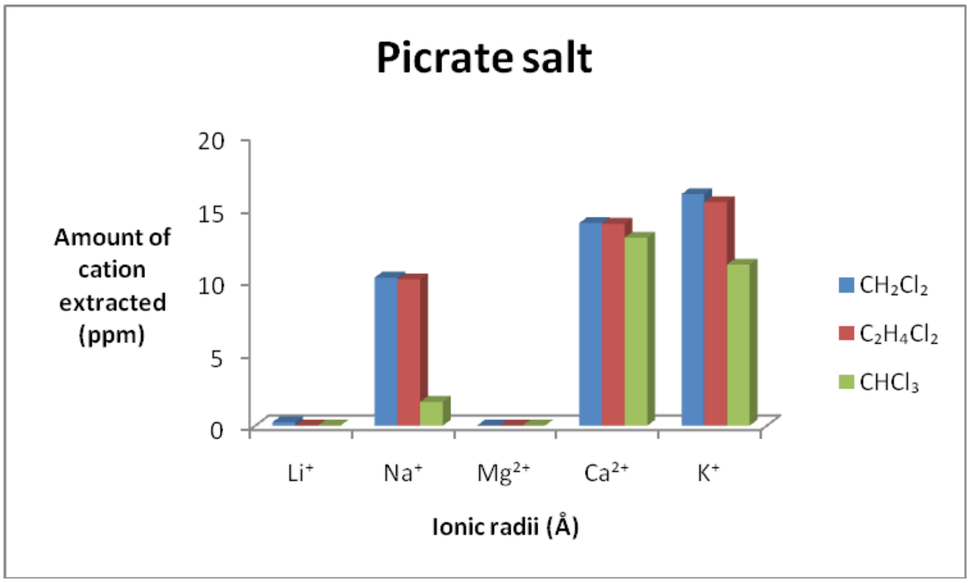


Fig. 5: Effect of different bulk liquid membranes on amount of cation extracted by podand A_4 using picrate salt

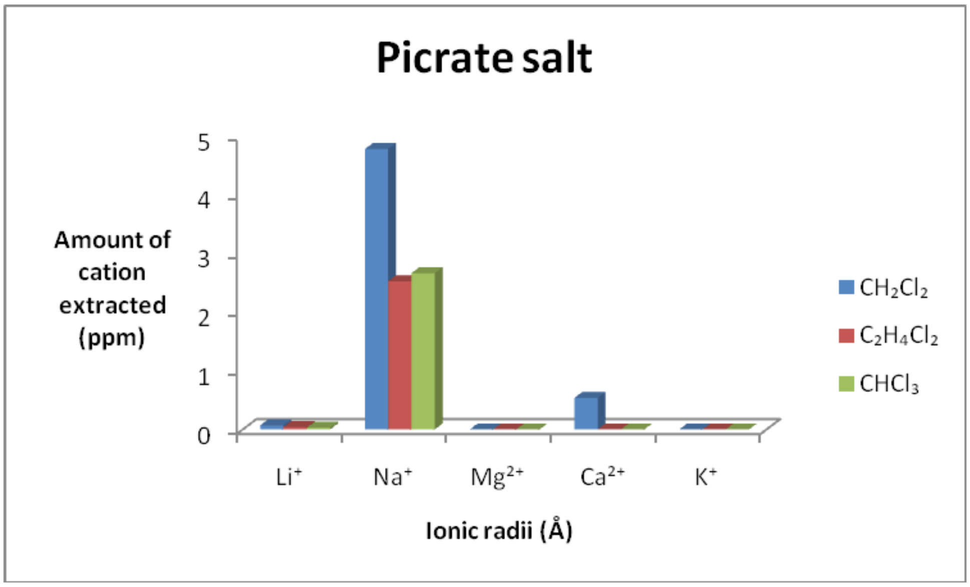


Fig. 6: Effect of different bulk liquid membranes on amount of cation extracted by podand A_5 using picrate salt

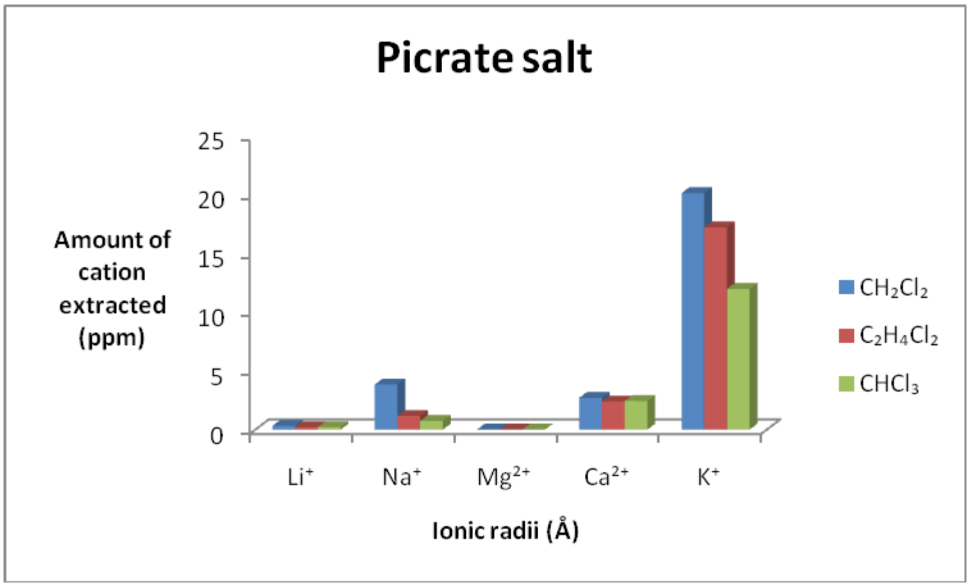


Fig. 7: Effect of different bulk liquid membranes on amount of cation extracted by podand A_6 using picrate salt

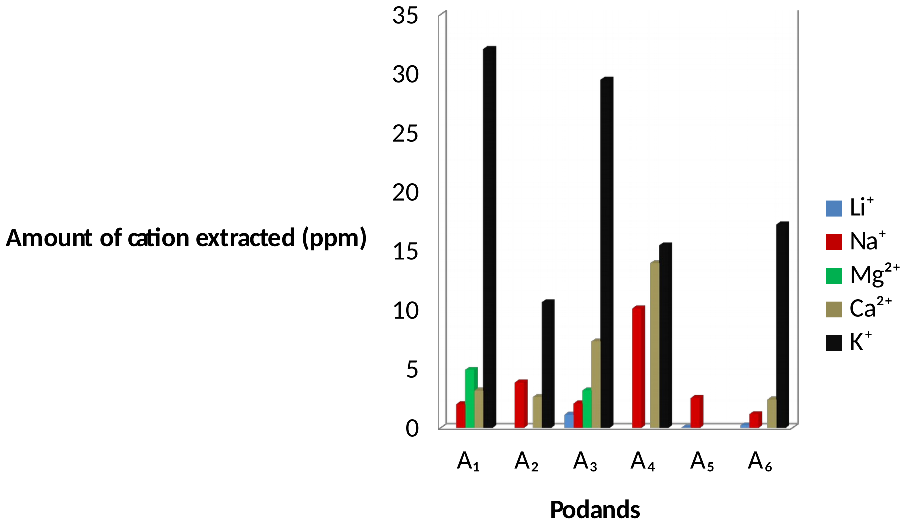


Fig. 8: Effect of different podands on the extraction of metal ions using picrate salt in dichloromembane membrane

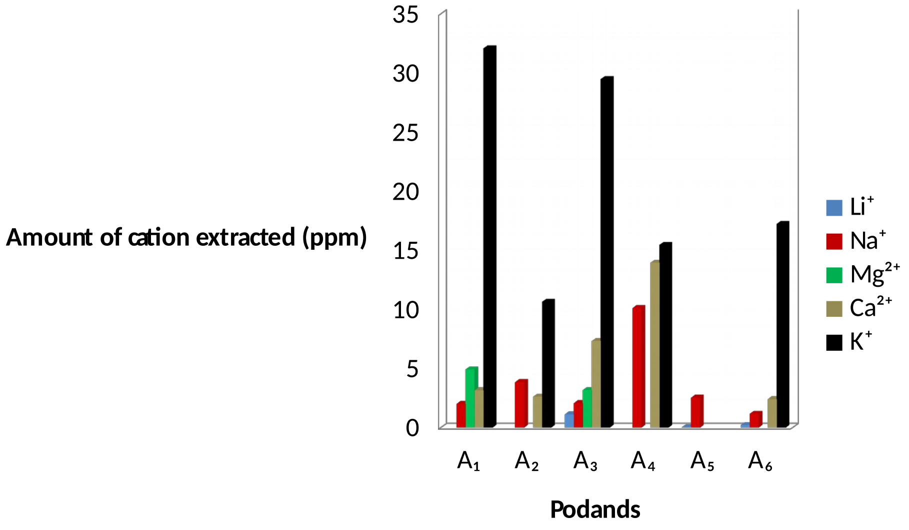


Fig. 9: Effect of different podands on the extraction of metal ions using picrate salt in 1,2-dichloroethane membrane

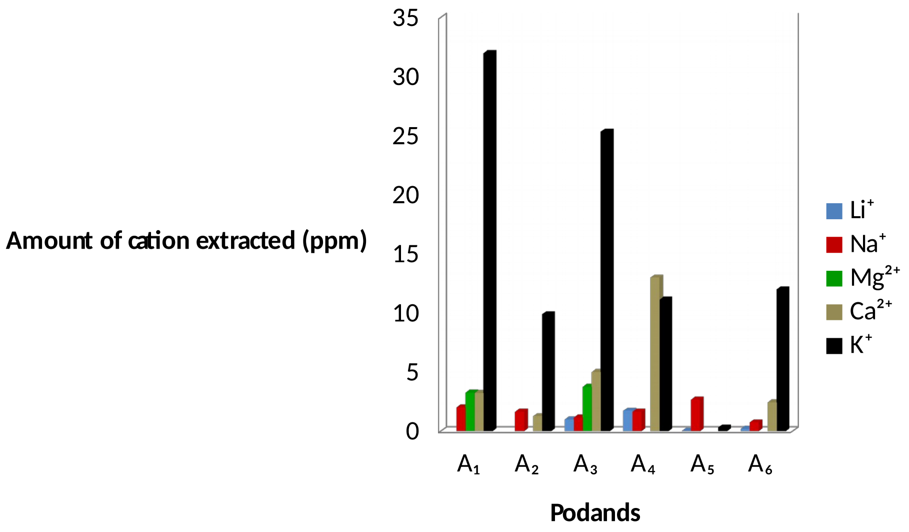


Fig. 10: Effect of different podands on the extraction of metal ions using picrate salt in chloroform membrane

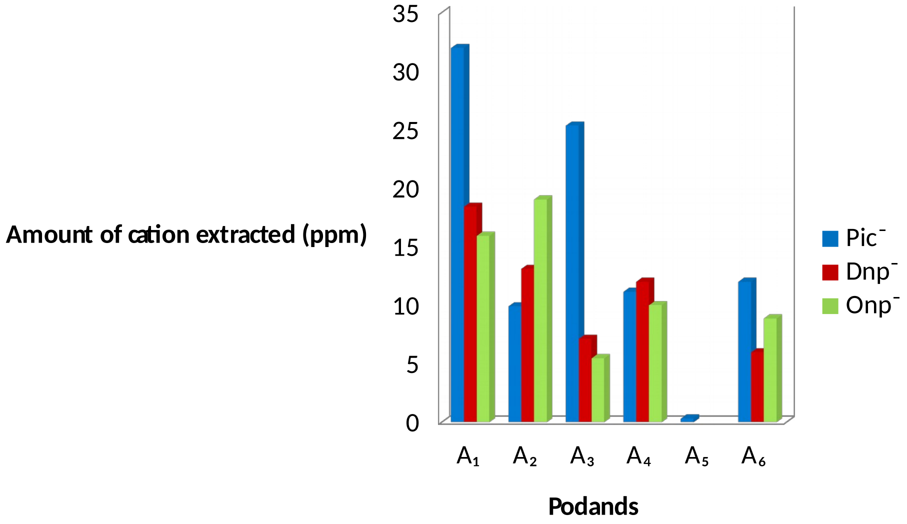


Figure 11: Effect of different podands on the extraction of K^+ ions using picrate, dinitrophenolate and orthonitrophenolate salts in dichloromethane membrane

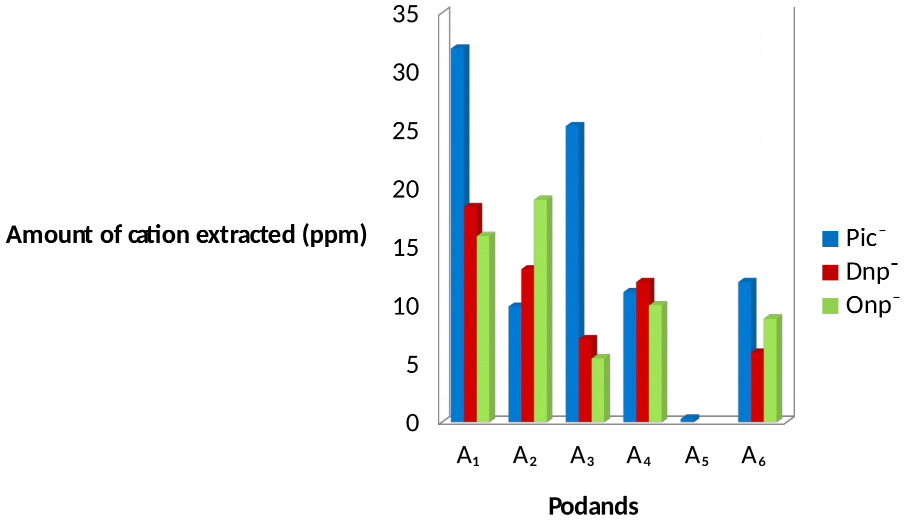


Figure 12: Effect of different podands on the extraction of K$^+$ ions using Picrate, dinitrophenolate and orthonitrophenolate salts in 1,2-dichloroethane membrane

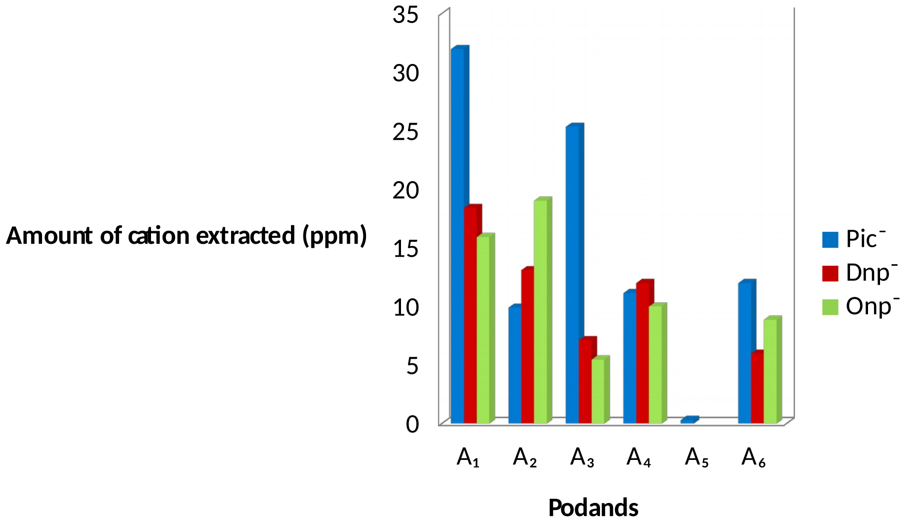


Figure 13: Effect of different podands on the extraction of K^+ ions using picrate, dinitrophenolate and orthonitrophenolate salts in chloroform membrane

Table 8

Amount of cation extracted in 4h using coexisting metal picrate salts by podands A_1-A_6 through dichloromethane, 1,2-dichloroethane and chloroform membranes. Metal salt concentration = 1X10^{-3} M; Podand concentration = 1X10^{-3} M

BLM	Podands	Na		K	
		Amount of cation extracted (ppm)	D_M	Amount of cation extracted (ppm)	D_M
CH_2Cl_2	A_1	2.34	0.49	14.92	1.7
	A_2	-	-	-	-
	A_3	4.4	0.82	24.02	3.71
	A_4	5	1.25	-	-
	A_5	-	-	-	-
	A_6	8.5	1.48	13.76	1.5
	A_1	2.17	0.44	10.01	0.53

$C_2H_4Cl_2$	A_2	-	-	-	-
	A_3	11.74	1.38	24.99	3.73
	A_4	4.8	1.14	-	-
	A_5	-	-	-	-
	A_6	5.66	1.03	6.08	0.31
$CHCl_3$	A_1	1.15	0.19	7.14	0.4
	A_2	-	-	-	-
	A_3	9.4	1.85	27.24	4.79
	A_4	4.6	1.04	-	-
	A_5	-	-	-	-
	A_6	8.1	0.54	0.45	0.41

D_M = Distribution ratio

Table 9

Amount of cation extracted in 4h using coexisting metal dinitrophenolate salts by podands A_1-A_6 through dichloromethane, 1,2-dichloroethane and chloroform membranes.

Metal salt concentration = $1X10^{-3}$ M; Podand concentration = $1X10^{-3}$ M

BLM	Podands	Na		K	
CH_2Cl_2		Amount of cation extracted (ppm)	D_M	Amount of cation extracted (ppm)	D_M
	A_1	1.0	0.21	11.86	1.47
	A_2	8.71	0.96	2.41	0.05
	A_3	1.86	0.31	18.11	1.56
	A_4	4.0	0.57	-	-
	A_5	-	-	-	-

	A_6	0.86	0.15	2.79	0.25
$C_2H_4Cl_2$	A_1	1.0	0.21	8.91	0.81
	A_2	7.49	0.73	5.31	0.37
	A_3	1.95	0.33	27.12	10.63
	A_4	3.5	0.46	-	-
	A_5	-	-	-	-
	A_6	-	-	2.48	0.22
$CHCl_3$	A_1	0.91	0.19	7.02	0.54
	A_2	6.55	0.59	-	-
	A_3	6.33	4.45	27.74	14.37
	A_4	3.1	0.39	-	-
	A_5	-	-	-	-
	A_6	-	-	0.39	0.01

D_M = Distribution ratio

Table 10

Amount of cation extracted in 4h using coexisting metal orthonitrophenolate salts by podands A_1-A_6 through dichloromethane, 1,2-dichloroethane and chloroform membranes.

Metal salt concentration = $1X10^{-3}$ M; Podand concentration = $1X10^{-3}$ M

BLM	Podands	Na		K	
		Amount of cation extracted (ppm)	D_M	Amount of cation extracted (ppm)	D_M

CH_2Cl_2	A_1	0.15	0.02	9.8	1.7
	A_2	8.98	0.60	5.86	0.29
	A_3	0.81	0.06	-	-
	A_4	2.9	0.21	-	-
	A_5	-	-	-	-
	A_6	-	-	-	-
$C_2H_4Cl_2$	A_1	0.12	0.01	5.8	0.60
	A_2	9.32	0.74	8.77	0.51
	A_3	2.55	0.25	16.32	2.55
	A_4	2.9	0.21	-	-
	A_5	-	-	-	-
	A_6	-	-	-	-
$CHCl_3$	A_1	0.01	-	4.4	0.40
	A_2	10.31	0.89	11.24	0.77
	A_3	4.44	0.55	22.69	-
	A_4	2.0	0.13	-	-
	A_5	-	-	-	-
	A6	-	-	-	-

D_M = Distribution ratio

Table 11

Amount of cation extracted in 4h using coexisting metal picrate salts by podands A_1-A_6 through dichloromethane, 1,2-dichloroethane and chloroform membranes.

Metal salt concentration = 1X10^{-3} M; Podand concentration = 1X10^{-3} M

BLM	Podands	Ca		Mg	
		Amount of cation extracted (ppm)	D_M	Amount of cation extracted (ppm)	D_M
CH_2Cl_2	A_1	11.81	2.93	-	-
	A_2	6.51	0.42	2.86	13.61
	A_3	2.32	0.77	0.74	0.35
	A_4	4.01	0.22	0.83	0.66
	A_5	-	-	-	-
	A_6	0.54	0.01	-	-
$C_2H_4Cl_2$	A_1	8.74	1.23	-	-
	A_2	5.34	0.32	1.32	0.75
	A_3	0.69	0.02	0.28	0.09
	A_4	3.64	0.20	0.80	0.62
	A_5	-	-	-	-
	A_6	-	-	-	-
$CHCl_3$	A_1	7.81	0.97	-	-
	A_2	2.87	0.15	0.83	0.37
	A_3	-	-	0.22	0.07
	A_4	3.23	0.17	0.70	0.62
	A_5	-	-	-	-
	A_6	-	-	-	-

D_M = Distribution ratio

Table 12

Amount of cation extracted in 4h using coexisting metal dinitrophenolate salts by podands A_1-A_6 through dichloromethane, 1,2-dichloroethane and chloroform membranes.

Metal salt concentration = $1X10^{-3}$ M; Podand concentration = $1X10^{-3}$ M

BLM	Podands	Ca		Mg	
		Amount of cation extracted (ppm)	D_M	Amount of cation extracted (ppm)	D_M
CH_2Cl_2	A_1	3.93	0.47	-	-
	A_2	6.06	0.53	1.88	1.37
	A_3	-	-	-	-
	A_4	3.24	0.35	0.79	0.21
	A_5	-	-	-	-
	A_6	-	-	-	-
$C_2H_4Cl_2$	A_1	3.54	0.4	-	-
	A_2	4.96	0.36	0.83	0.33
	A_3	-	-	-	-
	A_4	3.21	0.35	0.71	0.18
	A_5	-	-	-	-
	A_6	-	-	-	-
$CHCl_3$	A_1	3.15	0.34	-	-
	A_2	2.36	0.16	0.82	0.33
	A_3	-	-	-	-
	A_4	2.91	0.31	0.69	0.18
	A_5	-	-	-	-
	A_6	-	-	-	-

D_M = Distribution ratio

Table 13

Amount of cation extracted in 4h using coexisting metal orthonitrophenolate salts by podands A_1-A_6 through dichloromethane, 1,2-dichloroethane and chloroform membranes.

Metal salt concentration = $1X10^{-3}$ M; Podand concentration = $1X10^{-3}$ M

BLM	Podands	Ca		Mg	
		Amount of cation extracted (ppm)	D_M	Amount of cation extracted (ppm)	D_M
CH_2Cl_2	A_1	2.75	0.37	-	-
	A_2	2.27	0.17	1.38	0.53
	A_3	-	-	-	-
	A_4	1.51	0.25	1.23	-
	A_5	-	-	-	-
	A_6	-	-	-	-
$C_2H_4Cl_2$	A_1	2.36	0.30	-	-
	A_2	1.96	0.14	0.06	0.01
	A_3	-	-	-	-
	A_4	1.23	0.19	1.23	-
	A_5	-	-	-	-
	A_6	-	-	-	-
$CHCl_3$	A_1	1.96	0.24	-	-
	A_2	0.47	0.03	0.90	0.29
	A_3	-	-	-	-

	A_4	1.19	0.18	1.47	-
	A_5	-	-	-	-
	A_6	-	-	-	-

D_M = Distribution ratio

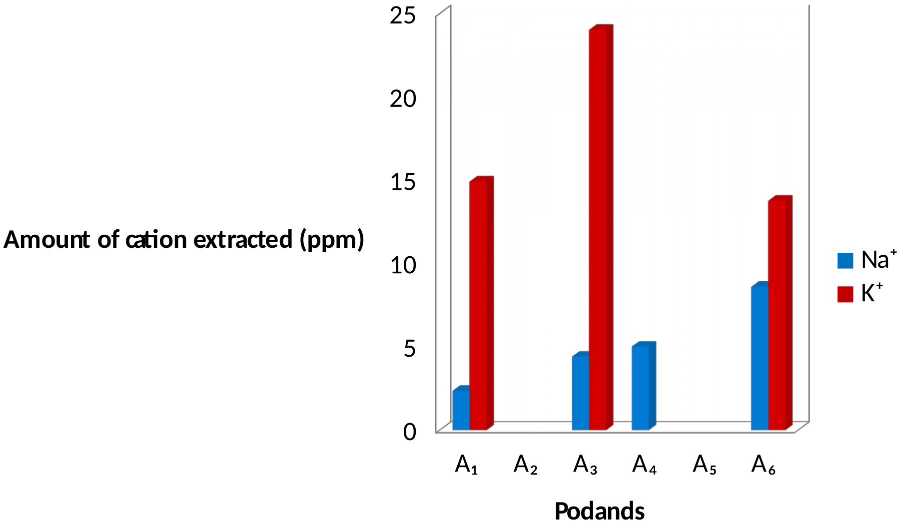


Figure 14: Effect of different podands on the coexisting extraction of Na^+/K^+ using picrate salts in dichloromethane membranes

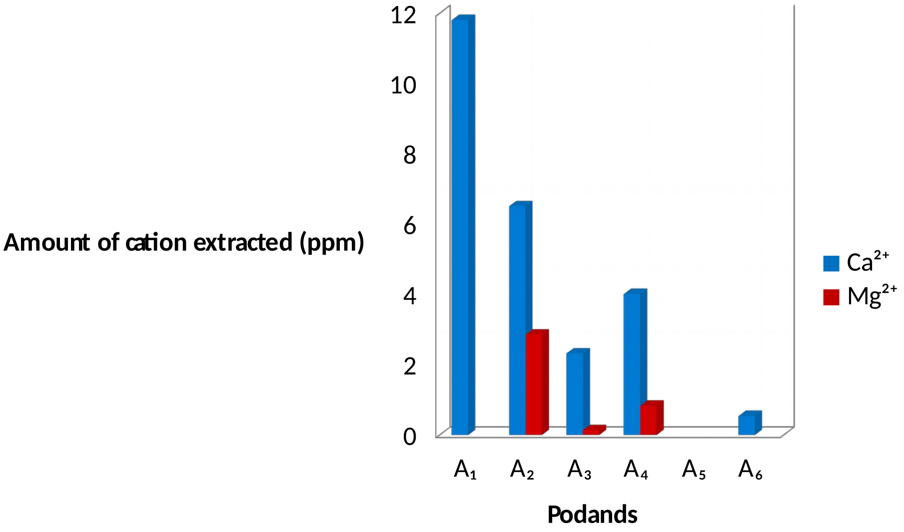


Figure 15: Effect of different podands on the co-existing extraction of Ca^{2+}/Mg^{2+} using picrate salts in dichloromethane membranes

Bulk liquid membrane transport studies –

Podands are frequently used to evaluate the complexation and their transport properties. The potential application of transport processes in separation and purification of biological compounds have been investigated during the last few years.

Membrane transport is an intriguing phenomenon in organisms. Much type of natural antibiotics selectively transports alkali metals or alkaline earth metal cations across lipid bilayer. Among them carboxylic ionophores such as nigericine and monensin consists of acyclic structure containing several types of donor sites.

It is important that these carriers posses a sufficient lipophilicity, which is necessary to transfer the complex from the aqueous media into the organic media (lipophilic membrane) and recognition site for the guest cation.

The liquid membrane transport techniques contain two processes in a single stage which is the extraction of metal ions from aqueous source phase to membrane containing the podand and relaxation of this metal ion from the membrane to aqueous receiving phase. Hence, the overall transport process consists of a mixture of diffusion steps and complexation/decomplexation reaction at two independent and possibly different interfaces [27].

Transport studies of alkali and alkaline earth metal ions were carried out with new series of podands (A_1-A_6) using picrate, dinitrophenolate and orthonitrophenolate anions.

The results of bulk liquid membrane transport studies of metal cations with podands (A_1-A_6) across dichloromethane, 1,2-dichloroethane and chloroform membranes in 24 hours are reported in **table 14-19** and **figure 16-24**.

Blank experiments were carried out for carrier facilitated transport studies in which the membrane was devoid of carrier. No leakage of cation from source phase into receiving phase was observed. All measurements were performed in duplicate to check the reproducibility.

In these studies the effect of different factors on the amount of cation transported has been discussed such as nature of podands, effect of cation, effect of anion and effect of membranes etc.

Metal concentration-

The metal salt concentration varied from $1.0X10^{-1}$ M to $1.0X10^{-3}$ M. But the optimum concentration of metal salts for transport studies with podands was found $1.0X10^{-3}$ M.

The results of transport studies have been discussed under following headings:

Nature of podands-

The structure of the podand plays an important role in extraction and transport process. It is observed that end group and chain length of podand affects the amount of cation transported and also the selectivity of metal ion [28]. Oligoethylene glycol derivatives with aromatic donor end groups at both ends were found to possess better complexation abilities in comparison with glymes [29].

Various reports [30,31] were found on crown, cryptand complexation, in which optimum stability range for cation-podand complexation and efficient transport occurs in bulk liquid membrane. Chelate effect [32] is responsible for cation-complex stability in case of noncyclic ionophores like macrocyclic effect in crown ethers. Shultz [33] & co-workers reported that rate of the transport reached a maximum at intermediate log K values. If binding is too weak and unfavorable (small log K), in sufficient amount of cation from the source phase will complex in the membrane in order to be transported through it. On the other hand, if binding is too strong and favourable (larger log K), the cation will not release into the RP and there will be a buildup of cation–podand complex.

From the results, it was observed that all the podands (A_1-A_6) are highly selective for K^+, Ca^{2+} and Na^+ ions in comparison to Li^+, Mg^{2+} ions. The trend of different podand towards transport of K^+, Ca^{2+} and Na^+ ions from its picrate salt [**Fig. 16-18**] in bulk liquid membranes is: $A_4>A_2>A_3>A_6>A_1>A_5$.

The flexibility of podands in different conformational forms is responsible for their carrier ability. Podands having large chain length with single aromatic end group formed less stable complexes with metal ions. While, the podands having small chain length with two rigid aromatic end groups show poor carrier ability. This is may be due to formation of stable complexes.

In case of A_2 and A_4 both podands have single aromatic (p-bromophenacyl) moiety with long oxyethylene chain. As the number of oxygen atoms are less in their structure they poorly interact with metal ion (via ion-dipole interaction) and single aromatic moiety of podand provides less π-electron density due to which less stable or loose complexes are formed and K^+, Ca^{2+} and Na^+ ions are transported to a greater extent.

Podands A_1 and A_3 with two rigid aromatic end groups decreases the flexibility of chain due to which the binding of metal ion is too tight in pseudocyclic cavity of podand results in transport of metal ions in lesser amount.

Podand A_5 has smallest chain length with non aromatic end groups. It has the least tendency to accommodate the metal ion in pseudocyclic cavity from the source phase results in minimum transport of metal ions.

In case of podand A_6, the absence of aromatic moiety increases the flexibility of chain for the formation of complex but due to less number of donor sites and absence of cation-π interaction the metal ions transported in lesser amount.

Comparison between podands A_4 and A_6, it has been observed that podand A_4 transports metal ions in greater amount than A_6. Podand A_4 was derived by the insertion of aromatic moiety in podand A_6 due to which there is cation π-interaction also occurs along with ion-dipole interaction. Hence, metal ions trapped in excess amount in pseudocyclic cavity of podand A_4, which were releases in receiving phase.

Among all podands A_4 shows maximum transport of cations (Na^+, K^+ and Ca^{2+}) with all three bulk liquid membranes dichloromethane, 1,2-dichloroethane and chloroform. It may be due to the long chain of tripropyleneglycolmonobutylether and one p-bromophenacyl end group which supports the metal complexation. This long chain is flexible and able to bend to coordinate the metal cation. Also, the aliphatic chain contributes greatly to lipophilicity of the podand, Hence, enhances its membrane transport ability.

It has been reported that glyme shows an increasing in their complexation abilities simply with a change in the number of donor atoms [34]. The presence of maximum transport efficiency as a result of changing the length of oxyethylene chain of the podand strongly suggests that these podands with aromatic end groups are stabilized not only by a spherical wrapping effect (shown by many glymes) but also by an additional effect (π-stacking effect) based on the aromatic end groups.

All the podands tend to form a pseudocyclic field which is stabilized by the aryl stacking effect for complexation. However, too long and too short an oxyethylene chain can disturbs the formation of complex between metal ion and podand and the amount of cation extracted/transported through bulk liquid membranes

The donor groups in polyethers decides the selectivity of complexation such host-guest complexation depends upon the interaction viz. H-bonding, charge transfer force, hydrophobic interaction. A rigid crown ring offered strong selective binding on basis of cavity size selectivity consideration but flexible polyethers led to dynamic complexation and acted as effective carrier.

The overall rate of transport depends upon the ratio $K_{complex}/K_{release}$. If cation binding is very strong then cation release rate will be very slow.

Presence of p-bromophenacyl moiety in podands enhances the amount of cation transported as compared to simple glycols.

The results reported here lead to the conclusion that end groups and chain length of the podand significantly contribute to the selective transport of Na^+, K^+ and Ca^{2+} ions.

Effect of cation-

The podands rapidly moves at the membrane interface with a cation. This podand-cation complex reacts with an anion to form an ion pair. When this podand ion pair diffuses slowly across the membrane both cation and anion leaving the podand at the membrane interface on the right.

From the results, It is observed that all the podands show maximum transport of K^+, Na^+ and Ca^{2+} ions [**Table 13-19, Fig. 16-18**]. The trend for transport of cations with podands (A_1-A_6) is: $K^+ > Na^+ > Li^+$ for alkali metal ions and $Ca^{2+} > Mg^{2+}$ for alkaline earth metal ions. The overall trend for amount of cation transported is: $Ca^{2+} > K^+ > Na^+ > Mg^{2+} > Li^+$.

The interaction between K^+, Ca^{2+} and Na^+ ions and podands provides loose complexes which easily get dissociates at the membrane/receiving phase interface, leading to more cation being transported into aqueous receiving phase.

It is observed that the podand A_4 and A_2 form loose complexes with Na^+, K^+ and Ca^{2+} which easily get dissociated at the receiving phase/membrane interfaces. This leads to more cation transported into the aqueous receiving phase.

The selectivity of the podands towards the Na^+, K^+ and Ca^{2+} ions can be explained by the fact that the amount of cation transported has the dependence on the amount of release rather than the amount of cation uptake by podands [35].

The pseudocyclic cavity of podand requires some conformational changes to adopt cations [36] which prefer the appropriate binding of Na^+, K^+ and Ca^{2+} ions in such a way that it gets released in receiving phase. Thus, the amount of cation transported is inversely proportional to degree of solvation of cation in organic phase.

From the tables [**14,16,19**], it can be seen that no transport of Li^+ ions with A_1 & A_3 and Mg^{2+} ion with podands A_1 & A_6 was observed. Podand A_5 totally fails to transport K^+, Ca^{2+} & Mg^{2+} ions.

The order of the diameter of all cations is: K^+ (2.66 Å)>Ca^{2+}(1.98 Å)>Na^+(1.90)>Mg^{2+}(1.38)>Li^+(1.20).

It could be suggested that the size of pseudocyclic cavity of podands matches with K^+, Ca^{2+} and Na^+ ions which is favourable for the formation of complex with these metal ions.

The minimum transport of Li^+ and Mg^{2+} ions can be explained by the smaller size and more charge density at their surface, which gets solvated them to a large extent than Na^+, K^+ and Ca^{2+} ions by the formation of primary and secondary solvation spheres and hence bulkiness to it, due to which it gets tightly fit in pseudocyclic cavity [37] of podand and lowers the chance to leave in receiving phase.

In case of Li^+ and Mg^{2+} ions, release takes place slowly than uptake allowing a much higher accumulation of Li^+ and Mg^{2+} ions in the organic phase as a complex compared with that of Na^+, K^+ and Ca^{2+} ions. All the podands are not capable to transport Li^+ and Mg^{2+} ions in considerable amount because of the highest heat of hydration.

Effect of anion-

It has been reported earlier that when uncharged ionophores are employed as carrier, the complexed cation carries its counter anion with it through the organic phase. The nature of associated counter anion should thus be a factor in determining the amount of cation transported [38,39].

The systematic study of alkali and alkaline earth metal cation picrate complexes provides a model for understanding how counter ion affect the cation extraction and transport [40]. The amount of cation transported also affected by the number of nitro groups in anion and its coordination modes.

The transport efficiency is sensitive to the presence of nitro group in these anions. The binding in these complexes results from attractive forces between electron acceptor polynitro compound and electron donor substances.

The appearance of yellow colour of metal salt in receiving phase proves the transportation of metal ions along with anion. The kind of the anion which was present with cation-carrier complex decided the selectivity order during transport.

The effective delocalization of the negative charge among the widely separated ortho and para nitro oxygen explains the existance and stability of picrate complexes in which the picrate is completely excluded from the coordination sphere of the cation. Hence, picrate shows better extractability and selectivity.

The functional group substituent and geometry of the anion are major factors that dictate its interaction modes with the cation [41].

This chelating versatility of the picrate might be regarded as disadvantage because the picrate may provide additional binding sites for unfavoured cations to saturate their coordination sphere. Therefore, more stabilized unfavoured complexes are formed, which contribute increased extractability of desirable cations.

The highly polarizable aromatic poly nitro system might be regarded as advantage in increasing extractability and transport rate of alkali and alkaline earth metal salts in hydrophobic organic solvents and membranes. This is one of the main reasons for the extensive use of picrate salt in extraction and transport experiments.

The overall trend for the effect of anion towards cation transport [**Fig. 19-21**] with all podands is $pic^{-}>dnp^{-}>onp^{-}$. This is because the charge on pictrate anion is self stabilized due to more delocalization of the charge than dinitro & orthonitrophenolate and hence less associated with the cation [42].

The K^{+} and Ca^{2+} ions tend to interact with low charge density picrate anion, results in more transport of cations.

Effect of solvent-

The amount of cation transported affected by the physical properties and nature of the solvent. It has been reported that the properties of the membrane solvent highly affect the cation transport using neutral carriers such as crown ethers [43]. The literature values for the selected physical properties of the solvent used are listed in **Table 1**.

The trend observed for transport of cations is: Dichloromethane > 1,2-dichloroethane > chloroform for all podands.

It was found that dichloromethane provides better medium for transport of cations. This is due to the highest dipole moment and lowest viscosity of dichloromethane. Chloroform does not provide a smooth flow of cations across membrane and produces a barrier to flow of cations because of its high density, low water solubility and lowest dipole moment.

High viscosity of membrane restricts the diffusion of the complex across the membrane. It was reported that the increase in viscosity [44] results in a steady decrease in the diffusivity of the carrier and also of the metal-carrier-complex. The degree of selectivity in transport [45] is found to be strong is influenced by the identity of organic solvent. No leakage of cation in the membrane as noted in the blank experiments. This indicates that the mode of transport is only carrier-facilitated.

Effect of time-

We have estimated the concentration of metal ion transported with A_1-A_6 podands after 24 hours and no considerable change could be seen in 24-48 hour estimation.

Effect of stirring rate-

The experiments were performed at several different speeds. The convenient transport of metal ions was happened at 200 rpm. At higher speed the reduction in transported amount was observed which may be due to the decomplexation.

Competitive transport-

The amount of cation transported with podands (A_1-A_6) using co-existing salts of alkali and alkaline earth metal ions (M^+= Na^+, K^+, Mg^{2+}& Ca^{2+}; X^-= Pic^-, Dnp^-& Onp) are used as described under experimental section. The results [**Table 20-25 & Figure 25-26]** indicate that all podands exhibit selectivity towards K^+ and Ca^{2+} ions using picrate salts in dichloromethane.

It is observed that selectivity decreased when binary mixture of salts were used in source phase. The reason for decreased selectivity in co-existing cation is due to the competition between both ions.

It was observed that ionophores are highly selective for transport of K^+ and Ca^{2+} ions when dichloromethane was used as solvent. This is because of highest dipole moment and lowest viscosity which provide better possibility of transport of metal ions.

Amount of cation transported is lesser in co-existing cation as compared to single cation.

Table 14

Amount of cation transported across dichloromethane, 1,2-dichloroethane and chloroform membranes by podand A_1 in 24h.

Metal salt concentration = $1X10^{-3}$ M; Podand concentration = $1X10^{-3}$ M

Metal salts	Dichloromethane		1,2-dichloroethane		Chloroform	
	Amount of cation transported (ppm)	Cation flux J_MX10^{-9} (mol m^{-2} sec^{-})	Amount of cation transported (ppm)	Cation flux J_MX10^{-9} (mol m^{-2} sec^{-})	Amount of cation transported (ppm)	Cation flux J_MX10^{-9} (mol m^{-2} sec^{-})
Li.Pic	-	-	-	-	-	-
Li.Dnp	-	-	-	-	-	-
Li.Onp	-	-	-	-	-	-
Na.Pic	8.44	2.20	7.01	1.83	6.92	1.80
Na.Dnp	6.90	2.19	6.23	1.98	6.20	1.97
Na.Onp	5.44	2.21	5.23	2.12	5.01	2.03
K.Pic	18.17	4.45	18.00	4.41	17.50	4.29
K.Dnp	17.46	5.15	17.01	5.02	17.01	5.02
K.Onp	16.32	6.04	16.23	6.00	16.20	5.99
$Mg.Pic_2$	-	-	-	-	-	-
$Mg.Dnp_2$	-	-	-	-	-	-
$Mg.Onp_2$	-	-	-	-	-	-
$Ca.Pic_2$	2.01	0.27	2.01	0.27	2.00	0.27
$Ca.Dnp_2$	1.50	0.25	1.40	0.23	1.02	0.17
$Ca.Onp_2$	0.89	0.19	0.88	0.19	0.88	0.19

Table 15

Amount of cation transported across dichloromethane, 1,2-dichloroethane and chloroform membranes by podand A_2 in 24h.

Metal salt concentration = $1X10^{-3}$ M; Podand concentration = $1X10^{-3}$ M

Metal salts	Dichloromethane		1,2-dichloroethane		Chloroform	
	Amount of cation transported (ppm)	Cation flux J_MX10^{-9} (mol m^{-2} sec^{-})	Amount of cation transported (ppm)	Cation flux J_MX10^{-9} (mol m^{-2} sec^{-})	Amount of cation transported (ppm)	Cation flux J_MX10^{-9} (mol m^{-2} sec^{-})
Li.Pic	0.88	0.24	0.80	0.24	0.41	0.12
Li.Dnp	0.08	0.02	-	-	-	-
Li.Onp	0.06	0.02	-	-	-	-
Na.Pic	2.17	0.56	1.62	0.42	0.90	0.23
Na.Dnp	1.84	0.58	1.55	0.49	0.85	0.27
Na.Onp	1.11	0.45	0.69	0.28	0.54	0.21
K.Pic	8.32	2.04	6.39	1.5	5.82	1.4
K.Dnp	2.65	0.78	2.38	0.70	2.28	0.67
K.Onp	2.55	0.94	2.15	0.79	2.01	0.74
$Mg.Pic_2$	5.09	0.69	2.64	0.36	1.52	0.20
$Mg.Dnp_2$	4.69	0.83	2.15	0.36	1.50	0.26
$Mg.Onp_2$	4.59	1.0	1.12	0.24	0.84	0.01
$Ca.Pic_2$	25.70	3.39	27.12	3.57	27.43	3.62
$Ca.Dnp_2$	27.20	4.38	27.50	4.48	28.40	4.58
$Ca.Onp_2$	27.65	5.71	28.58	5.94	29.01	6.01

Table 16

Amount of cation transported across dichloromethane, 1,2-dichloroethane and chloroform membranes by podand A_3 in 24h.

Metal salt concentration = $1X10^{-3}$ M; Podand concentration = $1X10^{-3}$

Metal salts	Dichloromethane		1,2-dichloroethane		Chloroform	
	Amount of cation transported (ppm)	Cation flux J_MX10^{-9} (mol m^{-2} sec^{-})	Amount of cation transported (ppm)	Cation flux J_MX10^{-9} (mol m^{-2} sec^{-})	Amount of cation transported (ppm)	Cation flux J_MX10^{-9} (mol m^{-2} sec^{-})
Li.Pic	-	-	-	-	-	-
Li.Dnp	-	-	-	-	-	-
Li.Onp	-	-	-	-	-	-
Na.Pic	2.75	0.71	2.72	0.71	2.51	0.65
Na.Dnp	6.01	1.91	4.16	0.89	2.82	0.32
Na.Onp	4.42	1.79	2.74	1.11	2.31	0.93
K.Pic	0.94	0.23	0.86	0.21	0.78	0.14
K.Dnp	1.08	0.31	1.00	0.29	0.86	0.25
K.Onp	1.34	0.49	1.18	0.43	1.12	0.41
$Mg.Pic_2$	1.21	0.16	1.93	0.26	4.66	0.63
$Mg.Dnp_2$	2.16	0.36	2.25	0.37	2.37	0.39
$Mg.Onp_2$	7.0	1.52	7.2	1.57	7.5	1.63
$Ca.Pic_2$	9.27	1.09	8.70	1.14	8.98	1.31
$Ca.Dnp_2$	8.56	0.75	6.83	1.08	5.90	1.43
$Ca.Onp_2$	6.93	1.18	520	1.11	5.27	1.12

Table 17

Amount of cation transported across dichloromethane, 1,2-dichloroethane and chloroform membranes by podand A_4 in 24h.

Metal salt concentration = $1X10^{-3}$ M; Podand concentration = $1X10^{-3}$ M

Metal salts	Dichloromethane		1,2-dichloroethane		Chloroform	
	Amount of cation transported (ppm)	Cation flux J_MX10^{-9} (mol m^{-2} sec^{-})	Amount of cation transported (ppm)	Cation flux J_MX10^{-9} (mol m^{-2} sec^{-})	Amount of cation transported (ppm)	Cation flux J_MX10^{-9} (mol m^{-2} sec^{-})
Li.Pic	0.51	0.14	0.46	0.12	0.45	0.12
Li.Dnp	0.33	0.11	0.25	0.08	0.20	0.06
Li.Onp	0.05	0.02	0.05	0.02	0.05	0.02
Na.Pic	24.89	6.69	24.50	6.39	24.13	6.29
Na.Dnp	22.01	7.0	22.0	6.99	21.63	6.88
Na.Onp	15.09	6.14	15.01	6.10	14.63	5.95
K.Pic	32.01	7.85	32.01	7.85	31.0	7.60
K.Dnp	28.96	8.54	28.90	8.53	28.80	8.51
K.Onp	27.09	1.00	27.01	9.99	27.01	9.99
$Mg.Pic_2$	5.80	7.91	5.17	0.70	4.23	0.57
$Mg.Dnp_2$	2.72	4.57	1.91	0.32	1.04	0.17
$Mg.Onp_2$	-	-	-	-	-	-
$Ca.Pic_2$	45.08	5.94	44.50	5.87	43.0	5.68
$Ca.Dnp_2$	40.08	6.46	38.55	6.22	38.07	6.14
$Ca.Onp_2$	35.74	7.41	35.5	7.42	35.96	7.43

Table 18

Amount of cation transported across dichloromethane, 1,2-dichloroethane and chloroform membranes by podand A_5 in 4h.

Metal salt concentration = $1X10^{-3}$ M; Podand concentration = $1X10^{-3}$ M

Metal salts	Dichloromethane		1,2-dichloroethane		Chloroform	
	Amount of cation transported (ppm)	Cation flux J_MX10^{-9} (mol m^{-2} sec^{-})	Amount of cation transported (ppm)	Cation flux J_MX10^{-9} (mol m^{-2} sec^{-})	Amount of cation transported (ppm)	Cation flux J_MX10^{-9} (mol m^{-2} sec^{-})
Li.Pic	0.88	0.24	0.91	0.25	0.87	0.24
Li.Dnp	0.98	0.33	0.94	0.32	0.93	0.31
Li.Onp	0.91	0.40	0.91	0.40	0.91	0.40
Na.Pic	3.86	0.98	2.82	0.72	3.37	0.85
Na.Dnp	2.64	0.78	2.03	0.64	2.00	0.63
Na.Onp	1.64	0.65	1.39	0.57	1.91	0.72
K.Pic	-	-	-	-	-	-
K.Dnp	-	-	-	-	-	-
K.Onp	-	-	-	-	-	-
$Mg.Pic_2$	-	-	-	-	-	-
$Mg.Dnp_2$	-	-	-	-	-	-
$Mg.Onp_2$	-	-	-	-	-	-
$Ca.Pic_2$	-	-	-	-	-	-
$Ca.Dnp_2$	-	-	-	-	-	-
$Ca.Onp_2$	-	-	-	-	-	-

Table 19

Amount of cation transported across dichloromethane, 1,2-dichloroethane and chloroform membranes by podand A_6 in 4h.

Metal salt concentration = $1X10^{-3}$ M; Podand concentration = $1X10^{-3}$ M

Metal salts	Dichloromethane		1,2-dichloroethane		Chloroform	
	Amount of cation transported (ppm)	Cation flux $J_M X10^{-9}$ (mol m^{-2} sec^{-})	Amount of cation transported (ppm)	Cation flux $J_M X10^{-9}$ (mol m^{-2} sec^{-})	Amount of cation transported (ppm)	Cation flux $J_M X10^{-9}$ (mol m^{-2} sec^{-})
Li.Pic	1.52	0.41	1.50	0.41	1.49	0.41
Li.Dnp	1.59	0.54	1.54	0.53	1.54	0.53
Li.Onp	1.59	0.71	1.56	0.70	1.58	0.71
Na.Pic	1.20	0.31	1.23	0.32	2.58	0.67
Na.Dnp	1.19	0.37	1.18	0.37	1.57	0.49
Na.Onp	1.26	0.51	2.05	0.83	2.38	0.96
K.Pic	0.95	0.23	0.83	0.20	0.87	0.21
K.Dnp	0.65	0.19	0.52	0.15	0.52	0.15
K.Onp	0.97	0.33	0.88	0.32	0.89	0.32
$Mg.Pic_2$	-	-	-	-	-	-
$Mg.Dnp_2$	-	-	-	-	-	-
$Mg.Onp_2$	-	-	-	-	-	-
$Ca.Pic_2$	17.75	2.56	17.16	2.26	17.09	2.25
$Ca.Dnp_2$	18.41	2.97	18.34	2.97	18.04	2.96
$Ca.Onp_2$	18.35	3.80	18.25	3.80	18.05	3.74

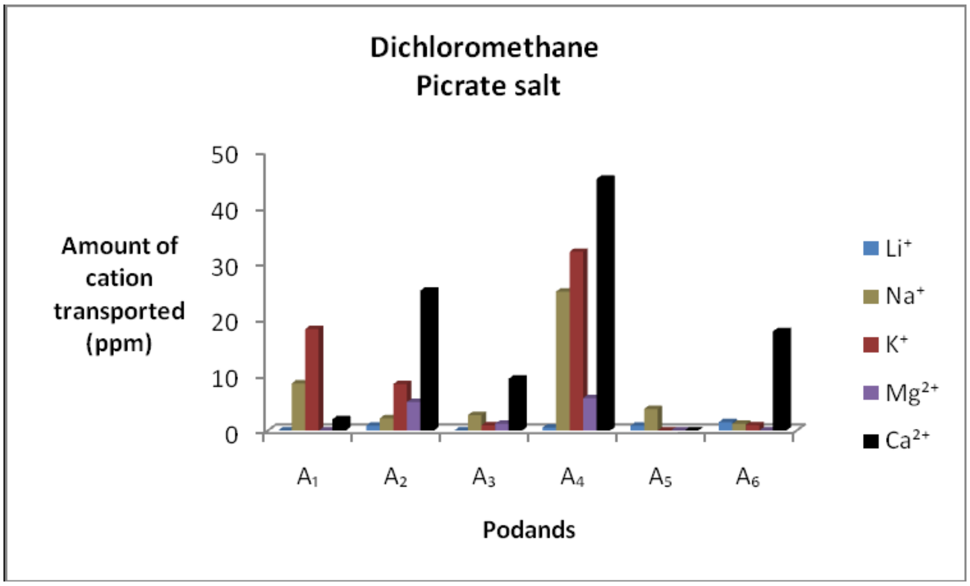


Fig. 16: Effect of different podands on the amount of cation transported through dichloromethane membrane using picrate salt

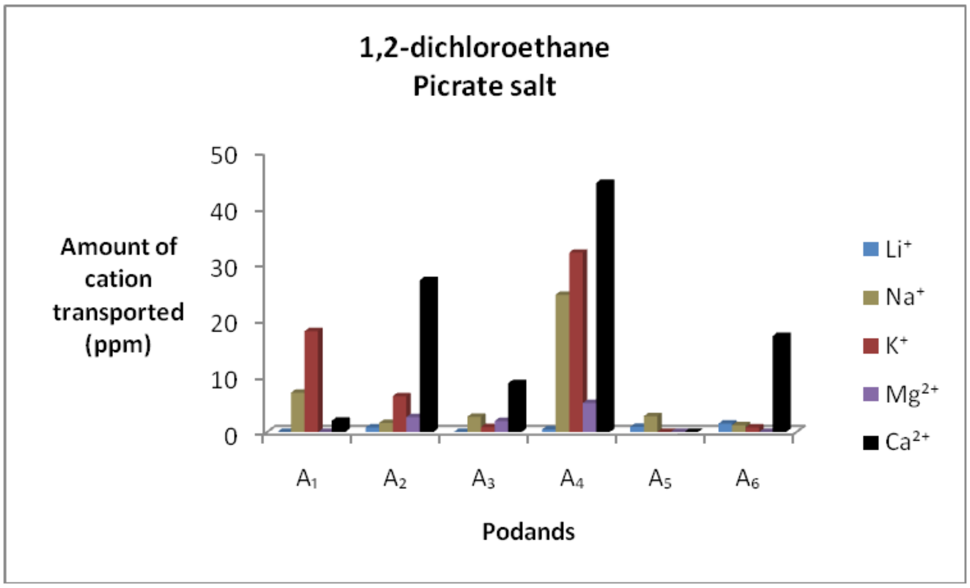


Fig. 17: ***Effect of different podands on the amount of cation transported through 1,2-dichloroethane membrane using picrate salt***

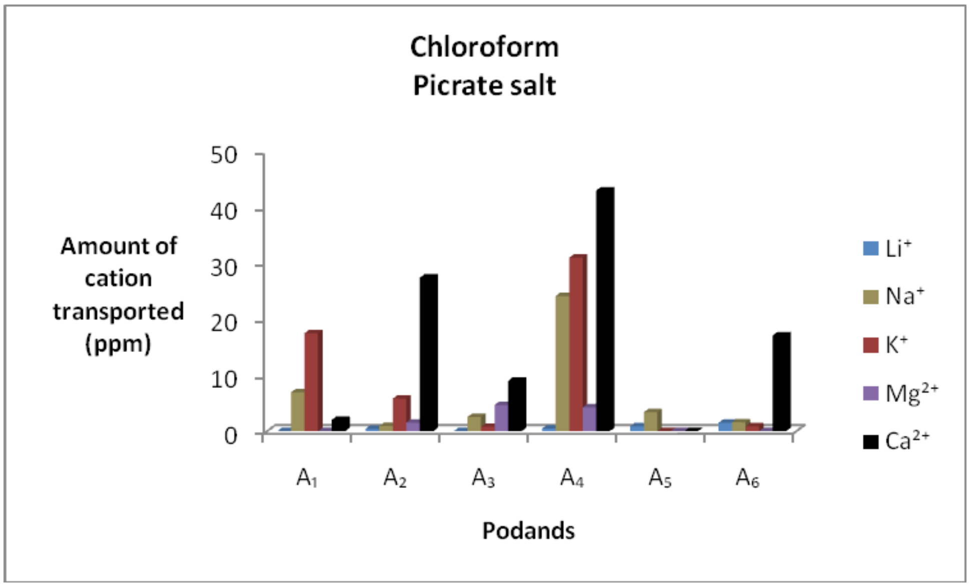


Fig. 18: ***Effect of different podands on the amount of cation transported through chloroform membrane using picrate salt***

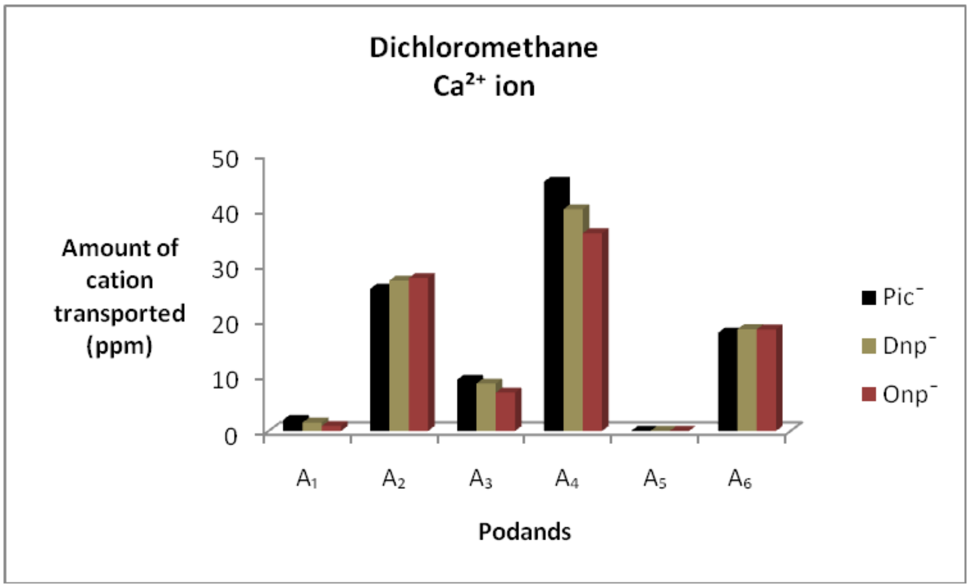


Fig. 19: Effect of different podands on the amount of calcium ion transported through dichloromethane membrane using metal salts (picrate, dinitrophenolate and orthonitrophenolate)

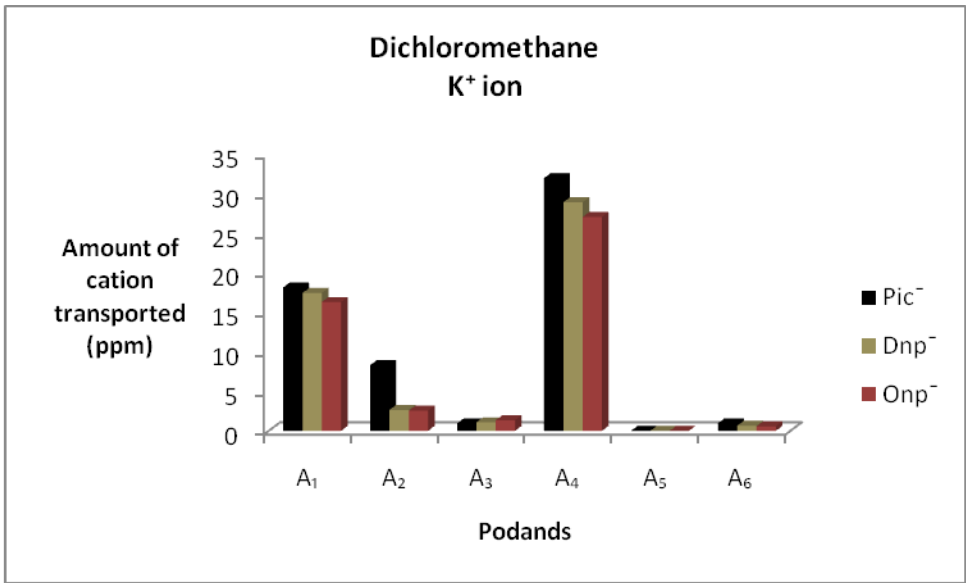


Fig. 20: Effect of different podands on the amount of potassium ion transported through dichloromethane membrane using metal salts (picrate, dinitrophenolate and orthonitrophenolate)

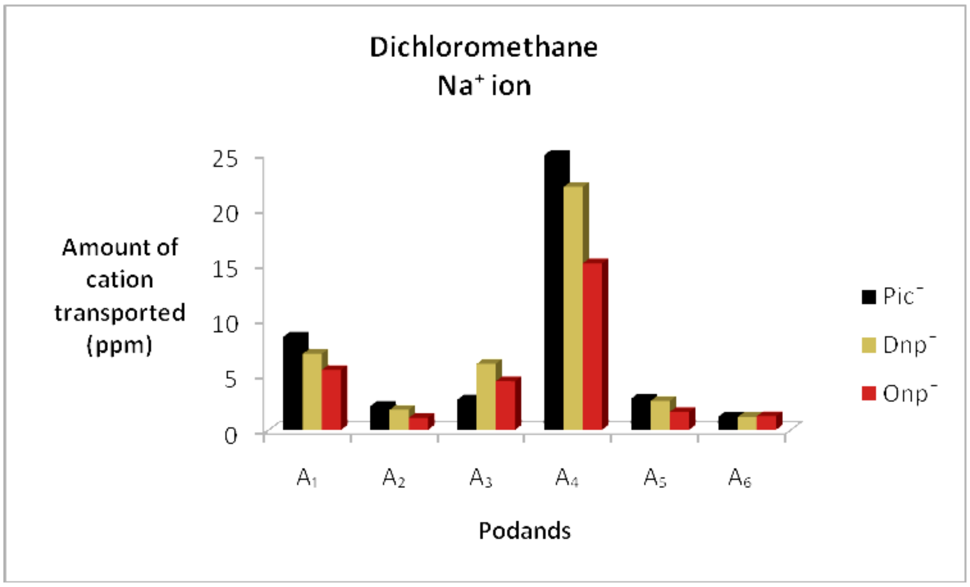


Fig. 21 : Effect of different podands on the amount of sodium ion transported through dichloromethane membrane using metal salts (picrate, dinitrophenolate and orthonitrophenolate)

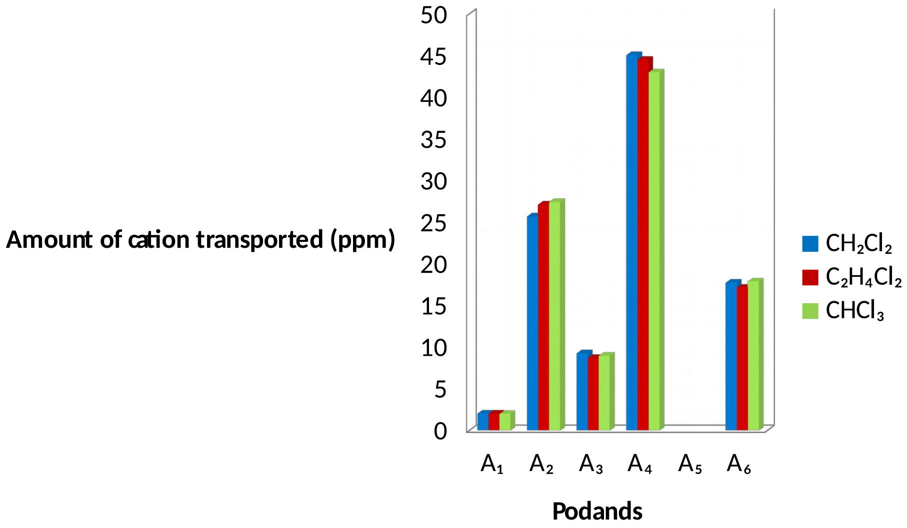


Fig. 22: Effect of different podands on the amount of sodium ion transported using picrate salt through dichloromethane,1,2-dichloroethane and chloroform membranes

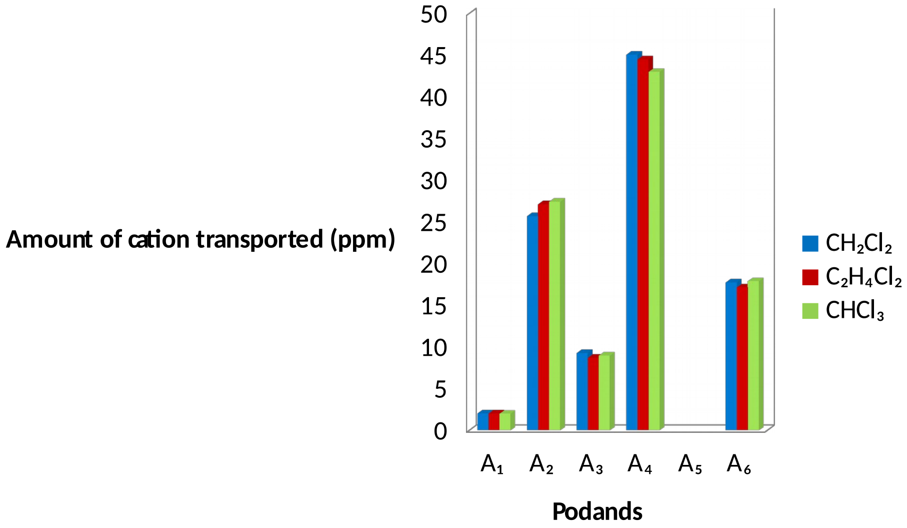


Fig. 23: Effect of different podands on the amount of potassium ion transported using picrate salt through dichloromethane,1,2-dichloroethane and chloroform membranes

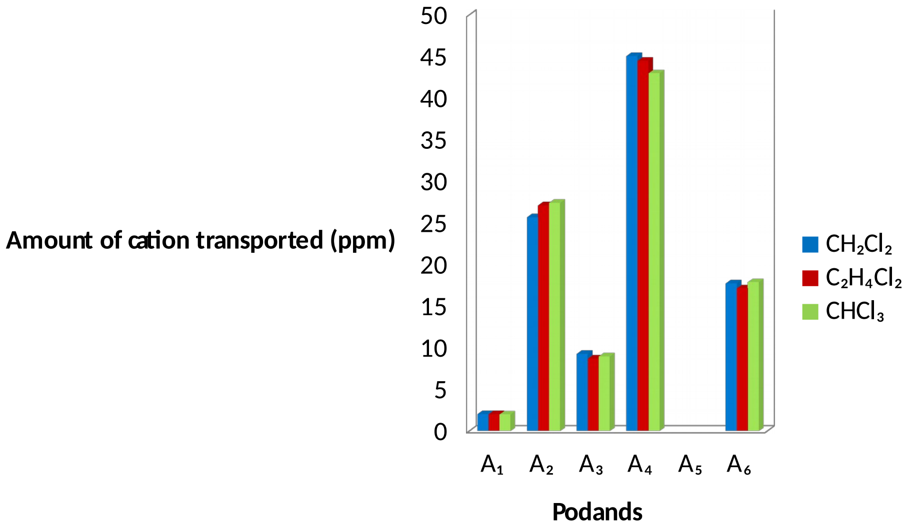


Fig. 24: Effect of different podands on the amount of calcium ion transported using picrate salt through dichloromethane,1,2-dichloroethane and chloroform membranes

Table 20

Amount of cation transported in 24h using coexisting metal picrate salts by podands A_1-A_6 through dichloromethane, 1,2-dichloroethane and chloroform membranes.

Metal salt concentration = $1X10^{-3}$ M; Podand concentration = $1X10^{-3}$ M

BLM	Podand	Na		K	
		Amount of cation transported (ppm)	Cation flux J_MX10^{-9} (mol m^{-2} sec^{-})	Amount of cation transported (ppm)	Cation flux J_MX10^{-9} (mol m^{-2} sec^{-})
CH_2Cl_2	A_1	-	-	22.24	5.45
	A_2	0.70	0.18	1.55	0.38
	A_3	-	-	-	-
	A_4	3.54	0.92	22.68	5.56
	A_5	-	-	0.43	0.10
	A_6	6.69	1.74	0.43	0.10
$C_2H_4Cl_2$	A_1	-	-	19.76	4.84
	A_2	0.62	0.16	1.63	0.39
	A_3	-	-	-	-
	A_4	3.15	0.82	13.6	3.33
	A_5	-	-	0.51	0.12
	A_6	4.23	1.17	0.18	0.04
$CHCl_3$	A_1	-	-	17.29	4.24
	A_2	0.27	0.06	2.13	0.52
	A_3	-	-	-	-
	A_4	2.45	0.63	9.07	2.22
	A_5	-	-	0.77	0.18
	A_6	4.09	1.04	0.15	0.03

Table 21

Amount of cation transported in 24h using coexisting metal dinitrophenolate salts by podands A_1-A_6 through dichloromethane, 1,2-dichloroethane and chloroform membranes.

Metal salt concentration = 1X10^{-3} M; Podand concentration = 1X10^{-3} M

BLM	Podand	Na		K	
CH_2Cl_2		Amount of Cation transported (ppm)	Cation flux J_MX10^{-9} (mol m^{-2} sec^{-})	Amount of cation transported (ppm)	Cation flux J_MX10^{-9} (mol m^{-2} sec^{-})
	A_1	-	-	14.82	4.37
	A_2	1.23	0.39	1.80	0.53
	A_3	-	-	-	-
	A_4	2.36	0.75	4.53	1.83
	A_5	-	-	1.28	0.37
	A_6	3.27	1.16	0.33	0.48
$C_2H_4Cl_2$	A_1	-	-	12.69	3.74
	A_2	1.61	0.35	1.32	0.48
	A_3	-	-	-	-
	A_4	1.96	0.62	4.08	1.20
	A_5	-	-	0.39	0.11
	A_6	3.70	1.30	0.15	0.04
$CHCl_3$	A_1	-	-	9.48	2.79
	A_2	2.86	0.78	5.59	1.67
	A_3	-	-	-	-
	A_4	1.57	0.49	3.62	1.06
	A_5	-	-	0.31	0.09
	A_6	3.29	1.58	-	-

Table 22

Amount of cation transported in 24h using coexisting metal orthonitrophenolate salts by podands A_1-A_6 through dichloromethane, 1,2-dichloroethane and chloroform membranes.

Metal salt concentration = 1X10^{-3} M; Podand concentration = 1X10^{-3} M

BLM	Podand	Na	K

CH$_2$Cl$_2$		Amount of cation transported (ppm)	Cation flux J_MX10^{-9} (mol m^{-2} sec^{-})	Amount of cation transported (ppm)	Cation flux J_MX10^{-9} (mol m^{-2} sec^{-})
	A$_1$	-	-	7.14	2.64
	A$_2$	1.30	0.52	2.27	0.84
	A$_3$	-	-	-	-
	A$_4$	1.18	0.48	3.17	1.17
	A$_5$	-	-	0.68	0.25
	A$_6$	2.87	0.10	0.20	0.12
C$_2$H$_4$Cl$_2$	A$_1$	-	-	4.94	1.82
	A$_2$	2.25	0.72	3.16	0.96
	A$_3$	-	-	-	-
	A$_4$	0.78	0.31	2.72	1.0
	A$_5$	-	-	0.33	0.12
	A$_6$	3.21	0.04	0.12	0.20
CHCl$_3$	A$_1$	-	-	2.47	9.14
	A$_2$	5.14	2.09	6.56	1.68
	A$_3$	-	-	-	-
	A$_4$	0.39	0.15	2.62	0.96
	A$_5$	-	-	0.61	0.22
	A$_6$	2.89	0.03	-	0.19

Table 23

Amount of cation transported in 24h using coexisting metal picrate salts by podands A$_1$-A$_6$ through dichloromethane, 1,2-dichloroethane and chloroform membranes. Metal salt concentration = 1X10^{-3} M; Podand concentration = 1X10^{-3} M

BLM	Podand	Ca		Mg	
		Amount of cation transported (ppm)	Cation flux J_MX10^{-9} (mol m^{-2} sec^{-})	Amount of cation transported (ppm)	Cation flux J_MX10^{-9} (mol m^{-2} sec^{-})

CH_2Cl_2	A_1	9.07	1.19	-	-
	A_2	9.81	1.29	1.32	0.18
	A_3	27.37	3.61	-	-
	A_4	14.48	1.91	-	-
	A_5	25.70	3.39	-	-
	A_6	34.81	4.59	-	-
$C_2H_4Cl_2$	A_1	5.36	0.73	-	-
	A_2	11.43	1.51	3.66	0.49
	A_3	27.31	3.61	-	-
	A_4	12.87	1.70	-	-
	A_5	27.12	3.57	-	-
	A_6	34.83	4.60	-	-
$CHCl_3$	A_1	4.02	0.53	-	-
	A_2	15.41	2.0	4.64	0.63
	A_3	27.29	3.61	-	-
	A_4	11.26	1.48	-	-
	A_5	27.43	3.62	-	-
	A_6	34.89	4.60	-	-

Table 24

Amount of cation transported in 24h using coexisting metal dinitrophenolate salts by podands A_1-A_6 through dichloromethane, 1,2-dichloroethane and chloroform membranes.

Metal salt concentration = $1X10^{-3}$ M; Podand concentration = $1X10^{-3}$ M

BLM	Podand	Ca		Mg	
		Amount of cation transported (ppm)	Cation flux J_MX10^{-9} (mol m^{-2} sec^{-})	Amount of cation transported (ppm)	Cation flux J_MX10^{-9} (mol m^{-2} sec^{-})

CH_2Cl_2	A_1	3.98	0.64	-	-
	A_2	11.81	1.91	0.43	0.07
	A_3	27.29	3.61	-	-
	A_4	9.56	1.54	-	-
	A_5	27.20	4.38	-	-
	A_6	36.86	5.50	-	-
$C_2H_4Cl_2$	A_1	3.45	0.55	-	-
	A_2	12.01	1.94	1.0	0.16
	A_3	27.27	3.61	-	-
	A_4	8.04	1.29	-	-
	A_5	27.50	4.48	-	-
	A_6	36.86	5.63	-	-
$CHCl_3$	A_1	2.91	0.46	-	-
	A_2	15.81	2.55	1.70	0.28
	A_3	27.20	3.59	-	-
	A_4	6.43	1.03	-	-
	A_5	28.40	4.58	-	-
	A_6	36.91	5.64	-	-

Table25

Amount of cation transported in 24h using coexisting metal orthonitrophenolate salts by podands A_1-A_6 through dichloromethane, 1,2-dichloroethane and chloroform membranes.

Metal salt concentration = 1X10^{-3} M; Podand concentration = 1X10^{-3} M

BLM	Podand	Ca		Mg	
CH_2Cl_2		Amount of cation transported (ppm)	Cation flux J_MX10^{-9} (mol m^{-2} sec^{-})	Amount of cation transported (ppm)	Cation flux J_MX10^{-9} (mol m^{-2} sec^{-})
	A_1	1.21	0.25	-	-
	A_2	16.01	3.32	0.90	0.19
	A_3	27.27	3.61	-	-

	A_4	3.28	0.68	-	-
	A_5	27.65	5.71	-	-
	A_6	37.42	7.84	-	-
$C_2H_4Cl_2$	A_1	1.19	0.24	-	-
	A_2	17.40	3.60	0.98	0.21
	A_3	27.12	3.54	--	-
	A_4	3.21	0.66	-	-
	A_5	28.58	5.94	-	-
	A_6	37.75	7.85	-	-
$CHCl_3$	A_1	1.01	0.20	-	-
	A_2	18.48	3.83	1.30	0.28
	A_3	27.12	3.54	-	-
	A_4	1.60	0.33	-	-
	A_5	29.01	6.01	-	-
	A_6	37.89	7.89	-	-

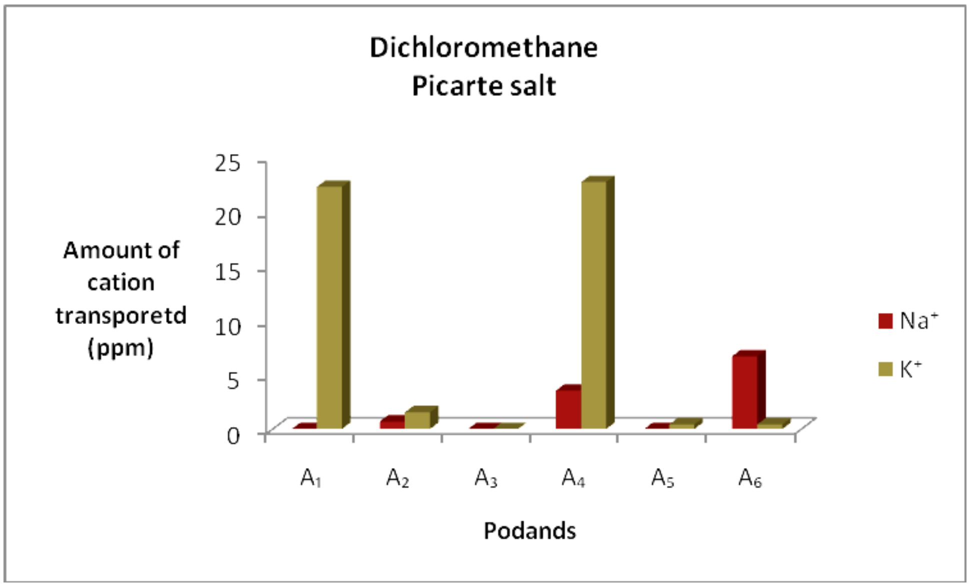


Fig. 25: Effect of different podands on the transport of coexisting picrate salts through dichloromethane membrane

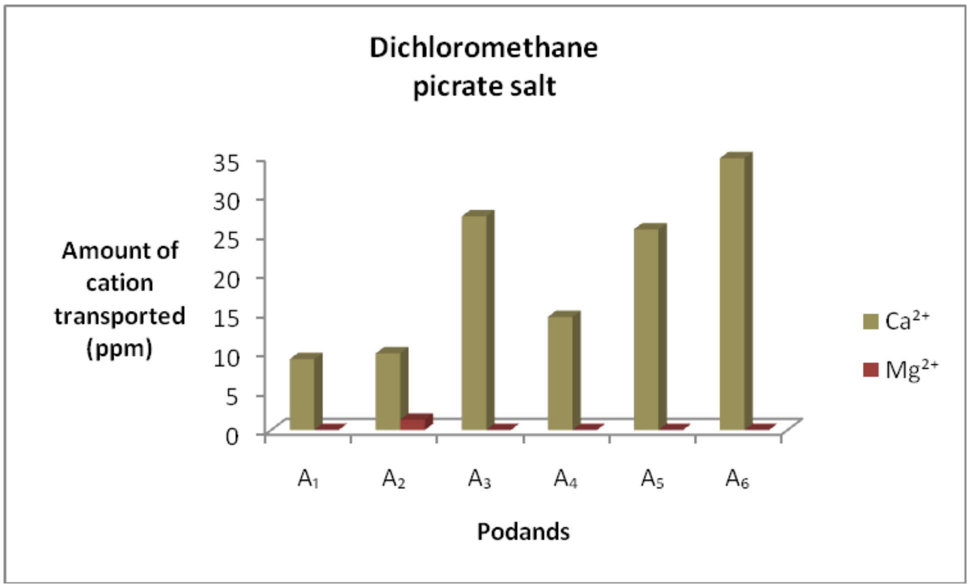


Fig. 26: Effect of different podands on the transport of coexisting picrate salts through dichloromethane membrane

Isolation studies-

The great interest in the chemistry of macrocyclic polyethers and podands is a result of their ability to form complexes with salts both in polar and in nonpolar solvents. The appearance of first comprehensive report by Pedersen [46], it has been belived that complexation of a cation with crown ether and stoichiometry of the crown-metal complexes determined by the fit of M^{Z+} in the cavity of ligand.

In this chapter, we are reporting here the isolation studies of alkali and alkaline earth metal salts with new series of podands. The main aim of this work is to understand the behaviour of newly synthesized podands to co-ordinate the alkali and alkaline earth metal ions i.e. stoichiometry of the complexes, effect of anion and charge density of cation on complexation.

The isolation studies of metal salts were carried out with podands (A_1-A_6) and during isolation studies it was found that podands A_2, A_3 & A_5 form complexes with metal salts and the characterization of complexes are summarized in **table 26-28**.

In the formation of complexes, two factors are appeared, the solvation of metal ion and solvation of the podand. All complexes were isolated in methanol. Almost all complexes were isolated with M.Pic and M.Dnp only. M.Onp salts were found not capable to form complex with podands. Podand A_3 shows complexation ability with Ca^{2+}, A_2 with Li^+, Na^+, K^+ and Ca^{2+} and A_5 with Li^+, K^+, Mg^{2+} and Ca^{2+}.

From the elemental analysis and metal estimation of isolated complexes on flame photometer and atomic absorption spectrophotometer it is observed that stoichiometric ratio (M:L) is 1:1 for alkali and alkaline earth metal complexes with podands A_2 & A_3, whether in case of podand A_5, stoichiometric ratio is 1:1 for alkali metal ions and 1:2 for alkaline earth metal ions.

Usually 1:1 complexes are formed when a cation diameter had very well fitted with the cavity size of the polyether [47]. The synthetic acyclic polyethers (podands) did not have intramolecular cavities for guest binding, but could form “pseudocyclic cavity” for guest species. Bivalent cations have higher charge density and smaller size. They undergo self encapsulation between two molecules of ligand along with anion and these encapsulates are comparable to those obtained from cyclic antibiotics [48]. Further 1:2 complexes are formed in case of alkaline earth metal ions as a sandwich structure (**Figure 27**) in which cation may be located slightly apart from the plane, in which donor oxygen on the polyether are arranged. This may be due to the larger size of cation than the pseudocyclic cavity of podand [49]. In reference to the above statement, podand A_5 which has shortest chain length, also form complexes with alkaline earth metal ions having 1:2 stoichiometry (**Table 26**).

From **Table 27**, it is observed that characteristics IR peaks of the podand A_2 at 1705 (C=O), 1587(C=C), 2956 (C-H) and 1071(C-O-C) cm^{-1} are shifted in the complexes. It shows the participation of these groups in the complexation. The peaks in complexes (**Figure 28,30,32,34**) A_2-Li.Pic, A_2-Na.Pic, A_2-Ca.Pic_2 and A_2-K.Dnp are founded at 1633-1600 (C=O), 1562-1538 (C=C), 2925-2943 (C-H) and 1069-1053 (C-O-C) cm^{-1}. Podand A_3 form complexe with Ca.Pic_2 in which the peaks of A_3 at 1701 (C=O), 1587 (C=C), 2930 (C-H) and 1010 (C-O-C) cm^{-1} are shifted to 1632 (C=O), 1342 (C=C), 2924 (C-H) and 1087 (C-O-C) cm^{-1} (**Figure 36**). In case of podand A_5 the peaks at 1743 (C=O) and 1080 (C-O-C) cm^{-1} are found to be shifted at 1650-1600 (C=O) and 1080-1108 (C-O-C) cm^{-1} (**Figure 38,40,42,44,46,48,50**).

A strong band in the region of 790-850 cm^{-1}, indicates the presence of p-substituted aromatic group. It was observed that IR peaks in complexes are shifted towards lower frequency and the participation of groups in complexation shows shifting of their peaks. Two strong bands from 1300 to 1370 and from 1500 to 1570 shows the N-O stretching which indicates the presence of nitro group in complex. The presence of band in between 600-800 cm^{-1} shows the stretching of C-Br bond and confirmed the presence of bromine in complex. If the shift is greater in complex then it indicates the greater extent of interaction of podand [50]. Results are further supported by ^1H NMR spectral data.

From **Table 28,** the data in case of A_2 reveal that the signals for the protons at (δ ppm) 3.54 (O-C**H**$_2$-CH$_2$-), 5.2 (-CO-C**H**$_2$-), 7.4-7.9 (Ar-**H**) are found to be shifted in the complexes at 3.6-3.7 (O-C**H**$_2$-CH$_2$-), 7.2 (-CO-C**H**$_2$-), 7.3-7.8 (Ar-**H**). It was observed that the peaks of –CO-C**H**$_2$ group at 5.2 ppm shifts in complexes which shows that this group is participating in complexation.

The signals of protons in podand A_3 at 3.54 (-O-C**H**$_2$-CH$_2$-), 4.63 (-CO-C**H**$_2$-), 7.5-7.7 (Ar-**H**) which found at 3.54 (-O-C**H**$_2$-CH$_2$-), 7.2 (-O-C**H**$_2$-), 7.6-7.8 (Ar-**H**) in complex which shows the participation of –CO-CH$_2$ group in complexation. This may be because of the conformational change in podand A_3 due to which the oxygen of carbonyl group interact with metal cation. In case of podand A_5 the signals of protons at 4.27 (O-C**H**$_2$-CH$_2$-) and 2.08 (CO-C**H**$_3$) are found shifted to 7.9 (-O-C**H**$_2$-CH$_2$-) which indicates the participation of –O-C**H**$_2$-CH$_2$- in complexation. The peak of CO-C**H**$_2$ group shifted upfield at 7.2 ppm in complexes. It may be due to the participation of carbonyl group by the breaking of double bond (π-bond) present between carbon and oxygen atoms [51].

The presence of signals at δ 7.2-7.9 indicating the presence of aromatic group in the complexes. All the signals in complexes also shown downfield shifting. Signals around δ 9.5, 8.4 and 7.9 ppm indicates the presence of picrate and dinitrophenolate anion (metal salts). Hence, it can be concluded that the insertion of the metal ion with podand results the formation of complexes.

Although bromine was not estimated on the basis of elemental analysis. But bromine was present there in the complexes and identified by IR spectra and its peaks are shown in the region of 600-800 cm^{-1}. Presence of bromine can be proved by x-ray diffraction only.

A maximum complexation occurred if diameter could fit well the pseudocyclic cavity of podand. Due to large size and more charge density of Ca^{2+} ions they form the stronger complex with all podands. It can be assumed that the diameter of metal ion matched with pseudocyclic cavity of podand which formed due to ion-dipole interactionThe solubility of such complexes in nonpolar solvents was attributed to the presence of hydrophobic groups in podands. The counter anion like picrate were immensely active as they exerted in solvents as “nacked anions” incapable of being solvated by solvents.

Podand A_2 shows good complexation with Li^+, Na^+, Ca^{2+} ions which may be due to long oxyethylene chain and single rigid aromatic end group. A_3 shows complexing ability with Ca^{2+} only. It may be due to the presence of longer oxyethylene chain & two rigid aromatic (p-bromo phenacyl) end groups. Podand A_5 form complexes with Li^+, K^+, Mg^{2+} and Ca^{2+} ions, due to the presence of short flexible oxyethylene chain without rigid end groups is easily adjustable for complexing metal cation of various sizes [52]. So, the flexible podands led to dynamic complexation and acted as effective carrier in solid state. The interaction of podands with M^{Z+} in solid state and solution state are not same.

From IR & ^{1}H NMR spectroscopic data it can be concluded that there are conformational change in the chain of podands during complexation and a pseudocyclic cavity is formed due to ion-dipole interaction between the coordination sites and the metal ion.

The selectivity of podand towards metal ion can be explained by pseudocyclic cavity fit concept [53]. The metal-podand interactions are of the ion-dipole and basically controlled by the fit of metal ion into the hole size of podand which have a clear tendency of the close relation between the size of pseudocyclic cavity of podand and the ionic diameter of metal cation. In these complexes the cation is located in the center of the main pseudocyclic cavity. The forces responsible for the formation of this complexes are ion-dipole interaction.

From our results, it can be concluded that for the molecular recognition and for self assembly the noncovalent interaction and the structural aspects of the podand such as end group, chain length etc. and the factors such as size and charge density of the metal ion are important.

Figure 27: Schematic representation of formation of "sandwich complex" formed by podand A_5

Table 26

Elemental analysis data of alkali and alkaline earth metal complexes with podands

		o. S.	saltMetal	Solvent	Podand	)Stoichi-ometry	)Yield	C)M.P.	FormulaMolecular	(%)Elemental analysis				
M											C	H	N	M
6.38		1	Ca.Pic$_2$	CH_3OH	A$_3$	1:1	92	135	$C_{60}H_{60}O_{28}N_6Br_4Ca$	C	43.06	3.58	5.02	2.39
6.01										**F**	**39.78**	**2.90**	**7.70**	**3.60**
1.83		2	Na.Pic	CH_3OH	A$_2$	1:1	80	140	$C_{24}H_{29}O_{12}N_3BrNa$	C	44.03	4.43	6.42	**3.51**
1.80										**F**	**43.09**	**4.35**	**6.50**	**3.24**
9.44		3	Li. Pic	CH_3OH	A$_2$	1:1	87	128	$C_{24}H_{29}O_{12}N_3BrLi$	C	45.14	4.54	6.58	**1.09**
9.01										**F**	**44.98**	**4.23**	**6.48**	**1.00**
5.02		4	Ca.Pic$_2$	CH_3OH	A$_2$	1:1	93	141	$C_{48}H_{58}O_{24}N_6Br_2Ca$	C	47.76	4.80	6.96	**3.31**
5.00										**F**	**40.04**	**3.44**	**9.34**	**4.41**

C- Calculated value, F-Founded value

S. No.	saltMetal	Solvent	podand	:L) Stoichi-ometry	%)Yield	C)M.P.	FormulaMolecular	(%)Elemental analysis				(%) Elemental analysis	
									C	H	N	N	M
5	K. Dnp	CH_3OH	A_2	1:1	52	99	$C_{24}H_{30}O_{10}N_2BrK$	C	44.13	4.90	2.90	10.88	3.10
								F	**44.00**	**4.39**	**2.9**	**10.40**	**2.98**
6	Li. Pic	CH_3OH	A_5	1:1	79	102	$C_{12}H_{12}O_{11}N_3Li$	C	37.79	3.14	11.02	7.60	10.5
								F	**36.0**	**3.10**	**10.89**	**7.51**	**10.2**
7	K. Pic	CH_3OH	A_5	1:1	85	98	$C_{12}H_{12}O_{11}N_3K$	C	34.86	2.90	10.16	10.65	5.07
								F	**34.01**	**2.90**	**10.12**	**10.09**	**4.99**
8	$Ca.Pic_2$	CH_3OH	A_5	1:2	92	109	$C_{24}H_{24}O_{22}N_6Ca$	C	36.54	3.04	10.65	10.88	3.10
								F	**37.01**	**2.95**	**10.40**	**10.90**	**2.98**

C- Calculated value, F-Founded value

S. No.	saltMetal	Solvent	Podand	(M:L) Stoichi-ometry	(%)Yield	(°C)M.P.	FormulaMolecular		C	H
9	Mg.Pic$_2$	CH_3OH	A$_5$	1:2	79	105	$C_{24}H_{24}O_{22}N_6Mg$	C	37.30	3.10
								F	**37.00**	**2.75**
10	K. Dnp	CH_3OH	A$_5$	1:1	54	122	$C_{12}H_{13}O_9N_2K$	C	39.13	3.54
								F	**39.00**	**3.24**
11	Ca.Dnp$_2$	CH_3OH	A$_5$	1:2	49	101	$C_{24}H_{24}O_{22}N_4Ca$	C	36.54	3.04
								F	**36.50**	**2.98**
12	Mg.Dnp$_2$	CH_3OH	A$_5$	1:2	59	95	$C_{24}H_{24}O_{22}N_4Mg$	C	37.30	3.10
								F	**37.20**	**3.10**

C- Calculated value, F-Founded value

Table 27

IR spectral data of alkali and alkaline earth metal complexes with podands

Podand	Complex	Selected IR bands in podand and respective shift in complex (cm^{-1})

A_2		1705 (C=O), 1587 (C=C), 2956 (C-H), 1071 (C-O-C), 516 (C-Br)
	A_2-Na.Pic	1633(C=O), 1562(C=C), 2925 (C-H), 1069 (C-O-C), 1333 & 1562 (N-O), 517 (C-Br)
	A_2-Li.Pic	1627 (C=O), 1509(C=C), 2943 (C-H), 1153(C-O-C), 1509 (N-O), 574 (C-Br)
	A_2-Ca(Pic)$_2$	1633(C=O), 1545(C=C), 2917 (C-H), 1071(C-O-C), 1345 & 1545 (N-O)
	A_2-K.Dnp	1600 (C=O), 1538 (C=C), 2928 (C-H), 1069 (C-O-C), 1345 & 1530 (N-O), 517 (C-Br)
A_3		1701 (C=O), 1587 (C=C), 2930 (C-H), 1010 (C-O-C), 515 (C-Br)
	A_3-Ca(Pic)$_2$	1632 (C=O), 1342 (C=C), 2924 (C-H), 1087 (C-O-C), 1342 & 1528 (N-O), 522 (C-Br)
A_5		1743 (C=O), 2962 (C-H), 1441 (C-H), 1052 (C-O-C)
	A_5-Li.Pic	1650 (C=O), 2900 (C-H), 1080 (C-O-C), 1350 & 1540 (N-O)
	A_5-K.Pic	1650 (C=O), 2900 (C-H), 1080 (C-O-C), 1345 & 1540 (N-O)
	A_5-Ca(Pic)$_2$	1630 (C=O), 2900 (C-H), 1060 (C-O-C), 1360 & 1570 (N-O)
	A_5-Mg(Pic)$_2$	1640 (C=O), 2900 (C-H), 1080 (C-O-C), 1570 (N-O)
	A_5-K.Dnp	1626 (C=O), 2953 (C-H), 1180 (C-O-C), 1333 & 1536 (N-O)
	A_5-Ca(Dnp)$_2$	1600 (C=O), 2854 (C-H), 1180 (C-O-C), 1347 & 1535 (N-O)
	A_5-Mg(Dnp)$_2$	1626 (C=O), 2953 (C-H), 1180 (C-O-C), 1347 & 1537 (N-O)

Table 28

^{1}H NMR spectral data of alkali and alkaline earth metal complexes with podands

Podand	Complex	Selected ^{1}HNMR peaks in podands and respective shift in complex (δ ppm)
A_2		3.54 (O-C$\mathbf{H}_2$-CH$_2$-), 5.2 (-CO-C$\mathbf{H}_2$-), 7.4-7.9 (Ar-**H**)
	A_2-Na.Pic	3.6-3.7 (O-C$\mathbf{H}_2$-CH$_2$-), 5.52 (-CO-C$\mathbf{H}_2$-),7.2-7.8 (Ar-**H**), 9.2 (picrate)
	A_2-Li.Pic	3.6-3.7 (O-C$\mathbf{H}_2$-CH$_2$-), 7.2 (-CO-C$\mathbf{H}_2$-), 7.3-7.8 (Ar-**H**), 9.0 (picrate)
	A_2-Ca(Pic)$_2$	3.6-3.7 (O-C$\mathbf{H}_2$-CH$_2$-), 7.2 (-CO-C$\mathbf{H}_2$-), 7.3-7.8 (Ar-**H**), 9.0 (picrate)
	A_2-K.Dnp	3.6-3.7 (O-C$\mathbf{H}_2$-CH$_2$-), 7.2 (-CO-C$\mathbf{H}_2$-), 7.3-7.8 (Ar-**H**), 8.4 & 7.9 (dinitrophenoleate)
A_3		3.54 (-O-C$\mathbf{H}_2$-CH$_2$-), 4.63 (-CO-C$\mathbf{H}_2$-), 7.5-7.7 (Ar-**H**)
	A_3-Ca(Pic)$_2$	3.54 (-O-C$\mathbf{H}_2$-CH$_2$-), 7.2 (-O-C$\mathbf{H}_2$-), 7.6-7.8 (Ar-**H**), 9.1 (picrate)
A_5		4.27 (-O-C$\mathbf{H}_2$-CH$_2$-), 2.08 (-CO-C$\mathbf{H}_3$)
	A_5-Li.Pic	8.0 (-O-C$\mathbf{H}_2$-CH$_2$-), 8.7 (picrate)
	A_5-K.Pic	5.3 (-O-C$\mathbf{H}_2$-CH$_2$-), 8.6 (picrate)
	A_5-Ca(Pic)$_2$	7.9 (-O-C$\mathbf{H}_2$-CH$_2$-), 8.6 (picrate)
	A_5-Mg(Pic)$_2$	8.6 (-O-C$\mathbf{H}_2$-CH$_2$-), 8.7 (picrate)
	A_5-K.Dnp	7.2 (-O-C$\mathbf{H}_2$-CH$_2$-), 8.3 & 8.6 (dinitrophenolate)
	A_5-Ca(Dnp)$_2$	7.2 (-O-C$\mathbf{H}_2$-CH$_2$-), 8.3 & 8.6 (dinitrophenolate)
	A_5-Mg(Dnp)$_2$	7.2 (-O-C$\mathbf{H}_2$-CH$_2$-), 8.3 & 8.6 (dinitrophenolate)

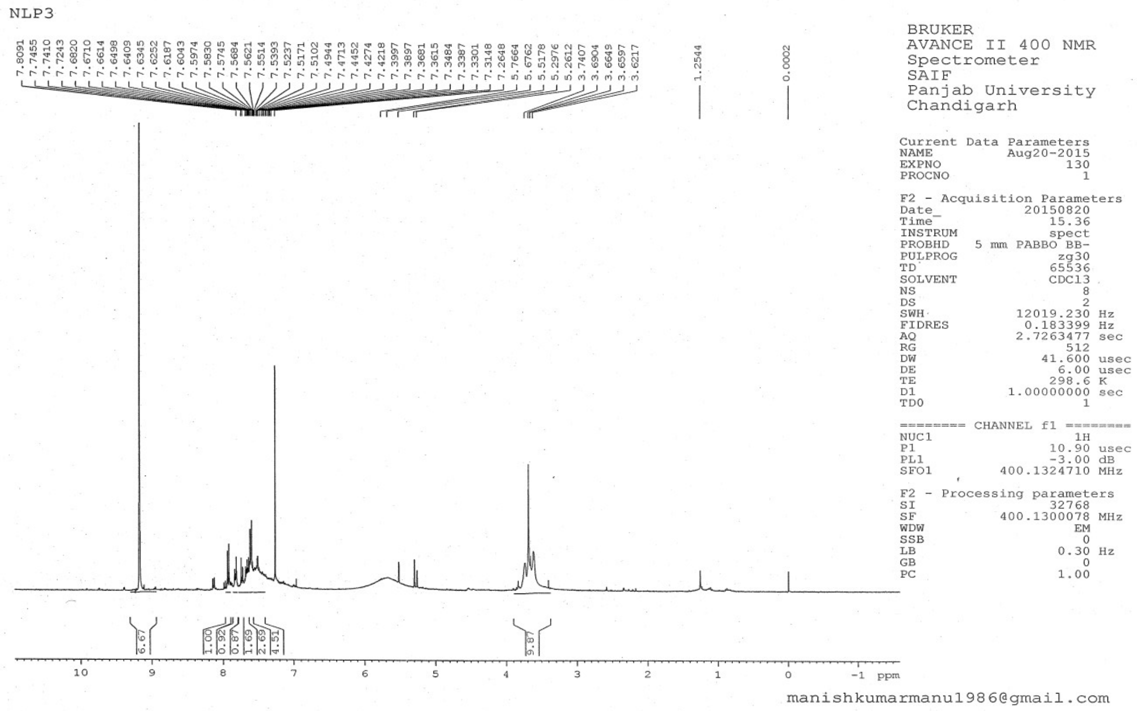


Fig. 29 : ^{1}H NMR Spectrum of Podand A_2-Li.Pic Complex

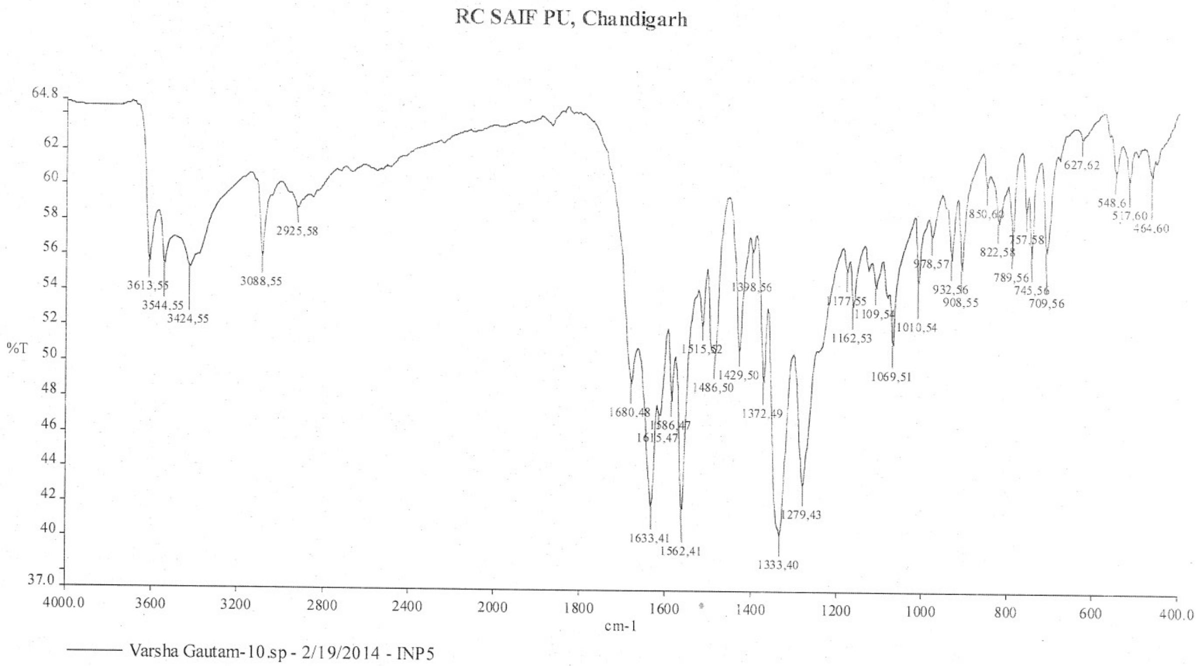
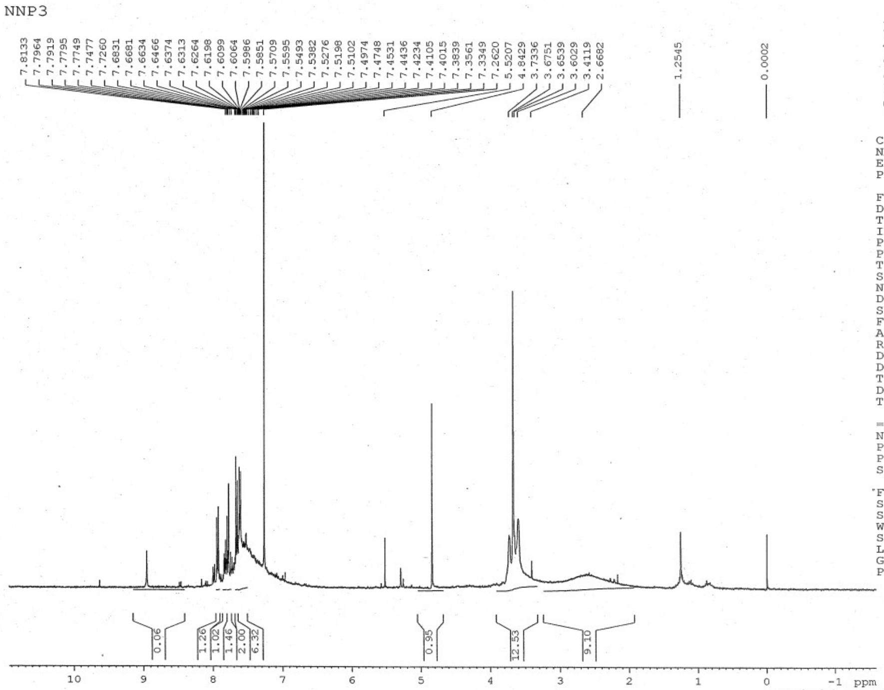


Fig. 30 : IR Spectrum of Podand A_2-Na.Pic Complex



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Panjab University
Chandigarh

Current Data Parameters
NAME          Aug20-2015
EXPNO                150
PROCNO                 1

F2 - Acquisition Parameters
Date_           20150820
Time               15.47
INSTRUM            spect
PROBHD   5 mm PABBO BB-
PULPROG             zg30
TD                 65536
SOLVENT            CDCl3
NS                     8
DS                     2
SWH            12019.230 Hz
FIDRES          0.183399 Hz
AQ             2.7263477 sec
RG                   645
DW                41.600 usec
DE                  6.00 usec
TE                 298.7 K
D1            1.00000000 sec
TD0                    1

======== CHANNEL f1 ========
NUC1                  1H
P1                 10.90 usec
PL1                -3.00 dB
SFO1         400.1324710 MHz

F2 - Processing parameters
SI                 32768
SF           400.1300089 MHz
WDW                   EM
SSB                    0
LB                  0.30 Hz
GB                     0
PC                  1.00
```

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Fig. 31 : ^{1}H NMR Spectrum of Podand A_2-Na.Pic Complex

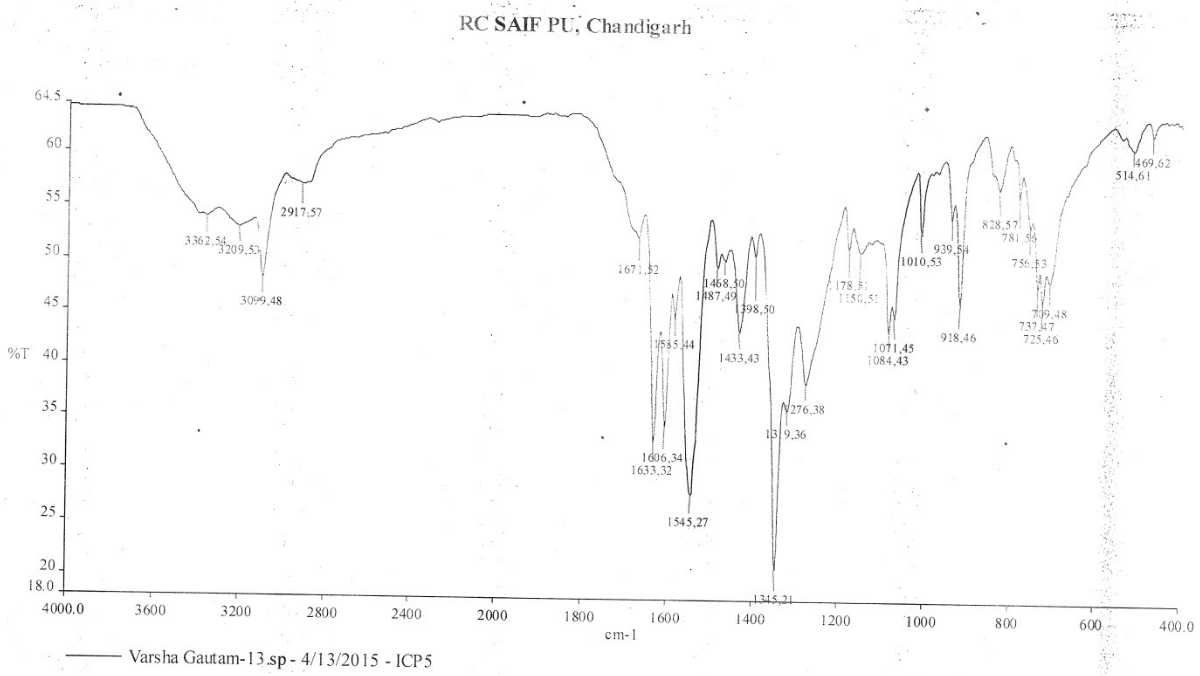
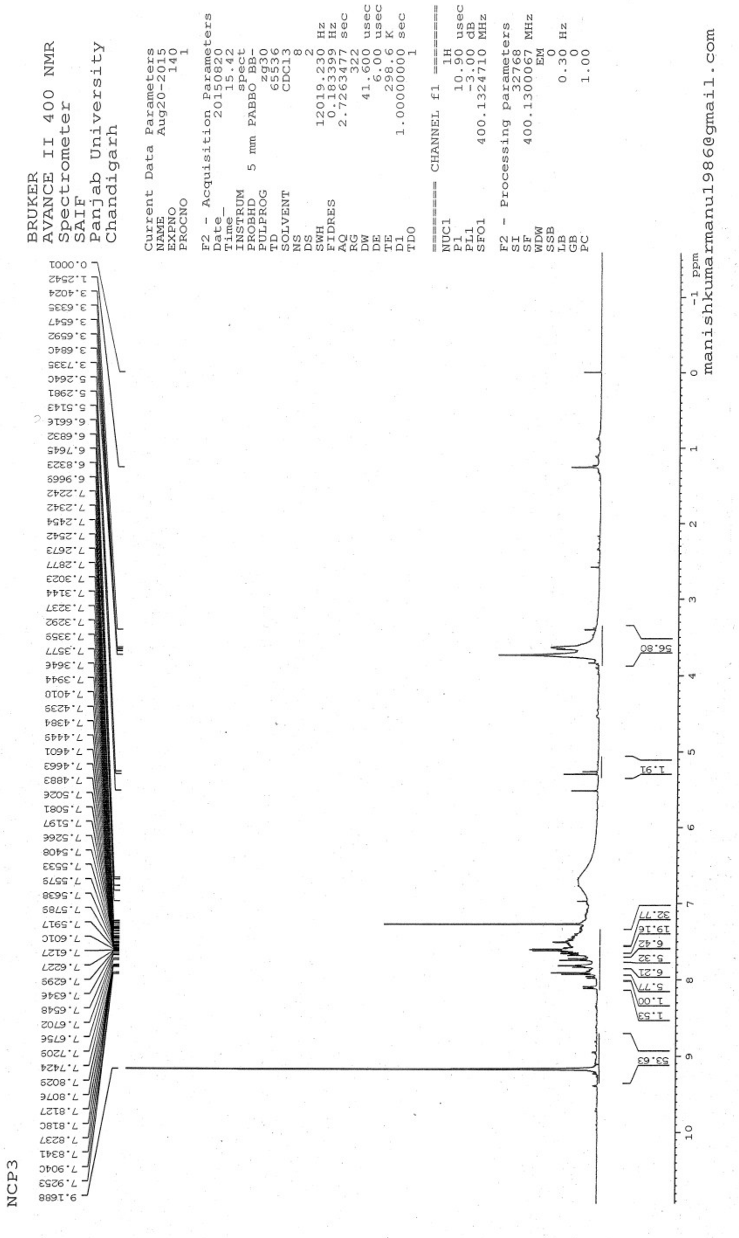


Fig. 32 : IR Spectrum of Podand A_2-Ca$(Pic)_2$ Complex



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BRUKER
AVANCE II 400 NMR
Spectrometer
SAIF
Panjab University
Chandigarh

Current Data Parameters
NAME          Aug20-2015
EXPNO                140
PROCNO                 1

F2 - Acquisition Parameters
Date_           20150820
Time               15.42
INSTRUM            spect
PROBHD   5 mm PABBO BB-
PULPROG             zg30
TD                 65536
SOLVENT            CDCl3
NS                     8
DS                     2
SWH            12019.230 Hz
FIDRES          0.183399 Hz
AQ             2.7263477 sec
RG                   322
DW                41.600 usec
DE                  6.00 usec
TE                 298.6 K
D1            1.00000000 sec
TD0                    1

======== CHANNEL f1 ========
NUC1                  1H
P1                 10.90 usec
PL1                -3.00 dB
SFO1         400.1324710 MHz

F2 - Processing parameters
SI                 32768
SF           400.1300067 MHz
WDW                   EM
SSB                    0
LB                  0.30 Hz
GB                     0
PC                  1.00
```

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Fig 33 : ^1H NMR Spectrum of Podand A_2-Ca(Pic)$_2$ Complex

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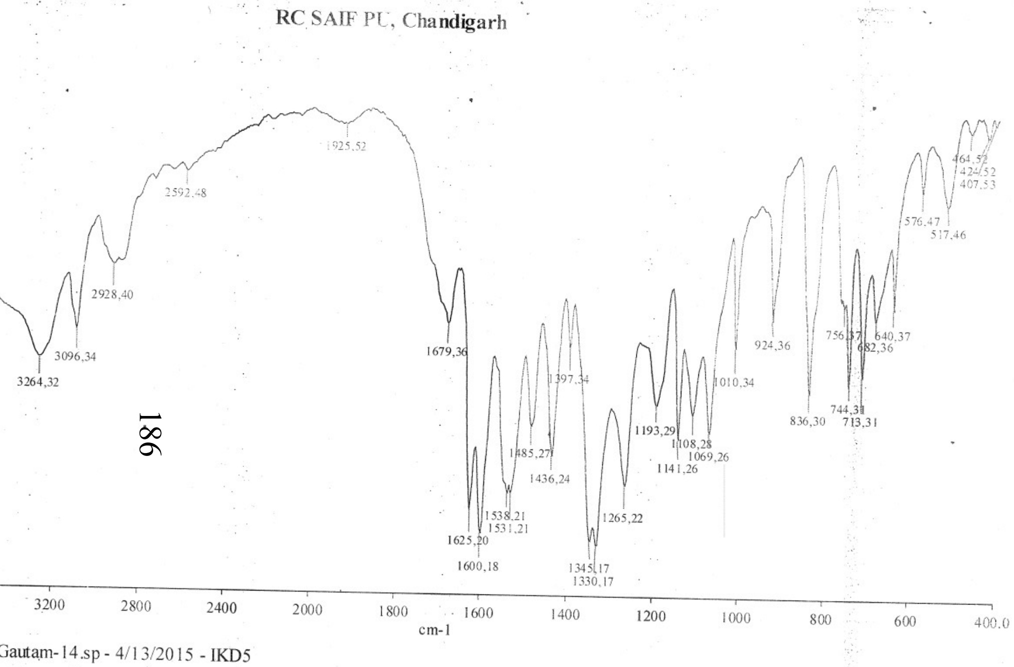
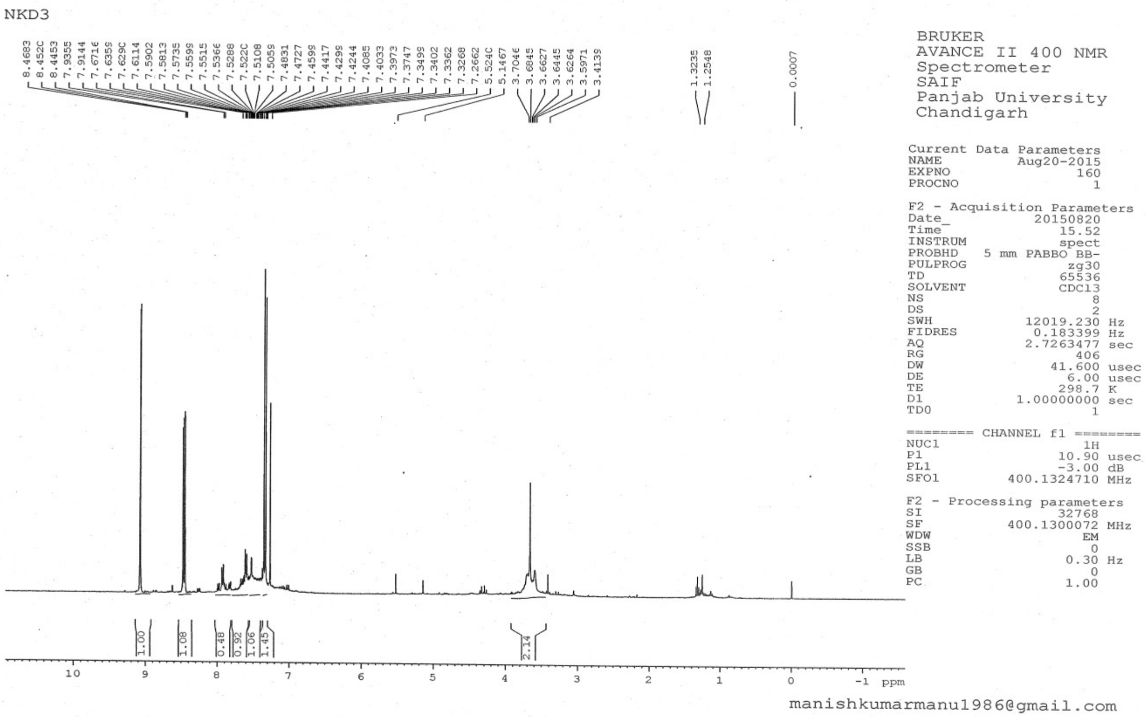


Fig. 34 : IR Spectrum of Podand A_2-K.Dnp Complex



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BRUKER
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Panjab University
Chandigarh

Current Data Parameters
NAME          Aug20-2015
EXPNO                160
PROCNO                 1

F2 - Acquisition Parameters
Date_           20150820
Time               15.52
INSTRUM            spect
PROBHD   5 mm PABBO BB-
PULPROG             zg30
TD                 65536
SOLVENT            CDCl3
NS                     8
DS                     2
SWH            12019.230 Hz
FIDRES          0.183399 Hz
AQ             2.7263477 sec
RG                   406
DW                41.600 usec
DE                  6.00 usec
TE                 298.7 K
D1            1.00000000 sec
TD0                    1

======== CHANNEL f1 ========
NUC1                  1H
P1                 10.90 usec
PL1                -3.00 dB
SFO1         400.1324710 MHz

F2 - Processing parameters
SI                 32768
SF           400.1300072 MHz
WDW                   EM
SSB                    0
LB                  0.30 Hz
GB                     0
PC                  1.00
```

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Fig. 35 : ^{1}H NMR Spectrum of Podand A_2-K.Dnp Complex

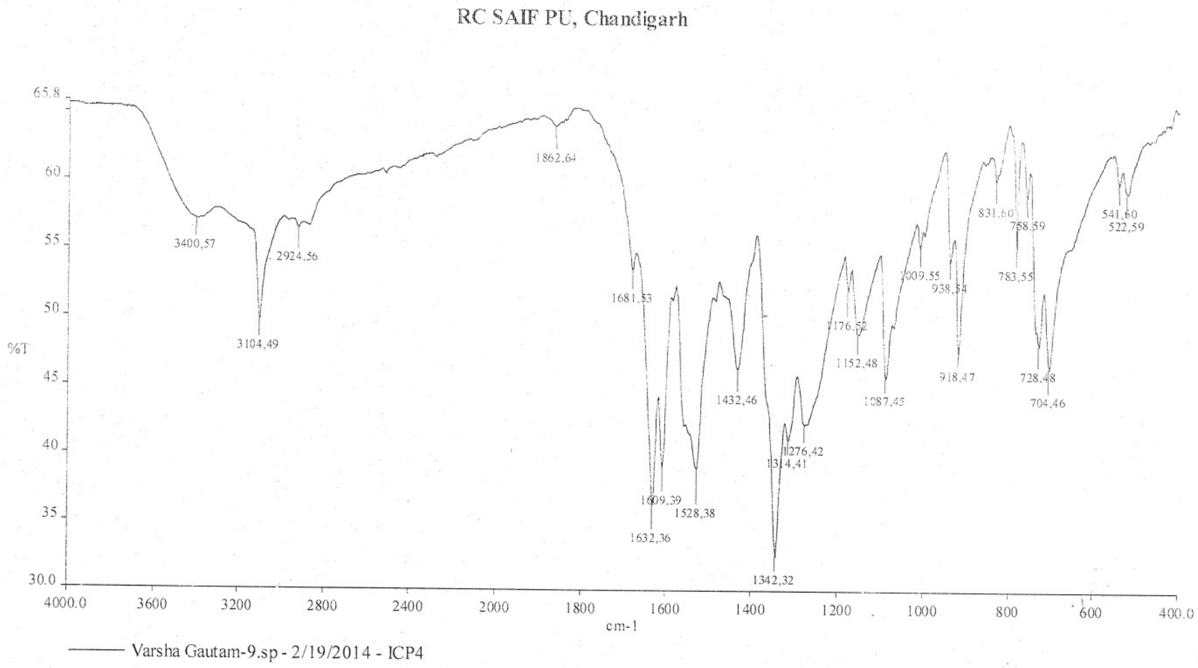
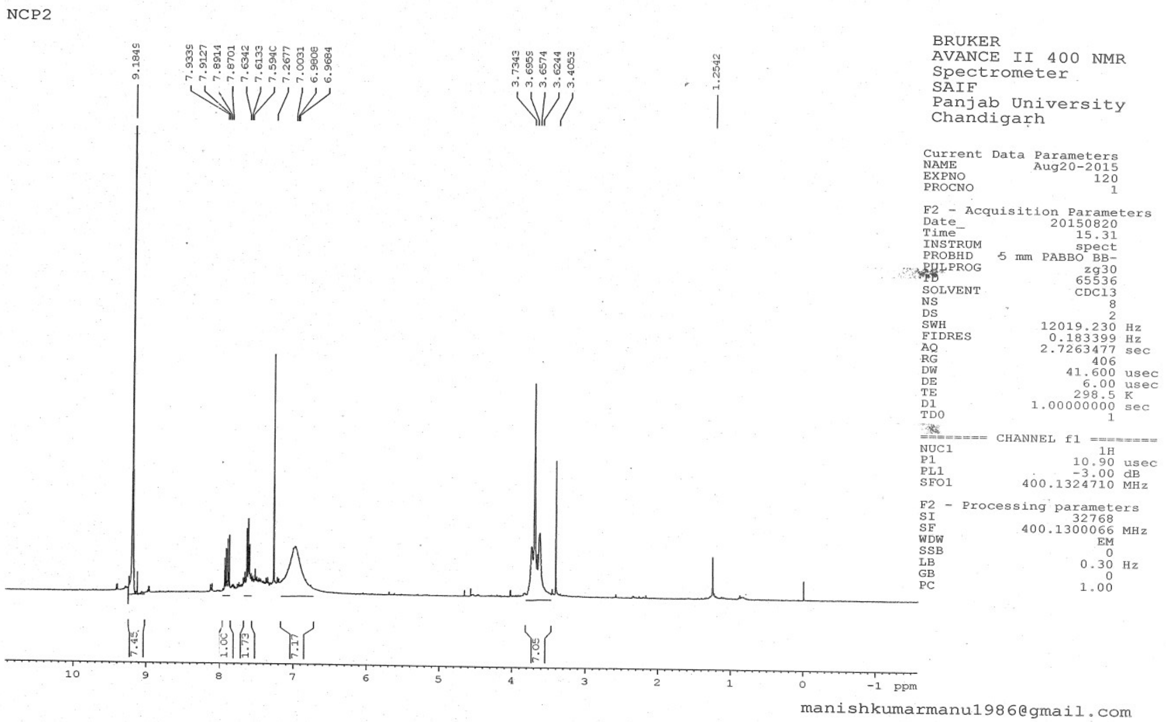


Fig. 36 : IR Spectrum of Podand A$_3$-Ca(Pic)$_2$ Complex



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BRUKER
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Spectrometer
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Panjab University
Chandigarh

Current Data Parameters
NAME            Aug20-2015
EXPNO                  120
PROCNO                   1

F2 - Acquisition Parameters
Date_             20150820
Time                 15.31
INSTRUM              spect
PROBHD   5 mm PABBO BB-
PULPROG               zg30
TD                   65536
SOLVENT              CDCl3
NS                       8
DS                       2
SWH              12019.230 Hz
FIDRES            0.183399 Hz
AQ               2.7263477 sec
RG                     406
DW                  41.600 usec
DE                    6.00 usec
TE                   298.5 K
D1              1.00000000 sec
TD0                      1

======== CHANNEL f1 ========
NUC1                    1H
P1                   10.90 usec
PL1                  -3.00 dB
SFO1           400.1324710 MHz

F2 - Processing parameters
SI                   32768
SF             400.1300066 MHz
WDW                     EM
SSB                      0
LB                    0.30 Hz
GB                       0
PC                    1.00
```

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Fig. 37 : ^{1}H NMR Spectrum of Podand A_3-Ca(Pic)$_2$ Complex

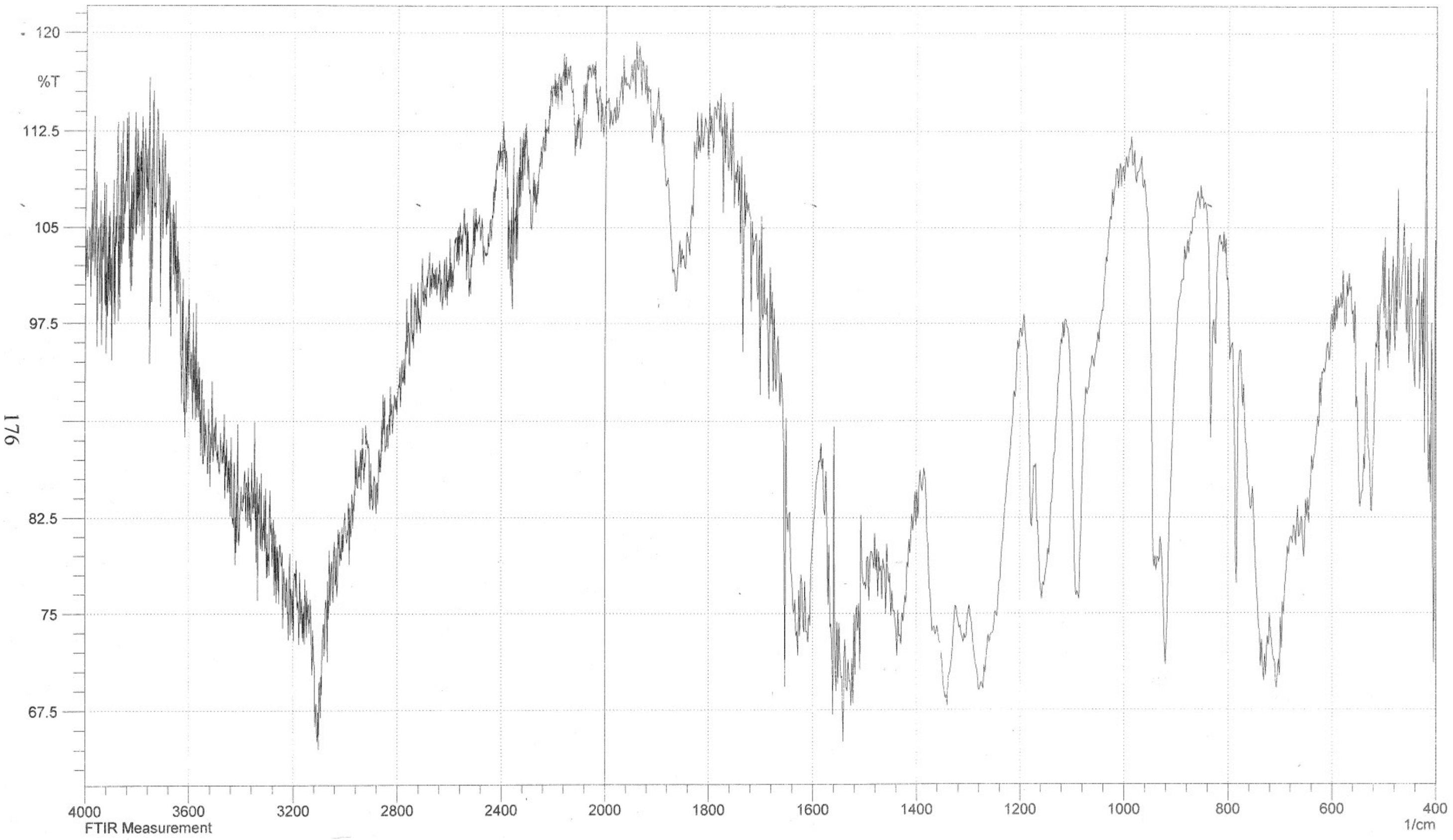
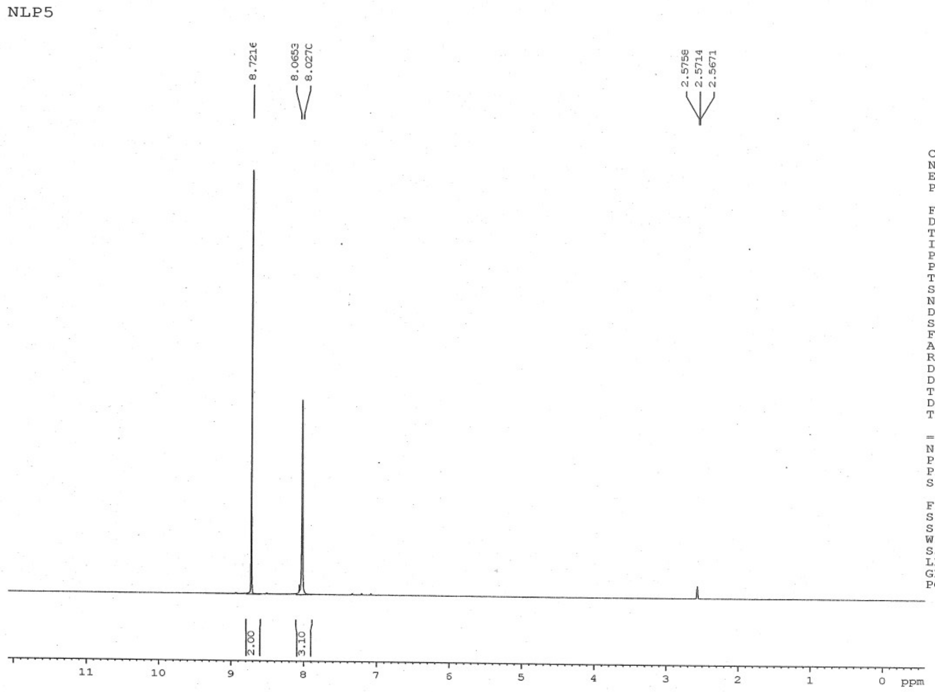


Fig. 38 : IR Spectrum of Podand A_5-Li.Pic Complex

Date/Time; 11/16/2011 12:42:44 PM
User; Intel Inside



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BRUKER
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Chandigarh

Current Data Parameters
NAME          Jun03-2015
EXPNO                 80
PROCNO                 1

F2 - Acquisition Parameters
Date_           20150603
Time               13.26
INSTRUM            spect
PROBHD   5 mm PABBO BB-
PULPROG             zg30
TD                 65536
SOLVENT             DMSO
NS                    16
DS                     2
SWH             8223.685 Hz
FIDRES          0.125483 Hz
AQ             3.9846387 sec
RG                   645
DW                60.800 usec
DE                  6.00 usec
TE                 297.2 K
D1            1.00000000 sec
TD0                    1

======== CHANNEL f1 ========
NUC1                  1H
P1                 10.90 usec
PL1                -3.00 dB
SFO1         400.1324710 MHz

F2 - Processing parameters
SI                 32768
SF           400.1299754 MHz
WDW                   EM
SSB                    0
LB                  0.30 Hz
GB                     0
PC                  1.00
```

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Fig 39: ^{1}H NMR Spectrum of Podand A$_5$-Li.Pic Complex

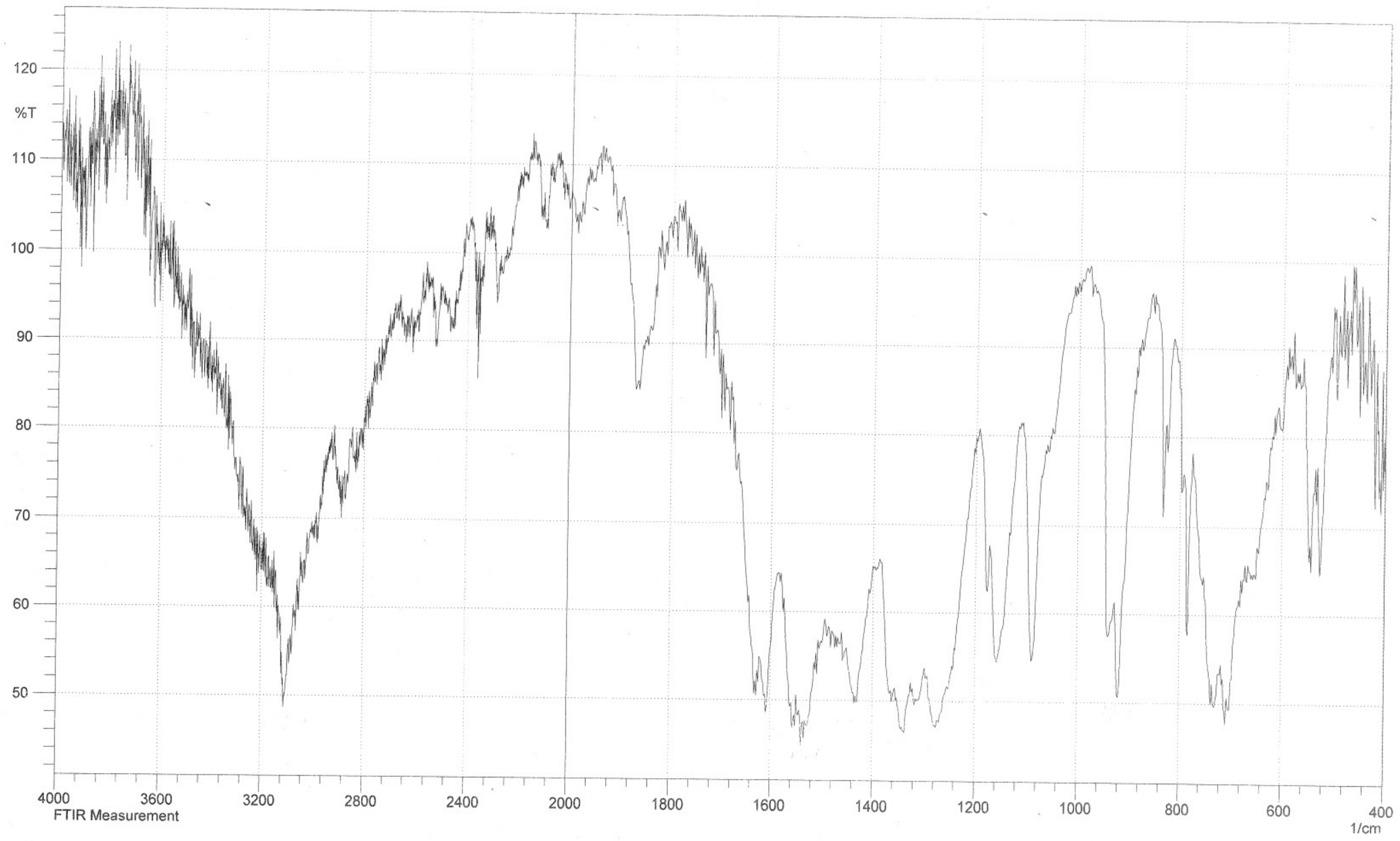

Fig. 40 : IR Spectrum of Podand A_5-K.Pic Complex

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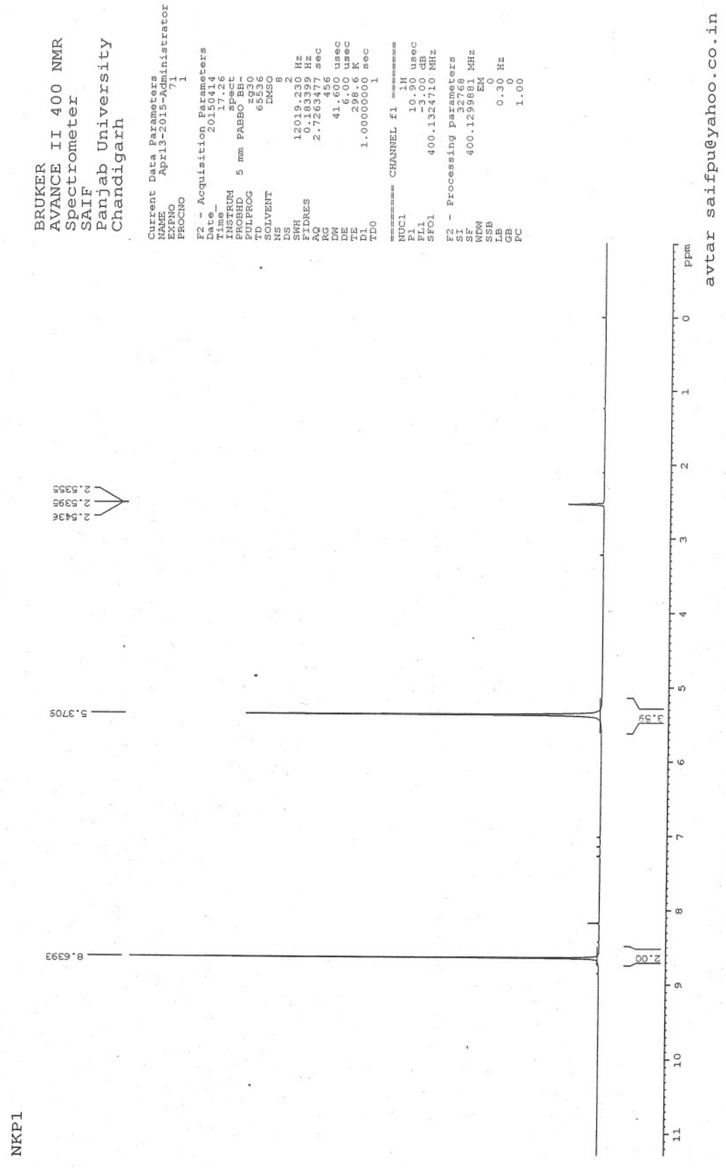


Fig. 41 : ^{1}H NMR Spectrum of Podand A_5-K.Pic Complex

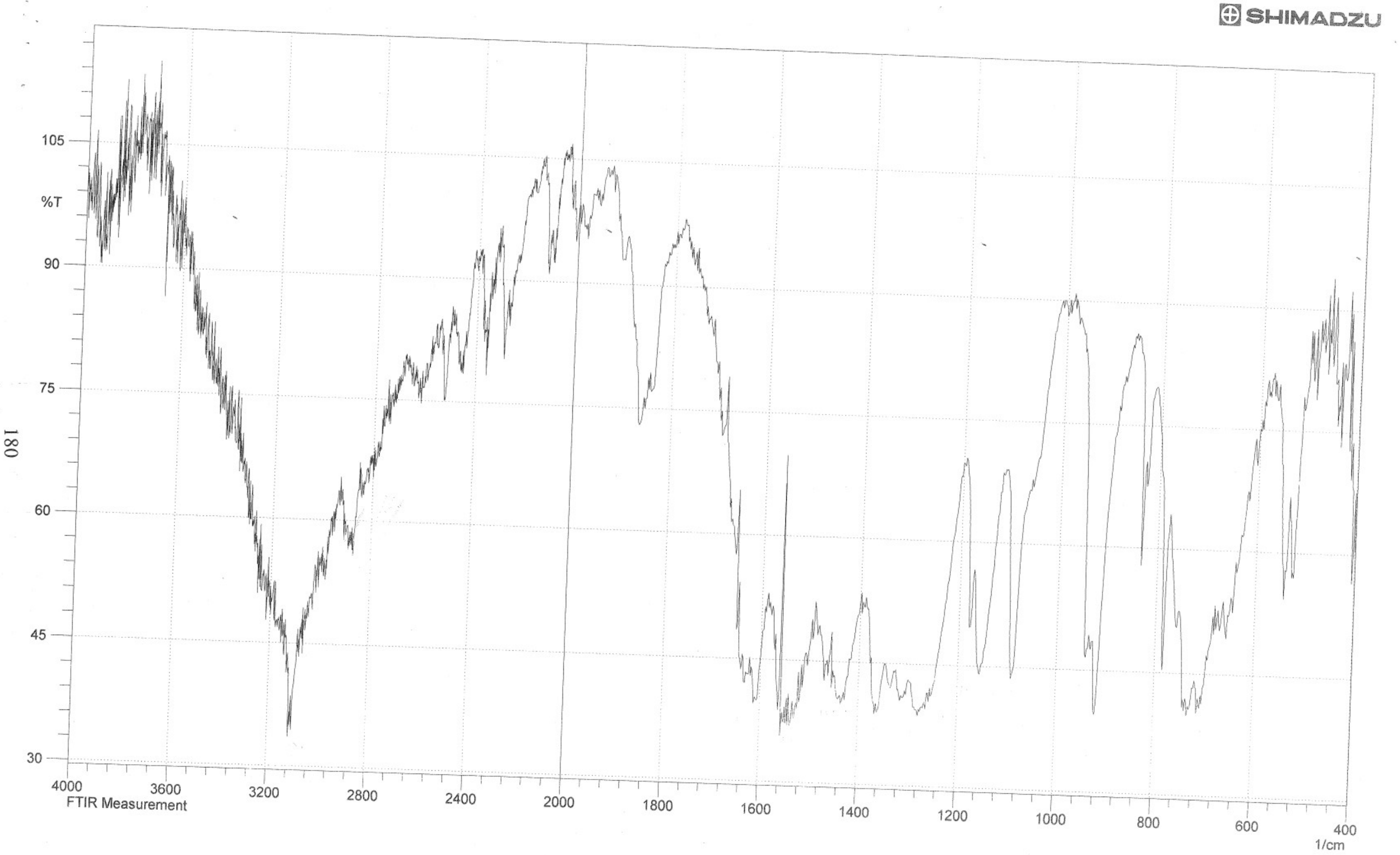


Fig. 42 : IR Spectrum of Podand A_5-$Mg(Pic)_2$ Complex

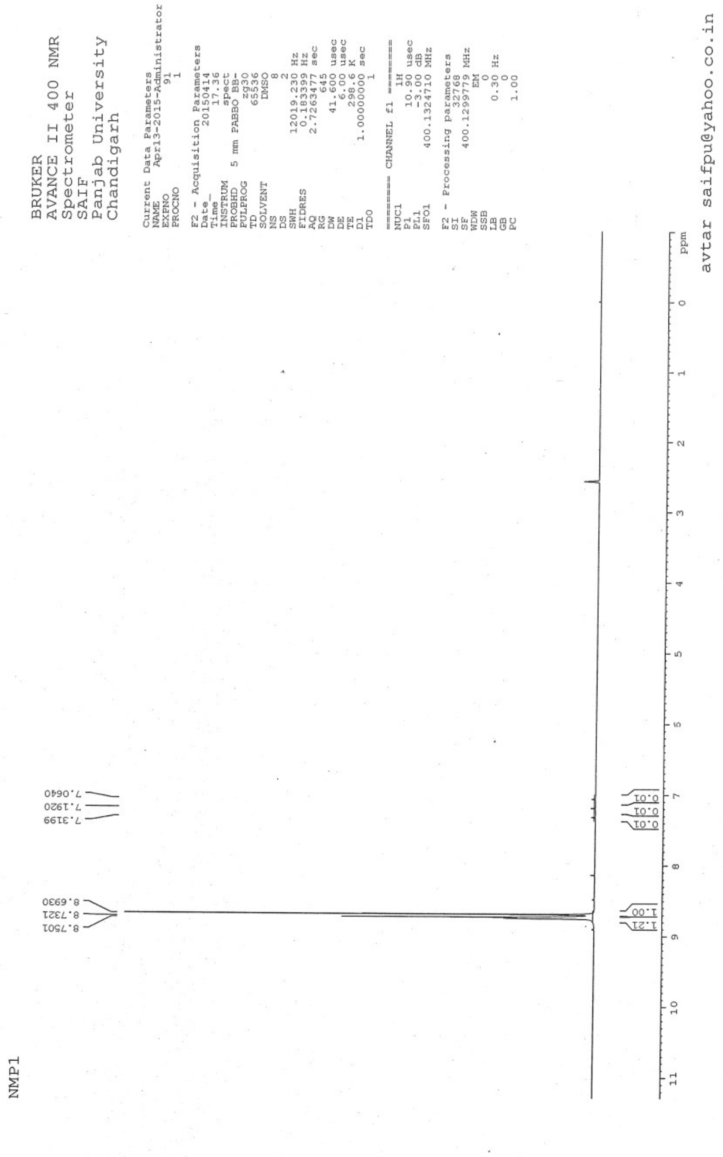


Fig. 43 : ^{1}H NMR Spectrum of Podand A$_5$-Mg(Pic)$_2$ Complex

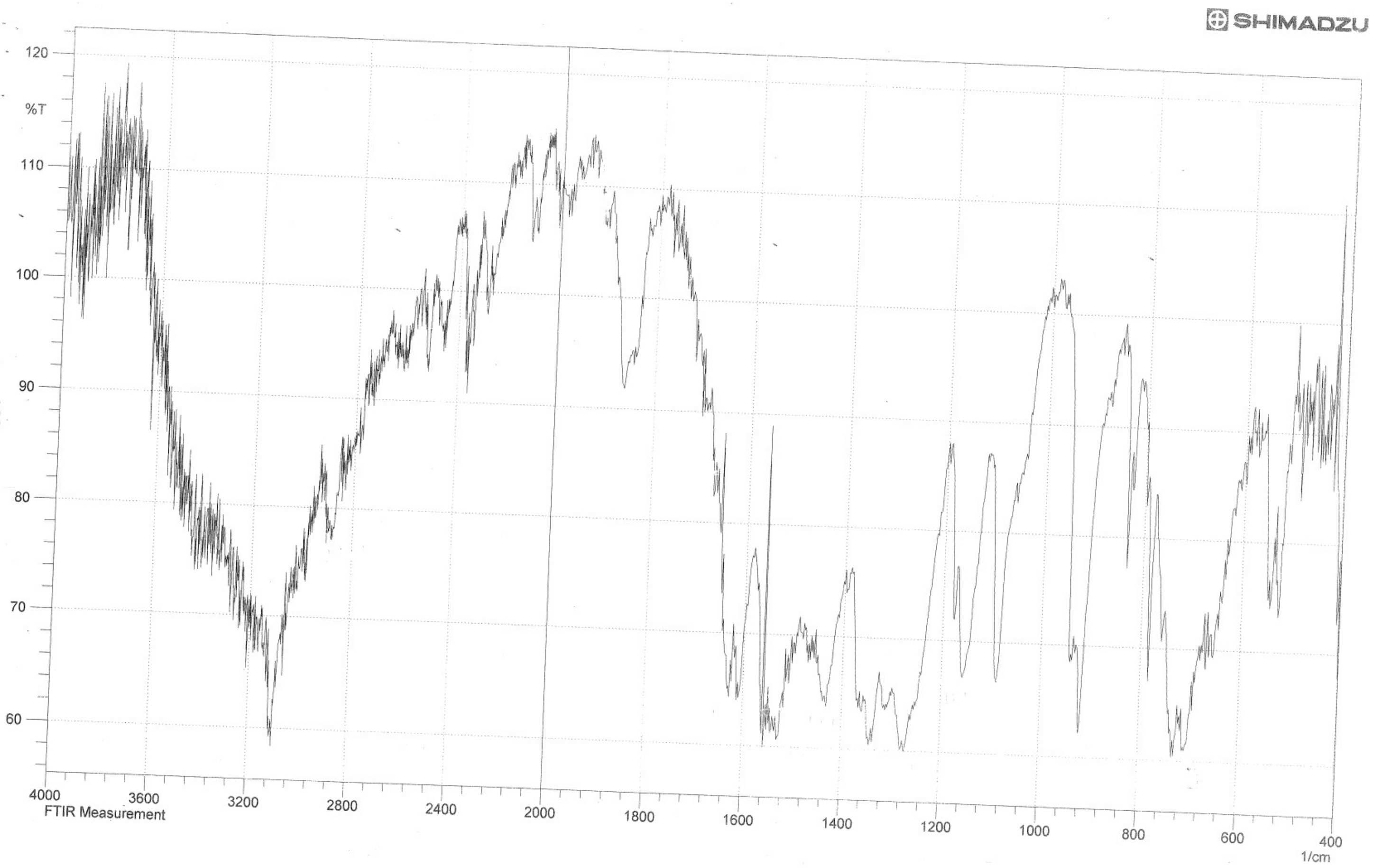
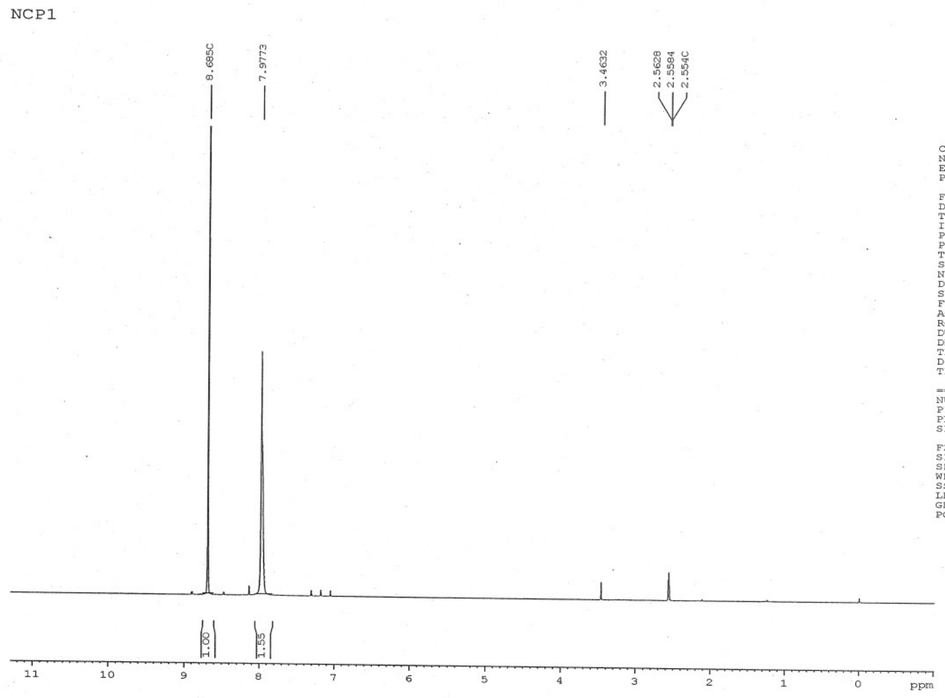


Fig. 44 : IR Spectrum of Podand A_5-Ca(Pic)$_2$ Complex



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BRUKER
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Panjab University
Chandigarh

Current Data Parameters
NAME      Apr13-2015-Administrator
EXPNO                     81
PROCNO                     1

F2 - Acquisition Parameters
Date_               20150414
Time                   17.31
INSTRUM                spect
PROBHD   5 mm PABBO BB-
PULPROG                 zg30
TD                     65536
SOLVENT                 DMSO
NS                         8
DS                         2
SWH              12019.230 Hz
FIDRES            0.183399 Hz
AQ               2.7263477 sec
RG                       362
DW                    41.600 usec
DE                      6.00 usec
TE                     298.6 K
D1              1.00000000 sec
TD0                        1

======== CHANNEL f1 ========
NUC1                      1H
P1                     10.90 usec
PL1                    -3.00 dB
SFO1             400.1324710 MHz

F2 - Processing parameters
SI                     32768
SF               400.1299807 MHz
WDW                       EM
SSB                        0
LB                      0.30 Hz
GB                         0
PC                      1.00
```

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Fig. 45 : ^{1}H NMR Spectrum of Podand A_5-Ca(Pic)$_2$ Complex

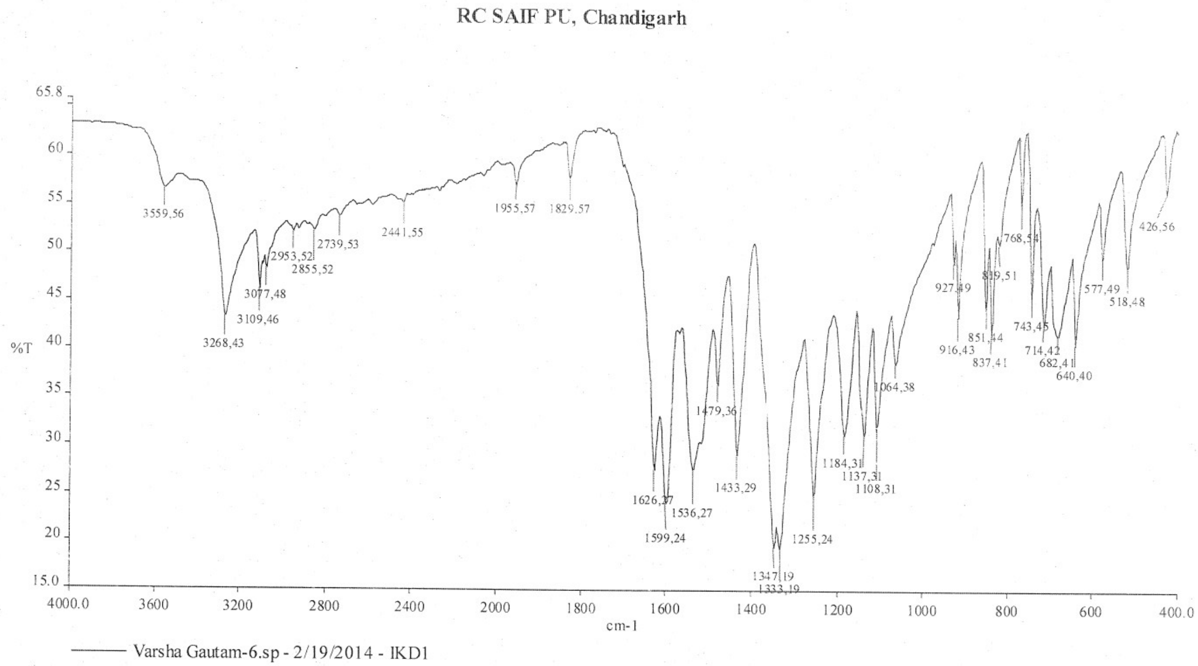
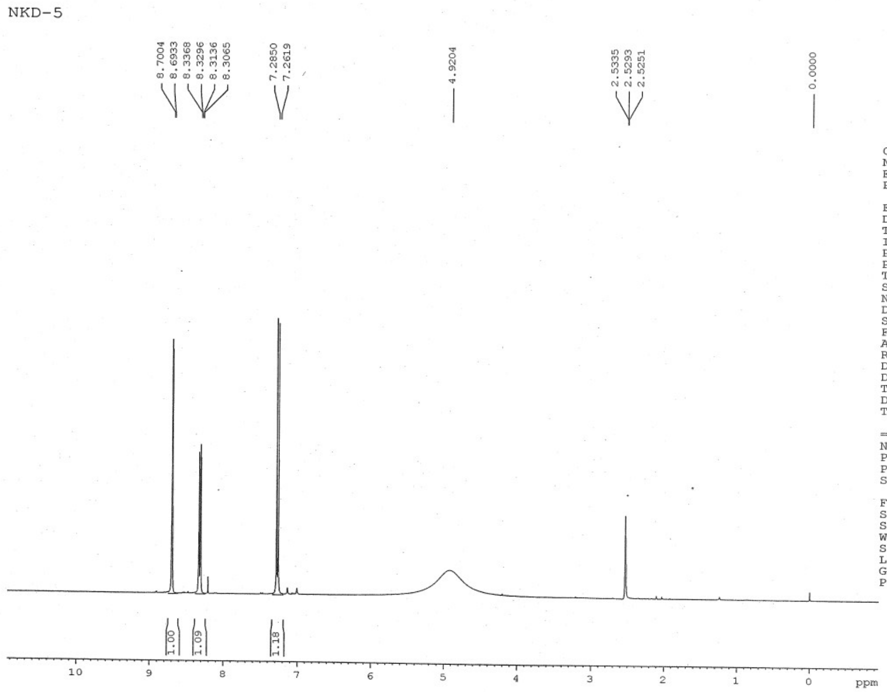


Fig. 46 : IR Spectrum of Podand A_5-K.Dnp Complex



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BRUKER
AVANCE II 400 NMR
Spectrometer
SAIF
Panjab University
Chandigarh

Current Data Parameters
NAME              Jun12-2015
EXPNO                     40
PROCNO                     1

F2 - Acquisition Parameters
Date_               20150612
Time                   14.09
INSTRUM                spect
PROBHD     5 mm PABBO BB-
PULPROG                 zg30
TD                     65536
SOLVENT                 DMSO
NS                        16
DS                         2
SWH                12019.230 Hz
FIDRES              0.183399 Hz
AQ                 2.7263477 sec
RG                       322
DW                    41.600 usec
DE                      6.00 usec
TE                     300.0 K
D1                1.00000000 sec
TD0                        1

======== CHANNEL f1 ========
NUC1                      1H
P1                     10.90 usec
PL1                    -3.00 dB
SFO1             400.1324710 MHz

F2 - Processing parameters
SI                     32768
SF               400.1299919 MHz
WDW                       EM
SSB                        0
LB                      0.30 Hz
GB                         0
PC                      1.00
```

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Fig. 47 : ^{1}H NMR Spectrum of Podand A$_5$-K.Dnp Complex

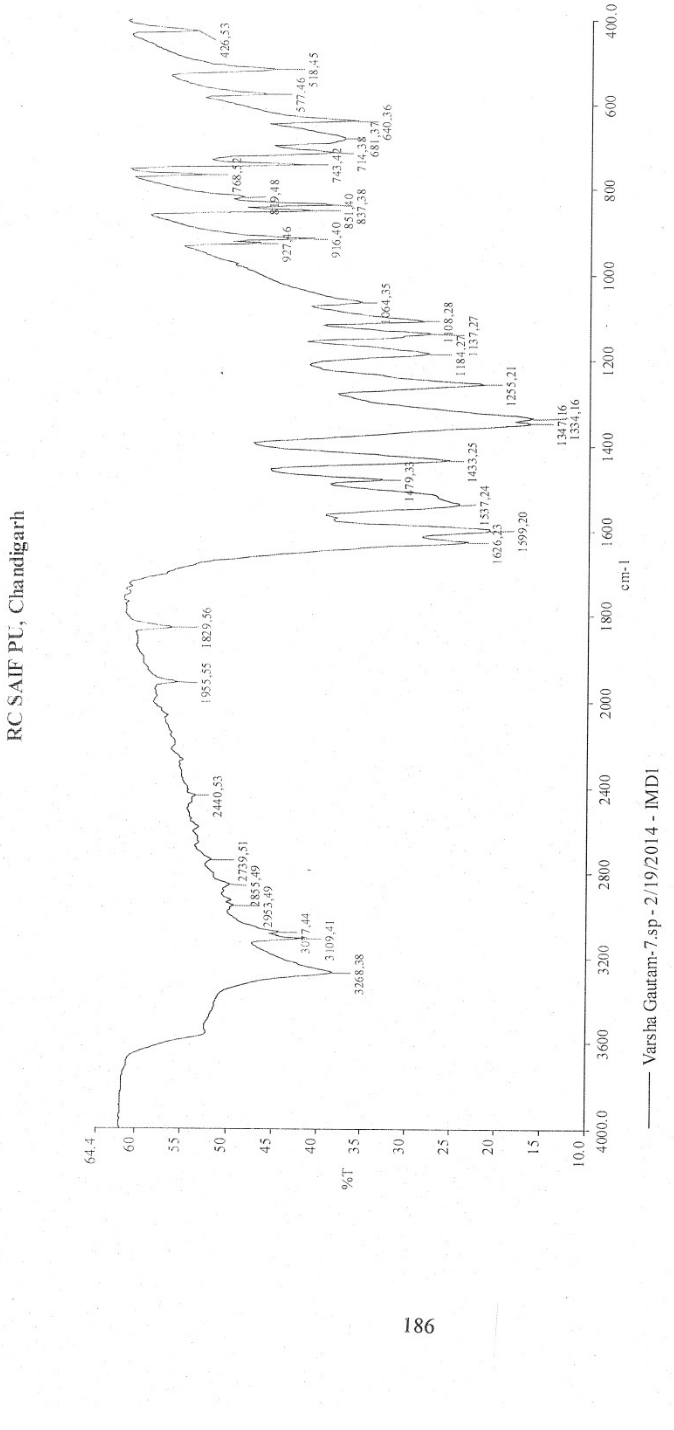
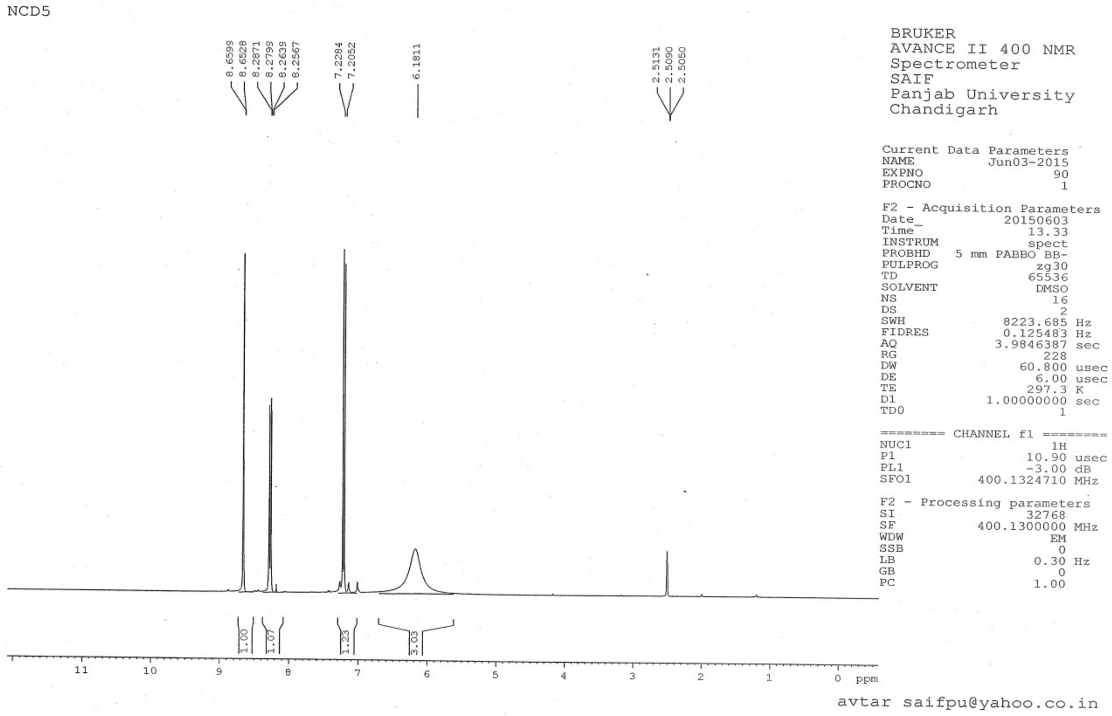


Fig. 48 : IR Spectrum of Podand A_5-Mg(Dnp)$_2$ Complex



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SAIF
Panjab University
Chandigarh

Current Data Parameters
NAME          Jun03-2015
EXPNO                 90
PROCNO                 1

F2 - Acquisition Parameters
Date_           20150603
Time               13.33
INSTRUM            spect
PROBHD   5 mm PABBO BB-
PULPROG             zg30
TD                 65536
SOLVENT             DMSO
NS                    16
DS                     2
SWH             8223.685 Hz
FIDRES          0.125483 Hz
AQ             3.9846387 sec
RG                   228
DW                60.800 usec
DE                  6.00 usec
TE                 297.3 K
D1            1.00000000 sec
TD0                    1

======== CHANNEL f1 ========
NUC1                  1H
P1                 10.90 usec
PL1                -3.00 dB
SFO1         400.1324710 MHz

F2 - Processing parameters
SI                 32768
SF           400.1300000 MHz
WDW                   EM
SSB                    0
LB                  0.30 Hz
GB                     0
PC                  1.00
```

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Fig. 49 : ^{1}H NMR Spectrum of Podand A_5-Mg(Dnp)$_2$ Complex

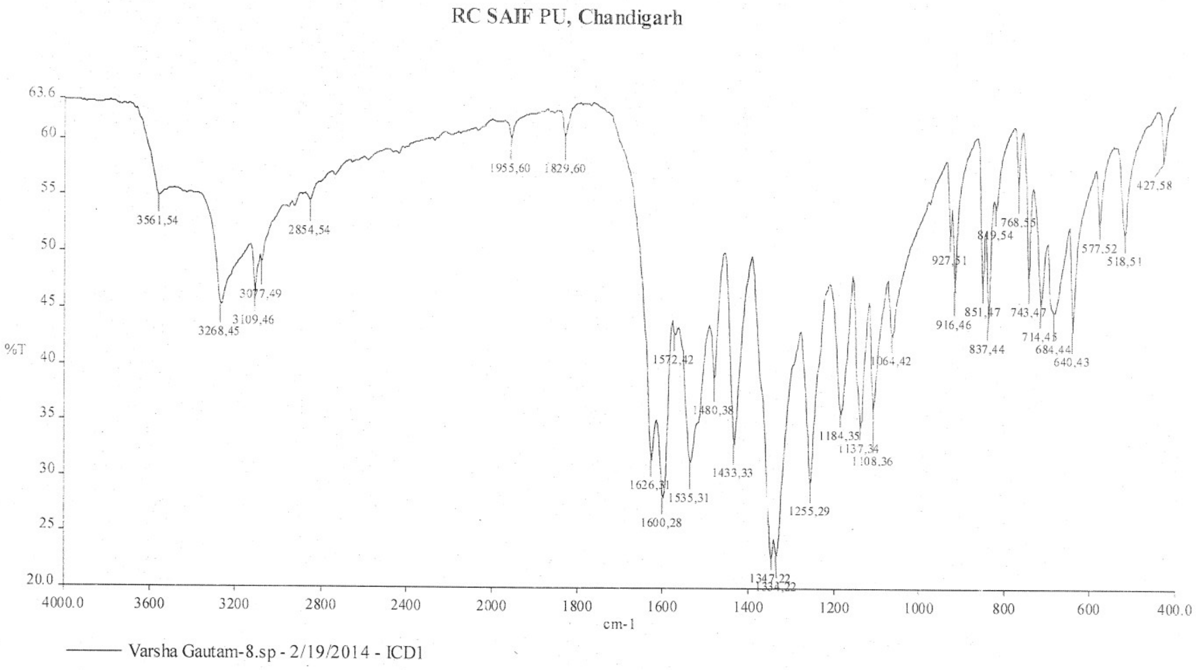
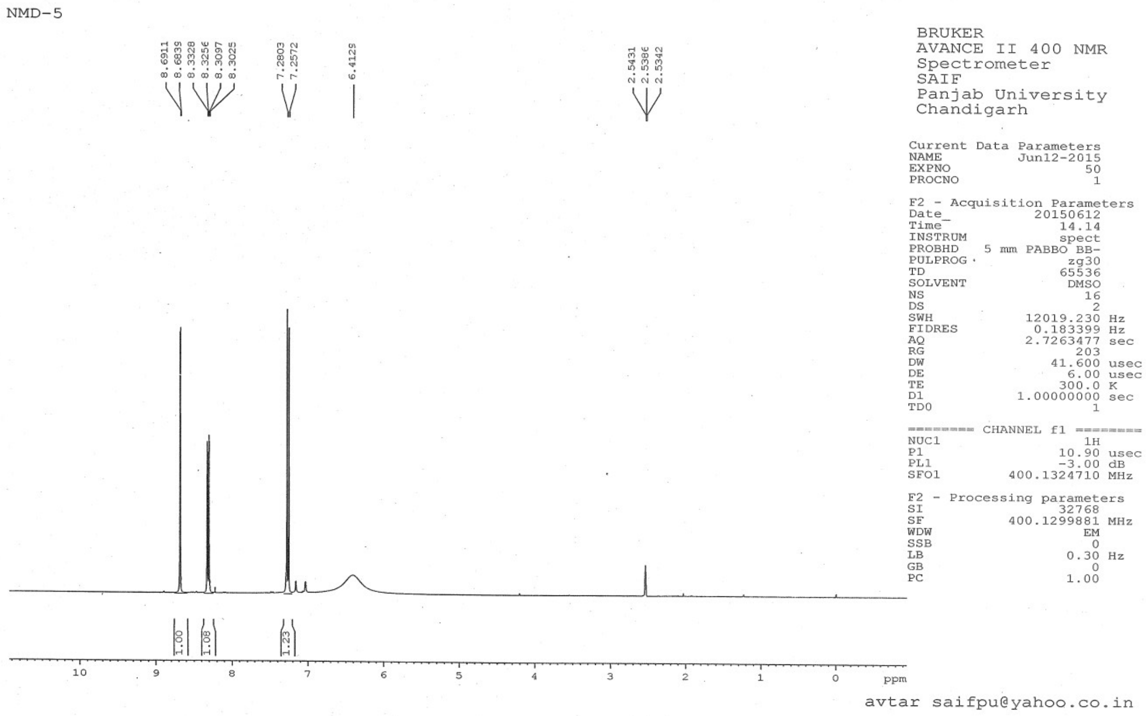


Fig. 50 : IR Spectrum of Podand A_5-Ca(Dnp)$_2$ Complex



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BRUKER
AVANCE II 400 NMR
Spectrometer
SAIF
Panjab University
Chandigarh

Current Data Parameters
NAME          Jun12-2015
EXPNO                 50
PROCNO                 1

F2 - Acquisition Parameters
Date_           20150612
Time               14.14
INSTRUM            spect
PROBHD   5 mm PABBO BB-
PULPROG             zg30
TD                 65536
SOLVENT             DMSO
NS                    16
DS                     2
SWH            12019.230 Hz
FIDRES          0.183399 Hz
AQ             2.7263477 sec
RG                   203
DW                41.600 usec
DE                  6.00 usec
TE                 300.0 K
D1            1.00000000 sec
TD0                    1

======== CHANNEL f1 ========
NUC1                  1H
P1                 10.90 usec
PL1                -3.00 dB
SFO1         400.1324710 MHz

F2 - Processing parameters
SI                 32768
SF           400.1299881 MHz
WDW                   EM
SSB                    0
LB                  0.30 Hz
GB                     0
PC                  1.00
```

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Fig. 51 : ^{1}H NMR Spectrum of Podand A_5-Ca(Dnp)$_2$ Complex

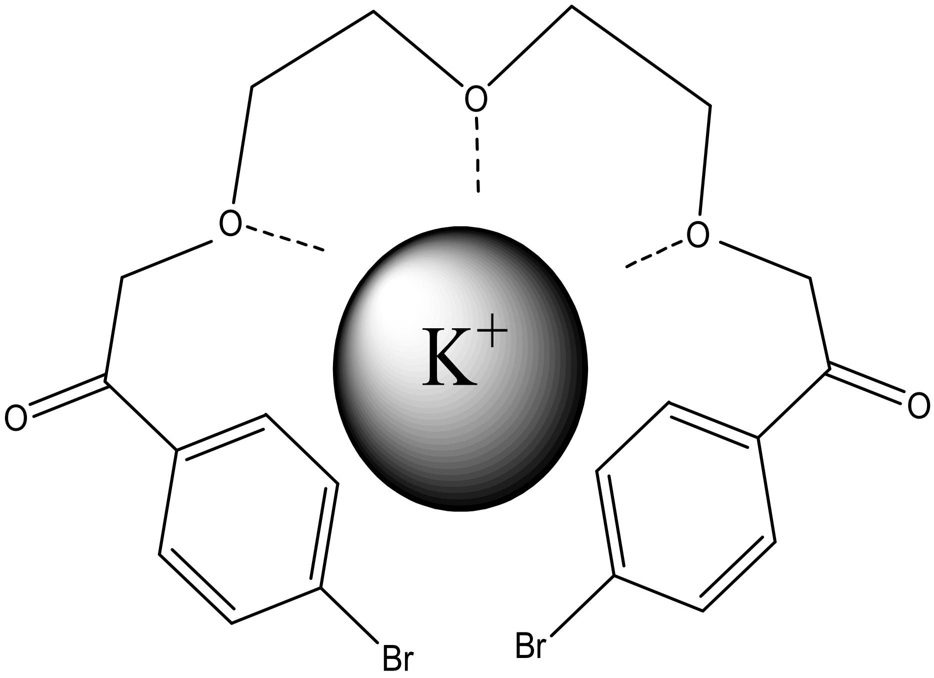

Figure 52: Schematic representation of complexation of K^+ ion in the pseudocyclic cavity of podand A_1

References-

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Conclusion & future prospects

The outcome of this work is:

- We have designed and synthesized a new series of podands (A_1-A_4) containing p-bromophenacyl moiety as aromatic end group.
- Two podands A_5 and A_6 were purchased from Aldrich.
- These podands (A_1-A_6) were used for extraction, transport and isolation studies of alkali and alkaline earth metal ions through bulk liquid membrane.
- Maximum extraction was observed with podand A_3, which indicates that podand A_3 form stable complex with metal ions through ion-dipole interactions.
- It was observed that podand A_1 and A_3 were found to be better extractants for Na^+, K^+ and Ca^{2+} ions. This extractability can be explained by the presence of double aromatic (p-bromophenacyl moieties) end group which enhance the extraction of metal ions in comparison to simple glycols.
- Among all podands, A_4 shows maximum transport of cations (Na^+, K^+ and Ca^{2+}) with all three bulk liquid membranes.
- All podands are highly specific for K^+ during extraction while highly specific for Ca^{2+} during transport.
- Noncyclic carriers are thought to complex Ca^{2+} ions rather loosely but transport it most efficiently.
- Podand A_5 was found to be least effective for extraction and transport studies due to its smallest chain length.
- Among anions picrate is found to be best in comparison to dinitrophenolate and orthonitrophenolate during extraction and transport studies.
- Among all three bulk liquid membranes dichloromethane was found to be the best in comparison to 1,2-dichloroethane and chloroform.
- In isolation studies, podand A_2 and A_5 form complexes with Li^+ and Mg^{2+} ions in solid state whereas these podands fails to extract and transport Li^+ and Mg^{2+} ions in solution state. The interaction of podands with M^{Z+} in solid state and solution state are not same.
- From the elemental analysis and metal estimation it is observed that stoichiometry is found 1:1 for alkali metal complexes and 1:2 for alkaline earth metal complexes.

- These results can be used to explore the possibility in designing a new and specific carrier for metal ion selective electrode.
- We found that on the insertion of aromatic end group (p-bromophenacyl moiety) in podands the isolation, extraction and transport efficiency enhanced. The molecular designing helps in chemical sensors and separation of metal ions.
- Compilation of our results indicates that this kind of studies will lead us to design and synthesized new carriers which will be effective in separation of different cations and helpful in understanding the mechanism of transport in biological membranes.

Future Prospects-

- We can say that the simplicity, low cost, high efficiency and selectivity for metal ions transport obtained by the bulk liquid membranes system demonstrate its potential applicability to selective removal, concentration and purification of metal ions from its mixtures or from environment.
- According to the experimental data we will develop new easily synthesizable and cheap system for the separation of metal ions.
- Variation in designing of podands governs their extraction and transport ability. In future new podands can be designed on the basis of molecular topology and our results.
- In biological cells have many curved membranes and the selective binding of proteins depending on curvature gives exciting possibility of a local microenvironment in which specific interaction with substrate/ ions are more likely to occur. This ability of protein to alter the membrane curvature is emerging field of study. Thus these podands folds and wrap around the metal ion/substrate accordingly. This opens a link to biomimetic chemistry.
- Thus, supramolecular chemistry is an inspiration, building block and method to study and understand the properties of complexes in biology, organic-inorganic and physical chemistry respectively. Metal ion selective podands can be used for the construction of devices for quantitative and qualitative estimation based on molecular designing and biomimmetics for enzymes.

List of seminars/ conferences attended-

1. National conference entitled "*Environmental Health Hazards-2009 (EHH-2009)*" at J.D.B. Girls College, Kota (Rajasthan) during ***December 17-18, 2009 (PAPER PRESENTED).***

2. National symposium entitled "*National Symposium on Recent Advances in Chemical Sciences (NSRACS-2011)"* at University of Kota, Kota (Rajasthan) during ***January 07-08, 2011 (POSTER PRESENTATION).***

3. International conference entitled "*Advanced Trends in Engineering, Technology and Research (ICATETR-2015)"* at Bal Krishna Institute of Technology, Kota (Rajasthan) during ***December 23-24, 2015 (PAPER PRESENTED & RECEIVED BEST PAPER AWARD).***

4. National conference entitled "*Advances Chemical, Environmental and Biological sciences (ACEBS-2016)*" at Department of Chemistry, Government Meera Girls College, Udaipur (Rajasthan) on ***September 10, 2016 (POSTER PRESENTATION).***

List of publications-

1. *Extraction and transport of alkali metal ions through bulk liquid membranes by ethyleneglycoldiacetate*. Varsha Gautam, Loni Lokwani, Sharda Sharma and

Uma Sharma, ***International Journal of Chemical and Pharmaceutical Research**,* Vol. 5920, PP. 243-249 **(2013)**

2. *Extraction and bulk liquid membrane transport of alkali metal ions facilitated by tripropyleneglycolmonobutylether*. Varsha Ggautam, Loni Lokwani and Sharda Sharma, ***International Journal of Innovative Research in Science, Engineeering and Technology***, Vol. 4(4), pp. 2079-2087 **(2015)**

3. *Extraction and bulk liquid membrane transport of* Mg^{2+} *and* Ca^{2+} *ions by tripropyleneglycolmonobutylether.* Varsha Gautam, Loni Lokwani and Sharda Sharma, ***Proc. Int. Conf. on " Advanced Trend in Engineering, Technology and Research", ISBN: 978-81-930823-1-7,*** pp. 122-126 **(2015)**

4. *Synthesis of new noncyclic ionophores and their use in extraction and bulk liquid membrane transport of alkali metal ions.* Varsha Gautam, Loni Lokwani, Sharda Sharma and Uma Sharma, ***International Journal of Chemical and Physical Sciences**,* Vol. 5940, pp. 81-91 **(2016)**

5. *Study of extraction and bulk liquid membrane transport of* Ca^{2+}*&* Mg^{2+} *ions by new synthesized noncyclic ionophores*. Varsha Gautam, Loni Lokwani and Sharda Sharma, **Proc. Natl. Conf. on " Advances in chemical, Environmental and Biological Sciences",** pp. 49-55 **(2016)**