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ABSTRACT

ORGANOCLAY AS TRIPHASE CATALYSTS

By

Chi-Li Lin

A new type of triphase catalysts has been synthesized by intercalation of quaternary onium cations in smectite clays. These clay-supported phase transfer catalysts, as well as other triphase catalysts, are easily recovered by filtration and ideally suited for continuous flow methods. However, the onium-ion functionalized smectite clays have certain advantages over conventional triphase catalysts: i) they are stable under reaction conditions and provide efficient interfacial surfaces for the catalysis of organic reactions. ii) their catalytic properties are comparable to analogous biphase catalysts. iii) they can avoid using polar solvent in the catalytic process.

The mechanistic investigation of this organoclay catalysis for alkylbromide displacement has indicated that the reaction mixtures form an oil-in-water emulsion in which the organoclay plays an essential role in stabilizing the emulsion. Three fundamental kinetic steps of the organoclay catalysis have also been proposed. In additional, the organoclays have been applied to a variety of useful synthetic transformations in which the organoclays were shown to be more efficient than the

analogous polymer-supported phase transfer catalysts. The catalytic properties of several commercial organoclays and organo-layered compounds were also studied in comparison with those of our organoclay.

Furthermore, the intercalation of chiral phase transfer cations in smectites has developed a new series of triphase chiral catalysts. The stereoselectivity and mechanism of these organoclays in the borohydride reduction of ketones and in the epoxidation of chalcone were studied. Although a great deal of research needs to be done before the kinetic steps of clay-supported chiral catalysis can be proposed. It has to be emphasized that the clay-supported chiral catalysts are practically superior to conventional biphase catalysts. Moreover, for a given chiral cation we are able to alter its optical selectivity by intercalating the cation on various clay hosts.

TO MY FAMILY

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Chapter I

INTRODUCTION

A. Structure and Properties of Layered Silicates

1. Structure

The layered silicate described in this dissertation belongs to a class of clay minerals known as smectite. The term " clay minerals" refers to specific structural types silicate with particle size less than 2 μm and with a definite stoichiometry and crystalline structure. Recent advances in X-ray crystallography and structural analysis have affirmed that completely ordered clay structures represent no more than ideal models (1,2).

Smectites are composed of units made up of two silica tetrahedra sheets and a central octahedral sheet of magnesia or alumina. The silicate tetrahedral are usually oriented so that the three basal oxygen atoms of each tetrahedron lie on the same plane, while the fourth oxygen atom defines a second common plane. The octahedral sheet contains a cation, usually Al or Mg, surrounded by six oxygens in an octahedral arrangement. The tetrahedral and octahedral sheets are combined so that the tips of the tetrahedrons of each silica sheet and the oxygens of the octahedral sheet form a common layer. Smectite clays are 2:1 layer minerals which are divided broadly into two structures : dioctahedral aluminum silicate minerals (Figure 1) and trioctahedral, magnesium silicate minerals (Figure 2). These can subdivided into groups in which the layer charge arises predominantly from isomorphous substitution in the octahedral layer and from substitution in tetrahedral layer. Further subdivisions can be made on the basis of layer charge density (Figure 3). Cations at particular locations of the silicate structure can be replaced by various other cations with similar ionic radii without changing the structural characteristics of the mineral. If the replacing cation has a lower valence, a net negative charge will develop. Charge neutrality is achieved either by an opposing substitution with cations of higher valence or, as is usually the case, by the presence of additional cations, normally, arrays of hydrated alkaline earth or alkali metal cations in the interlayer region of the structure. The charge balancing cations are usually located adjacent to the points of anionic charge on the basal planes. However, small anhydrous cations, mainly H^+ or Li^+, can migrate through the oxygen sheet to the neighborhood of the substitution, where the anionic charge arises. Hectorite, Laponite and Fluorohectorite are the three smectites of principal interest in the present work. The idealized unit cell composition for hectorite is

$$M_{0.67}[Mg_{5.33}Li_{0.67}]^{VI}(Si_{8.0})^{IV}O_{20}(OH,F)_4$$

in which the superscripts (IV) and (VI) refer to the respective cation in tetrahedral and octahedral sites, and M represents a univalent or equivalent compensating cation (1). The commercial filler, Laponite is a synthetic low-charge hectorite (about 0.4 e^- per $O_{20}[OH,F]_4$) which, unlike the natural mineral, can be obtained with a negligible iron content. Fluorohectorite is another synthetic high-charge smectite (about 1.8 e^- per $O_{20}F_4$) in which the octahedral lattice hydroxyl groups have been replaced with fluoride ions. The idealized unit cell composition for Laponite and Fluorohectorite are

$$Li_{0.36}[Li_{0.36}Mg_{5.64}](Si_{8.00})O_{20}(OH)_4$$

$Li_{1.6}[Li_{1.6}Mg_{4.4}](Si_{8.00})O_{20}F_4$

Interlamellar spacings in general depend upon the species of exchangeable cation present, the nature of solvent, and whether or not any electrolytes are present.

2. Ion Exchange

The hydrated compensating cations of minerals are exchangeable. However, there is a size limitation for ion replacement. Hectorite, for example, exhibits an average distance about 8.7 Å between exchange sites based on the calculation of a cation exchange capacity (73 milliequivalents per 100 g of air dried clay) and the a and b unit cell parameter of the mineral (5.25 x 9.18 Å) (3). Thus, cations with cross-section diameters greater than this value will fill the interlamellar spaces before an homoionic clay is achieved. And although the interlamellar surface is very large (750 m^2/g), the size of the exchanging ion can be a limiting factor in determining ion loading.

The kinetics and equilibria of the exchange reaction depend on several variables (4,5). In general the exchange equilibrium favors a) cations with higher valence charge; b) the larger cation between species of a particular valence. Certain cations because of their size can take up a very favorable interlayer position. The rate of exchange reaction is determined mainly by the swelling properties of the mineral, the nature and concentration of cations. In smectite the position of exchangeable cations are about 80 percent on the basal plane surfaces, with the remainder on the edges.

3. Swelling and Catalytic Properties of Smectites

Smectite clays can be swelled by adsorption of water or organic solvent. With multiple layers of solvents the galleries become liquid-like, and accessible for chemical reactions. The osmotic swelling of smectite clays is limited by the electrostatic interactions between the anionic silicate layers and compensating interlayer cations. As the solvent content increases the basal spacings of smectite clays also increase. The

Figure 1. The schematic structure of a 2 : 1 dioctahedral aluminum silicate mineral

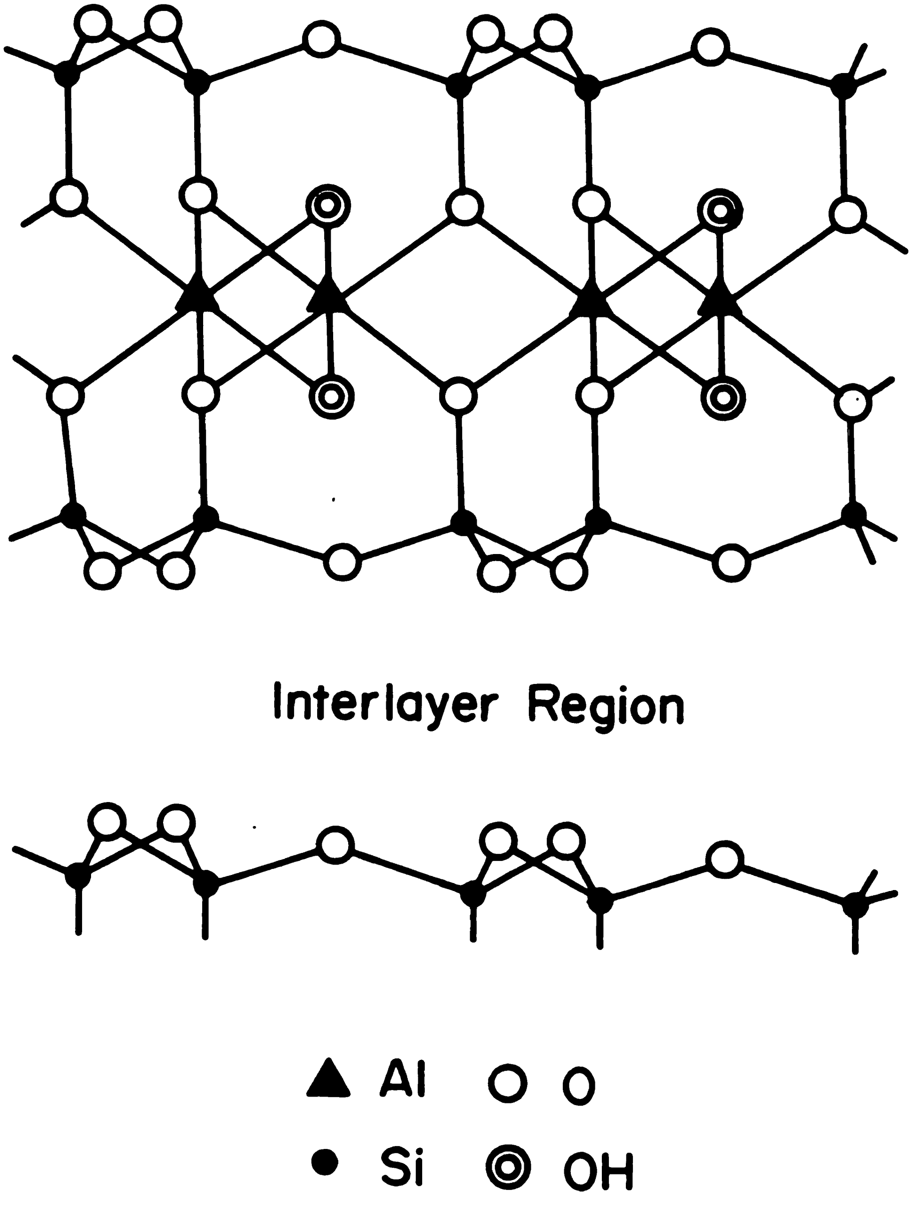
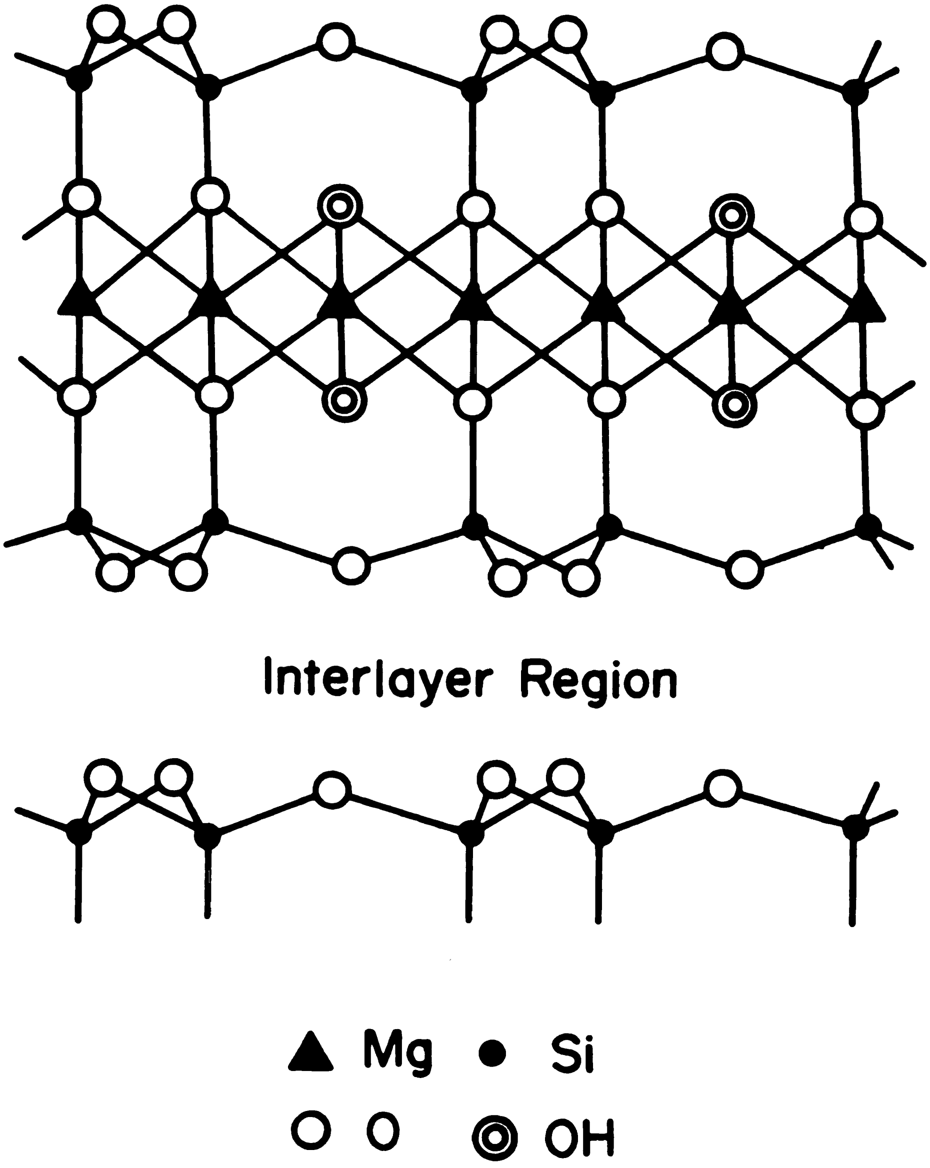

Interlayer Region
Al
O
Si
OH

Figure 2. The schematic structure of a 2 : 1 trioctahedral magnesium silicate mineral


Interlayer Region
▲ Mg
● Si
○ O
◎ OH

SMECTITE CLAYS

DIOCTAHEDRAL	TRIOCTAHEDRAL
MONTMORILLIONITE	HECTORITE
BEIDELITE	SAPONITE
NONTRONITE	

Figure 3 Smectite clays classification

swelling and increases in basal spacing on treatment with solvent not only can be used for identification of these minerals but also plays a very important role in catalytic reaction as well.

In the last few decades, smectite clays and their derivatives have shown catalytic activity in numerous reactions (6-8). Most of the reactions make use of the acidic nature of cation-exchanged or acid treated clay. Both Lewis and Bronsted activity have been noted, the former deriving from aluminum or iron species located at crystal edges (9). The Bronsted activity, however, results either from free acid or from the dissociation of interlayer water molecules coordinated to polarizing interlayer exchangeable cations.

Catalytic organic reactions have often been shown to take place in the interlamellar space. We should expect, therefore, to find instances of unusual factors in these reactions since they occur in a region of high acidity and possibly, in a restricted 2D reaction space.

B. The Principles of Phase Transfer Catalyst

1. The Nature of Phase Transfer Catalyst

Chemists frequently encounter the problem of bringing together two mutually insoluble reagents in sufficient concentration to attain conveniently rapid reaction rates. The traditional procedure would involve dissolving the reactants in a homogeneous medium. But a suitable solvent is not always available and it is usually expensive and difficult to remove after reaction and may present environmental problems in large scale operations.

The technique of " phase transfer catalysis " can permit or accelerate reactions between ionic compounds and organic, water-insoluble substrates in solvents of low polarity (10-12). The basic function of the phase transfer catalyst is to transfer ions, free radicals, neutral molecules, or even energy (in a chemical form) from one phase to another. It is clear that PTC has considerable advantages over conventional procedures since it can: a) remove the requirement for expensive anhydrous or aprotic solvents, b) improve reaction rates, c) lower reaction temperatures, d) simplify work-up e) permit reactions that do not proceed using conventional methods, f) modify selectivity, and g) increase yields.

Reactions involving phase transfer phenomena were performed since 1913 (13). A considerable number of such reactions are buried in older literature (14-16) and especially in patents (17-29) in which quaternary ammonium or phosphonium salts were used as catalysts for two phase reactions. Since some of the authors entered the field more or less incidentally and did not reflect on the mechanisms involved in such catalytic reactions, few realized the potential and scope of the new technique.

PTC techniques as we know them today originated in the work of Makosza and coworker in 1965 (30) and the term "Phase Transfer Catalysis" was coined by Starks and first used in patents in 1968 (11). Although PTC has emerged only in the last decade it already has become a widely useful synthetic technique.

2. Mechanism of Phase Transfer Catalysis

The mechanism of phase transfer catalysis varies to some extent with the type of system involved (neutral, acidic or basic condition). All phase transfer catalyzed reactions involve at least two steps: a) transfer of one reagent from its "normal" into the second phase; and b) reaction of the transferred reagent with the nontransferred reagent. For the simplest S_N2 displacement reactions the mechanistic pathway is illustrated in Figure 4 (31, 32).

In this Figure Q^+ represents an onium salt cation which forms an ion pair with anion Y^- in the aqueous phase and extracts the anion into the organic phase. Once the anion has been transferred into the organic phase it reacts with RX and forms a new salt $[Q^+X^-]$. The new salt $[Q^+X^-]$ then returns to the aqueous phase, where Q^+ picks a new Y^- ion for the next cycle. It is necessary to consider the mechanism by which the anion is transferred when we study the system of phase transfer catalysis. There are several possible mechanisms for the phase transfer step (33) : a) simple ion exchange across the

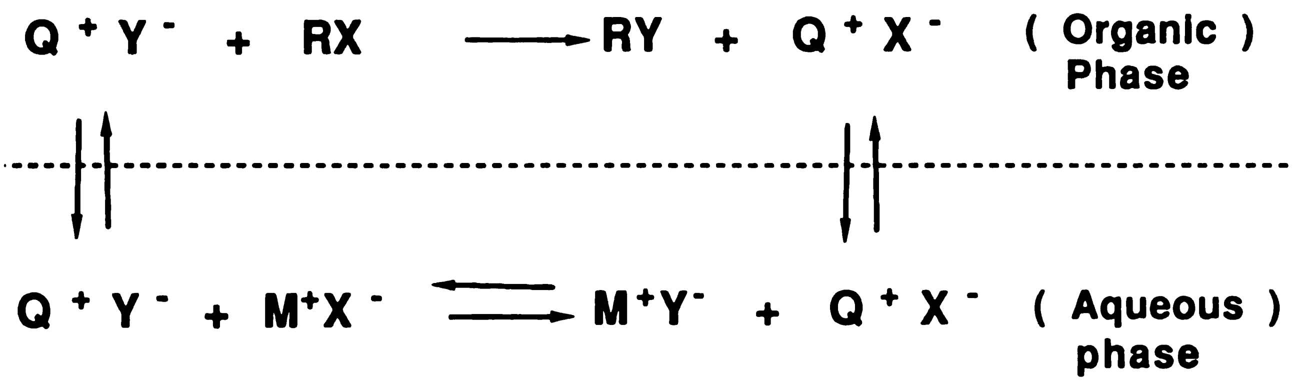


Figure 4. The mechanism of phase transfer catalysis with S_{N2} displacement reactions

interface; b) transfer of Q^+ back and forth across the interface with anion exchange in the aqueous phase; c) transfer of the inorganic salts into the organic phase for exchange d) transfer of anion at the organic-crystalline solid interface (at SL systems) e) formation of micelles in the aqueous phase and transfer of anions across the micelle interface. PTC as it being defined is not based on any mechanism. Hence, extensive investigations are need to elucidate the mechanism of any PTC systems.

3. Applications of Phase Transfer Catalysis

Since the discovery of phase transfer catalysis, numerous applications have been described (32-37), not only in organic chemistry, but also in inorganic chemistry (38), analytical applications (39), electrochemistry (40, 41), photochemistry (42, 43), and especially in polymer chemistry (44-50).

In organic synthesis PTC has emerged as a broadly useful tool for : a) nucleophilic displacement reactions b) alkylation and condensation reactions c) reactions of dihalocarbenes and other carbenes d) ylide-mediated reactions e) oxidation and reduction reactions f) and various miscellaneous reactions. In those reactions the technique of phase transfer catalysis provides a method which can avoid the use of polar aprotic solvent and also improve the reaction rate. Although phase transfer catalysis has suffered difficulties of separation at some later stage it appears to have high potential along synthetic lines.

4. Systems Related to Phase Transfer Catalysis

a) Reactions at the interface (51) Reactions occurring at an interface tend to be rate limited by the amount of interfacial area available and are therefore highly sensitive to the amount of agitation and concentration of reactant species at the interface.

b) Micelle-catalyzed reactions (52-54) Surfactant molecules possessing well defined diphilic properties usually form small aggregations of 10-50 organic molecules dispersed in the aqueous phase. These small aggregations are called micelles, wherein the nonpolar organic part of the molecules occupy the internal volume while the highly polar groups of the surfactant occupy the outer surface. The positively charged outer surface attracts and concentrates anions from the bulk aqueous solution into a counter ion layer near the surface of the micelle and reaction may occur at the micelle surface.

C. Some Aspect of Chiral Phase Transfer Catalysis

In the recent literature three different approaches have been used for asymmetric induction : chiral reagents (55, 56), chiral auxiliaries (57-62) and chiral catalysts (63-65). The disadvantage of the first two methods with respect to an economical process is that both are used in stoichiometric amounts and have to be recycled. Chiral phase transfer catalysts offer a potentially simple, one step solution to this problem.

1. Nature of Chiral Phase Transfer Catalysis

Phase transfer catalysis involves ion pairs with a rather close association. Therefore with strongly orienting chiral catalyst cations it is possible to obtain significant asymmetric induction.

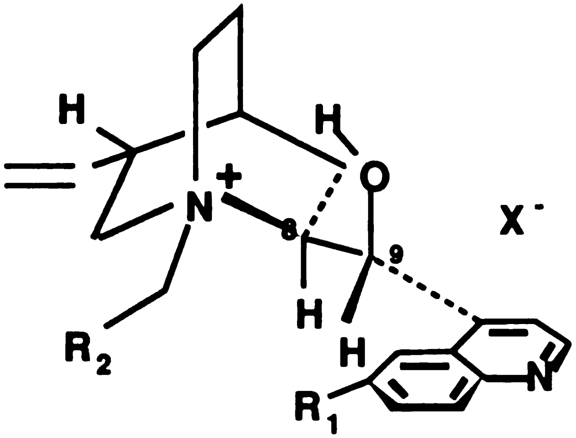
To date virtually all the work has employed onium salts based on ephedrine and its relatives, the cinchona alkaloids and crown ethers (Figure 5). Some confusion still remains in the literature concerning the effectiveness of these catalysts (66). However, the recent results reported by Cram (67) show a great optical yield (~99%).

Two generalizations seem to be emerging in the area of phase transfer chiral catalysis. An hydroxy substituent β to the quaternary ammonium center of the chiral catalyst is required for significant enantioselectivity. The enantiomeric excess increases with higher dilution of organic substrates, lower temperature, faster agitation and less polar solvents. The concentration of catalyst controls the rate of reaction but to have little effect on the enantiomeric excess.

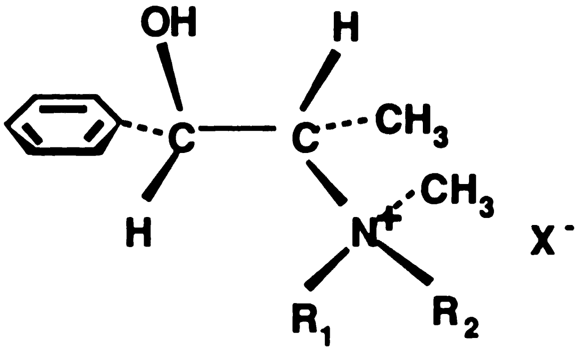
2. Mechanism

In order to establish a reasonable mechanism of asymmetric induction it is necessary to determine the preferred conformations of chiral phase transfer catalysts in solution . At present, the accurate determination of ground-state conformations of the

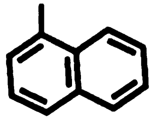
Figure 5. Chiral phase transfer catalysts : salts of quinine (a-f), salts of ephedrine (g-j), 8 S, 9 R-quinine (k), 8 S, 9 R-cinchonidine (l), 8 R, 9 S-quinidine (m) and 8 R, 9 S-cichonine (n).



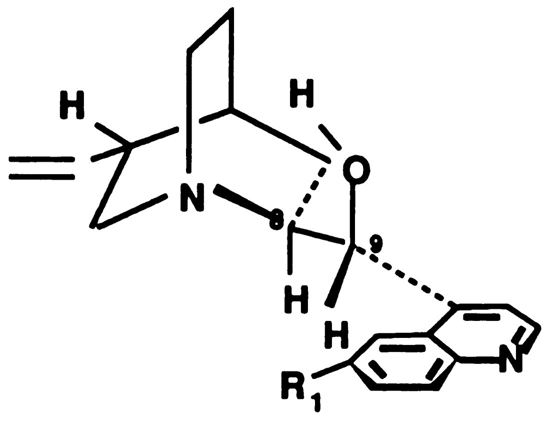
a - f



g - i

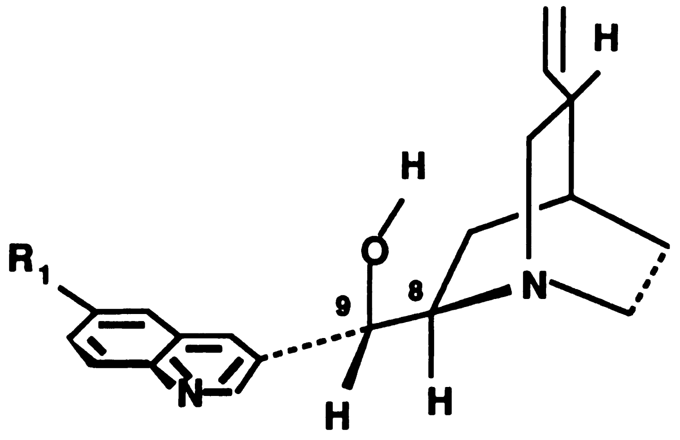
	R_1	R_2
a	OCH_3	C_6H_5
b	OCH_3	$C_6H_5NO_2$
c	OCH_3	$C_6H_4CH_3$
d	OCH_3	$C_6H_4C(CH_3)_3$
e	OCH_3	
f	OCH_3	$C_6H_4CF_3$

	R_1	R_2
g	$CH_2C_6H_5$	$CH_2C_6H_5$
h	CH_3	$CH_2C_6H_5$
i	$CH_2C_6H_5$	$C_{12}H_{25}$
j	CH_3	$C_{12}H_{25}$



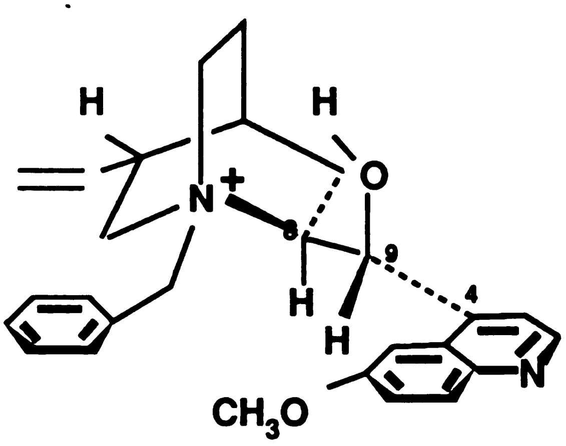
k - l

	R$_1$
k	OCH_3
l	H
m	OCH_3
n	H

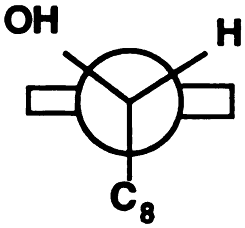


m - n

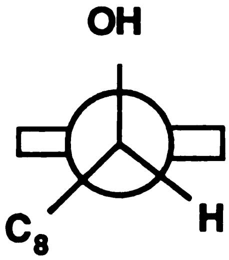
Figure 6. Preferred conformation of benzylquinium cation (I). Preferred conformation of benzylquinium cation about C_4-C_9 bond (A and B). Preferred conformation of benzylquinium cation about C_8-C_9 bond (C and D) (63, 64)



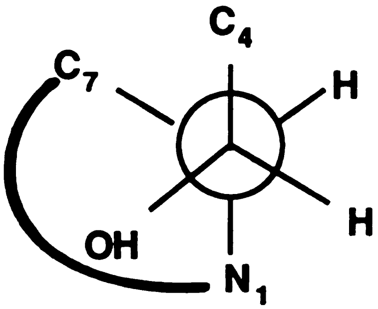
I



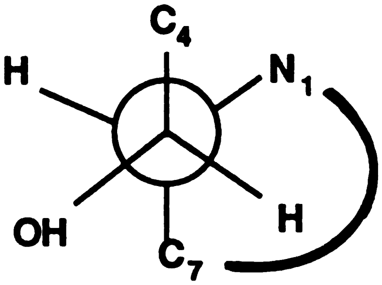
A



B



C



D

chiral phase transfer catalysts in solution is rarely feasible. Nevertheless, several preferred conformations of chiral catalysis in the transition state have been proposed by Wynberg (63) and Dolling (64) (Figure 6). In the following the mechanism of two particular reactions catalyzed by cinchona alkaloids will be discussed.

a) Epoxidation of Electron-Poor Olefins

So far the enantiomeric excesses (ee) obtained by using chiral phase transfer catalysts in epoxidation reactions have not been exceedingly high, except in a few cases (68,69). The reaction, however has a large scope and furnishes optically active epoxides inaccessible by other routes. Because of the lack of kinetic data and the complexity of phase transfer asymmetric catalysis it is very difficult to propose a mechanism.

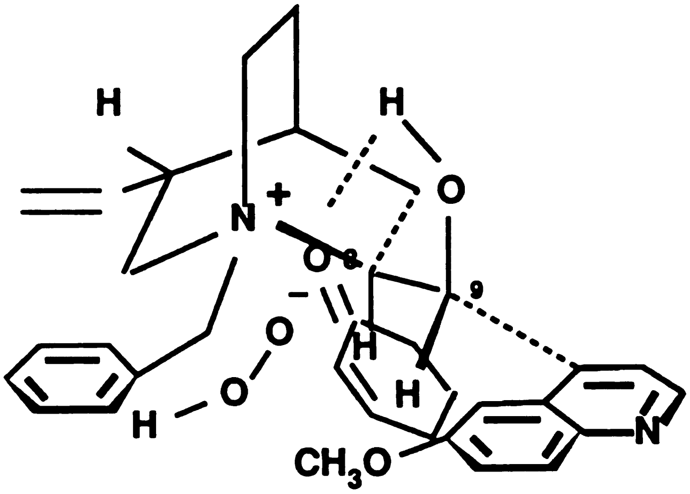
Wynberg has presented a hypothetical mechanism for the cyclohexenone epoxidation catalyzed by chalcone (63). By using a preferred conformation of the benzylquininium salt (Figure 6), assuming a tight ion pair between the catalytic cation and the peroxide anion with the hydrogen bonding between the hydroxyl of the alkaloid and the carbonyl oxygen of the ketone he predicted a transition structure fitting the description in Figure 7. When t-butyl hydroperoxide is the reagent, it forms an ion pair with the quinuclidine nitrogen of the alkaloid in a fairly compact structure. This t-$BuOO^-$ quininium complex allows the approach of cyclohexenone or chalcone from one side and favors one of two possible enantiomers only.

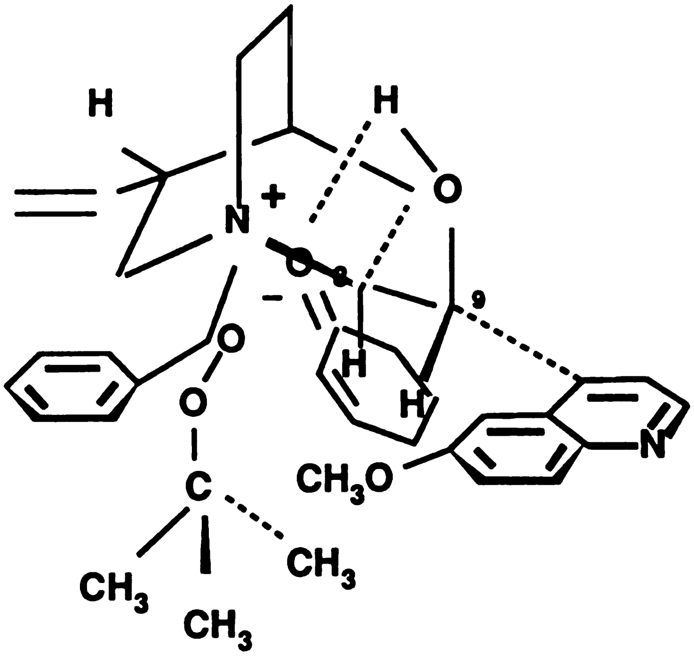
b) Borohydride Reductions

There are a few references on borohydride reductions of ketones with chiral catalysts, mainly ephedrine and the cinchona alkaloids (68-71). These limited results imply that the catalysts decomposed under the reaction conditions (66, 72), however the decomposition is slow.

No detailed mechanisms have been proposed. But most research groups recognize that the borohydride anion will form an ion pair with the catalyst cation, and the interaction of the β hydroxyl of the catalyst with the ketone will favor one of two

Figure 7. The transition states for asymmetric epoxidation of cyclohexenones catalyzed by (-) N-benzylquininium cation 63).


H
H
O
N
+
O
8
−
9
O
H
O
H
H
CH3O
N


H
H
O
N
+
O
8
−
9
O
H
O
H
C
CH3O
N
CH3
CH3
CH3

possible diastereomeric transition states. Further investigations are required before a clear picture emerges in this system.

3. Other Reactions

The use of optically resolved catalysts for the direct synthesis of enantiomerically pure compounds remains one of the dreams of the chemist. It would seem that chiral phase transfer catalysts are particularly well adapted to this problem. Recently, Wynberg and Dehmlow have written detailed reviews of the applications of chiral phase transfer catalysis (34, 63).

Several successful applications of chiral phase transfer catalysts in asymmetric reactions have been investigated. Dolling and his co-workers (73) demonstrated the methylation of a substituted indanone in 95% yield and 92% ee by using 8-R, 9-S, N-(p-trifluoromethylbenzyl) cinchonium bromide as catalyst (Figure 8). For the Michael reaction, Wynberg (63, 74) found an 87% yield with an ee of 76% by adding methyl vinyl ketone (MVK) to 2-carbomethoxy-1-indanone catalyzed by quinine (Figure 9). Later studies by Cram showed that ee's approaching 99% could be obtained using chiral crown ethers as catalyst (67).

Similarly Michael additions of thiols to a,b unsaturated ketones catalyzed by cinchonidine obtained relatively high ee's (Figure 10) (63, 75). The wide range of enones and thiols potentially amenable to this reaction and the versatility of the sulfur and carbonyl functionality (Figure 10) make this reaction useful in many ways. In Figure 11 it shows that a variety of aldehydes were able to react with ketene to form the corresponding b-lactones in excellent chemical and nearly quantitative enantiomeric yields (63, 76). Also chalcones (63, 77, 78), quinones (79-82) and cyclohexenones (83) are epoxidized successfully to optically active epoxyketones and epoxyquinones by 30% hydrogen peroxide, t-butyl hydroperoxide, and 28% sodium hypochlorite (Figure 12).

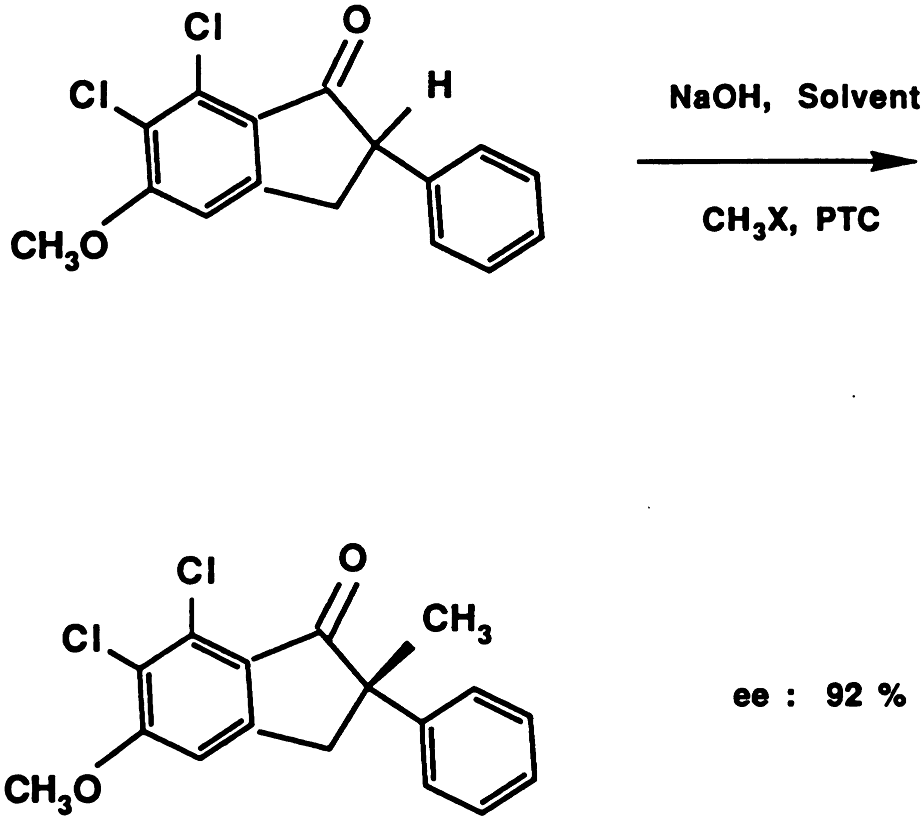
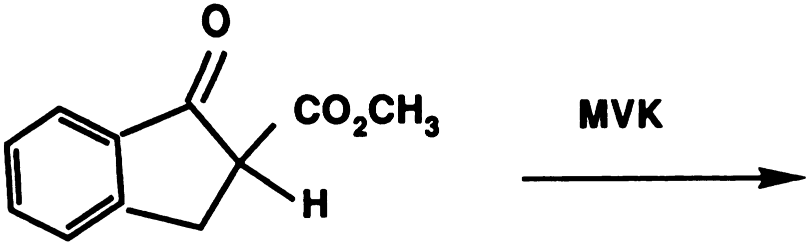
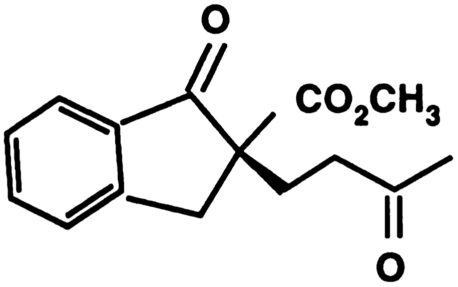


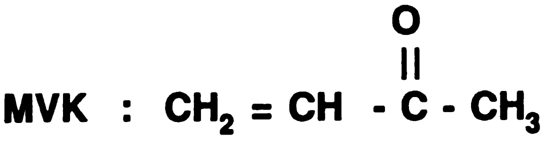
Figure 8. Asymmetric methylation of 6,7-dichloro-5-methoxy-2-phenyl-1-indanone catalyzed by 8-R, 9-S, N-(p-trifluoromethylbenzyl) cinchonium bromide catalysts (the catalyst structure is in the Figure 5f) (73).

Figure 9. Asymmetric alkylation of 2-carbomethoxy-1-indanone catalyzed by chiral crown ethers (67) and quinine (The catalyst structure is in Figure 5k) (63, 74).





Cram	1981	Crown	99%
Wynberg	1975	QN	76%



$$\text{MVK} : CH_2 = CH - \overset{\overset{O}{\parallel}}{C} - CH_3$$

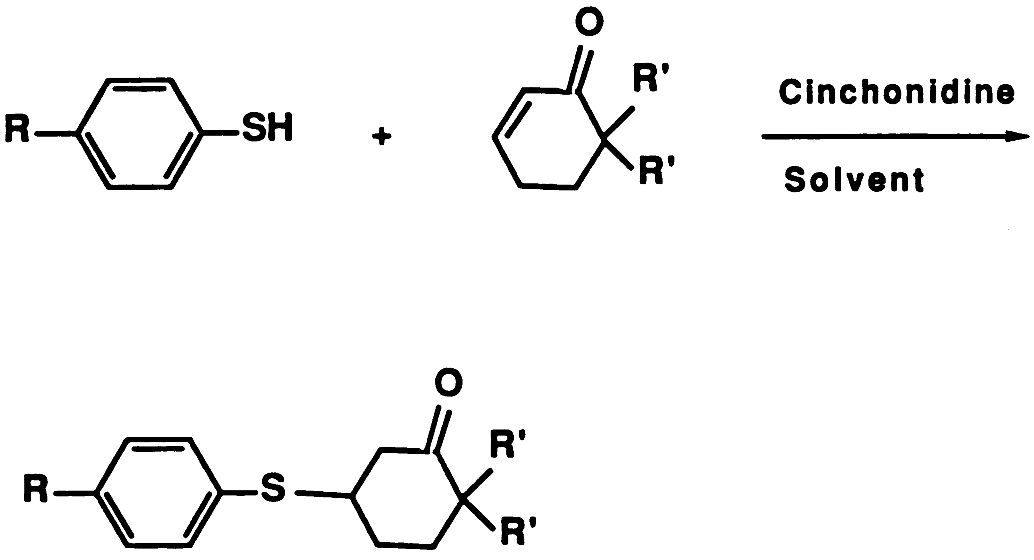
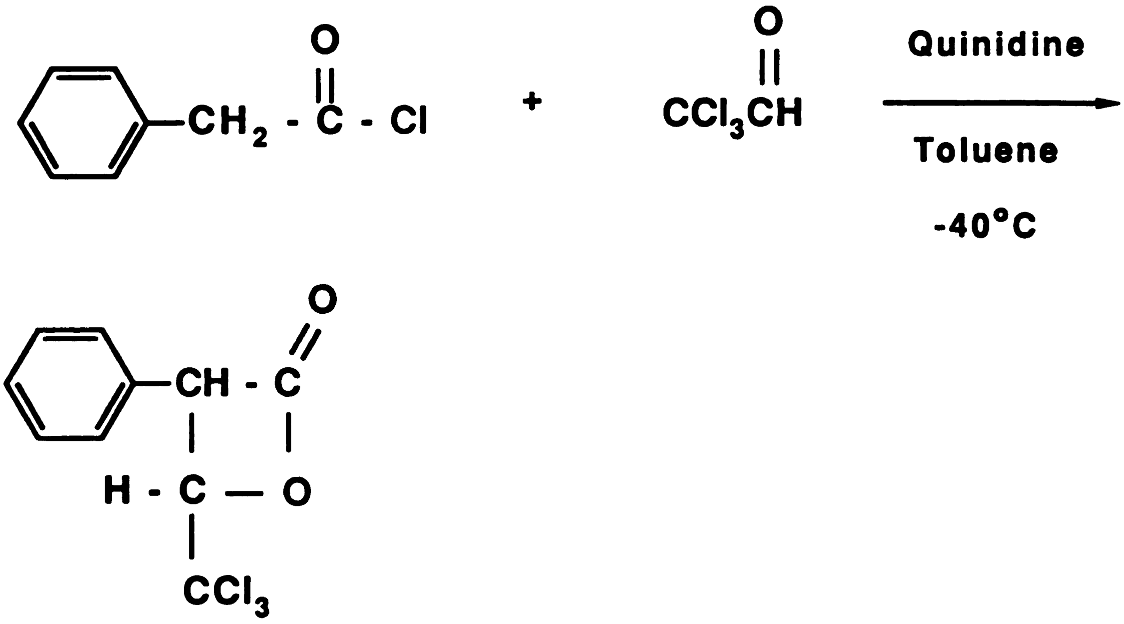


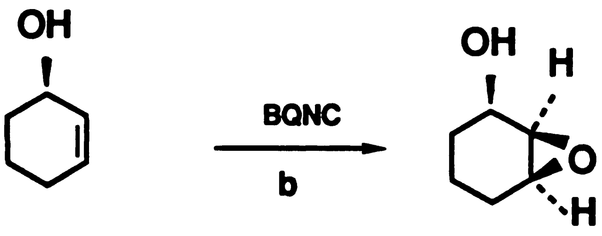
Figure 10. Michael addition of thiols to α β unsaturated ketones catalyzed by cinchonidine (The catalyst structure is in Figure 5*l*) (63, 75).

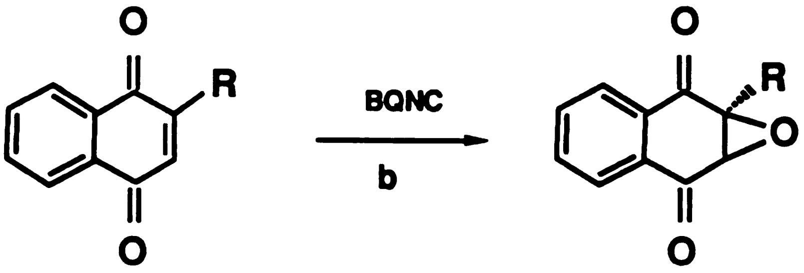


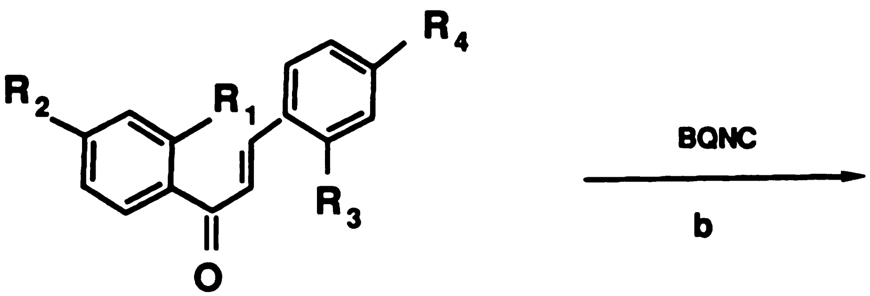
enantiomeric excess > 95%

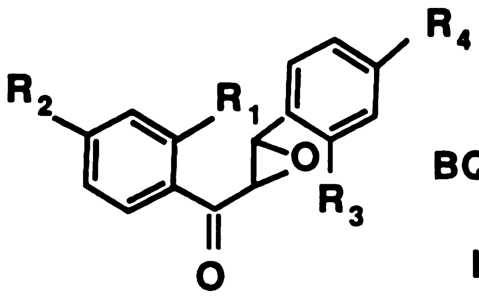
Figure 11. 2+2 Cycloaddition reactions catalyzed by quinidine (The catalyst structure is in Figure 5k) (63, 76)

Figure 12. Asymmetric epoxidation of electron- poor olefins catalyzed by benzyl quininium chloride. (The catalysts structure is in figure 5a) (63, 83-69, 77-78)







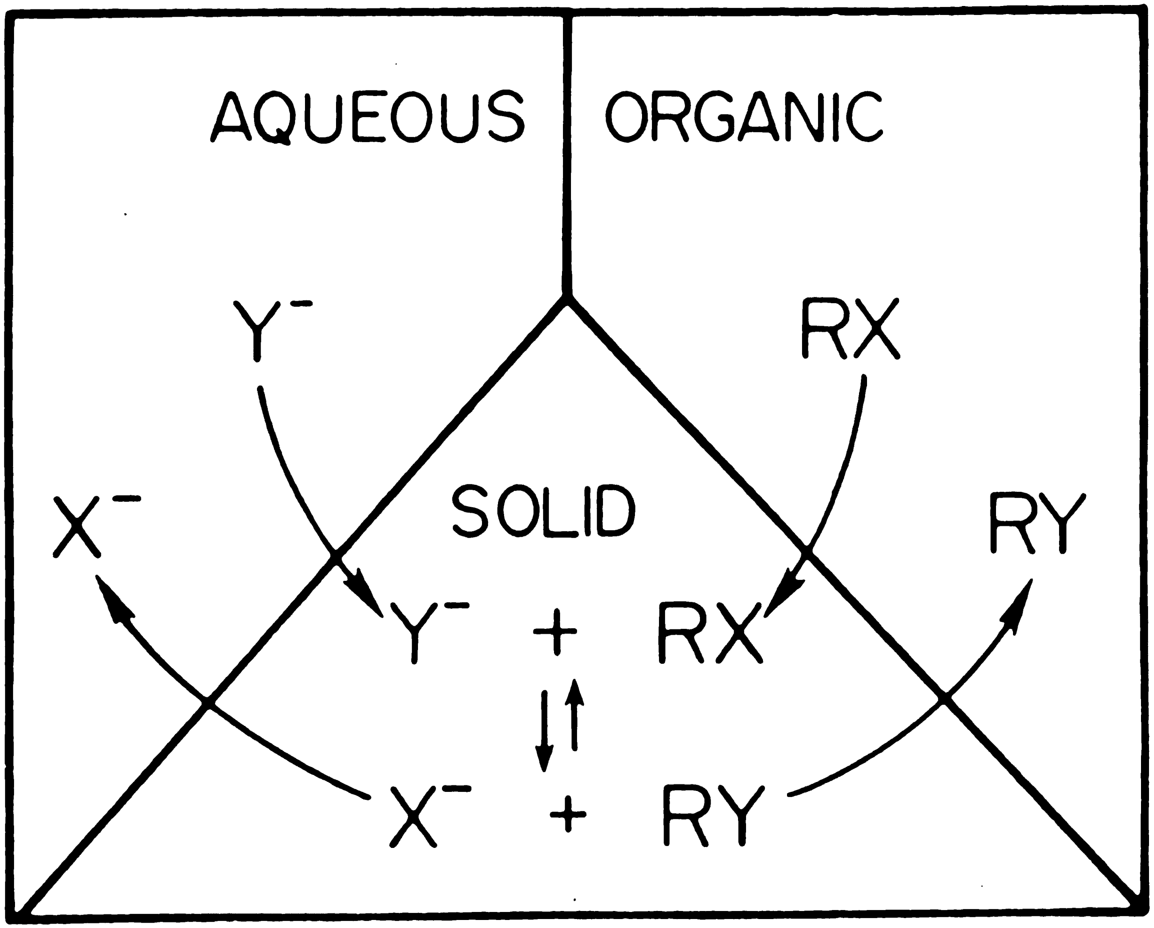


BQNC : **benzylquininium chloride**

b : **30% H_2O_2 10% NaOH,**
or t-BuOOH,
or 28% NaOCl

Figure 13. The process of triphase catalysis for S_{N2} displacement reactions.

TRIPHASE CATALYSIS



D. Development of Triphase Catalysis

1. Nature of Triphase Catalysis

A new type of heterogeneous catalysis, termed "triphase catalysis", has recently been introduced (84), in which the catalyst and each one of a pair of reactants is located in separate phases. Figure 13 illustrates the general features of a simple displacement reaction of a triphase catalyst system.

In general, the reactivity of triphase catalysts is lower than that for a comparable biphase catalytic process. But triphase catalysis makes the catalyst recovery processes facile, and from the practical point view, it is very attractive. Also, the low energy, and capital requirements for processing, together with its ideal suitability for continuous flow methods, give triphase catalysis appears to have great potential as a versatile technique in organic synthesis.

Several triphase catalysts have been attempted previously by bonding of biphase transfer catalysts to some polymers (84-99) or inorganic supports (100-105, 106-108). The general application of these catalysts is still under investigation.

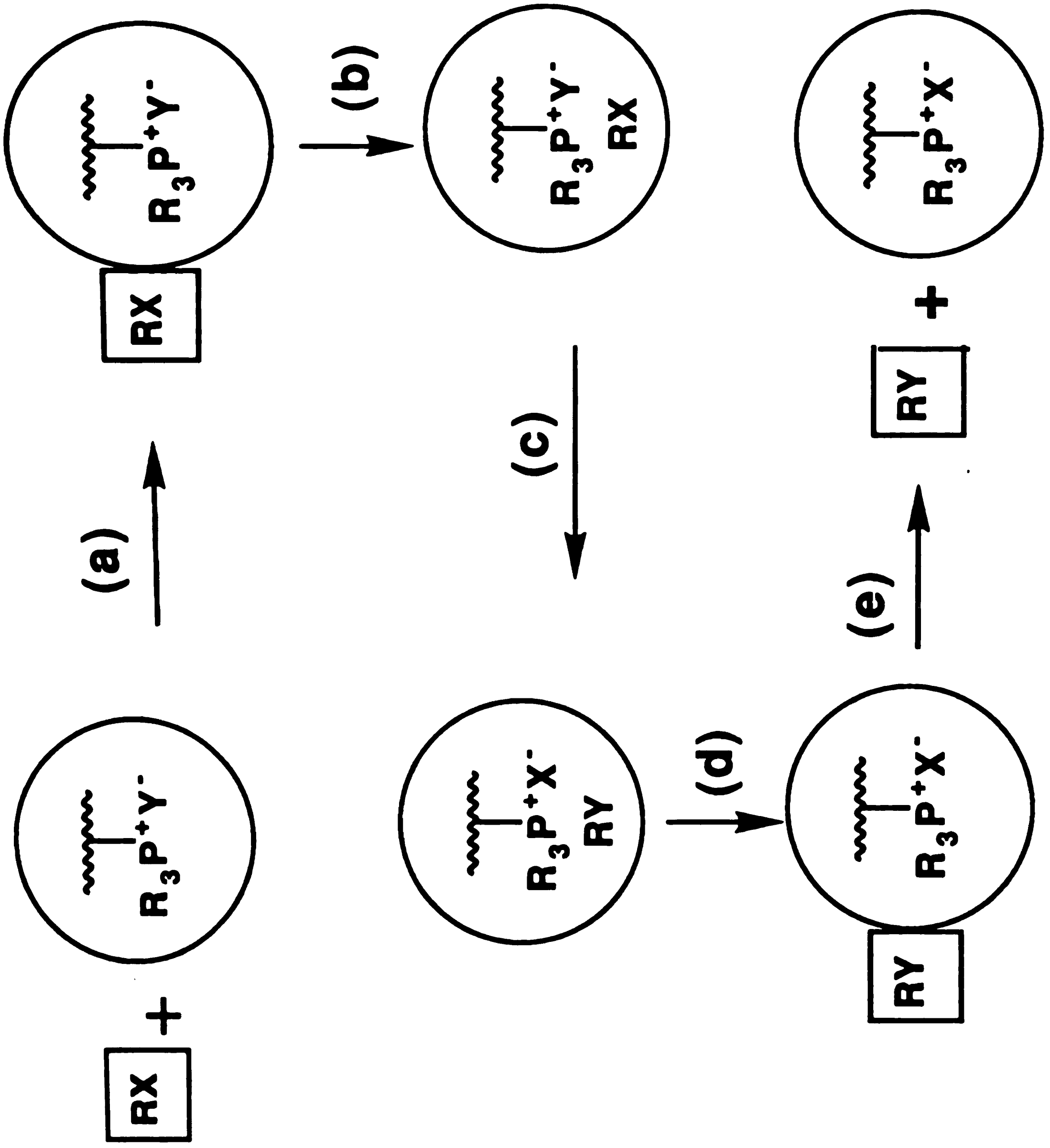
2. Polymer-Supported Phase Transfer Catalysis

Polymer-supported phase transfer catalysts are the first and the best studied triphase catalysts that have been employed. This approach originally showed great promise for solving two important PTC deficiencies : lowering catalyst cost by recycling and eliminating residual catalyst in the product. But this promise has not been realized because in the polymer-supported phase transfer catalysis, the reaction rates are limited by diffusion processes which have recently been reviewed by Ford (44, 45).

a) Mechanism

There is considerable debate concerning the mechanism of polymer-supported phase transfer catalysis in liquid-liquid systems (94, 96, 109-112). In general, the fundamental kinetic steps for polymer-supported phase transfer catalysis are as follows (Figure 14): a) mass transfer of reactant from bulk liquid to the surface of the catalyst

Figure 14. The mechanism of polymer-supported phase transfer catalysis : a) mass transfer or reactant form bulk liquid to the surface of the catalyst particle b) diffusion or reactant trough the polymer matrix to the active sites, c) intrinsic reaction at the active sites, d) diffusion of product through the polymer matrix to the particle surface and e) mass transfer of product from the surface of the catalyst to the bulk solution. A Phosphonium substituted catalyst is used for illustration here, but this basic mechanism can apply to most polymer-supported-supported PTC's.


RX
+
$R_3P^+Y^-$
(a)
RX
$R_3P^+Y^-$
(b)
$R_3P^+Y^-$
RX
(c)
$R_3P^+X^-$
RY
(d)
RY
$R_3P^+X^-$
(e)
RY
+
$R_3P^+X^-$

particle, b) diffusion of reactant through the polymer matrix to the active sites, c) reaction at the active sites, d) diffusion of product through the polymer matrix to the particle surface, e) mass transfer of product from surface of the catalyst to bulk solution. The same five fundamental kinetic steps must occur in catalyst regeneration.

The major disagreement is whether the reaction occur in an aqueous solvation shell, at an organic-aqueous interface (111, 112) or in an organic solvation shell (94, 96, 109, 110) within the polymer (Figure 14 step (c)) . No clear conclusion has been reached. Probably different polymer (e.g. chloromethyated,crosslinked polystyrene or commercial anion exchange resin) and different supported phase transfer catalyst (e.g. onium cation, crown ether, cryptand, polyethylene glycol, phosphoric acid amide, phosphonic ester amine oxide or aza-crown ether) will cause changes in the reactive site from a hydrophilic to hydrophobic shell.

b) Applications of Polymer-Supported Phase Transfer Catalysts

Recently synthetic applications of polymer-supported phase transfer catalyst have been reviewed by Dehmlow & Dehmlow (34). But none of them has found any industrial applications because polymer-supported phase catalysts generally suffer from diffusion limitation, gradual loss of activity and mechanical instability. A new type of polymer-supported phase catalyst called "chiral polymeric phase transfer catalyst" has been under investigation since 1978 (113). But none of these more results are satisfactory due to the fundamental problem involving diffusion through the polymeric matrix (113-119).

3. Inorganic-Based Catalysis

So far there are only a few reports describing the study and use of inorganic-based triphase catalysts. Silica gel or alumina (55, 100-103, 106-108, 120), Aerosil-200 or aminoalkyl Corning Glass (121) and clay (104, 105) are three general types of inorganic supports that have been used. These inorganic-based triphase catalysts show different properties from the corresponding onium salts supported on polymer matrices. Because different inorganic matrices having different chemical structures, surface area, size and geometries of the micropores are differently functionalized, there is not any general mechanism that can apply to those systems. The following sections will focus on silica gel and alumina as inorganic supports.

a) Synthesis, Structure Characteristics and Behavior of Inorganic Based Phase Transfer Catalysts

The synthesis of these supported onium salts starts from the anchoring of an alkyltrialkoxysilane (either a haloalkyl or aminoalkytrialkoxysilane) on the surface of silica gel or alumina to afford the alkyl functionalized inorganic matrix (Figure 15). However, the surface of silica gel or alumina needs to be activated before the anchoring process by refluxing with 35% hydrochloric acid to transform the strained siloxane linkages into free OH groups.

The degree of functionalization of alumina is less than that of silica gel, consistent with the fact that the surface concentration of hydroxyl groups is lower in alumina than in silica gel (0.1-2.5 OH / nm^2 and 4-10 OH / nm^2 respectively). The linkage between the inorganic matrix and the organic function is very stable under acidic conditions but is less stable to base. For examples, $60SiC_3NH_3^+Br^-$ (0.89) loses 43% functionalization after 24 hours in aqueous 0.1N NaOH at room temperature (108) (where 60Si indicates that silica gel with a mean pore diameter of 60 Å is the matrix, C3 indicates the length of the alkyl chain supporting the ammonium salt, and the value in parenthesis represents the loading as millimoles of the counterion of the onium salt per gram of catalytic support).

The exact structure of these systems during catalysis remains unknown and not all the questions concerning the disposition of the aqueous and organic phases in the functionalized pores have been answered. The major advantage of silica gel or alumina-based triphase catalysts is that under liquid-liquid phase transfer catalysis these systems can catalyze reactions without being stirred and do not need the use of polar solvent. This catalysis is not controlled by diffusion but by the regeneration of the catalytic

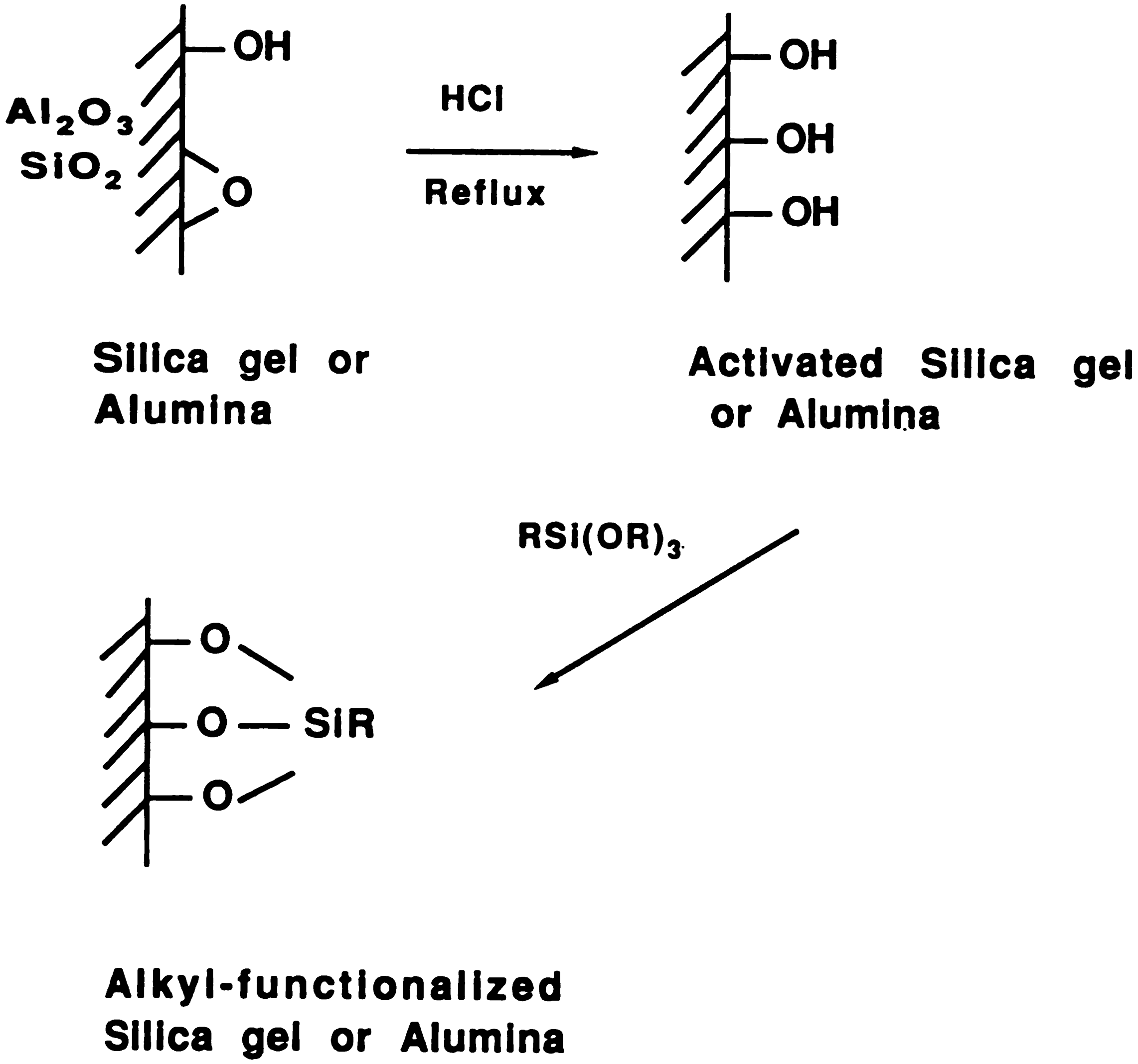


Figure 15. Alkyl-functionalization of silica gel and alumina

centers and the long alkyl chains of catalytic centers act as an anion pump between the aqueous, organic phases, both of which are present in the third solid phase.

b) Mechanism and Applications

A general mechanism similar to those for polymer-supported phase transfer catalysts are operate in these systems. However, the diffusion steps are replaced by the adsorption of the organic substrate and desorption of organic products on the matrix. The precise mechanism of these systems during catalysis remains unknown, due to the complex nature of the interactions of the inorganic salts, organic species and solvents within the different domains of the functionalized support.

Various applications concerning the use of silica gel or alumina-based triphase catalyst in nucleophilic substitution reactions have been reported : halogen exchange (101, 102, 106), synthesis of alkyl chlorides from alcohols (101), synthesis of phenyl ethers and sulfides (101), reduction of carbonyl compounds with aqueous sodium borohydride (101), synthesis of nitriles, thiocyanates (103) and N-alkylphthalimides (106). Depending on the reaction conditions, however, the functionalized inorganic matrices could lose some of their functionalization during some reactions. Then, reactions were actually catalyzed both by the phase transfer catalyst and the silica gel or alumina-based triphase catalysts as well as the hydrolysed catalytic groups .

4. Polymer-Supported Chiral Phase Transfer Catalysts

a) Nature of Polymer-Supported Chiral Phase Transfer Catalysts

The use of polymer-supported chiral phase transfer catalysts for asymmetric synthesis has increased significantly in recent years, and there are a number of reviews concerning this topic (48, 122-123).

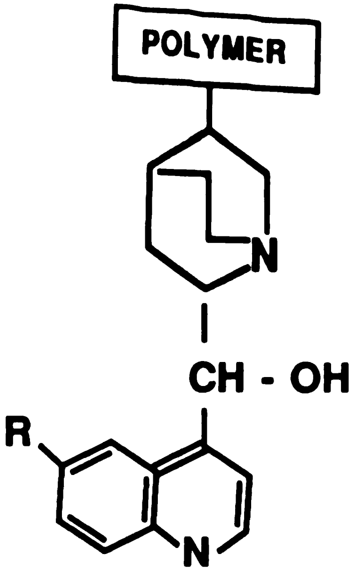
In order to prepare an effective polymer-supported chiral phase transfer catalyst there are several requirements that have to be met : i) The polymer support must be compatible with the reaction solvent as well as being chemically, thermally and mechanically stable under the reaction condition. ii) The rate of the catalytic reaction should not be appreciably diminished and the chemical selectivity and enantiomeric excess should be at least comparable to the homogeneous analog. However, high enantiomeric excesses have not be obtained under the triphase systems. Nevertheless, the experiments confirm that the solution reactions can be translated successfully into the supported system.

The polymer supported chiral phase transfer catalysts can be divided into two main classes: polymer-bound alkaloids and polymeric amines (Figure 16). By varying the loading of chiral phase transfer catalyst on the polymer, the nature of the polymer backbone (polar or nonpolar), the nature of the chiral phase transfer catalyst and degree of cross-linking of the polymer, one is able to design an effective polymer-supported chiral phase transfer catalyst for a particular utilization.

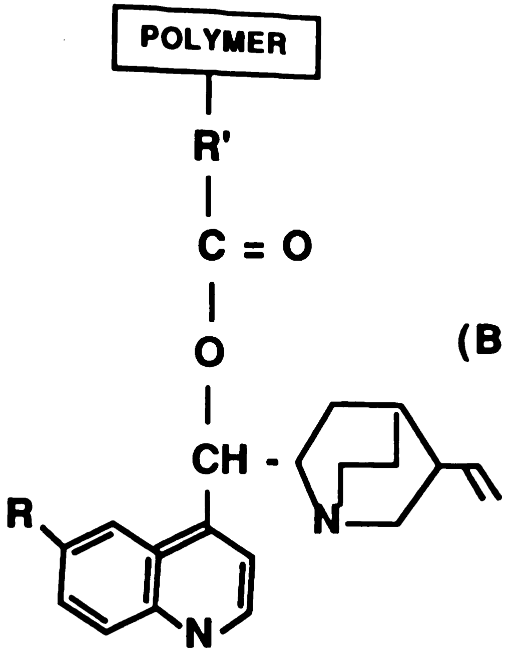
b) Mechanism and Applications

So far the enantiomeric excesses obtained by using polymer-supported chiral phase transfer catalysts are lower than those obtained by using the analogous homogeneous chiral phase transfer catalysis, except in few cases. Both Chiellini and Kobayashi have showed that the steric course of the reaction catalyzed by cinchona alkaloids is dominated by the configurations of C-8 and C-9 in the alkaloids and by the nature of the C-3 group only in the case of bulky substituted alkaloids (48, 124, 125). Figure 17 shows the reaction mechanism in Michael type addition in the presence of polymer-supported cinchonal alkaloids. A multicenter transition state involving the activated double bond, the nitrogen atom and the hydroxyl group is proposed. Although little promise of supported chiral phase transfer catalysts has appeared, the optimism remains. Furthermore recent work has attempted aim to exploit the chiral functional polymer as a chiral reagent.

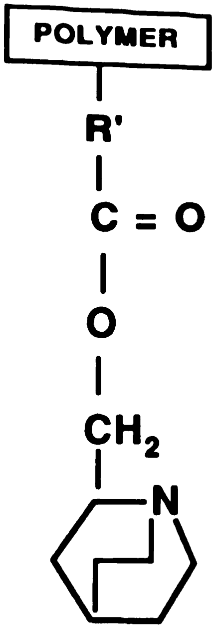
Figure 16. The structure of polymer-bound alkaloids (A-C) and polymeric amines (D-E) (48).



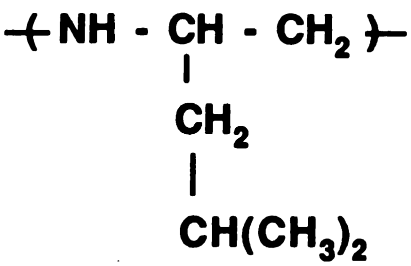
(A)



(B)

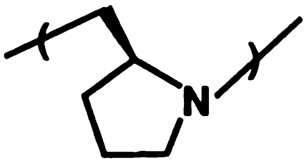


(C)



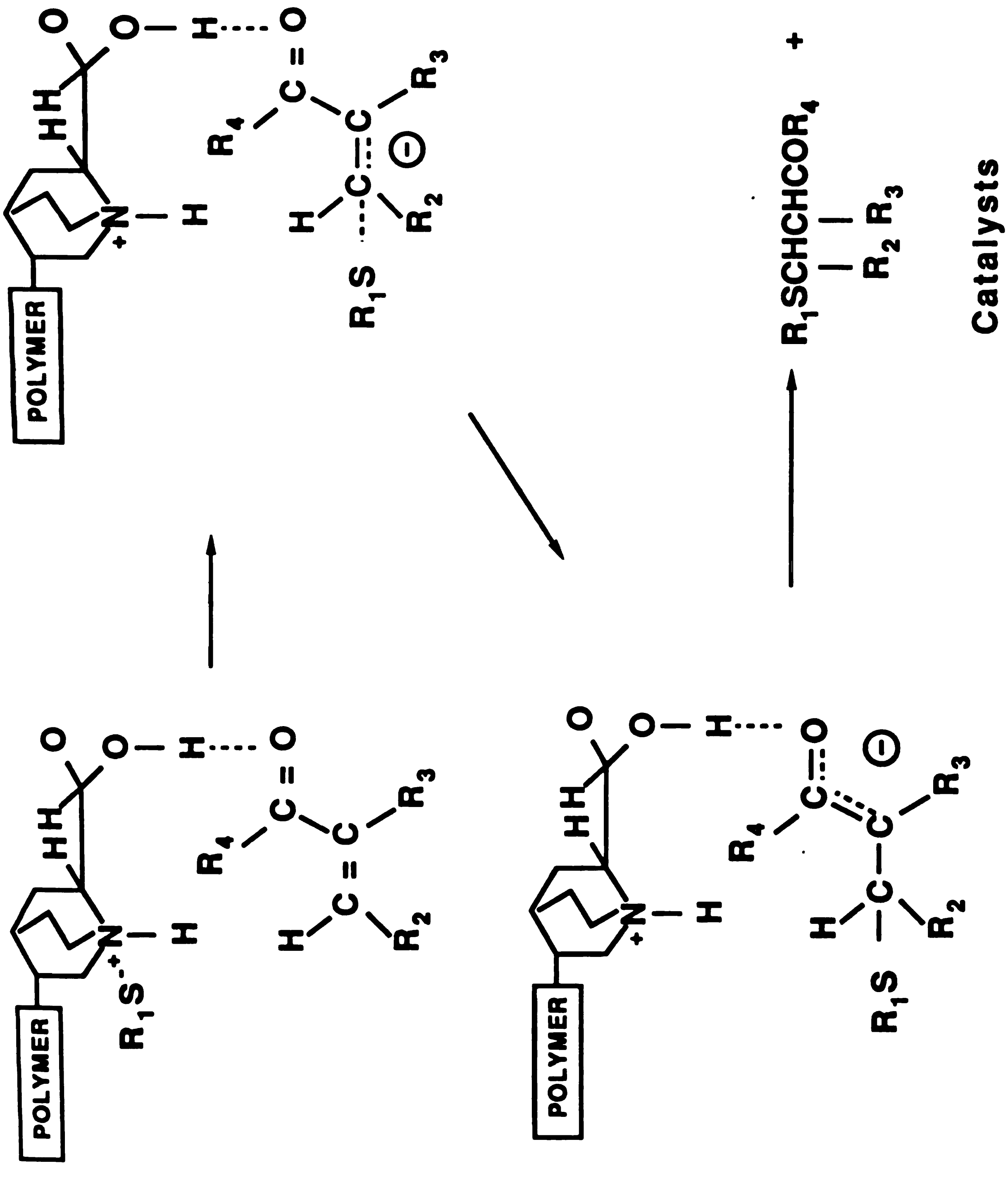
$$-\!\left(NH - \underset{\substack{| \\ CH_2 \\ | \\ CH(CH_3)_2}}{CH} - CH_2\right)\!-$$

(D)



(E)

Figure 17. The mechanism of Michael addition catalyzed by polymer-bound cinchonal alkaloids (48).


POLYMER
R_1S^-
N^+
H
HH
O
O — H····O
R_4
C = O
C = C
H
R_2
R_3
POLYMER
R_1S
$R_1SCHCOR_4$
R_2 R_3
+
Catalysts

E. Research Objectives :

Smectite Clays as Phase Transfer catalysts

Phase transfer catalysis has found use both in research and commercial applications because of its advantages of simplicity, mild reaction conditions, and high efficiency. One serious disadvantage of phase transfer catalysts is that they are very expensive and difficult to remove from the reaction mixture at some later stage. Also, phase transfer catalysts sometimes form undesirable emulsions and do not lend themselves to convenient chemical processing methods.

Triphase catalysis has been developed to solve these problems. From the point of view of industrial applications, these triphase catalysts are very attractive due to being easily recovered by filtration and ideally suited for continuous flow methods. The triphase catalysts developed to date make use of polymer or inorganic matrices (e.g., silica gel, alumina, glass). Polymer supported phase transfer catalysis is sometimes limited by diffusion of reaction substrates to the polymer matrix and suffers from the necessity to use polar solvent. Inorganic based phase transfer catalysts are not stable under mild basic reaction conditions and lose functionalization at room temperature. Both of polymer and inorganic-supported phase transfer catalysts have lower catalytic reactivity and higher manufacturing costs than comparable soluble phase transfer catalysts.

Smectite clays, having an ordered layer structure, provide certain advantages over polymer and inorganic matrices as phase transfer catalysts supports. This study has shown that onium-ion functionalized smectite clays are stable under various reaction conditions and provide efficient interfacial surfaces for the catalysis of organic reactions. There is no need to use polar solvents in clay-supported phase transfer catalysis and the catalytic reactivity of the clay-supported phase transfer catalysts is comparable to analogous biphase transfer catalysts.

The main objective of this study was to explore different approaches to intercalated clay phase transfer catalysts and to investigate the mechanism and the applications of clay-supported phase catalysts.

The first part of this work examines the dependence of onium cation loading and the catalytic reactivity of clay-supported onium catalysts. Also, in order to study the mechanism of clay-supported phase transfer catalysis in a nucleophilic displacement reaction several parameters controlling the efficacy of these triphase systems have been investigated (e.g., the structure of substrates and supported onium cations, the concentrations of substrates and catalyst, the layer charge of the clay support and the polarity of the organic solvent). In this part the triphase catalysis technique has been expanded by applying it to variety of other useful synthetic transformation.

In the last few years, polymer-supported chiral phase transfer catalysis for asymmetric induction has received a great attention for the growing demand for optically pure compounds in the pharmaceutical and agro-chemical industries. The success of clay-supported phase transfer catalysts inspired the idea of studying the clay-supported chiral phase transfer catalysts. Thus, the second part of this dissertation describes the preparation and study of clay-supported chiral phase transfer catalysts.

The mechanism of borohydride reduction using clay-supported chiral phase transfer catalysis has been examined by studying the dependence of enantiomeric excess on several experimental parameters (e.g., the structure of the supported chiral catalyst and substrates, the concentration of catalyst and substrates, the layer charge of the clay support, the reaction temperature and the polarity of the organic solvent). Further applications of clay-supported chiral phase transfer catalysts in epoxidations of unsaturated ketones have also been examined.

Chapter II

EXPERIMENT

A. Material

1. Natural Sodium Hectorite

Naturally-occurring California sodium hectorite with a particle size less than 2 μm was obtained from the Source Clay Mineral Depository, University of Missouri, in the pre-centrifuged and spray dried form. The mineral was purified by removing carbonates and free iron oxides according to procedures described in the literature (126).

The idealized anhydrous unit-cell formula of hectorite is $Na_{0.67}[Li_{0.67}Mg_{5.33}(Si_{8.00})O_{20}(OH,F)_4]$ and experimentally determined cation-exchanged capacity is about 73 meq. / 100g of air dried clay.

2. Laponite R

Synthetic hectorite with a structural formula of $Li_{0.36}[Li_{0.36}Mg_{5.64}(Si_{8.00})O_{20}(OH)_4]$ was obtained from Laporte Company, England and was used as supplied from the manufacturer. The particle size of this mineral is approximately 2 μm with a cation exchange capacity around 55 meq. / 100g of air dried clay.

3. Fluorohectorite

This synthetic hectorite was donated as an aqueous suspension by Corning Glass Works USA and used without further purification. In this mineral the octahedral lattice hydroxyl groups have been replaced by fluoride ions. The unit cell formula is $Li_{1.6}[Li_{1.6}Mg_{4.4}(Si_{8.00})O_{20}F_{4}]$. The mineral has a particle size less than 2 μm and cation exchange capacity of approximately 125 meq. / 100 g air dried clay.

4. Commercial Organoclay and Organo-Layered Compounds

Commerical organoclay, Benton 34, was donated by Baroid Co. and the ECCT organoclay series was obtained from English China Clay Co.. Layered compounds were synthesized by Ahmad Moini according to literature techniques and intercalated with onium ions using procedures analogous to the intercalation of organoclays (127-137)

5. Reagents

All onium salts were obtained from Chemical Dynamics Corporation and Aldrich Chemical Company. (-) N-dodecyl N-methylephedrinium bromide and tris[3-(heptafluoropropyl-hydroxymethylene)-(+)-camphorato], europium (III) derivative (Eu(hfc)3) were obtained from Aldrich Chemical Company. (-) N-benzyl quininium chloride was obtained from Fluka Chemie. All other organic and inorganic reagents and organic solvents were obtained from Aldrich Chemical Company. All reagents and organic solvents were ACS grade and were used as obtained except ethyl ether and absolute alcohol (138, 139).

Phenyl t-butyl ketone was synthesized as described in ref. 138 : The Grignard reagent was prepared from 0.32 mole of magnesium, 0.34 mole of bromobenzene and 250 ml of ether distilled from phosphorus pentoxide. Without cooling, pivalonitrile (0.33 mole) was added rapidly to the Grignard reagent solution. The solution was then refluxed and the mixture was poured onto cracked ice mixed with 20% hydrochloric acid and allowed to stand overnight for complete hydrolysis. The phenyl t-butyl ketone was extracted with ether and the extracts being washed further with water, saturated sodium bicarbonate solution and then dried with sodium sulfate and distilled at reduced pressure (138). The ^{1}H NMR and FT IR spectra of product (Table.20) were identical with those of authentic samples.

Synthesis of (+) n-benzylquinidium chloride was conducted as described in ref. 139 : Fifty mmole of quinidin was dissolved in a mixture of 50 ml benzene and 10 ml ethanol and allowed to stand at room temperature with 50 mmole of benzyl chloride for 26 hr. The solvent was evaporated and product was washed with pentane and recrystallized from absolute alcohol which was purified as in ref 139.

B. Preparation of Organoclay Phase Transfer Catalysts

1. A 0.5 wt% aqueous suspension of a sodium hectorite was stirred vigorously for 24 hr with a known amount of an tetrabutyl ammonium or hexdecyltributylphosphonium salt dissolved in water or methanol solution (0.073M). The products were washed free of excess onium salt with ethanol, resuspended in deionized water, collected by centrifugation, and air dried at room temperature. In order to study the loading of onium ion corresponding to the number of onium ion equivalents used in the reaction the meq. ratios of onium ion to clay employed ranged from 0.25 to 10.0. The products were then examined by X-ray diffraction (Table 1 and 2 samples 1AA-14AM).

2. A 1.0 wt% aqueous suspension of smectite clay was stirred vigorously for 24 hr with 2 cation exchange capacity (CEC) of alkylammonium or alkylphosphonium salt dissolved in water or methanol solution (0.073M). The products were washed free of excess onium salt with ethanol (testing by bromide or chloride electrode), resuspended in deionized water, collected by centrifugation, and air dried at room temperature. The products were examined by X-ray diffraction (Table 3 Samples 15AA-26AM and Table 7 Samples L18AA, F18AA, L22AA, F22AA, L26AA, F26AA).

C. Preparation of Clay-Supported Chiral catalyst

In a typical experiment, a 1.0 wt% smectite clay aqueous suspension was added to a vigorously stirred aqueous solution containing of 2CEC chiral onium salt ((-) N-dodecyl N-Methylephedrinium bromide or (-) benzyl quininium chloride) (0.073 M). After 24 hr of reaction, the products were washed free of excess chiral onium salt with ethanol (monitored by a polarimeter), resuspension in deionized water and air dried at room temperature. The products were examined by X-ray diffractiometer (Table 19 Samples 131AA, F131, 151AA and F151AA).

D. Organoclay Phase Transfer Catalysis

General Methods.

The reactions of alkyl bromides with potassium cyanide under triphase conditions were carried out as follows: The air dried organoclay phase transfer catalyst was dispersed in 3.0 ml aqueous solution of potassium cyanide in a 15 x 150 mm pyrex culture tube with magnetic stirring bar and fitted with a teflon screw cap. After the mixture was stirred for a few hours 2.0 mmole alkylbromide and 0.5 ml decane as internal standard were added in 6 ml of toluene or other organic solvent. The tubes were immersed in an oil bath maintained at $90.0 \pm 0.5^{o}C$ and reaction rates were determined by withdrawing 1 μl samples from the upper excess organic layer and analyzing the products mixtures by GLC (see section K. Physical Measurements for details of instrumentation used). The reproducibility of the observed rate constants were high and the errors are within 5%. Pseudo first-order rate constants were calculated with a least-squares program.

Similar methods were used in studying the reaction rates under biphase conditions, except that an appropriate amounts of onium salts were used in place of the organoclay phase transfer catalyst. Parameters which have been investigated to control the efficacy of organoclay phase transfer catalyst are listed as follows: 1. Loading of intercalated onium cation; 2. Molecular structure of intercalated phase transfer catalysts; 3. Molecular structure of substrate; 4. Concentration of organoclay and potassium cyanide; 5. Layer charge of clay host; and 6. Polarity of solvent.

E. Applications of Organoclay Phase Transfer Catalyst in Organic Synthesis

In the following reactions the $[MeN(C_8H_{17})]_3^+$-hectorite (25AA) and $[Bu_3PC_{16}H_{33}]_3^+$-hectorite (26AA) were utilized as catalysts. The stabilities of organoclays in the reaction condition were examined by the X-ray d-spacing of the recovered catalysts and the control reactions described below.

1. Synthesis of Ethers

To a Corning no. 9826 culture tube containing 0.05 mmole of organoclay phase transfer catalyst was added to 2.5 M sodium hydroxide solution (6ml), followed by 10 mmole pentyl bromide, 5 mmole phenol and 0.5 ml of decane as internal standard. The tube was placed in an oil bath maintained at 90 ± 0.5°C for the time indicated in Table 7. The reaction mixtures were quenched to room temperature by cooling with an ice bath. The catalyst was removed by filtering and the chemical yields were determined by withdrawing 1 ul samples from the upper organic layer of the filtrate and analyzing the product mixtures by GLC. The organic layer was then extracted by ethyl ether, washed with 2.5 M sodium hydroxide solution, neutralized by sodium bicarbonate solution and dried over sodium sulfate. The product was collected by distillation and analyzing by FT IR, and ^1H NMR (Table 7 and Table 16).

2. Oxidation of Benzyl Alcohol

Organoclay phase transfer catalyst (0.05 mmole) was dispersed in 5 ml of 10% aqueous sodium hypochlorite in a Corning no. 9826 culture tube. After the mixture was stirred for 2 h, 1.0 mmole of benzyl alcohol dissolved in 2 ml toluene and 0.5 ml of decane as internal standard were added. The tubes were immersed in an oil bath maintained at 50 ± 0.5°C for the time indicated in Table 8 and the reaction mixtures were cooled rapidly to room temperature by use of an ice bath. The catalyst was removed by centrifugation or filtering and the chemical yield were determined by withdrawing 1 ul samples from the upper organic layer of the filtrate and analyzing the product mixtures by GLC. The organic phase was extracted with ethyl ether and dried over sodium sulfate. The product was collected by distillation and analyzed by analogous procedure to the procedures described above (Table 8 and Table 16).

3. Synthesis of n-Pentyl Thiocyanate

Organoclay phase transfer catalyst (0.05 mmole), sodium thiocyanate (10 mmole), 2 ml of water 0.5 ml of internal standard, decane, and n-pentyl bromide (5.0 mmole)were added to a Corning 9826 culture tube and placed in a oil bath maintained at 90 ± 0.5°C. The reaction times were given in Table 9 and the analogous procedure as above was performed in the determination of the chemical yield and the purification of the product. The product was analyzed by FT IR and ^{1}H NMR (Table 9 and Table 16).

4. Synthesis of Dipentyl Sulfide

Organoclay phase transfer catalyst (0.05 mmole) was mixed with 0.5 ml decane, 3.0 ml of water containing dissolved sodium sulfide (6.0 mmole) and 1-bromopentane (5.0 mmole). The mixtures were stirred vigorously at 90 ± 0.5 °C for 0.5 hr. The emulsion was broken by centrifugation and the same workup procedure as above was used for the determination of chemical yield and product collection. Analogous analysis as above was used to identify the product (Table 10 and Table 16).

5. C-Alkylation of benzyl cyanide

Organoclay phase transfer catalyst (0.05 mmole) was added to a culture tube containing decane (0.5 ml) 1-pentyl bromide (5.0 mmole), benzyl cyanide (5.0 mmole) and 50% sodium hydroxide solution (2.0 ml). Reaction temperature was maintained at 50 ± 0.5°C for the time indicated in Table 12. Product was collected by the usual workup procedures and analyzed by GLC, FT IR, ^{1}H NMR (Table 12 and Table 16).

6. Dehalogenation of vis-Dibromides

Organoclay phase transfer catalyst (0.05 mmole) was mixed with 2.0 ml of water containing dissolved sodium iodide (0.264 mmole) and sodium thiosulfate (32.0 mmole) and toluene (2.0 ml) containing dissolved 1,2-dibromo-1,2-diphenyl ethane (1.0 mmole).

After vigorous stirring for the reaction time indicated in Table 13 at 90 ± 0.5°C the emulsion was broken by centrifugation, and product was obtained and analyzed in the similar procedure (Table 10 and Table 16).

7. Halogen Exchange Reaction

Organoclay phase transfer catalyst (0.05 mmole) was added to 6 ml of toluene containing n-alkyl bromide (2.0 mmole) and 3 ml of water containing sodium chloride (6.67 mmole). Reaction temperature was maintained at 90 ± 0.5°C for the time indicated in Table 14 and emulsion was broken by centrifugation. Similar collection and analysis procedure of product was used (Table 15 and Table 16).

8. Blank Reactions and Control Reactions

Each blank reaction was run under the same condition as described except without using catalyst. Each catalyzed reactions was repeated for controlled reaction in the same procedure, except that the catalysts were removed by filtration after half the reaction time and the reaction was continued under the same procedure with the filtrate. The recovered catalyst was washed with ethanol and water and X-ray d_{001} spacing were measured. The stabilities of organoclays in the reaction condition were proved by the retention of d-spacing of recovered catalysts, and the discontinuation or slowdown of the reaction after the filtration of catalysts.

F. Comparison of the Catalytic Properties of Organoclay

The catalytic properties of a series of commercial organoclay (Benton 34, ECCT 40, ECCT AF and ECCT PS) were investigated in cyanation reactions. The triphase conditions were carried out as follows : Commercial organoclay (0.13 g) was dispersed in 3.0 ml aqueous solution of potassium cyanide (20.0 mmole) in a Corning no. 9826 culture tube. After the mixture was stirred for 2 h 2.0 mmole n-pentylbromide and 0.5 ml decane as internal standard were added in 6 ml of toluene. The reaction mixtures were placed in an oil bath maintained at 90 ± 0.5°C. The reaction times are indicated in Table 17. The reaction mixtures were quenched to room temperature by cooling with an ice bath. The catalyst was removed by filtration. The organic layer was then extracted by ethyl ether, washed with 2.5 M sodium hydroxide solution, neutralization by sodium bicarbonate solution and dried on sodium sulfate. The chemical yield of product was determined by GLC.

G. Comparison of the Catalytic Properties of Some Organo-Layered Compounds

The catalytic properties of some organo-layered compounds were examined for bromide displacement both by cyanide and by chloride. The cyanation was carried using analogous procedures as in commercial organoclay except that 0.1 g of organo-layered compound was used. However, all of the organo-layered compounds in these studies underwent de-intercalation or decomposition under the cyanation reactions as indicated by the X-ray data for the recovered catalysts. The triphase reaction conditions for chloride displacement of alkylbromide are performed as follows : Air dried organo-layered compound (0.1 g) was added to 6 ml of toluene containing n-alkylbromide (2.0 mmole) and 3 ml of water containing sodium chloride (6.67 mmole). Decane (0.5 ml) was also added as internal standard. The reaction temperature was maintained at 90 ± 0.5^{o}C for the time given in Table 18. Product was collected and purified by usual workup procedure. The chemical yield of reaction was determined by GLC.

H. Asymmetric Reduction of Ketones

1. In a typical experiment, potassium borohydride (3 mmole), 0.25 mmole ketones (phenyl t-butyl ketone or phenyl n-butyl ketone), benzene (6 ml), water (5 ml), and clay-supported chiral catalyst were mixed in a flask and stirred at various temperatures for suitable times. The reaction was followed by GLC and catalyst was separated by filtering. The aqueous phase was extracted with benzene and the combined organic fraction were dried over sodium sulfate. After the evaporation of the solvent, the residue was examined by FT IR, ^{1}H NMR, GLC and polarimetry. Enantiomeric excesses were determined by ^{1}H NMR spectroscopy with Eu(hfc)$_3$ as chiral shift reagents.

The parameters which have been studied to control the optical purity of products were as follows : 1. Layer charge of clay support; 2. Structure of chiral catalyst; 3. Structure of carbonyl compound; 4. Concentration of substrates and clay-supported chiral catalyst; 5. Reaction temperature; and 6. Polarity of solvent.

2. Blank reaction

Blank reactions 1 and 2 in Table 21 were run using analogous procedures to those described above except that clay-supported chiral catalysts were not used. The reaction mixtures consisted of 6 mmole potassium borohydride dissolved in 5 ml of water and 3 ml of benzene solution containing 0.25 mmole phenyl n-butyl ketone and phenyl t-butyl ketone respectively at 4°C.

In order to examine the degree of desorption of chiral cation inside the gallery and decomposition of the clay-supported chiral catalysts under the reaction conditions, similar reactions were run without carbonyl compounds and catalyzed by 131AA ((-) N-Dodecyl N-Methyl ephedrinium hectorite), F131AA ((-) N-Dodecyl N-Methyl ephedrinium F-hectorite), 151AA ((-) N-Benzylquininium hectorite), and F151AA ((-) N-Benzylquininium F-hectorite) in blank reactions 3, 4, 5 and 6 respectively (Table 21). After three reaction days the organic phases were collected and purified as described before and examined by polarimetry. The stabilities of the organoclays under the reaction conditions were proved by the absence of specific rotation of the reaction residues when no carbonyl compound was used.

I. Asymmetric epoxidation of chalcones

The reactions were performed as follows : 0.48 mmole chalcone dissolved in benzene or other organic solvents (3 ml), 1.5 ml of 30 wt.% H_2O_2 , 1.5 ml of 12 wt.% NaOH and 0.2 mmole homoionic clay-supported chiral catalyst were mixed with a magnetic stirring bar in a flask placed in a orbit shaker with speed 360 rpm at various temperatures. The reaction was followed by TLC and the catalyst was separated by filtration from the reaction residues after the reaction was completed. The aqueous phase was extracted with benzene, and the organic fraction were combined and dried over sodium sulfate. After the evaporation of the organic solvent at reduced pressure, the residue was examined by FT IR, ^{1}H NMR and polarimeter. The enantiomeric excess was determined by ^{1}H NMR with Eu(hfc)$_3$ as a shift reagent.

Several components were investigated to control the enantiomeric excess of epoxychalcone : 1. Molecular structure of intercalated chiral catalysts; 2. Layer charge density of clay host; 3. The reaction temperature; 4. The polarity of organic solvents; 5. Concentration of chalcone; and 6. Volume ratios of aqueous and organic phases.

J. The Determination of Enantiomeric Excess of Reaction by ^{1}H NMR

Shift reagents, introduced in 1969, provide a method for the determination of molecular structures. The shift reagents, in general, are ions in the rare earth series coordinated to organic ligands. Addition of shift reagents to appropriately functionalized samples can result in substantial magnification of the chemical shift differences of nonequivalent protons. The closer the group of interest coordinations to the functional group, the greater is the shift per increment of shift reagent. In a typical experimental procedure 0.4 ml CDCl$_3$ solution containing 0.6 M alcohols or epoxychalcones were prepared at 0.87 mole ratio [mole of chemical shift reagent Eu(hfc)$_3$ per mole of alcohols or epoxychalcone].

K. Physical Measurements

1. Infrared Spectroscopy

Infrared spectra were recorded on a IBM single beam FT IR44 model spectrophotometer. Solution spectra were obtained by using 0.1mm NaCl cells and solid spectra were recorded by mixing the samples with KBr and pressing them into disks.

2. X-ray Diffraction Studies

X-ray d$_{001}$ basal spacings were determined for oriented film samples with a Philips X-ray diffractometer by using Ni-filtered Cu-Kα radiation (λ (Kα) = 1.5405 Å). The film samples were prepared by allowing an aqueous suspension of the samples to evaporate on a microscope glass slide and monitoring the diffraction over a 2θ ranging from 2^{o} to 45^{o}. The peak positions in the angle 2θ were converted to d-basal spacing with a standard chart.

3. Gas Chromatography

All product mixtures along with solvent and internal standards were analyzed by gas-liquid chromatography on a Hewlett-Packard model 5880A with a flame ionization detector and a capillary 25 m x 0.25 mm crosslinked dimethylsilicone column with GB-1 liquid phase and 0.25 µm film tickness. The output of the detector was recorded on high speed printer/plotter with key stroke programme for data handling system. Products were identified by comparison of GLC retention times with those of an authentic sample. The percentage yield of products was determined by integration of the chromatographic peaks of starting reagents and internal standard. Integrations were carried out by the dual channel integration and computation, cartridge tape units, and BASLIC programming.

4. Proton NMR Spectroscopy

Proton nuclear magnetic resonance spectra were recorded on a Bruker WM-250 MHz spectrometer. Chemical shifts were usually measured relative to tetramethyl silane as an internal standard and are reported in units of ppm.

5. Specific Rotation

All specific rotations were measured on a Perkin-Elmer Co. model 141 polarimeter with sodium D line (5890 Å) or mercury line (5780 Å, 5460 Å) at room temperature.

6. Orbit Shaking Water Baths

The shaker used in this study are orbit shaker models 3545 from Lab-Line instruments Inc. The shaker speed were ranging form 25 to 400 rpm and temperature control has platinum RTD sensor within ± 0.05 ^{O}C error.

Chapter III

RESULTS AND DISCUSSION

A. Preparation of Organoclay Phase Transfer Catalysts

The reaction of sodium hectorite in aqueous suspension with various amounts of hexadecyltrimethyl ammonium salt dissolved either in water or methanol results in products in which the sodium ion is displaced by hexadecyltrimethyl ammonium ion (samples 1AA-7AA and 1AM-7AM). Analogous products are obtained by reaction of the aqueous sodium hectorite with tetrabutylammonium salt in water (samples 8AA-14AA) or methanol (samples 8AM-14AM). For both types of reaction conditions, the displacement of sodium ion by onium ions was strongly favored. Nearly complete cation exchange was achieved by using stoichiometric amounts of reagents. The use of a two to ten fold excess of onium ion assured complete cation exchange and formation of a homoionic product. Figure 18 represents the exchange reaction, wherein the negatively charged silicate layers have thickness of 9.6 Å.

Table 1 and Table 2 illustrate, respectively, the d-spacing of a series of various cation loadings of hectorite-supported hexadecyltrimethyl ammonium and hectorite-supported tetrabutyl ammonium cations. The d-spacing of clay-supported hexadecyltrimethyl ammonium cation increases as the amount of onium ion used increases until the organoclay becomes a homoionic product. This could be explained by

Figure 18. Schematic representation of onium cation intercalation in smectite clay

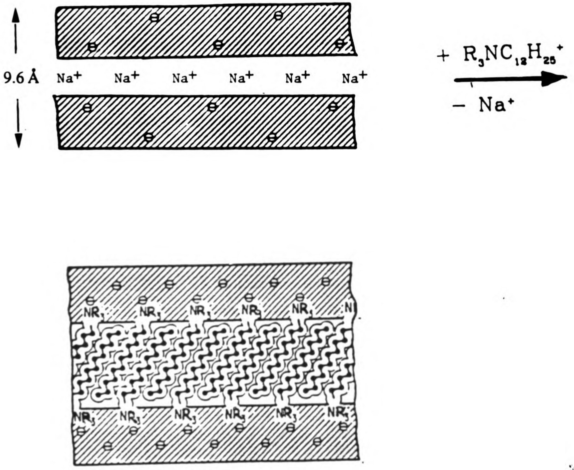
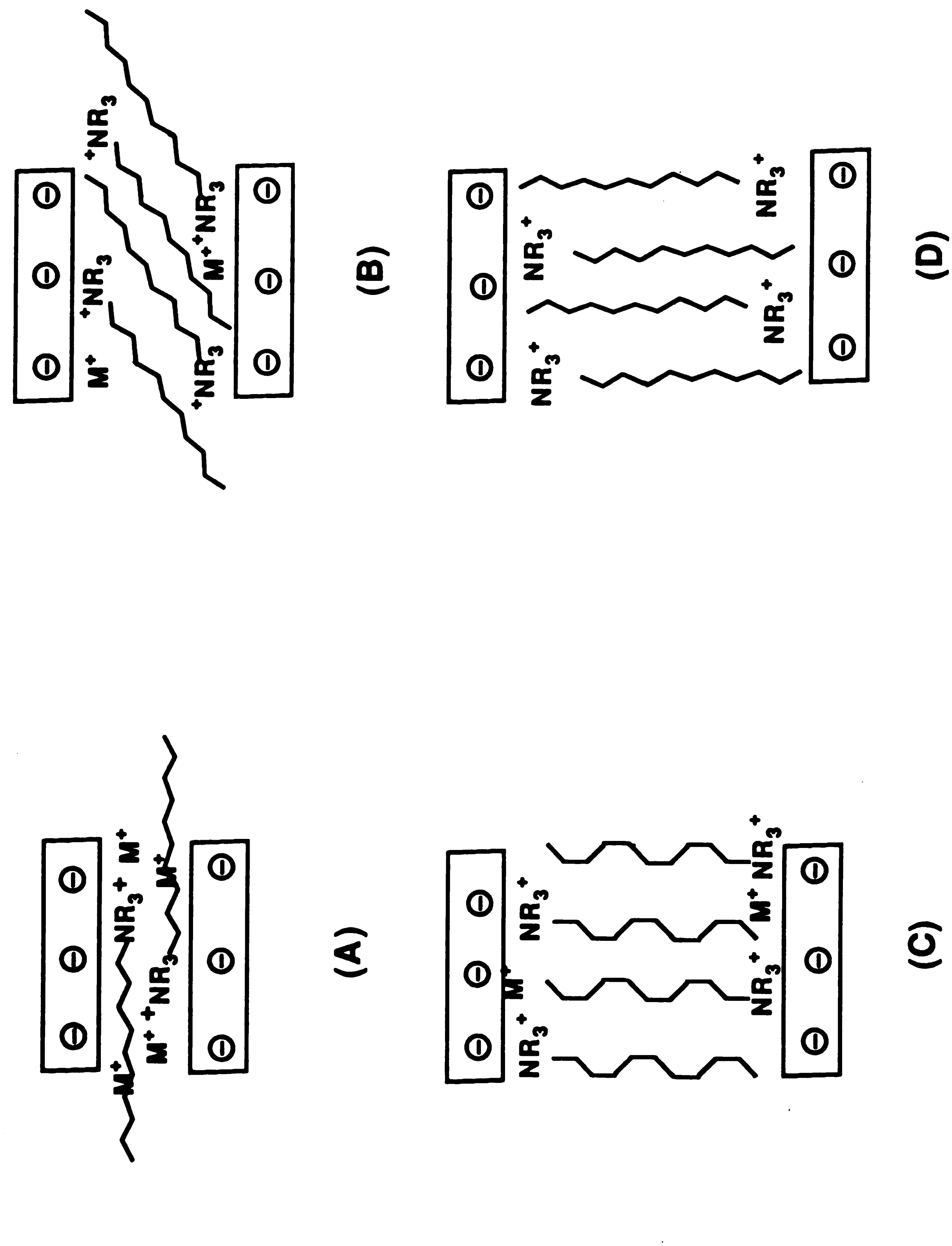

9.6 Å
Na+ Na+ Na+ Na+ Na+ Na+
+ R3NC12H25+
− Na+
NR3

Figure 19. Arrangements of alkylammonium ions in the layer silicates with different loading of the onium cation cation. a) very low cation loading b) medium cation loading c) high cation loading d) homoionic compound


(A)
(B)
(C)
(D)
M$^+$
$^+$NR$_3$
NR$_3$$^+$

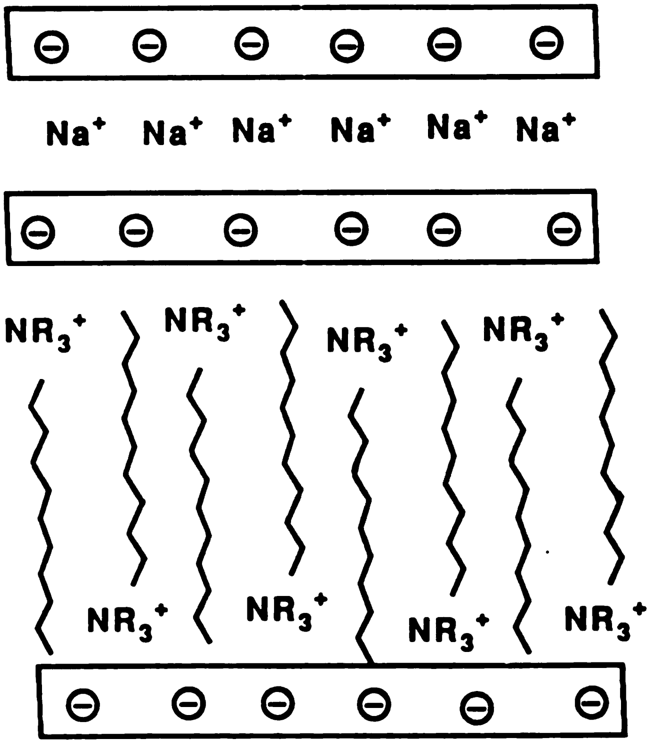


Figure 20. A combination system of sodium hectorite and homoionic organoclay

the fact that the loading of organoclay increase as the number of onium ions used increases until it reaches the cation exchange capacity, then even by using the excess onium cation will not increases the loading of onium cation. The crowding caused by increasing of the loading may alter the orientation of the long alkyl chain of onium cation inside the gallery from parallel to perpendicular relative to the a, b plane of clay host. Thus, an increase in the d-spacing with increasing loading is expected (Figure 19). Besides the mixed cation product (Figure 19 A-C), a combination of sodium hectorite and homoionic product is another possible system (Figure 20). This combination system would result in a similar dependence of d-spacing on the cation loading. However, the d-spacing of hectorite-supported tetrabutyl ammonium cations are independent of cation loading. Since the tetrabutyl ammonium cation has four equivalent alkyl chains, changing the orientation of the cation dose not affect the d-spacing.

A series of onium ion exchanges form of hectorite was prepared using similar procedures (Table 3). For a given onium cation, samples were prepared either in an aqueous system (samples given a AA designation) or in an aqueous methanol system (samples given in AM designation). Both methods resulted in analogous organoclays with similar d_{001} spacing and catalytic activity (Table 3) .

B. The Catalytic Properties of Organoclays in Alkylbromide Displacement by Cyanide Ion

The catalytic activity of each organoclay under "triphase" reaction conditions was established by determining the pseudo first-order rate constant, k_{obs}, for the reaction of an alkylbromide in organic solvent (toluene) with potassium cyanide in aqueous solution to yield a nitrile. A similar method was utilized in studying the catalytic reactivity under "biphase" conditions, except that the onium ion was dissolved in solution rather than being supported in clay galleries. The blank reactions that were conducted under conditions without catalyst (Table 1 and 2, blank 1) or with sodium hectorite as catalyst (Table 1 and 2, blank 2) showed little or no catalytic reactivity.

These studies found that the more reactive triphase reaction mixtures formed uniform organic liquid-water-clay colloidal emulsions. The results, along with the catalytic activity data discussed below, demonstrated that organoclays which formed emulsions under triphase reaction conditions were more active than those which did not. Hence, organoclays which formed emulsions were the materials of choice for efficient triphase catalysts. The emulsions are relatively stable and need a long time to break on their own. However, they were easily broken by low speed centrifugation or by filtering.

Under typical reaction conditions, all three phases will enter into emulsion formation of the oil-in-water type. The clay phase plays an essential role in stabilizing the emulsion, making it more effective than the biphase mixtures formed without organoclay. More water can be added to the emulsion without the water separating from the emulsion. However, if more organic phase is added to the emulsion it will separate from the emulsion as a separate liquid. These observations along with a phase diagram of toluene-water-organoclay (Figure 21) prove that the reaction emulsions are organoclay stabilized organic liquid droplets dispersed in an aqueous phase. The emulsion is indeed a triphase system, consisting of two liquid phases and a solid phase (Figure 22).

1. The Dependence of Catalytic Reactivity on the Loading of Onium Cation

Table 1 and Table 2 show the pseudo first order rate constants for conversion of pentylbromide to pentylcyanide catalyzed by samples 1AA-14AA and 1AM-14AM under triphase reaction conditions. The catalytic activity of hectorite-supported onium ions increases as the loading of catalytically active onium ion increases. The optimum reaction rates were obtained with the homoionic exchange forms of the clay (sample 4AA-7AA, 4AM-7AM, 11AA-14AA, 11AM-14AM). Swelling clays having as few as about 25% of the inorganic exchange ions replaced by onium ions were catalytically active, but homoionic derivatives in which all of the exchange ion were onium ions were preferred.

Figure 21. The three-component system toluene/ water/ hectorite supported $[C_{16}H_{33}PBu_3]^+$ is presented by mass ratio at room temperature. o , emulsion; △, wet solid paste; ▲, gel; ● , suspension; ■,emulsion with extra toluene.

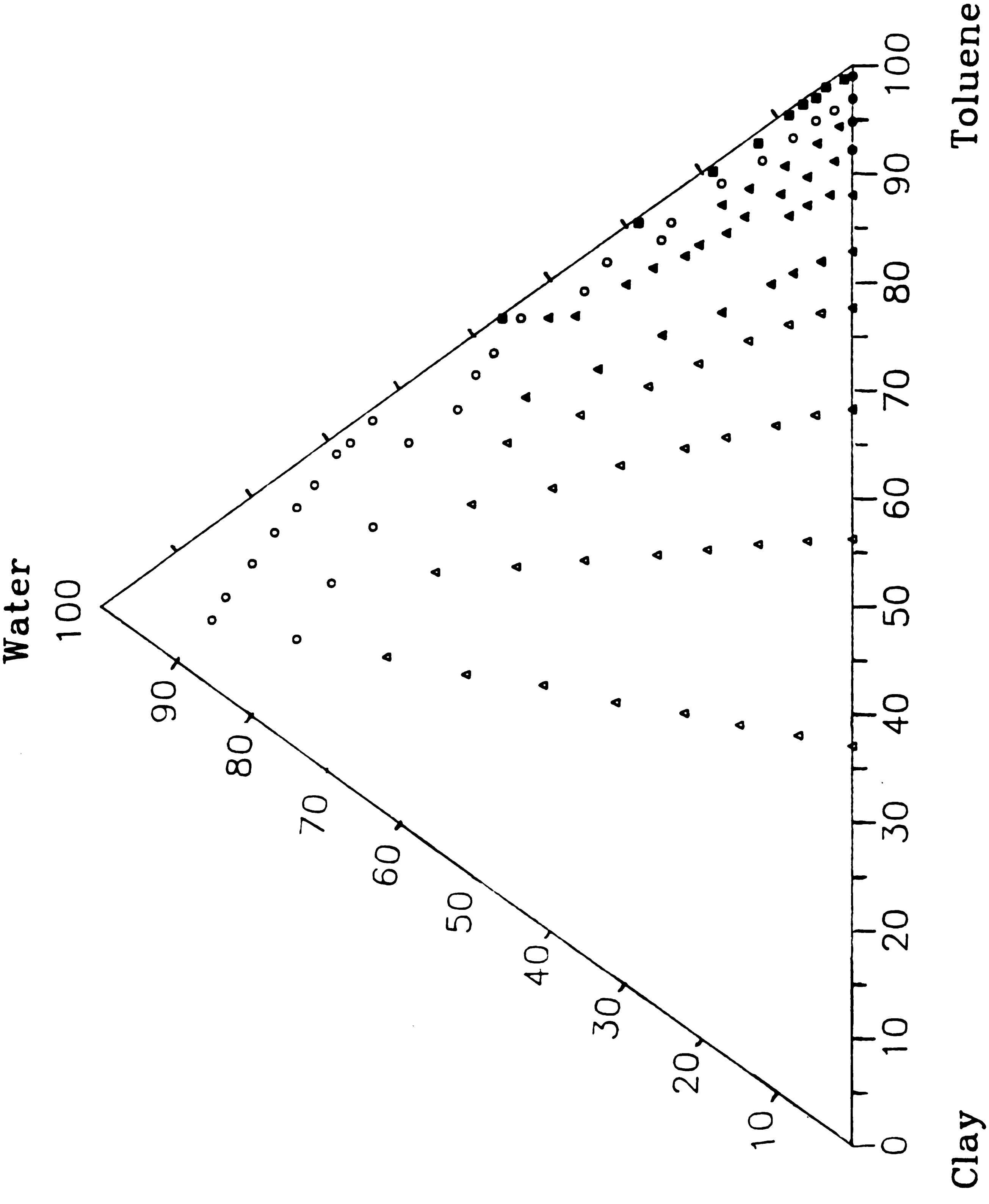
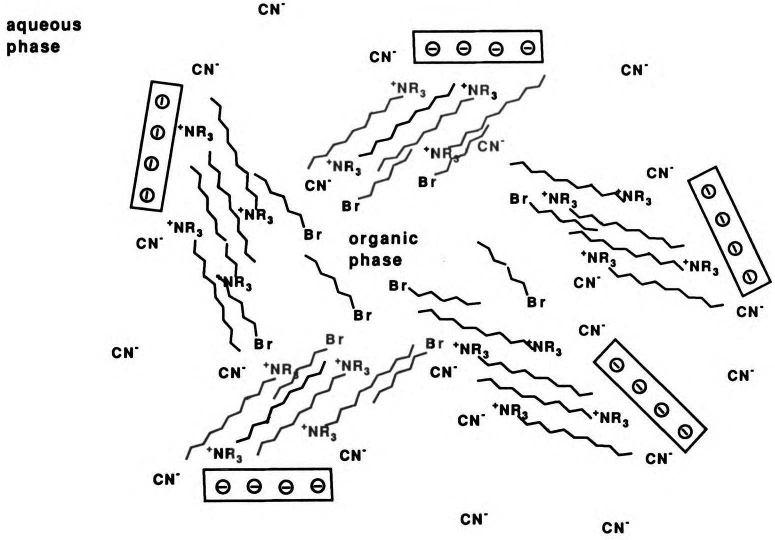

Water
100
90
80
70
60
50
40
30
20
10
Clay
0
10
20
30
40
50
60
70
80
90
100
Toluene

Figure 22. A proposed model for the uniform organoclay colloid emulsion formed under triphase reaction conditions.


aqueous phase
organic phase
CN⁻
⁺NR₃
Br

The hectorite-supported hexadecyltrimethylammonium ion having as little as about 50% loading of onium cation exhibit an ability to stabilize an emulsion of the reaction mixtures. In contrast, in the hectorite-supported tetrabutylammonium ion system the triphase reaction mixtures spontaneously separated into different phases upon cessation of stirring.

The catalytic activities of hectorite-supported hexadecytrimethylammonium ion and tetrabutylammonium ion are not expected to be linearly related to the loading of onium cation inside the gallery, because a substantial factor of the reaction occurs at external rather than internal surfaces. Increasing the loading of onium cations will increase the total cation sites in the organoclay and this will enhance the ability of organoclay to form a stabilized emulsion. The emulsion forming ability is also influenced by the clay particle size , the nature of the onium ion, the orientation of the onium cation and the degree of onium cation loading. The difference in the PTC activity for the hectorite-immobilized hexadecyltrimethylammonium ion and the tetrabutylammonium ion are probably related to the difference in a combination of these factors. For the hectorite-supported tetrabutyl ammonium ion system, the organoclay showed a poor catalytic performance even in its homoionic exchange form (Table 2).

2. The Dependence of Catalytic Reactivity on the Molecular Structure of the Onium Cation

There are two basic requirements for a phase transfer catalyst for nucleophilic substitution : the catalyst must be a cation with enough organic structure to transfer the desired anion into the organic phase; the effective cation-anion bonding must be "loose" enough to allow high anion reactivity. However, the intrinsic biphasic activity of the onium ion does not play a determinative role in the catalytic activity of their corresponding triphase catalytic systems, because the triphase systems involve a different reaction mechanism from that of the biphase system.

For instance, $[Bu_4N]^+$, $[(C_{12}H_{25})_2NMe_2]^+$ and $[C_{16}H_{33}PBu_3]^+$ salts are known as efficient phase transfer catalysts. However, in the triphase system clay-supported $[Bu_4N]^+$ exhibited a poor catalytic properties being only 0.13 times as active as the unsupported catalyst (Table 3, samples 18AA, 18AM) while clay-supported $[(C_{12}H_{25})_2NMe_2]^+$ and $[C_{16}H_{33}PBu_3]^+$ retained their catalytic properties. On the contrary, $[C_{16}H_{33}NMe_3]^+$ and $[C_{14}H_{29}NMe_3]^+$ which are poor phase transfer catalysts in biphase system, were about 2.2 and 2.0 times more active when they were clay-supported, respectively (Table 3, samples 19AA, 19AM and 20AA, 20AM). Thus, the clay environment can substantially moderate the properties of onium ions as phase transfer catalysts.

A survey of clay-supported onium ions as catalysts in the conversion of pentylbromide to pentylcyanide is illustrated in Table 3. Equivalent reaction conditions were investigated for both triphase and biphase systems. Values in parentheses are k_{obs} values determined under biphase conditions. In most cases the k_{obs} values under triphase conditions were lower than those under biphase reaction conditions, except for the hectorite-supported hexadecyltrimethylammonium ion and tetradecyltrimethyl ammonium ion systems which were more active than the corresponding biphase catalyst. However, the convenience and efficiency of recovery of the organoclay catalyst more than compensated for the reduced activity of the onium ion.

The phase transfer catalytic activity of the immobilized onium ion derivatives does not correlate linearly with their d_{001} spacingis or with the intrinsic activity of the onium ion as a biphase catalyst (Table 3).

The homoionic onium ion exchange forms of hectorite which formed uniform emulsions under triphase reaction conditions (Table 3, samples 19AA through 26AM) are more active than those which did not (Table 3, samples 15AA through 18AM). In these studies one observed that the organoclay with onium cations containing a long alkyl chain (samples 19AA through 26AM) can function as an emulsion former while the

Table 1 Products Formed by Ion Exchange Reaction of Hexadecyltrimethylammonium Chloride with Na+-Hectorite and Their Activity for Triphase Catalysts

	Synthesis Conditions					
number	ml 0.5 Wt% Na-hectorite in water	ml 0.073 M Onium Ion in water	ml 0.073 M Onium Ion in methanol	$\frac{\text{meq onium}}{\text{meq clay}}$	d_{001}. Å Air-dry Product	TPC Activity k_{obs}[a] hr^{-1}
Blank 1[b]	-	-	-	-	-	0.000
Blank 2[c]	-	-	-	-	9 6	0.001
1AA	200	2.5	-	0.25	14.0	0.009
2AA	200	5.0	-	0.50	15.0	0.040
3AA	200	7.5	-	0.75	17.4	0.093
4AA	200	10.0	-	1.00	17.7	0.130
5AA	200	20.0	-	2.00	18.2	0.138
6AA	200	30.0	-	3.00	18.0	0.126
7AA	200	100.0	-	10.00	18.0	0.129
1AM	200	-	2.5	0.25	14.0	0.016
2AM	200	-	5.0	0.50	14.1	0.038
3AM	200	-	7.5	0.75	16.4	0.095
4AM	200	-	10.0	1.00	18.0	0.118
5AM	200	-	20.0	2.00	18.0	0.138
6AM	200	-	30.0	3.00	18.0	0.134
7AM	200	-	100.0	10.00	18.0	0.129

[a] Pseudo first order rate constant for conversion of pentylbromide to the corresponding nitrile at 90°C. The following reagents were used: 2.0 mmole pentylbromide in 6 ml toluene; 20.0 mmole potassium cyanide in 3.0 ml water; 0.10 g organoclay ($[Me_3NC_{16}H_{33}]^+$-hectorite).

[b] No clay or onium ion was used in this blank run.

[c] Sodium hectorite was used as catalyst in this blank run.

Table 2 Products Formed by Ion Exchange Reaction of Tetrabutylammonium Chloride with Na^+-Hectorite and Their Activity for Triphase Catalysts

	Synthesis Conditions					
number	ml 0.5 Wt% Na-hectorite in water	ml 0.073 M Onium Ion in water	ml 0.073 M Onium Ion in methanol	$\frac{\text{meq onium}}{\text{meq clay}}$	d_{001}. Å Air-dry Product	TPC Activity k_{obs}[a] hr^{-1}.
Blank 1[b]	-	-	-	-	-	0.000
Blank 2[c]	-	-	-	-	9 6	0.001
8AA	200	2.5	-	0.25	14.5	0.003
9AA	200	5.0	-	0.50	14.7	0.038
10AA	200	7.5	-	0.75	14.7	0.042
11AA	200	10.0	-	1.00	15.1	0.055
12AA	200	20.0	-	2.00	15.1	0.083
13AA	200	30.0	-	3.00	14.7	0.067
14AA	200	100.0	-	10.00	14.7	0.059
8AM	200	-	2.5	0.25	14.7	0.001
9AM	200	-	5.0	0.50	14.7	0.029
10AM	200	-	7.5	0.75	14.7	0.044
11AM	200	-	10.0	1.00	14.7	0.047
12AM	200	-	20.0	2.00	14.7	0.047
13AM	200	-	30.0	3.00	14.7	0.067
14AM	200	-	100.0	10.00	14.7	0.046

[a] Pseudo first order rate constant for conversion of pentylbromide to the corresponding nitrile at 90°C. The following reagents were used: 2.0 mmole pentylbromide in 6 ml toluene; 20.0 mmole potassium cyanide in 3.0 ml water; 0.10 g organoclay ($[Bu_4N]^+$-hectorite).

[b] No clay or onium ion was used in this blank run.

[c] Sodium hectorite was used as catalyst in this blank run.

Table 3 Homoionic Organohectorites as Phase Transfer Catalysts for the Displacement Reaction of Alkylbromide with Cyanide

Onium Ion	Sample Number[a]	d001, Å Air-dried	Triphase k_{obs}, hr^{-1}[b]
$[C_6H_5CH_2NMe_3]^+$	15AA	14.7	0.006
	15AM	14.7	0.006
			(0.005)[c]
$[C_6H_5CH_2P(C_6H_5)_3]^+$	16AA	18.4	0.012
	16AM	18.4	0.014
			(0.005)
$[CH_3NC_5H_4\text{-}C_5H_4NCH_3]^{2+}$	17AA	13.0	0.003
			(0.000)
$[Bu_4N]^+$	18AA	14.7	0.074
	18AM	14.7	0.067
			(0.563)
$[Me_3NC_{16}H_{33}]^+$	19AA	18.0	0.164
	19AM	18.0	0.161
			(0.073)
$[Me_3NC_{14}H_{29}]^+$	20AA	17.0	0.142
	20AM	17.0	0.122
			(0.066)
$[C_6H_5CH_2NMe_2C_{14}H_{29}]^+$	21AA	18.1	0.163
	21AM	18.0	0.153
			(0.383)
$[C_6H_5CH_2NMe_2C_{16}H_{33}]^+$	22AA	18.3	0.161
	22AM	18.3	0.165
			(0.369)
$[C_6H_5CH_2NMe_2C_{18}H_{37}]^+$	23AA	18.3	0.164
	23AM	18.3	0.162
			(0.418)
$[Me_2N(C_{12}H_{25})_2]^+$	24AA	20.1	0.162
	24AM	20.5	0.165
			(0.541)
$[MeN(C_8H_{17})_3]^+$	25AA	21.0	0.181
	25AM	20.1	0.185
			(1.100)
$[Bu_3PC_{16}H_{33}]^+$	26AA	20.1	0.846
	26AM	20.5	0.860
			(2.200)

Table 3 continued

a The description AA indicates that the clay was synthesized by ion exchange of sodium hectorite in aqueous medium. The designation AM indicates that the organoclay was prepared in aqueous methanol. In both types of synthesis 2 meq. of onium ion was used per meq.of clay and the organoclay was washed free of excess onium ion.

b The triphase k_{obs} values are for the conversion of pentylbromide to pentylcyanide at 90°C under the following conditions: 2.0 mmole pentylbromide in 6.0 ml toluene, 20 mmole potassium cyanide in 3 ml water, 0.073 meq. organoclay.

c Values in parenthesis are k_{obs} values determined under equivalent biphase conditions, wherein an equivalent amount of onium ion was present as a soluble bromide or chloride salt.

organoclay with onium cation containing short alkyl chain (samples 15AA through 16AA) do not have this ability. These results indicated that molecular structure of the onium ions inside the gallery affect the ability of the organoclay to serve as an emulsion former and an effective catalyst. The emulsion forming property allows the reagents to be brought together in sufficient concentration by stirring and thereby attain conveniently rapid reaction rates. This could explain why the key to efficient phase transfer catalytic activity by an organoclay is the ability of the clay to form an emulsion containing the clay, the organic phase and the aqueous phase.

3. The Dependence of Catalytic Reactivity on the Molecular Structure of the Organic Substrates

Other parameters that controlled the efficiency of this triphase systems were also investigated. The results in Table 4 show that organohectorites were useful catalysts for the chemical conversion of other alkylbromides to alkylcyanides. Increasing the alkybromide chain length from five to nine or twelve carbon atoms slightly slowed but did not dramatically alter the reaction rates. These results are in accord with the hypothesis that the crucial requirement for an effective triphase catalysis is the formation of an emulsion. Since the length of alkyl chain of the organic substrates does not influence the conformation of the colloid emulsion, it will not affect substantially the catalytic reactivity. The slight differences in k_{obs} values for the $C_5H_{11}Br$, $C_9H_{19}Br$ and $C_{12}H_{25}Br$ substrates are due to the nature of organic substrates (Table 4).

4. The Dependence of Catalytic Reactivity on the Concentration of Substrates and Catalysts

The data in Tables 5 and 6 as well as in Figures 23 and 24 illustrate that the pseudo first-order rate constants for the organoclay catalysts were linearly dependent on the concentration of potassium cyanide and organoclay. It is too early to derive a reaction mechanism on organoclay catalysts. However, future studies of the dependence of the reaction rate on the concentration of organic substrate will help in understanding whether the reaction occurs at a aqueous-clay interface or at a organic-clay interface.

5. The Dependence of Catalytic Reactivity on the Layer Charge of Clay Host

The effects of clay layer charge on the catalytic efficiency of organoclay were intensively studied. Three clays of different layer charge densities were examined : Laponite, and a synthetic hectorite with a charge density of about 0.4 e^- per $O_{20}(OH)_4$ unit and a cation exchange capacity of about 55 meq. per 100 g of air dried clay; a natural hectorite (California) with a charge density of about 0.6 e^- per $O_{20}(OH,F)_4$ unit and a cation exchange capacity of about 73 meq. per 100 g of air dried clay; a synthetic fluorohectorite with about 1.8 e^- per $O_{20}F_4$ unit and a cation exchange capacity of about 122 meq. per 100 g of air dried clay. The k_{obs} values of the homoionic $[C_{16}H_{33}NMe_3]^+$, $[C_{16}H_{33}PBu_3]^+$ and $[Bu_4N]^+$ exchange forms for the pentylbromide to pentylcyanide conversion show that catalytic activity was lowest for Laponite, but the hectorite and fluorohectorite supported catalysts were highly efficient. The k_{obs} value of $[C_{16}H_{33}NMe_3]^+$-hectorite is 15 times as high as k_{obs} of $[C_{16}H_{33}NMe_3]^+$-Laponite. In the $[C_{16}H_{33}PBu_3]^+$ system, a similar result was obtained, the k_{obs} value of hectorite being 10 time as high as k_{obs} of Laponite. But changing the layer charge density from hectorite to F-hectorite did not affect the reaction rate dramatically in both clay-supported $[C_{16}H_{33}NMe_3]^+$ and $[C_{16}H_{33}PBu_3]^+$ systems (Table 7).

The low d_{001} for $[C_{16}H_{33}NMe_3]^+$-Laponite and $[C_{16}H_{33}PBu_3]^+$-Laponite indicated that the onium ion is oriented with the long hydrocarbon chain essentially parallel to the silicate surface. In $[C_{16}H_{33}NMe_3]^+$-hectorite, with d_{001} = 18.0 Å the chains are inclined with regard to the layers. The $[C_{16}H_{33}NMe_3]^+$ in F-hectorite forms a lipid-like bilayer, as indicated by d_{001} of 28 Å. These results, along with the catalytic activity data discussed eariler, indicate that the catalytic activities of organoclays depend nonlinearly on the orientation and loading of the onium cation inside the gallery. The

Table 4 The Dependence of kobs Values on Alkyl Chain Length for Conversion of Alkylbromides to Cyanide[a]

Organoclay Catalyst	Alkylbromide $C_5H_{11}Br$	 $C_9H_{19}Br$	 $C_{12}H_{25}Br$
$[MeN(C_8H_{17})_3]^+$-hectorite	0.140	0.123	0.165
$[Bu_3PC_{16}H_{33}]^+$-hectorite	0.575	0.458	0.378
$[Me_3NC_{16}H_{33}]^+$-hectorite	0.129	0.081	0.057
$[Me_3NC_{14}H_{29}]^+$-hectorite	0.115	0.095	0.066
$[Me_2N(C_{12}H_{25})_2]^+$ hectorite	0.127	0.075	0.059

[a] Reaction conditions: 2.0 mmole RBr in 6 ml toluene; 20.0 mmole KCN in 3 ml water; 0.10 g homoionic organoclay; 90°C.

Table 5 Dependence of k_{obs} Values on Potassium Cyanide Concentration for Conversion of Pentylbromide to Pentylcyanide[a]

Concentration of KCN moles/liter	k_{obs}, hr^{-1}
1.67	0.146
3.33	0.278
5.00	0.423
6.67	0.575

[a] Reaction conditions: 2.0 mmole pentylbromide in 6.0 ml toluene; 3.0 ml potassium cyanide solution: 0.1 g homoionic $[Bu_3PC_{16}H_{33}]^+$-hectorite; 90°C.

Figure 23. Dependence of k_{obs} values on potassium cyanide concentration for the conversion of pentylbromide to pentylcyanide catalyzed by $[C_{16}H_{33}PBu_3]^+$-hectorite.

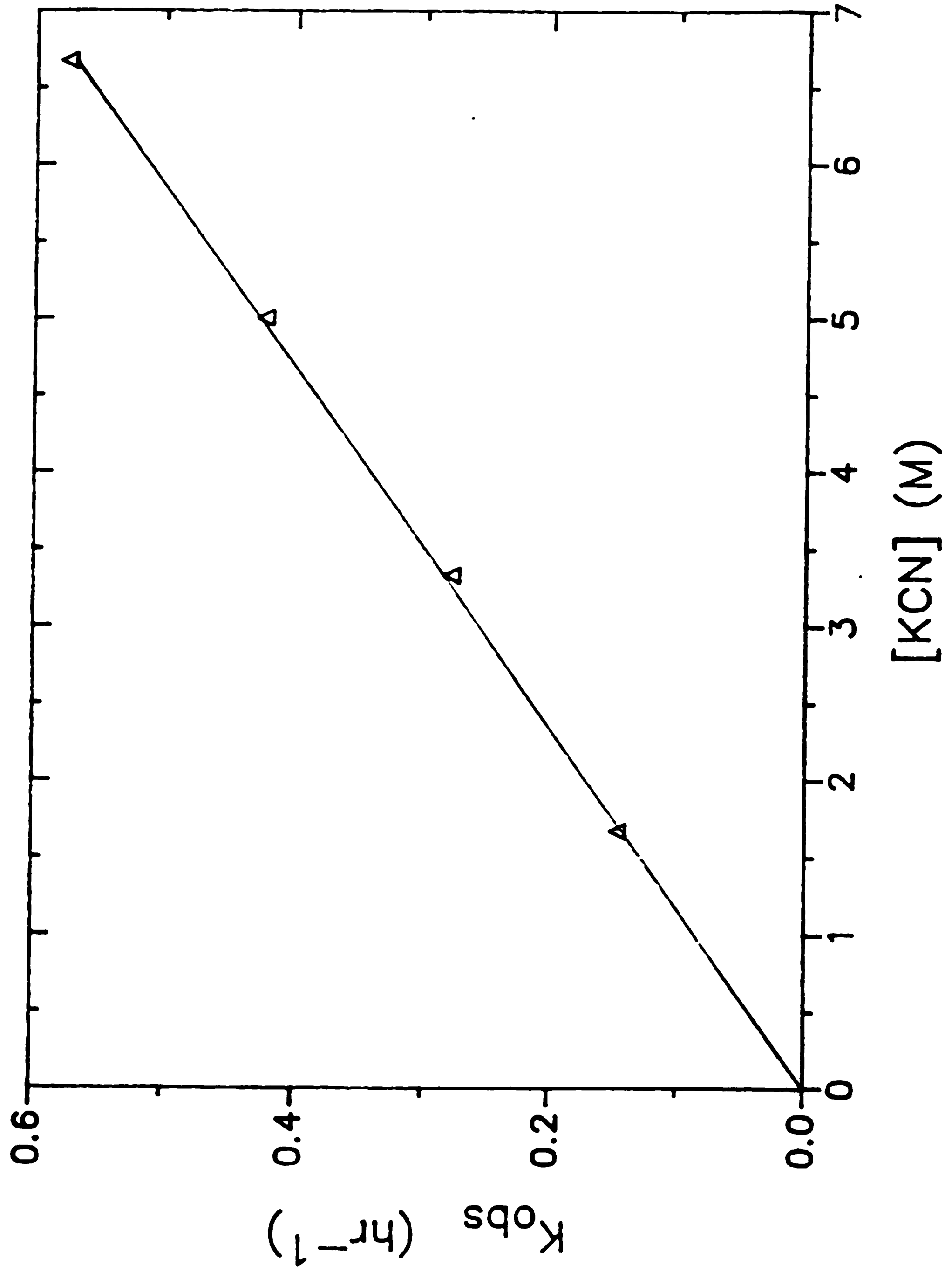

0.0
0.2
0.4
0.6
k_{obs} (hr^{-1})
0
1
2
3
4
5
6
7
[KCN] (M)

Table 6 Dependence of k_{obs} Values on Organoclay Concentration for Conversion of Pentylbromide to Pentylcyanide[a]

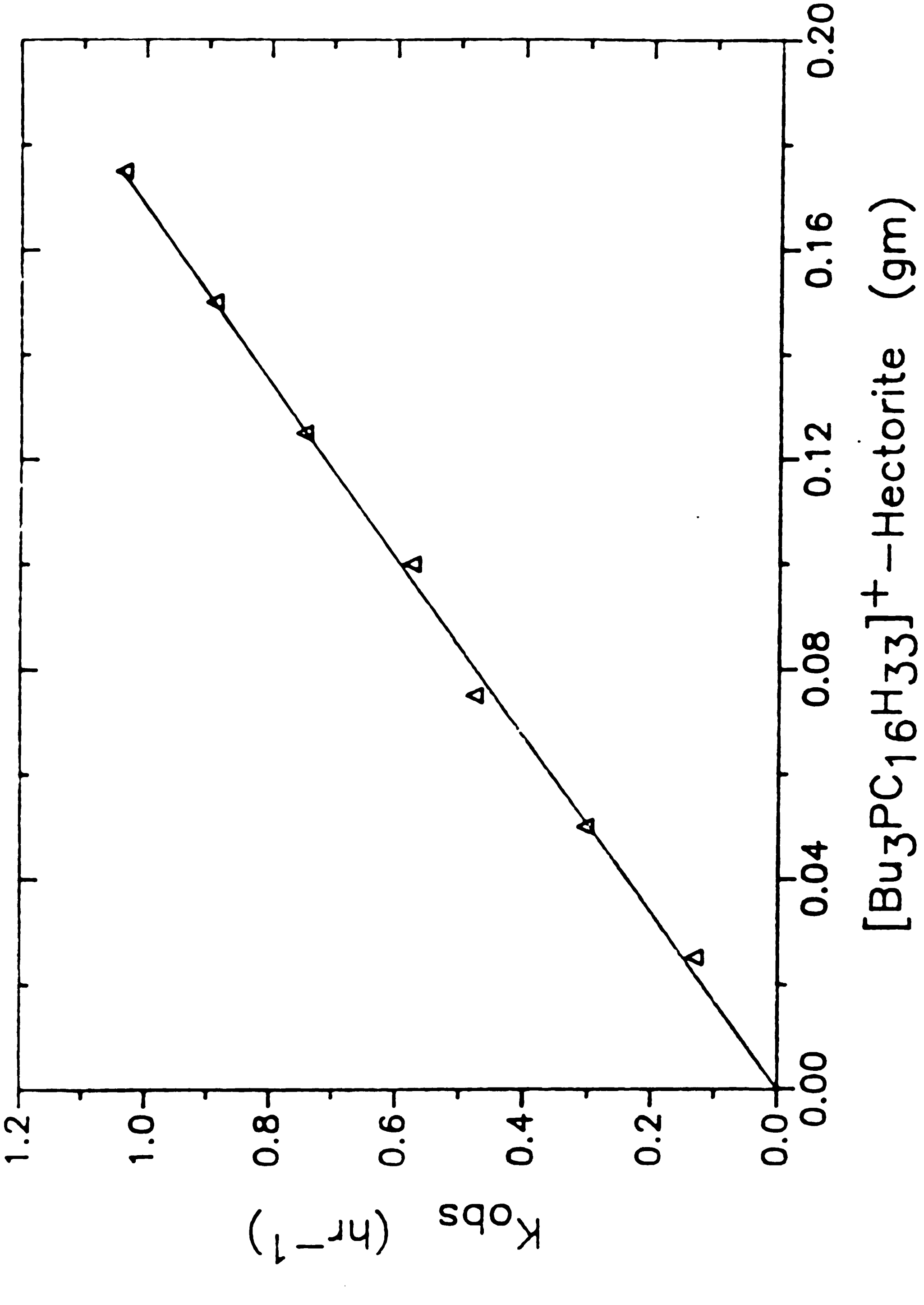
$[Bu_3PC_{16}H_{33}]^+$-Hectorite[b] in Suspension, gms.	k_{obs}, hr^{-1}
0.025	0.130
0.050	0.303
0.075	0.476
0.100	0.575
0.125	0.746
0.150	0.891
0.175	1.036

---

[a] Reaction conditions: 2.0 mmole pentylbromide in 6.0 ml toluene; 20.0 mmole potassium cyanide in 3.0 ml water; 90°C.

[b] Fully exchanged homoionic organoclay.

Figure 24. Dependence of k_{obs} values on organoclay concentration for conversion of pentylbromide to pentylcyanide catalyzed by $[C_{16}H_{33}PBu_3]^+$-hectorite.


K_{obs} (hr^{-1})
0.0
0.2
0.4
0.6
0.8
1.0
1.2
$[Bu_3PC_{16}H_{33}]^+$–Hectorite (gm)
0.00
0.04
0.08
0.12
0.16
0.20

cation orientation determined the ability of the clay to form stable emulsion. A similar relationship between the d_{001}, k_{obs}, and the layer charge density of the clay host was observed for both the clay-supported $[C_{16}H_{33}PBu_3]^+$ and clay-supported $[C_{16}H_{33}NMe_3]^+$ systems.

Hence, a given onium ion with a long hydrocarbon chain, and a clay host with sufficient layer charge to cause inclination of the alkyl chains relative to the clay layer, is preferred. The charge density needed to cause inclination of the onium ion chains will depend on the size of the onium ion, but a value near 0.6 e^- per $O_{20}(OH,F)_4$ unit is typical.

In the clay-supported $[Bu_4N]^+$ systems, changing the layer charge density of the clay support from laponite to hectorite does not alter d_{001} dramatically. Since $[Bu_4N]^+$ has four equivalent alkyl chains, changing the orientation of $[Bu_4N]^+$ ion in the interlayers of clay does not alter d_{001} significantly. Yet, the k_{obs} value for hectorite was 4.35 times as high as that for Laponite. Thus, higher clay charge densities increase the loading of onium cation and enhance both the active sites and the organophilic character of the organoclay and thereby improve the catalytic activity. However, the second factor is not expressive in the clay-supported $[Bu_4N]^+$ system, Therefore, poor catalytic activity was observed in this system even with a catalyst of hectorite exchange form.

6. The Dependence of Catalytic Reactivity on the Polarity of Organic Solvent

Phase transfer catalysis, in general, involves a formation of an ion pair and the transfer of this ion pair from its "normal" phase into the second phase. Therefore, one can expect that the physical and chemical properties of this ion pair will affect the reactivity of phase transfer catalysis. Although little systematic information is available in biphase systems, it is known that the interactions with solvent will strongly influences the behavior of ion pairs.

Table 7 Dependence of k_{obs} Values on the Clay Host for Conversion of Pentylbromide to Pentylcyanide[a].

	Laponite 55meq./100 of clay		Hectorite 73meq./100 of clay		F-Hectorite 122meq./100 of clay	
Onium Ion	d_{001}, Å	k_{obs}	d_{001}, Å	k_{obs}	d_{001}, Å	k_{obs}
$[Me_3NC_{16}H_{33}]^+$	14.0	0.011	18.0	0.164	28.0	0.120
$[Bu_3PC_{16}H_{33}]^+$	14.5	0.083	20.1	0.846	28.0	1.118
$[Bu_4N]^+$	14.0	0.017	14.7	0.074	-	-

[a] All clays were fully exchanged with the onium ion indicated and used for conversion of pentylbromide to pentylcyanide at 90°C under the following triphase conditions:
2.0 mmole pentylbromide in 6 ml toluene; 20.0 mmole potassium cyanide in 3 ml water; 0.073 meq. organoclay.

Table 8 Dependence of k_{obs} Values on the Polarity of Organic Solvent for Conversion of Pentylbromide to Pentylcyanide[a]

Organic Solvent	k_{obs}, hr^{-1}
Chlorobenzene	0.254
Toluene	0.575
Decane	0.950

a Reaction conditions: 2.0 mmole pentyl bromide in 6 ml toluene; 20.0 mmole potassium cyanide in 3 ml water; 0.10 g $[Bu_3PC_{16}H_{33}]^+$-hectorite; 90°C.

Three groups of solvents have been classified in this respect : 1) Polar protic solvents readily solvate both anions and cations and give a high degree of dissociation of ion pairs. 2) Polar aprotic solvents readily solvate cations but not anion. Ion pairs are highly dissociated in such solvents. 3) Nonpolar aprotic solvents exhibit good solubilities toward onium salts but negligible solubility of inorganic salts . In these solvents the dominant species are ion pairs and the interaction of ion pairs and solvent is weak.

In PTC reactions it has been found that nonpolar and dipolar aprotic solvents function well. In general, reactions are faster in the solvents of greater dielectric constant.

In polymer-based triphase catalyst systems the nature of the organic solvent will affect the catalytic activity for different reasons. Regen has proposed that the organic solvent can determine the absorption of reactant on the polymer and control the extent of swelling, which in turn will determine the number of active sites available for catalysis, and establish the nature of the microenvironment at the active site, thus affecting the free energy of activation. In the reaction of an alkylbromide with aqueous sodium cyanide catalyzed by polystyrene-bound phase transfer catalysts, Regen's work has shown a modest dependence of rate on the type of organic solvent used (89), and Ford has demonstrated a reaction rate decreasing with solvent in the order chlorobenzene > toluene > decane over wide ranges of particle sizes and polymer cross-linking (95).

An analogous reaction catalyzed by the hectorite-supported $[C_{16}H_{33}PBu_3]^+$ showed the opposite dependence of catalytic reactivity on the polarity of solvent (Table 8). The pseudo first rate constant increased as the polarity of the solvent decreased (chlorobenzene < toluene < decane). By using the reaction model shown in Figure 22, we can predict that the kinetics of bromide displacement by cyanide occurring in organoclay systems are determined partially by the hydrophobic interactions between the emulsion phase and the organic substrates (alkylbromide), and partially by the electrostatic interactions between the the emulsion phase and inorganic anion (cyanide anion). Increasing the polarity of organic solvent utilized will increase the interaction between the organic solvent and organic substrates and consequently weaken the interactions between the emulsion phase and the organic substrates. This will decrease the partition of the organic substrates in the reactive center and decrease the catalytic reactivity.

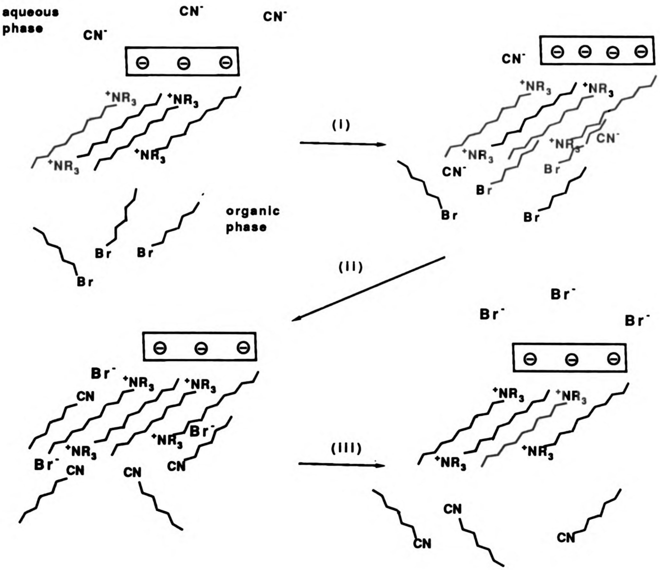
7. The Mechanism of Organoclay in Alkylbromide Displacement by Cyanide Ion

On the basis of the investigations discussed above, the organoclay catalysis mechanism for alkylbromide displacement can be summarized as follows. The reaction mixtures formed an oil-in water type emulsion in which the organoclay plays an essential role in stabilizing the emulsion. The ability of organoclay to serve as an emulsion former of reaction mixtures is controlled by three factors : the loading of onium ion, the orientation of the onium cation inside the gallery (both are affected by the preparation method and layer charge of the clay host) and the molecular structure of the intercalated onium cation. The fundamental kinetic steps of the organoclay systems for the cyanide displacement reaction are : i) the alkybromide are attracted to the alkyl chain of catalysts by hydrophobic interaction, and the CN^- are attracted to the polar end of catalysts by electrostatic interactions; ii) displacement reaction occur in the emulsion phase; iii) the products, alkylcyanide and Br^- are transferred from the emulsion phase back to the organic phase and aqueous phase respectively (Figure 25).

C. Organic Synthesis Catalyzed by Organoclay

In the previous studies we have demonstrated the feasibility of triphase catalysis for the attack of cyanide ion on alkylbromides catalyzed by organoclay. In addition to the cyanation reactions, we now demonstrate that organoclays can be applied to a variety of useful synthetic transformations, including : 1) ether synthesis, 2) oxidation of alcohols, 3) synthesis of thiocyanates and sulfides, 4) C-alkylation of nitriles, 5) dehalogenation of

Figure 25. The fundamental kinetic steps of the organoclay in the alkylbromide displacement by cyanide ion : i) the organic substrates are attracted to the alkyl chain of catalysts by hydrophobic interaction and the inorganic anions are attracted to the polar end of catalysts by electrostatic interactions. ii) displacement reaction occur in the emulsion phase. iii) the products are transferred from the emulsion phase back to the organic phase or aqueous phase.


aqueous phase
CN⁻
⁺NR₃
organic phase
Br
(I)
(II)
(III)
Br⁻
CN

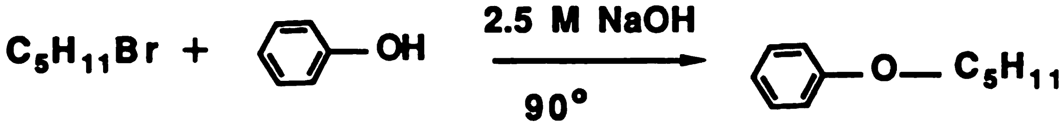
vic-dibromides, and 6) halogen exchange. Analogous applications of other triphase catalysis systems have been surveyed by Dehmlow (34). In the following examples $[MeN(C_8H_{17})]_3^+$-hectorite (25AA) and $[Bu_3PC_{16}H_{33}]^+$-hectorite (26AA) were utilized as catalysts.

The X-ray d_{001} values of the recovered catalysts used in the above reactions showed that the catalysts retained their initial d-spacing after the reactions. This indicates that the organoclays are very stable and do not lose their functionization under the reaction conditions. The slight difference in X-ray d_{001} values between the original catalysts and recovered catalysts are probably due to the adsorption of organic species from the reaction mixture. The products were identified by comparing their ^1H NMR spectrum and IR spectra with those for authentic samples (Table 16) or their GLC spectra with those of standard samples.

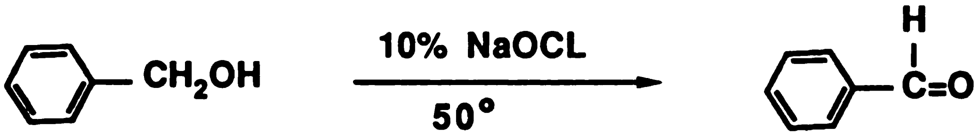
1. Synthesis of aromatic ethers from phenol

Conventional methods for the preparation of alkyl and aryl ethers are many in number. However, considerable effort is still being expended in developing new and more convenient procedures. Organoclays were found to be useful triphase catalysts in the synthesis of ethers. A phenoxide ion generated by treatment of phenol with aqueous sodium hydroxide (2.5 M), was reacted with n-pentylbromide at 90°C. The reactions were catalyzed by organoclays 25AA and 26AA (Table 9). Phenyl 1-pentylether was produced in 83% yield within 1.5 and 2 h respectively (Table 9). The molar ratio of nucleophile, pentylbromide, and catalyst used was 2/1/0.01. In this reaction, unlike the previous triphase reaction, catalyst 25 AA exhibited better catalytic reactivity than 26AA. Reeves has reported a similar reaction catalyzed by a polymer-supported phase transfer catalyst that gave 81% conversion in 1 hr at 110°C and the molar ratio of nucleophile, pentylbromide and catalyst used was 3/1/0.01 (120). Since the reaction conditions were not identical, it is hard to compare the efficiency of those two catalyst systems.

1. Ether Synthesis



2. Oxidation of Alcohol

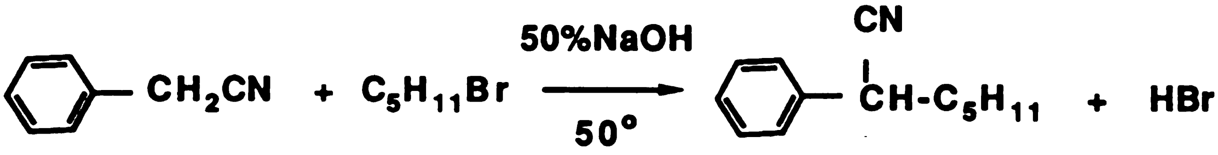


3. Synthesis of Thiocyanates and Sulfides

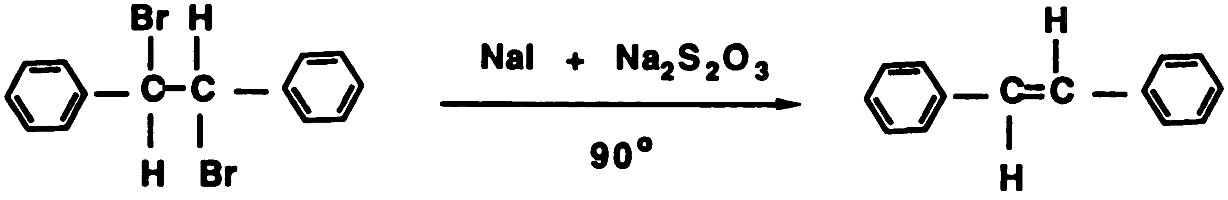
$$C_5H_{11}Br \ + \ NaSCN \ \xrightarrow[90^\circ]{} \ C_5H_{11}SCN \ + \ NaBr$$

$$C_5H_{11}Br \ + \ Na_2S \ \xrightarrow[90^\circ]{} \ (C_5H_{11})_2S \ + \ 2\ NaBr$$

4. C-Alkylation at Activated CH-Bonds



5. Dehalogenation of vic-Dihalide



6. Halogen Exchange

$$RBr + NaCl \xrightarrow[90^\circ]{} RCl + NaBr$$

However, in other studies of similar reaction conditions, the organoclay exhibit a higher catalytic activity than polymer-supported phase transfer catalysts.

2. Oxidation of Alcohols

Reaction of benzyl alcohol dissolved in toluene with 10% aqueous sodium hypochlorite in the presence of catalysts 25AA or 26AA at 50°C gave benzaldehyde in 83.2% and in 98.4% yield within 10.0 h (Table 10). Further oxidation to benzyl acid occurred for a longer reaction timer. Regen has attempted a similar reaction catalyzed by a polymer-supported phase transfer catalysts but it afforded only 51% conversion after 50 h at 50°C (86). These results demonstrate that for the oxidation of alcohols, a higher catalytic reactivity was found for the organoclay than for the polymer-supported phase transfer catalyst.

3. Synthesis of alkyl thiocyanate

The reaction between aqueous sodium thiocyanate solution and n-pentylbromide was conducted at 90°C with organoclay as the triphase catalyst. With a 2/1/0.01 molar ratio of thiocyanate, n-pentylbromide and catalyst used, n-pentylthiocyanate was obtained in 99% and 95% chemical yield after reaction time of 1.5 h and 0.5 h in the presence of organoclay 25AA and 26AA, respectively (Table 11). By using a polymer-supported catalyst, Reeves carried out the same reaction under an analogous reaction condition except at a higher reaction temperature (110°C). He observed a 94% chemical yield of n-pentylthiocyanate after 2 h (120). This example shows that an organoclay exhibits better catalytic properties than a polymer-supported phase transfer catalysts.

4. Synthesis of sulfide

The conversions of n-pentyl bromide to n-dipentyl sulfide were catalyzed by organoclay 25AA or 26AA at 90°C. The chemical yields obtained for the two catalysts were 91% and 97%, respectively after a reaction time of 0.5 h (Table 12). Reeve used polymer as support in preparation of his triphase catalysts (polystyrene supported-$(CH_3)_3$-PBu_3^+). A similar alkylsulfide synthesis with a 1.2/1/0.01 molar ratio of sulfide,

Table 9 Synthesis of Phenyl n-pentyl ether[a]

Catalyst	Time, hr	Yield,%	d_{001},Å[b]
Blank[c]	1.0	38.5	-
$[MeN(C_8H_{17})_3]^+$-hectorite	1.5	83.0	21.0
$[Bu_3PC_{16}H_{33}]^+$ hectorite	2.0	83.0	22.9

[a] Reaction conditions: 5.0 mmole n-pentylbromide; 10.0 mmole phenol and 6.0 ml of 2.5 M sodium hydroxide solution; no organic solvent is used; 0.05 mmole homoionic organoclay; 90°C.

[b] X-ray d_{001} spacing for recovered catalyst.

[c] No homoionic organoclay was used in this blank run.

Table 10 Oxidation of Benzyl Alcohol[a]

Catalyst	Time, hr	Yield,%	d_{001},Å[b]
Blank[c]	10	10.7	-
$[MeN(C_8H_{17})_3]^+$-hectorite	10	83.2	22.5
$[Bu_3PC_{16}H_{33}]^+$ hectorite	10	98.4	22.5

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[a] Reaction conditions: 2 mmole benzyl alcohol in 3 ml toluene; 5 ml 10% sodium hypochlorite; 0.05 mmole homoionic organoclay; 50°C.

[b] X-ray d_{001} spacing for recovery catalyst.

[c] No homoionic organoclay was used in this blank run.

Table 11 Synthesis of n-Pentyl Thiocyanate[a]

Catalyst	Time, hr	Yield,%	d_{001},Å[b]
Blank[c]	1.5	28.7	-
$[MeN(C_8H_{17})_3]^+$-hectorite	1.5	99.0	19.2
$[Bu_3PC_{16}H_{33}]^+$ hectorite	0.5	95.0	19.0

[a] Reaction conditions: 10.0 mmole sodium thiocyanate in 4 ml water; 5.0 mmole n-pentyl bromide; no organic solvent is used ; 0.05 mmole homoionic organoclay; 90°C.

[b] X-ray d_{001} spacing for recovered catalyst.

[c] No homoionic organoclay was used in this blank run.

Table 12 Synthesis of n-Dipentyl Sulfide[a]

Catalyst	Time, hr	Yield,%	d_{001},Å[b]
Blank[c]	1.0	20.0	-
$[MeN(C_8H_{17})_3]^+$-hectorite	0.5	91.0	21.0
$[Bu_3PC_{16}H_{33}]^+$ hectorite	0.5	97.0	23.2

[a] Reaction conditions: 6.0 mmole sodium sulfide in 3.0 ml water; 5.0 mmole n-pentylbromide; no organic solvent is used; 0.05 mmole homoionic organoclay; 90°C.

[b] X-ray d_{001} spacing for recovered catalyst.

[c] No homoionic organoclay was used in this blank run.

n-pentylbromide and catalyst was undertaken by Reeve at 110°C. He observed a 98% chemical yield after a reaction time of 1.5 h (120). The reaction rates of organoclays are three time as great as the rate observed for a polymer-supported phase transfer catalyst when the reaction is run of the same temperature. Organoclays proved to be highly efficient catalysts in the application of sulfide synthesis.

5. C-alkylation of nitriles

The alkylation of phenylacetonitrile with n-pentylbromide was carried out under triphase system with 50% sodium hydroxide aqueous solution at 50°C. The molar ratio of phenylacetonitrile, n-pentylbromide and catalyst was 1/1/0.01. After 6 h reaction time a 85% monalkylation was obtained when it catalyzed by 25AA while a 82% chemical yield was received after 2 h when it catalyzed by 26AA (Table 13). Only monalkylation was obtained in both reactions. Organoclay 25AA inherits a lower catalytic activity than 26AA as usual.

Dou attempted analogous reactions under both biphase and triphase condition by using tributyhexadecyl phosphonium bromide and the corresponding polymer-supported cation as catalysts (142). Under biphase condition, 88% monoalkylation and 9% dialkylation (in percent for 100% of substrate) was achieved after 10 h at 70°C with a 1/1/0.01 molar ratio of phenylacetonitrile, n-pentylbromide and catalyst. Increasing the amount of catalyst by altering the molar ratio to 1/1/0.1, gave 70% monalkylation and 13% dialkylation after reaction time of 5 h under the analogous conditions. Triphase reaction conditions gave a best overall yield, up to 72%, and 4.5% dialkylation at 70°C for 10 h reaction time. Comparisons of the catalytic properties of $[Bu_3PC_{16}H_{33}]^+$-hectorite (26AA), polymer supported $[Bu_3PC_{16}H_{33}]^+$ and $Bu_3PC_{16}H_{33}Br$ indicated that the organoclays are not only better catalysts than the corresponding polymer supported catalysts but sometimes they exhibit higher catalytic reactivities and specificities than the analogous biphase catalysts.

6. Dehalogenation of vic-dibromides

Dehalogenation of meso-1,2-dibromo-1,2diphenylethane to stilbene in toluene was carried out through the use of sodium thiosulfate and sodium iodide. When the reaction was catalyzed by organoclays 25AA or 26AA, completely stereospecific conversion to trans-stilbene with 95% and 98% yield, respectively, was obtained at 90°C after 7 h reaction time (Table 14). Under similar reaction conditions Regen observed the same product in 100% chemical yield after 12 h by utilizing polymer-supported phase transfer catalysts (86). As expected, organoclays are better catalysts than other triphase catalysts.

7. Halogen Exchange

The reactions of aqueous sodium chloride and alkybromide in toluene were catalyzed by $[MeN(C_8H_{17})]_3^+$-hectorite (25AA) and $[Bu_3PC_{16}H_{33}]^+$-hectorite (26AA) at 90°C. Table 15 illustrates the conversions for a series of alkybromides to the corresponding alkylchlorides. The reaction rates were not altered drastically by increasing the hydrocarbon chain length of the alkylbromides. These reactions were limited by the thermodynamic equilibrium values at 3 : 10 for a Br^- : Cl^- ratio.

By using excess sodium chloride, Regen was able to obtain a modest reaction rate when the chloride-bromide exchange reaction was catalyzed by polymer-CH_2-Bu_3P^+ at elevated temperature, 110°C (86, 95). We can expect our reaction rates to increase more than 11 times if we use an analogous concentration of sodium chloride.

D. Comparison of the Catalytic Properties of Organoclay

The catalytic properties of a few commercial organoclays were studied in comparison with that of our organoclay (Table 17). In the cyanation reaction organoclay, Benton 34, exhibited no catalytic activity and gave 0% chemical yield after 24 h reaction time. Under analogous reaction conditions organoclay ECCT 40 , ECCT AF and ECCT PS showed modest catalytic activity and received a similar result of 73% chemical conversion within 8 h. These results, in comparison with our previous work listed in

Table 13 C-Alkylation of Nitriles[a]

Catalyst	Time, hr	Yield,%	d_{001},Å[b]
Blank[c]	6.0	3.5	
$[MeN(C_8H_{17})_3]^+$-hectorite	6.0	85.8	21.5
$[Bu_3PC_{16}H_{33}]^+$ hectorite	2.0	82.0	21.9

[a] Reaction conditions: 5.0 mmole n-pentylbromide; 5.0 mmole benzylcyanide; 2.0 ml of 50% sodium hydroxide solution; no organic solvent is used; 0.05 mmole homoionic organoclay; 50°C.

[b] X-ray d_{001} spacing for recovered catalyst.

[c] No homoionic organoclay was used in this blank run.

Table 14 Dehologenation of vic-Dibromides[a]

Catalyst	Time, hr	Yield,%	d_{001},Å[b]
Blank[c]	21.0	0.0	-
$[MeN(C_8H_{17})_3]^+$-hectorite	7.0	95.0	22.5
$[Bu_3PC_{16}H_{33}]^+$ hectorite	7.0	98.0	20.0

[a] Reaction conditions: 1.0 mmole meso-1,2-dibromo-1,2 diphenylethane in 2.0 ml toluene, 0.246 mmole sodium iodide; 32.0 mmole sodium thiosulfate in 2.0 ml water; 0.05 mmole homoionic organoclay; 90°C.

[b] X-ray d_{001} spacing for recovered catalyst.

[c] No homoionic organoclay was used in this blank run

Table 15 Synthesis of Alkylchloride from Alkylbromide[a]

Catalyst	alkylbromide	Time, (hr)	Yield (%)	d_{001}[b] (Å)
Blank1[c]	$C_5H_{11}Br$	48.0	0.0	-
$[MeN(C_8H_{17})_3]^+$-hectorite	$C_5H_{11}Br$	78.0	73.4	21.8
$[Bu_3PC_{16}H_{33}]^+$ hectorite	$C_5H_{11}Br$	48.0	64.5	22.4
Blank2[c]	$C_9H_{19}Br$	48.0	0.0	-
$[MeN(C_8H_{17})_3]^+$-hectorite	$C_9H_{19}Br$	54.0	73.5	21.8
$[Bu_3PC_{16}H_{33}]^+$ hectorite	$C_9H_{19}Br$	48.0	62.8	22.4
Blank3[c]	$C_{12}H_{25}Br$	48.0	0.0	-
$[MeN(C_8H_{17})_3]^+$-hectorite	$C_{12}H_{25}Br$	54.0	63.3	21.8
$[Bu_3PC_{16}H_{33}]^+$-hectorite	$C_{12}H_{25}Br$	48.0	56.4	22.4

Table 15 continued

[a] Reaction conditions: 2.0 mmole alkylbromide in 6.0 ml toluene; 6.67 mmole sodium chloride in 3.0 ml water; 0.05 mmole homoionic organoclay; 90°C.
[b] X-ray d_{001} spacing for recovered catalyst.
[c] No homoionic organoclay was used in this blank run.

Table 16 Infrared Data and ^{1}H NMR Data for the Products by Organoclay Triphase Catalysis[a]

Sample	ν cm^{-1}[b]	^{1}HNMR[c]
Pentyl n-Pentyl Ether	3073 w, 3041 w, 2958 vs 2937 sh, 2875 m, 1604 s, 1596 sh, 1500 s, 1479 m, 1395 w, 1291 w, 1250 s, 1167 w, 1063 w, 1041 w, 896 w, 875 w, 813 w, 750 s, 688 s	
Benzyl Aldehyde	3080 sh, 3060 w, 3030 sh, 2740 sh, 2710 m, 1700 s, 1700 m, 1595 s, 1580 s, 1455 s, 1390 m, 1310 s, 1290 sh, 1205 s, 1165 m, 1070 w, 1020 w, 1000 w, 830 s, 745 s, 690 s, 650 s, 500 m	7.55ppm, 7.79ppm, 9.94ppm s
n-Pentyl Thiocyanate	2958 sh, 2937 vs, 2854 s, 2140 s, 1438 m, 1354 w, 1270 w, 1250 w, 1104 w, 1020 w,	0.95ppm t, 1.40ppm q, 1.85ppm, 2.95ppm t

Table 16 continued

Sample	ν cm^{-1}[b]	^{1}HNMR[c]
Dipentyl Sulfide	2958 sh, 2937 vs, 2854 s, 1458 s, 1375 m, 1333 w, 1291 m, 1270 m, 1250 sh 1208 m, 1104 w, 916 w, 500 sh, 479 m	0.87ppm t, 1.37ppm q, 1.55ppm, 2.49ppm t
2-Pentyl hexanenitrile	3062 m, 3036 m, 2964 sh, 2911 vs, 2875 s, 2250 m, 1607 m, 1500 m, 1464 s 1375 w, 1071 w, 1018 w, 750 m, 730 sh, 696 vs,	0.86ppm t, 1.25ppm q, 1.41ppm, 1.80ppm, 3.72ppm t, 7.28 ppm
Trans-Stilbene	3080 w, 3060 w, 3020 w, 1600 w, 1580 w, 1500 m, 1450 m, 1070 w, 960 s, 910 sh, 760 s, 700 s 700 s, 540 sh, 530	7.1ppm s, 7.26ppm, 7.35ppm 7.50ppm

Table 16 continued

a The products were washed according the methods described in chapter 2 and dried by sodium sulfate and collected by distillation.

b Solution spectra were obtained by using 0.1 mm NaCl cells. Solid spectra were obtained by mixing the samples with KBr and pressing them into a disk.

c Chemical shifts were measured relative to tetramethysilane as an internal standard by using deutrated chloroform as solvent.

Table 3, indicated that similar catalytic properties are obtained for the commercial organoclay of the ECCT series, and our 19AA-25AM organoclays. However, $[Bu_3PC_{16}H_{33}]^+$-hectorite exhibited a reaction rate which is about four times as fast as that of the organoclay of ECCT series.

E. Comparison of the Catalytic Properties of Some Organo-Layered Compounds

A series of layered compounds and their intercalation with alkylamonium ions were synthesized . The six major layered compound are alpha-zirconium phosphate ($Zr(HPO_4)_2$), sodium molybdenum bronze (Na_xMoO_3), sodium titanate ($NaTi_3O_7$), sodium tintanium sulfides ($NaTiS_2$), Zn-Cr layered double hydroxide ($Zn_2Cr(OH)_6$) and layered chloro tin phosphate ($SnCl(OH)(HPO_4)$. The intercalated onium ions were $(C_{12}H_{25})NH(CH_3)_2^+$, $(C_{16}H_{33})N(CH_3)_3^+$ and $(C_{12}H_{25})_2N(CH_3)_2^+$, except for the layered double hydroxide in which case the intercalated ion was dodecylsulfate. The catalytic properties of organo-layered compounds were investigated for bromide displacement both by cyanide and chloride. All of the organo-layered compounds in these studies were either deintercalated or decomposed in the cyanation reactions, as indicated by the X-ray data of the recovered catalysts. In the chloride displacement of pentylbromide reaction, only $(C_{12}H_{25})NH(CH_3)_2^+$-zirconium phosphate gave a positive results (Table 18). Emulsion formation was observed in the $(C_{12}H_{25})NH(CH_3)_2^+$-zirconium phosphate system and an analogous chemical conversion, 62.8% yield after 48 h, was observed for organoclay 26AA. The catalytic conversions, observed for $(C_{12}H_{25})_2N(CH_3)_2^+$-$[Zr_2Cr(OH)_6]$-$[C_{12}H_{25}SO_4]$, $(C_{12}H_{25})NH(CH_3)_2^+$-chloro tin phosphate and $(C_{12}H_{25})_2N(CH_3)_2^+$-sodium tintanium sulfides were due to the de-intercalation of the onium cations and their subsequent involvement as biphase catalysts, and can be proved by the continuation of the reaction after removing the solid catalysts. Although the catalytic reactivities of the organo-layered compounds were disappointing, these triphase technique might be able to improve by varying the crystallinity of the

Table 17 Catalytic Reactivities of Commercial Organoclay in the Synthesis of n-Pentylcyanide from n-Pentylbromide under Triphase Reaction Conditions[a]

Catalyst	Time, hr	Yield,%
Benton 34[b]	24.0	0.0
ECCT 40[b]	8.0	73.0
ECCT AF[b]	8.0	73.0
ECCT PS[b]	8.0	72.0
$[MeN(C_8H_{17})_3]^+$-hectorite	8.0	77.0
$[Bu_3PC_{16}H_{33}]^+$-hectorite	3.5	95.0

[a] Reaction conditions: 2.0 mmole n-pentylbromide in 6.0 ml toluene; 20.0 mmole sodium cyanide in 3.0 ml water; 0.13 g of organoclay; 90°C.

[b] Benton 24 was donated by Baroid Co. and ECCT organoclay series were obtained from English China Clay Co.

Table 18 Catalytic Reactivities of Organolayered Compounds for the Synthesis of n-Pentylchloride from n-Pentylbromide under Triphase Catalysis Conditions[a]

Catalysts	Time,hr	Yield,%	Stability	Emulsion Formation
$(C_{12}H_{25})N(CH_3)_2^+$—— $Zr(HPO_4)_2$	48.0	62.8	stable	yes
$(C_{16}H_{33})N(CH_3)_3^+$—— Na_xMoO_3	24.0	0.0	stable	no
$(C_{12}H_{25})N(CH_3)_2^+$—— Na_xMoO_3	24.0	0.0	stable	no
$(C_{12}H_{25})N(CH_3)_2^+$—— $SnCl(OH)(HPO_4)$	24.0	11.3	unstable	yes

Table 18 continued

Catalysts	Time,hr	Yield,%	Stability	Emulsion Formation
$(C_{12}H_{25})N(CH_3)_2^+$—— $[Zn_2Cr(OH)_6][C_{12}H_{25}SO_4]$	24.0	15.5	unstable	no
$[Zn_2Cr(OH)_6][C_{12}H_{25}SO_4]$	24.0	0.0	unstable	no
$(C_{12}H_{25})_2N(CH_3)_2^+$—— $NaTiS_2$	24.0	48.6	unstable	no
$(C_{12}H_{25})N(CH_3)_2^+$—— $NaTi_3O_7$	24.0	0.0	stable	no

a The following reagents were used: 2.0 mmole n-pentylbromide in 6 ml toluene; 6.67 mmole potassium cyanide in 3.0 ml water; 0.10 g organolayered compounds; 90°C.

layered host compounds and by altering the molecular structure of the intercalated onium ion.

F. Preparation of Clay-Supported Chiral Catalysts

Asymmetric synthesis by using chiral phase transfer catalysts or polymer-supported chiral phase transfer catalysts has been a subject of interest to several authors in the last few years. Although the optical purity of the resulting products is low, and few reaction mechanism have been studied, they are important as an imaginative new series of catalysts.

In our previous studies of clay-supported phase transfer catalysts we successfully have translated the solution reactions into triphase systems. With this background, we attempt to develop a clay-supported chiral phase transfer catalysis. The intercalation of (-) N-dodecyl-N-methyl ephedrinium and (-) N-benzylquininium on hectorite or flurohectorite was achieved following an analogous preparation procedure as for the clay-supported phase transfer catalysts reported earlier. Table 19 illustrates that the d-spacing of the clay supported (-) N-dodecyl N-methyl ephedrinium increases from 18.57 Å to 25.80 Å when the layer charge density of clay host increase from 0.6 e^- per $O_4[OH, F]_4$ (hectorite) to 1.8 e^- per O_4F_4 (F-hectorite). A similar dependence of d-spacing on the layer charge density of clay support was observed for the clay-supported (-) N-benzylquininium. This dependence, as previous discussed, is due to the different orientations of the chiral cation on the clay host of different layer charge density. Cation orientation appears to be a determinative factor on the efficiency and stereoselectivity of the asymmetric synthesis.

G. The Stereoselectivity and Mechanism of the Asymmetric Reduction of Ketones Catalyzed by Organoclay

There are few studies on asymmetric borohydride reduction of carbonyl compounds catalyzed by chiral phase transfer catalysts. Colonna and his co-workers reported that (-) N-dodecyl N-methylephedrinium bromide and (-) N-benzylquininium

Table 19 X-ray Basal Spacings Data of Clay-supported Chiral Catalysts[a]

Samples	Number	d001, Å
(-) N-Dodecyl N-Methyl ephedrinium hectorite	131AA	18.57
(-) N-Dodecyl N-Methyl ephedrinium F-hectorite	F131AA	25.80
(-) N-Benzylquininium hectorite	151AA	19.60
(-) N-Benzylquininium F-hectorite	F151AA	22.84

[a] Clay-supported chiral catalysts were prepared under following condition: 1% aqueous clay solution was stirred vigorously with 0.073 M aqueous chiral onium salt solution for 24 hours. The products were washed free of excess onium salt, and collected by centrifugation, and air dried at room temperature; for 1 meq of clay, 2 meq of chiral onium ion was used.

chloride gave 10.6% and 22% ee, respectively, in the reduction of t-butyl phenyl ketone under biphase condition (69, 143, 141) (the ee numbers given in the literatures were 13.9% and 28.5% according the maximum value of $[\alpha]^{D}{}_{20} = 30.0$ in acetone, but we recalculated the ee number assuming the value of $[\alpha]^{D}{}_{20} = 39.6$ in acetone (143)). However, neither chiral catalyst was able to promote asymmetric induction in the reaction of ketones with less hindered reactive center such as phenyl n-propanone.

So far, no detailed mechanism of asymmetric borohydride reduction catalyzed by (-) N-dodecyl N-methylephedrinium bromide and (-) N-benzylquininium chloride has been proposed. However, most research groups have recognized that in order to obtain a high optical activity in the borohydride reduction, a tight ion pair between the borohydride anion and the chiral cation has to form, and the β hydroxy group of the chiral cation should interact with the ketone by oxygen H-bonding.

Several authors have recognized that the stereoselectivity of chiral catalysis is affected by the polarity of the solvent employed, the molecular structure of the chiral phase transfer catalyst, the molecular structure of the substrate and the conditions of the reaction (temperature, time and catalyst-substrate molar ratio). We have investigated the behavior of clay-supported chiral phase transfer catalysts in the asymmetric reduction of ketones by consideration of similar experimental parameters.

In the following experiments, t-butyl phenyl ketone was synthesized according to the reported literature. The identification of the t-butyl phenyl ketone and the reaction products was achieved by comparing their ^{1}H NMR spectra and IR spectra with those of authentic samples (Table 20). The enantiomeric excess of products were determined by ^{1}H NMR in the presence of $Eu(hfc)_3$ as a chiral shift reagent (Figure 26). The non-catalyzed reactions run under analogous conditions gave 11% chemical yield after 48 h and 75% conversion after 24 h for n-butyl phenyl ketone and t-butyl phenyl ketone respectively (Table 21 blank 1-2). Other blank reactions run without ketones exhibited a zero specific rotation after 72 h under similar reaction conditions (Table 21 blank 3-6). These results indicated that the organoclay of this study are stable under the reaction conditions and the onium cation is not desorbed into solution.

1. The Dependence of Enantiomeric Excess on the Layer Charge of Clay Host

In the reduction of n-butyl phenyl ketone, hectorite-supported (-) N-dodecyl N-methylephedrinium (131AA) afforded a low reaction rate but high optical activity compared with the corresponding chiral phase transfer catalysts 100% chemical yield with 7.9-9.7% enantiomeric excess was obtained after a reaction time of 24 h (Table 22). Replacing the hectorite support (sample 131AA) by F-hectorite (sample F131AA) resulted in enhancing the catalytic reactivity but decreasing the stereoselectivity of organoclay, giving a 100% chemical conversion but essentially no optical yield after 16 h (Table 22).

Similar influences of support on catalytic activity were observed for hectorite and F-hectorite-supported (-) N-benzylquininium (151AA and F151AA). However, both 151AA and F151AA show no significant stereoselectivity (0~1.6% and 1.6~5.0% ee respectively) (Table 22). When the layer charge densities of the clay host are increased, the active sites and organophilic characters of the organoclay are enhanced. This enhancement leads to improvement of the catalytic activity of the organoclay.

The predominant enantiomer for the products had R configurations when the reactions were catalyzed by a hectorite-support chiral catalysts. In contrast, F-hectorite supported chiral catalysts favored the S isomer. This effect was seen clearly for low temperature reactions (Table 24). It is evident that the clay host plays an important role in asymmetric borohydride reduction. The important energy difference between hectorite and F-hectorite may express themselves in the "best fits" of the transition states. Since the hydroxy-group and reactive cation center of the catalysts are involved in the transition state of reaction, their positions and orientations relative to clay support will

Table 20 Infrared Data and ^{1}H NMR Data for t-Butyl Pentyl Ketone t-Butyl Pentyl Alcohol and n-Butyl Pentyl Alcohol

Sample	ν cm^{-1}[c]	^{1}HNMR[d]
t-Butyl pentyl Ketone[a]	3061 m, 2970 s, 2872 sh, 1676 s, 1600 m, 1477 s, 1460 sh, 1446 sh, 1395 m, 1366 m, 1278 m, 1192 s, 1176 s, 960 s, 717 sh, 686 s,	1.33ppm s, 7.20ppm
t-Butyl Pentyl Alcohol[b]	3448 b, 3084 sh, 3062 w, 3030 w, 2970 sh, 2954 s, 2906 sh, 2869 m, 1480 m, 1453 m, 1394 w, 1363 m, 1047 m, 1007 m, 899 w, 784 w, 734 s, 703 s,	0.93ppm s, 1.90ppm s 4.20 ppm, 7.15ppm
n-Butyl Pentyl Alcohol[b]		0.86ppm t, 1.28ppm, 1.70ppm, 2.18ppm s, 4.62ppm t, 7.26ppm

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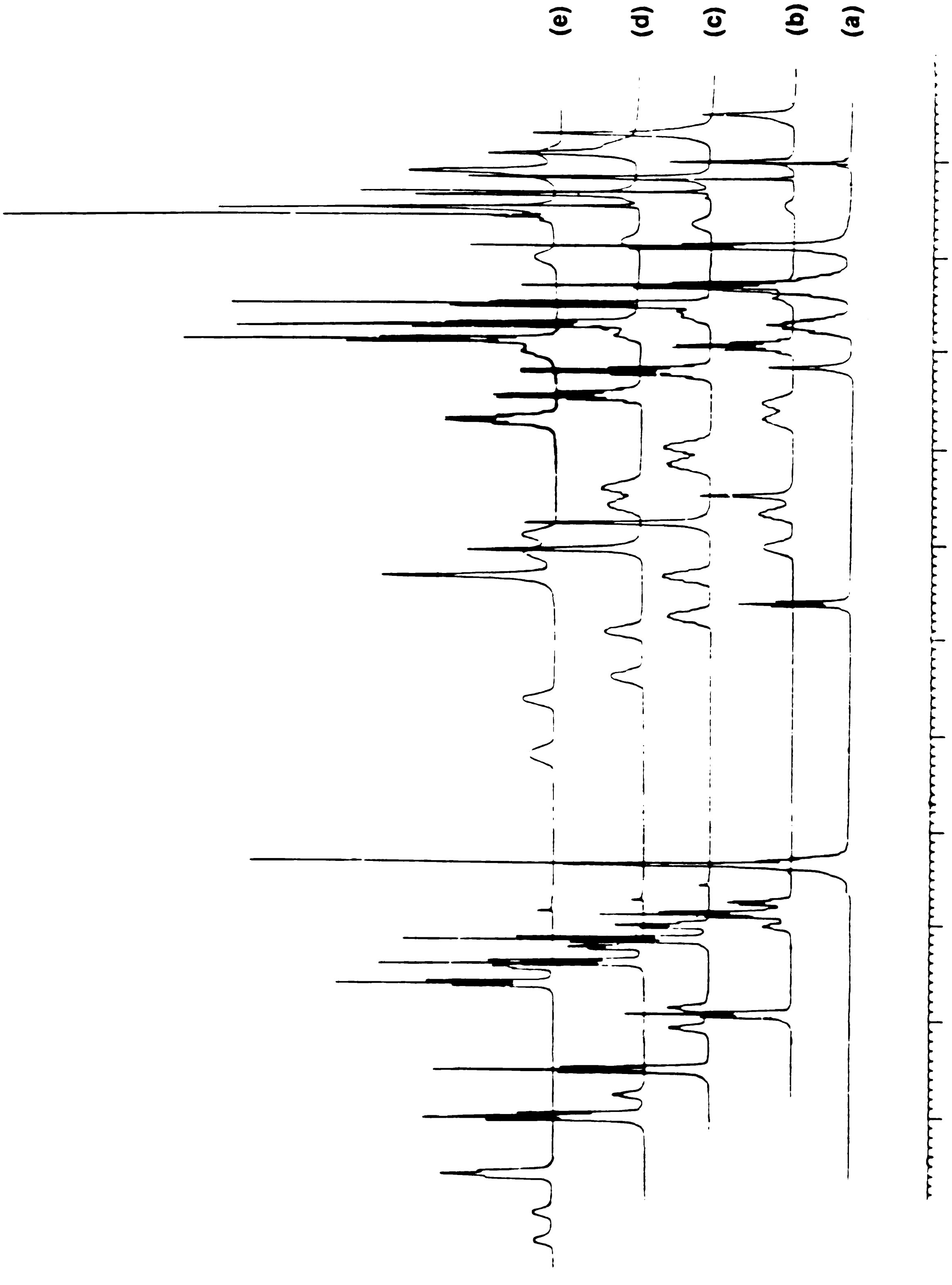
[a] The t-butyl pentyl ketone was extracted with ether and the extracts were washed with water, saturated sodium bicarbonate solution, and then dried with sodium sulfate and collected by distillation.

[b] The products were extracted from the aqueous phase with benzene and dried by sodium sulfate. The products were collected by evaporation of the organic solvent.

[c] Solution spectra were obtained by using 0.1 mm NaCl cells.

[d] Chemical shifts were measured relative to tetramethysilane as an internal standard by using deutrated chloroform as solvent.

Figure 26. The ^{1}H NMR Spectrum of n-butyl phenyl alcohol (0.06 M in $CDCl_3$) in presence of various amount of chemical shift reagent $Eu(hfc)_3$. The molar ratios of chemical shift reagent and the alcohol are 0, 0.32, 0.43, 0.52 and 0.87 in (a)-(e), respectively.


(e)
(d)
(c)
(b)
(a)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
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8.0
9.0
10.0
PPM

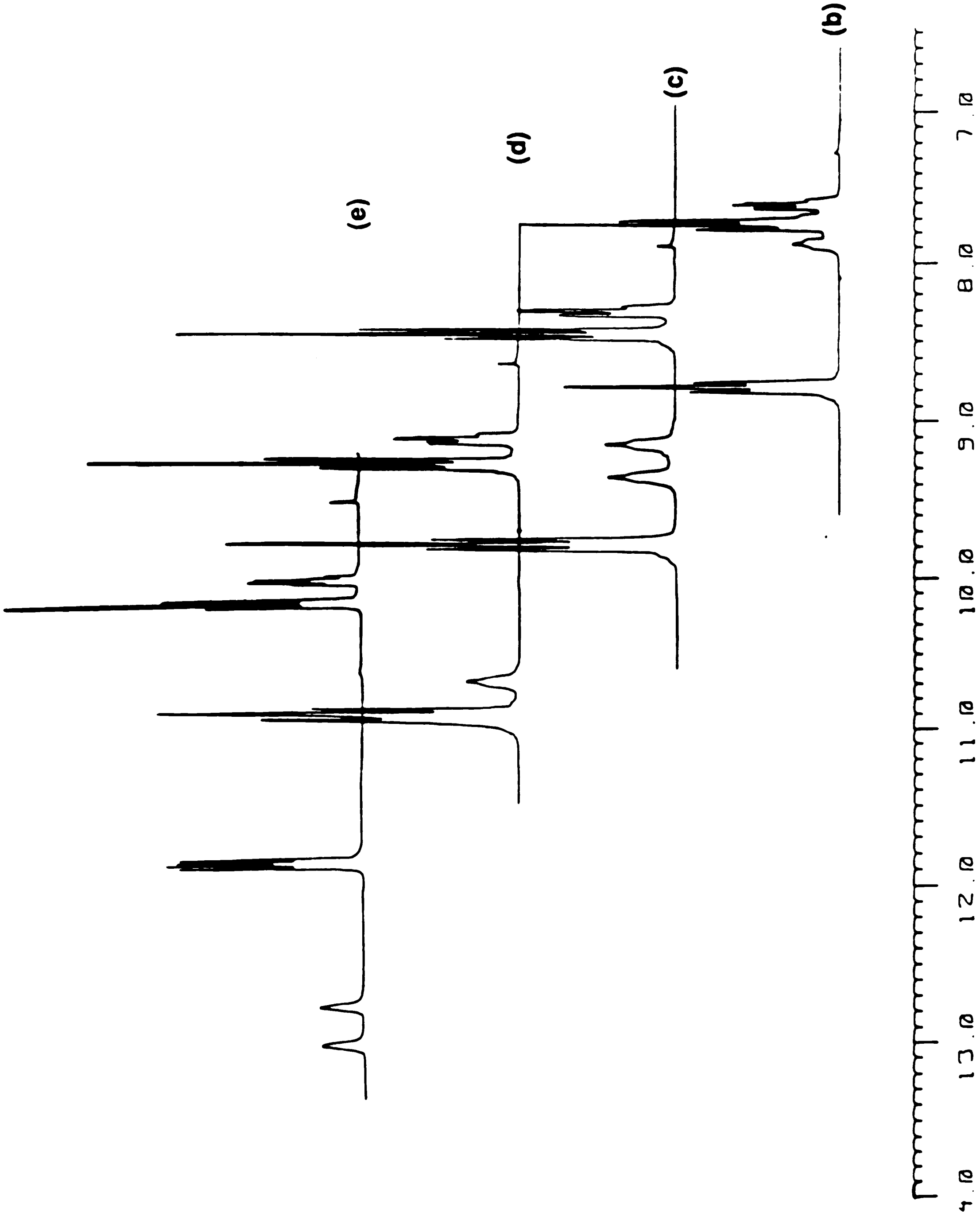

(b)
(c)
(d)
(e)
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
ppm

Table 21 The Blank Reactions of Borohydride Reduction of Butyl Pentyl Ketone [a]

Reaction Number	Catalyst	Pentyl Ketone R-Group	Reaction Time, hr	Chemical Yield, % [c]	Specific Rotation [d]
Blank 1[a]	-	n-butyl	48.0	11.0	0.0
Blank 2[a]	-	t-butyl	24.0	75.0	0.0
Blank 3[b]	131AA	-	72.0	0.0	0.0
Blank 4[b]	F131AA	-	72.0	0.0	0.0
Blank 5[b]	151AA	-	72.0	0.0	0.0
Blank 6[b]	F151AA	-	72.0	0.0	0.0

[a] Reaction conditions: 2.5 mmole ketone in 3.0 ml benzene;6 mmole potassium borohydride in 5.0 ml water; no homoionic organoclay was used ;4°C.

[b] Reaction conditions: 3.0 ml benzene; 6 mmole potassium borohydride in 5.0 ml water; 0.2 mmole homoionic organoclay;4°C.

[c] Chemical yield of alcohol was based on starting ketone and detected by GLC with decane as internal standard.

[d] The specific rotations were measured on a Perkin-Elmer Co. Model 141 polarimeter with sodium D line (5890 Å).

certainly play an important role on the stereochemical course of the asymmetric induction in the triphase system. Therefore, for a given chiral cation, the ion will orient differently in the clay host and these differences in orientation will (Table 19) result in different stereoselectivities.

In presence of hectorite-supported (-) N-dodecyl N-methylephedrinium (131AA), t-butyl phenyl alcohol was produced within 24 h with no significant optical yield (Table 22). However, utilizing F-hectorite-N-dodecyl N-methylephedrinium (F131AA), hectorite-(-) N-benzylquininium (151AA) and F-hectorite-(-) N-benzylquininium (F151AA) as catalysts, the t-butyl phenyl alcohols were formed with 11.2%, 19.7% and 32.7% ee, respectively. These optical yields are comparable to the analogous biphase system catalyzed by (-) N-dodecyl N-methylephedrinium bromide and (-) N-benzylquininium chloride (10.6% and 22% ee respectively)(144). Comparing these results with previous data of the reduction of n-butyl phenyl ketone, a opposite stereoselectivity was observed for a given organoclay. Also for a given intercalated chiral catalyst, the organoclay with F-hectorite as the support afforded a t-butyl phenyl ketone with higher optical purity than the organoclay with hectorite as the support.

The generalizations concerning the dependence of the catalytic reactivity and stereoselectivity of organoclays on the clay host can be summarized as follows : 1) For a given chiral cation the effectiveness of F-hectorite supported catalysts is higher than that of hectorite supported catalysts; 2) Hectorite supported catalysts favor R isomers in the reduction of n-butyl phenyl ketones (Table 22 and 24); 3) F-hectorite supported catalysts favor of S isomers in the reduction of n-butyl phenyl ketones (Table 22 and 24) and R isomers in the reduction of t-butyl phenyl ketones (Table 22).

2. The Dependence of Enantiomeric Excess on the Molecular Structure of Chiral Cations and Organic Substrates

In PTC systems it has been reported by several authors that catalysts derived from cinchona alkaloids have higher catalytic activity and stereoselectivity than those derived from ephedra alkaloids (63, 64, 143, 144). In the organoclay systems the degree of stereoselectivity depends both on the molecular structure of chiral cation, and on the clay support. The general rule about the dependence of the stereoselectivity of the reaction on the molecular structure of biphase catalysts is not held in the organoclay. For example in the reduction of n-butyl phenyl ketones, F-hectorite-(-) N-dodecyl N-methylephedrinium (F131AA) was more efficient than hectorite-(-) N-benzylquininium (151AA) and as active as F-hectorite-(-) N-benzylquininium (F151AA) (Table 22). Furthermore, hectorite-supported (-) N-dodecyl N-methylephedrinium (131AA) exhibited a higher asymmetric induction than hectorite, and F-hectorite-supported (-) N-benzylquininium cation (151AA and F151AA) (Table 22).

In contrast, for the reduction of t-butyl phenyl ketones, clay supported (-) N-benzylquininium (151AA and F151AA) have higher efficiency and stereoselectivity than clay supported (-) N-dodecyl N-methylephedrinium (131AA and F131AA). These results can be rationalized by the molecular structures of catalysts and organic substrates. The (-) N-dodecyl N-methylephedrinium cation and n-butyl phenyl ketones, with linear alkyl chains fit naturally on top of each other. (-) N-benzylquininium has been suggested to prefer a conformation in which the quinoline ring, the C9-O bond, and the n-benzyl group lie in one plane (Figure 6). This structure does not prefer either ketone. Therefore, steric effects introduced by the molecular structure of the ketones become important factors on the stereochemical course of the asymmetric reduction of ketones. Since the t-butyl group is more hindered than n-butyl group, we can expect a higher optical yield in the reduction of the t-butyl phenyl ketone catalyzed by (-) N-benzylquininium chloride under biphase system (131, 132). One must emphasize that, while most chiral catalysts and polymer-supported chiral catalysts fail to promote the asymmetric reduction of less hindered ketones, organoclay 131AA is able to achieve about 25.1% optical yield in the reduction of n-butyl phenyl ketone (Table 24).

3. The Dependence of Enantiomeric Excess on the Concentration of Catalyst and Substrates

For the borohydride reduction of ketones the influences of catalyst concentration on the enantiomeric excess have not been studied for the biphase catalyst systems. However, for the reduction of t-butyl phenyl ketone catalyzed by polystyrene-(-) N-benzylquininium Lamaty reported that the effects of catalyst concentration on the enantioselectivity depended on the method of mixing the reactants (145). Since Lamaty did not report the stability of catalysts, we suspect that the variation of specific rotation of products are partially due to decomposition of the catalysts under the reaction conditions (25 ^{o}C and 12 hr). Our studies indicated that for the reduction of n-butyl phenyl ketone catalyzed by the F-hectorite-(-) N-dodecyl N-methylephedrinium cation (F131AA) the optical purity of products were the same when 0.2 mmole or 10.0 mmole of catalyst was used (Table 23). Since the concentration of catalyst will not affect the conformation of the transition state, increasing the concentration of catalyst will affect the excess enantiomers of products by decreasing the relative reaction rate of the non-catalyzed pathway. For the reduction of n-butyl phenyl ketone the non-catalyzed reaction rates are very low (Table 21) and negligible compared to that of the catalyzed reaction. Therefore, the effect of catalyst concentration is not significant. However, for the reduction of t-butyl phenyl ketone the non-catalyzed reaction rate is comparable to the catalyzed reaction rate (Table 21). We can expect a dependence of catalyst concentration on the enantioselectivity until the catalyzed reaction rate is high enough that the non-catalyzed reaction pathway becomes negligible. In the future it would be worthwhile to study the dependence of enantiomeric excess on the catalyst concentration in the t-butyl phenyl ketone.

The effects of enantiomeric excess on the concentrations of ketone and borohydride anion have also been studied (Table 22). Increasing the concentration of the substrates enhanced the non-catalyzed reactions but it does not change the conformation

Table 22 Asymmetric Borohydride Reduction of Pentyl Ketones in the Presence of Clay-Supported Chiral Catalysts[a]

Sample Number	C_6H_5COR R-Group	C_6H_5COR mmole	KBH_4 mmole	Reaction Time, hr	Chemical Yield, % [b]	Optical Yield, % [c]
131AA	n-butyl	2.5	3.0	24	100.0	7.9 R
131AA	n-butyl	5.0	3.0	24	100.0	8.8 R
131AA	n-butyl	2.5	6.0	24	100.0	9.7 R
131AA	n-butyl	5.0	6.0	24	100.0	9.1 R
131AA	t-butyl	2.5	6.0	24	100.0	0.6 S
131AA	t-butyl	5.0	6.0	24	100.0	1.0 S

Table 22 continued

Sample Number	C_6H_5COR		KBH_4 mmole	Reaction Time, hr	Chemical Yield, % <u>b</u>	Optical Yield, % <u>c</u>	
	R-Group	mmole					
F131AA	n-butyl	2.5	6.0	16	100.0	0.8	S
F131AA	n-butyl	5.0	6.0	16	100.0	2.5	S
F131AA	t-butyl	2.5	3.0	10	100.0	11.2	R
F131AA	t-butyl	5.0	3.0	10	100.0	10.5	R
F131AA	t-butyl	2.5	6.0	10	100.0	8.7	R
F131AA	t-butyl	5.0	6.0	10	100.0	10.4	R

Table 22 continued

Sample Number	C_6H_5COR R-Group	mmole	KBH_4 mmole	Reaction Time, hr	Chemical Yield, % b	Optical Yield, % c
151AA	n-butyl	2.5	3.0	24	100.0	1.6 R
151AA	n-butyl	5.0	3.0	24	100.0	0.7 R
151AA	n-butyl	2.5	6.0	24	100.0	1.7 R
151AA	n-butyl	5.0	6.0	24	100.0	0.0 R
151AA	t-butyl	2.5	3.0	24	100.0	19.7 R
151AA	t-butyl	5.0	3.0	24	100.0	17.5 R
151AA	t-butyl	2.5	6.0	24	100.0	15.9 R
151AA	t-butyl	5.0	6.0	24	100.0	17.1 R

Table 22 continued

Sample Number	C_6H_5COR		KBH_4	Reaction	Chemical	Optical
	R-Group	mmole	mmole	Time, hr	Yield, % b	Yield, % c
F151AA	n-butyl	2.5	3.0	16	100.0	5.0 S
F151AA	n-butyl	5.0	3.0	16	100.0	1.6 S
F151AA	n-butyl	2.5	6.0	16	100.0	2.5 S
F151AA	n-butyl	5.0	6.0	16	100.0	3.0 S
F151AA	t-butyl	2.5	3.0	10	100.0	31.3 R
F151AA	t-butyl	5.0	3.0	10	100.0	31.7 R
F151AA	t-butyl	2.5	6.0	10	100.0	31.2 R
F151AA	t-butyl	5.0	6.0	10	100.0	32.7 R

Table 22 continued

[a] Remaining reaction conditions: 3.0 ml benzene; 5.0 ml water; 0.2 mmole homoionic organoclay;4^{o}C.

[b] Chemical yield of alcohol was based on starting ketone. Products were detected by GLC with decane as internal standard.

[c] Enantiomeric excess was determined by ^{1}H NMR (250 M Hz) in the presence of $Eu(hfc)_3$ as chiral shift reagent.

Table 23 The Dependence of Excess Eenantiomer on the Concentration of Clay Supported Chiral Catalysts in Asymmetric Borohydride Reduction of Ketones[a]

Sample Number	Amount of Catalyst mmole	Time, hr	Chemical Yield, % [b]	Optical Yield, % [c]
F131AA	0.2	48	100.0	12.1 S
F131AA	10.0	36	100.0	11.4 S

[a] Remaining reaction conditions: 2.5 mmole n-butyl phenyl ketone in 3.0 ml benzene; 6 mmole potassium borohydride in 5.0 ml water; -10°C.

[b] Chemical yield of alcohol was based on starting ketone. Product was detected by GLC with decane as internal standard.

[c] Enantiomeric excess was determined by ^1H NMR (250 MHz) in the presence of $Eu(hfc)_3$ as chiral shift reagent.

of the transition state. Thus, when the non-catalyzed reaction pathways are insignificant, the concentrations of substrates do not affect the enantiomeric purity of the products.

4. The Dependence of Enantiomeric Excess on the Temperature

For both n-butyl phenyl ketone and t-butyl phenyl ketone reduction the enantiomeric purity of the corresponding alcohols increased with decreasing the temperature (Table 24). For F-hectorite-(-) N-dodecyl N-methylephedrinium (F131AA) as catalyst, the reduction of n-butyl phenyl ketone afforded 12.1%, 0.8%, 0%, 0% ee at the reaction temperatures of -10^{o}C, 4^{o}C, 25^{o}C and 50^{o}C respectively. The reduction of t-butyl phenyl ketone gave 11.4% and 8.7% ee at -10^{o}C and 4^{o}C respectively. For the reduction of n-butyl phenyl ketone hectorite-(-) N-dodecyl N-methylephedrinium (131AA) showed a similar dependence and afforded 25.1% and 9.7% ee at -10^{o}C and 4^{o}C respectively. Temperature can affect the degree of asymmetric induction in two ways. First, as the temperature increases, it promotes the reaction through the non-catalyzed pathway, which results in racemic mixtures. At lower reaction temperatures the reaction rate of the non-catalyzed pathway, which has a higher activation energy, is not comparable to that of the catalyzed pathway. Therefore, the catalyzed reaction becomes the major reaction pathway (according to the Arrehenius equation : rate coefficient $k = A \exp(-Ea/RT)$) . Similarly the small energy difference between diastereomeric reaction paths will caused greater stereoselectivity at low temperature.

Also, molecular motion increases with temperature and the conformation of the transition state through the catalyzed pathway will lose its rigidity and decrease the stereoselectivity. This second effect may not be as drastic for the more hindered t-butyl group as for the n-butyl group. Thus, in the reduction of t-butyl phenyl ketone, the temperature effects are higher than those in n-butyl phenyl ketone.

5. The Dependence of Enantiomeric Excess on the Polarity of Organic Solvent

Another important generalization that seems to be emerging in enantioselectivity concerns the nature of the organic solvent employed. In a biphase catalyst system, more often than not, the highest inductions are observed with non-polar solvents. Ion pairs with strong association play a crucial role in the asymmetric induction. Media capable of hydrogen bonding or solvating chiral ion pairs generally inhibit induction because of a weakening of the ion pair interaction. This could also explain why in solvents with high dielectric constant, where the force between two charged species is weak, the enantiomeric purities are substantially lower than in solvents with low dielectric constant. Similarly, in clay-supported chiral catalysis one observed the dependence of stereoselectivity on the polarity of organic solvents employed. In the presence of benzene, hectorite-(-) N-dodecyl N-methylephedrinium (131AA) afforded a predominant enantiomer of R configuration with 9.7% optical yield in the n-butyl phenyl ketone reduction, whereas in THF, 131AA afforded a predominant enantiomer of opposite configuration with 8.6% ee (Table 25). The complexity of clay-supported chiral catalysts and the lack of kinetic data make it difficult to rationalize the results. However, from our knowledge of previous experiments, the organic solvents can affect the emulsion formation of reaction mixtures which in turn affect the reaction rate of catalyzed pathway. When the catalyzed reaction becomes the major reaction pathway we can expect to obtain a higher degree of enantioselectivity. The organic solvents can also alter the interaction of the chiral ion pair and influence the asymmetric induction. There is no generalization of the solvent effects in this system. It is necessary to study each clay-supported chiral catalyst individually for this subject.

6. Conclusion

Although a great deal of research needs to be done before the mechanism of clay-supported chiral catalysis can be proposed, it appears worthwhile to summarize the results of the study of ketone reduction : 1) For a given intercalated chiral cation, the organoclays of hectorite and F-hectorite supports tend to afford predominant enantiomers with opposite configurations; 2) The concentrations of substrates do not affect the degree of enantioselectivity; 3) The concentration of hectorite-supported (-) N-dodecyl N-methylephedrinium (131AA) catalyst affects the reaction rate but not the stereoselectiviy for the reduction n-butyl phenly ketone. However, this concentration effect of catalyst should be studied individual for different clay-supported chiral catalysts and organic substrates. 4) In general, low temperature favors the stereochemical course of asymmetric ketone reduction. However, the extent of the temperature dependence is different for various ketones. 5) Changing the solvent can afford products in favor of opposite isomer. However, the effects of organic solvents are not clear at this point.

It has to be said that the clay-supported chiral catalysts are practically superior to conventional biphase catalysts. Moreover, for a given chiral catalyst we are able to alter its optical selectivity by intercalating the chiral catalysts on various clay hosts.

H. The Stereoselectivity and Mechanism of Asymmetric Epoxidation of Chalcones Catalyzed by Organoclays

The epoxide function plays an important role in metabolic processes. It is surprising therefore that the catalytic synthesis of optically active epoxides leaves much to be desired. Wynberg has attempted to epoxidize chalcone under the influence of quinine and ephedrine but the results were disappointing. However, chalcones and related compounds could be transformed in excellent chemical yields into optically active epoxides by using quaternary salts derived from quinine as chiral phase transfer catalysts in biphase systems (63). A limited study and the lack of kinetic data make it difficult to drive conclusions concerning the role of the catalyst structure and to propose reaction mechanisms. Nevertheless, Wynberg and Dolling have stated that the cinchona alkaloids are by far the better all around catalysts; and that the absolute configuration at C-8-C-9 of

Table 24 The Dependence of Enantiomeric Excess on Temperature in Asymmetric Borohydride Reduction of Ketones with Clay-Supported Chiral Catalysts[a]

Sample Number	ketone R-Group	Temp. °C	Time, hr	Chemical Yield, %,[b]	Optical Yield, %,[c]
F131AA	n-butyl	-10	48.0	100.0	12.1 S
F131AA	n-butyl	4	16.0	100.0	0.8 S
F131AA	n-butyl	25	8.5	100.0	0.0
F131AA	n-butyl	50	5.0	100.0	0.0
F131AA	t-butyl	-10	22.5	100.0	11.4 R
F131AA	t-butyl	4	10.0	100.0	8.7 R
131AA	n-butyl	-10	72.0	100.0	25.1 R
131AA	n-butyl	4	24.0	100.0	9.7 R

[a] Reaction conditions: 2.5 mmole ketone in 3.0 ml benzene; 6 mmole potassium borohydride in 5.0 ml water; 0.2 mmole homoionic organoclay.

[b] Chemical yield of alcohol was based on starting ketone and detected by GLC with decane as internal standard.

[c] Enantiomeric excess was determined by ^{1}H NMR (250 MHz) in the presence of Eu(hfc)$_3$ as chiral shift reagent.

Table 25 The Dependence of Enantiomeric Excess on the Polarity of Organic Solvent in Asymmetric Borohydride Reduction of Ketones with Clay-Supported Chiral Catalysts[a]

Sample Number	Organic Solvent	Time, hr	Chemical Yield, % [b]	Optical Yield,% [c]
131AA	CCl4	24.0	100.0	5.4 R
131AA	C6H6	24.0	100.0	9.0 R
131AA	THF	24.0	100.0	8.6 S

[a] Reaction conditions: 2.5 mmole benzyl n-butyl ketone in 3.0 ml organic solvent; 6 mmole potassium borohydride in 5.0 ml water; 0.2 mmole homoionic organoclay;4°C.

[b] Chemical yield of alcohol was based on starting ketone and detected by GLC.

[c] Enantiomeric excess was determined by ^1H NMR (250 MHz) in the presence of $Eu(hfc)_3$ as chiral shift reagent.

the alkaloids govern the absolute configurations of the products. A mechanism, as discussed in chapter 1, concerning a compact ion pair was presented by Wynberg (63).

Epoxidation of chalcone catalyzed by benzyl quininium chloride affords a 34% optical yield in the presence of 30% hydrogen peroxide and 10% sodium hydroxide. The predominant configuration of epoxychalcone is S with an R configuration at the α-carbon and an S configuration at the β-carbon (Figure 27). Kobayashi has utilized a polystyrene supported quininium salt as a catalyst in chalcone epoxidations, and the results do parallel those of the analogous non-supported reactions (43).

The phase transfer-mediated asymmetric epoxidation by using clay-supported ephedrinium salt (131AA) was attempted with little success (Table 26). However, clay-supported cinchona alkaloids (151AA, F151AA) exhibit a higher stereoselectivity than analogous non-supported or polymer supported cinchona alkaloids and afforded products with maximum optical yield, up to 46.7% (Table 29). The blank reactions were carried out under the conditions either without the chalcone or clay-supported chiral catalysts (Table 27). No specific rotations was observed by polarimeter when no chalcone was used. These results indicated that both 151AA and F151AA were stable under the reaction conditions. If organoclays lost their functionizations or the intercalated cation decomposed under the reaction conditions the specific rotations of the reaction residence should be greater than 0. The non-catalyzed reaction rate was very low and non significant product was observed after 3 days (Table 27).

1. The Dependence of Enantiomeric Excess on the Layer Charge of Clay Host

According to the previous discussion, the layer charge density of the clay host affects both the loading and the orientation of onium cation. This, in turn, influences the catalytic and stereoselective properties of clay supported chiral catalysts. For the epoxidation of chalcone catalyzed by the F-hectorite supported n-benzyl quininium (F151AA) the reaction rate was about 5 times as fast as that of the analogous reaction catalyzed by hectorite supported n-benzyl quininium (151AA). Nevertheless, these two clay-supported chiral catalysts possess a similar enantioselectivity and afforded predominant enantiomers of opposite configuration. For instance, with F151AA as catalyst, the reactions afford a 100% chemical yield and 27.9% enantiomeric excess of epoxychalcone with a predominant isomer of S configuration (Table 28). In contrast, a predominant R enantiomer was found in the analogous reaction catalyzed by 151AA (21.0% ee). These results were consistent with the observations in the asymmetric borohydride reduction. For a given intercalated chiral cation, the F-hectorite support and hectorite support afforded analogous products with predominant enantiomers of opposite configuration.

For a preferred conformation of benzyl quininium cation (Figure 6), tight ion pairing between the chiral cation and the peroxide anion, and hydrogen bonding between the hydroxyl of the alkaloid and the carbonyl oxygen of the chalcone, suggest the conformations of transition state shown in Figure 28. The various possible conformations of transition state introduced by diverse clay hosts have different activation energies. The various organophilic characteristics of diverse clay hosts also affect the catalytic activity of the organoclay. These may explain the influence of clay hosts on the catalytic and enantiomeric properties of clay-supported chiral catalysts.

2. The Dependence of Enantiomeric Excess on the Temperature

Colonna has reported that in the presence of polymer-supported chiral catalysts, the degree of asymmetric induction in the epoxidation of chalcones decreases as the temperature increases (146). A similar dependence of stereoselectivity on the temperature were reported for other asymmetric induction under biphase systems (63, 147). However, in the organoclay catalysis, we discovered, that for the chalcone epoxidation, the enantiomeric purity of the epoxychalcone increased with temperature. Table 29 illustrates that the reaction catalyzed by F511AA in presence of carbon tetrachloride afforded 46.7% ee at 25°C and 17.0% ee at 4°C. Analogous reactions in

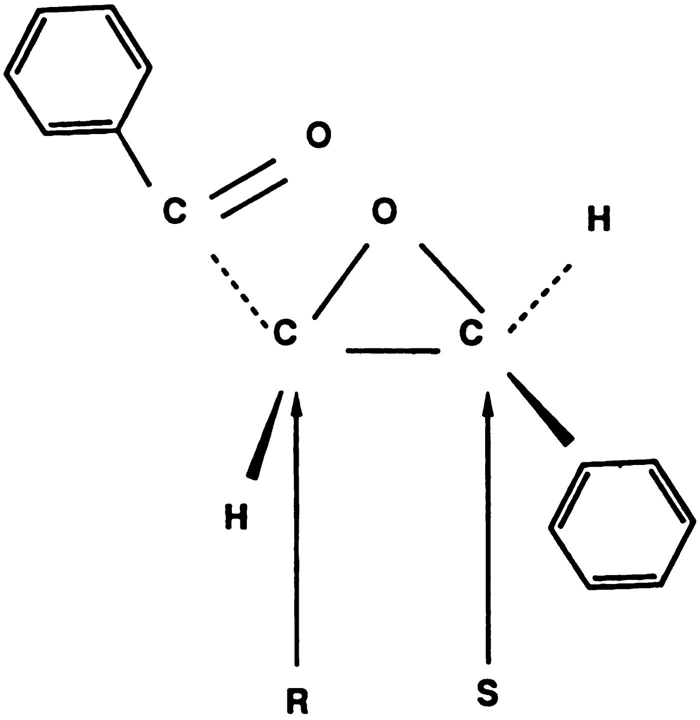


Figure 27. Configuration of (-) Epoxychalcone.

Table 26 Dependence of Enantiomeric Excess on the Molecular Structure of Chiral Catalysts for Asymmetric Epoxidation of Chalcone with Clay Supported Chiral Catalysts[a]

Sample Number	Reaction Time, hr	Chemical Conversion, % [b]	Optical Yield,% [c]	
131AA	102	100.0	0.7	α–S, β–R
151AA	102	100.0	21.0	α–S, β–R

[a] Reaction conditions : 0.48 mmole chalcone in 3 ml benzene; 30% H_2O_2 1.5ml and 12% NaOH 1.5 ml; 25°C; 0.2 mmole homoionic organoclay.

[b] The reaction was monitored by TLC until no trace of the starting reagent (chalcone) was present.

[c] Enantiomeric excess was determined by ^1H NMR (250 MHz) in the presence of $Eu(hfc)_3$ as chiral shift reagent.

Table 27 The Blank Reaction of Epoxidation of Chalcone [a]

Reaction Number	Catalyst	Reaction Time, hr	Chemical Conversion %, [c]	Specific Rotation [d]
Blank 1[a]	-	72.0	0.0	0.0
Blank 2[b]	151AA	102.0	-	0.0
Blank 3[b]	F151AA	102.0	-	0.0

[a] Reaction conditions: 0.96 mmole chalcone in 3.0 ml benzene; 30% H_2O_2 1.5 ml and 12% NaOH 1.5 ml; 25°C.

[b] Reaction conditions: 3.0 ml benzene; 30% H_2O_2 1.5 ml and 12% NaOH 1.5 ml; 0.2 mmole homoionic organoclay; 25°C.

[c] The TLC trace of the reaction product was not found after the reaction time indicated in Table 26.

[d] The specific rotations were measured on a Perkin-Elmer Co. Model 141 polarimeter with mercury line (5780 Å 5460 Å).

Figure 28. The possible conformation of transition state of the chalcone epoxidation catalyzed by 151AA

Table 28 Dependence of Enantiomeric Excess on the Layer Charge of the Clay Host for Asymmetric Epoxidation of Chalcone with Clay-Supported Chiral Catalysts[a]

Sample Number	Reaction Time, hr	Chemical conversion, % [b]	Optical Yield, % [c]
F151AA	20	100.0	27.9 α–R, β–S
151AA	102	100.0	21.0 α–S, β–R

[a] Remaining reaction conditions : 0.48 mmole chalcone in 3 ml organic solvent: 30% H_2O_2 1.5ml and 12% NaOH 1.5 ml; 25°C; 0.2 mmole homoionic organoclay.

[b] The reaction was monitored by TLC until no trace of the starting reagent (chalcone) was present.

[c] Enantiomeric excess was determined by ^1H NMR (250 M Hz) in the presence of $Eu(hfc)_3$ as chiral shift reagent.

the presence of benzene bear 27.9% ee at 25°C and 10.6% ee at 4°C. In contrast utilizing 151AA as the catalyst, a predominant isomer of opposite configuration was obtained with 25.3% ee at 25°C and 14.2% ee at 4°C.

Although increasing the temperature will enhance the reaction through the non-catalyzed pathway, this is not significant for chalcone epoxidation at the experimental temperatures used here (Table 27). Figure 29 presents a hypothesis concerning the dependence of reaction rate on the temperature. For the expoidation catalyzed by F151AA the formation rate of R isomer is higher than that of S isomer at high temperature . However, the formation rate of the S isomer does not respond to temperature as drastically as that of the R isomer. Therefore, as the temperature decreases the formation rates of R and S isomers become equal and no enantioselectivity will be observed. Furthermore at extremely low temperatures one can expect that the S isomer to become the predominant product. An analogous dependence of optical yield on the temperature was obeyed for the epoxidation catalyzed by 151AA. The reaction rate of S isomer instead of the R isomer responds more drastically to temperature change. Thus, the prevalent enantiomers have an R configuration at high temperature while a predominant S isomer is expected at low temperature.

3. The Dependence of Enantiomeric Excess on the Polarity of Organic Solvent

Both Wynberg and Colonna have claimed that the quininium salt catalyzed phase transfer reaction are subject to strong solvent effects (63, 148). Non-polar aprotic solvents give higher asymmetric induction than solvents with high dielectric constants which inhibit the asymmetric induction by weakening the ion pair interaction (63, 148). However, in the polymer-supported chiral catalyst systems there is no direct correlation between the dielectric constant of the solvent and the enantiomeric excess of the epoxychalcone obtained (146). The epoxidation of chalcone catalyzed by F151AA afford 46.7%, 27.9% and 8.2% ee in the presence of carbon tetrachloride, benzene and THF respectively (Table 30).

While utilizing 151AA as catalysts the degree of stereoselectiviy in the epoxidation of chalcones was nearly the same in the presence of carbon tetrachloride and benzene (25.3% and 21.0%). Since CCl_4 and C_6H_6 have similar dielectric constant (2.23 and 2.28 respectively). An analogous solvent effect on the optical activity should be observed in CCl_4 and C_6H_6, if there is a direct correspondence between the polarity of solvent and the optical activity of the reaction. It is too early to rationalize the solvent effects on the stereoselectivity of the organoclay systems. However, according to previous studies we can expect different organoclays to have varying dependencies of organic solvent on the enantioselectivity of the epoxidation reaction.

4. The Dependence of Enantiomeric Excess on the Concentration of Chalcone

Since the concentration of chalcone does not affect the conformation of transition state of reaction, there is no substantial change of the stereoselectivity of the reaction when the different concentrations of chalcone are employed (Table 31). This observation is identical with that of the asymmetric borohydride reduction in the organoclay systems.

5. The Dependence of Enantiomeric Excess on the Volume Ratio of Aqueous and Organic Phases

Table 31 illustrates the results concerning the dependence of enantiomeric excess of products on the volume ratio of the aqueous and organic phases. For a constant concentration of catalyst and substrate, the catalytic reactivity and stereoselctivity of the reaction decreases as the aqueous volume employed increases. The epoxidation of chalcone was complete after 44 h and the optical yield was 29.1% when the volume ratio of aqueous and organic phases equal to 1. It took 64 h and 102 h to complete the reactions when the volume ratio was increased to 5/3 and 7/3, and the optical yield were 20.8% and 15.4% optical purities, respectively. The volume ratio of aqueous and organic phases is especially important in determining the characteristics of the emulsion for reaction. This, in turn affects the reaction through the catalyzed pathway and influences the degree of enantioselectivity.

6. Conclusions

A few results of epoxidation of chalcone catalyzed by organoclay are summarized as follows : 1) For a given intercalated chiral cation the F-hectorite and hectorite supports yielded epoxychalcones with predominant enantiomers of opposite configuration. 2) The concentration of chalcone does not affect the optical purity of product. 3) Over the experimental temperature range, 25°C to 4°C, the stereoselectivity of the reaction increases with temperature. 4) Carbon tetrachloride is thus for the solvent of choice in the asymmetric epoxidation of chalcone catalyzed by organoclay 151AA or F151AA. 5) The volume ratio of aqueous and organic phases is especially important in determining a characteristics of the emulsion of reaction mixtures, which in turn affects the catalyzed reaction rate and influences the degree of enantioselectivity.

Table 29 Dependence of Enantiomeric Excess on the Temperature for Asymmetric Epoxidation of Chalcone with Clay-Supported Chiral Catalysts[a]

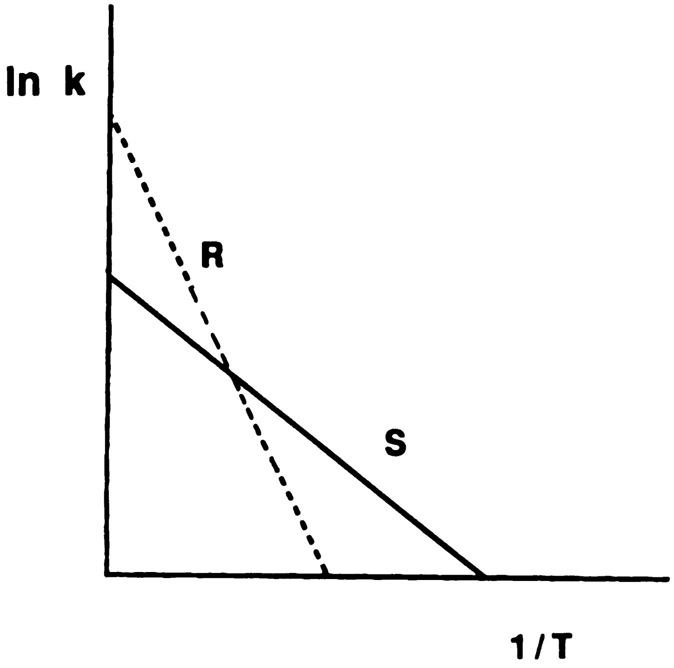
Sample Number	Temp. °C	Organic Solvent	Reaction Time,hr	Chemical Conversion, % [b]	Optical Yield,% [c]	
F151AA	4	CCl_4	72	100.0	17.0	α–R, β–S
F151AA	25	CCl_4	20	100.0	46.7	α–R, β–S
F151AA	4	C_6H_6	72	100.0	10.6	α–R, β–S
F151AA	25	C_6H_6	20	100.0	27.9	α–R, β–S
151AA	4	CCl_4	150	100.0	14.2	α–S, β–R
151AA	25	CCl_4	102	100.0	25.3	α–S, β–R

[a] Remaining reaction conditions : 0.48 mmole chalcone in 3 ml organic solvent: 30% H_2O_2 1.5ml and 12% NaOH 1.5 ml; 0.2 mmole homoionic organoclay.

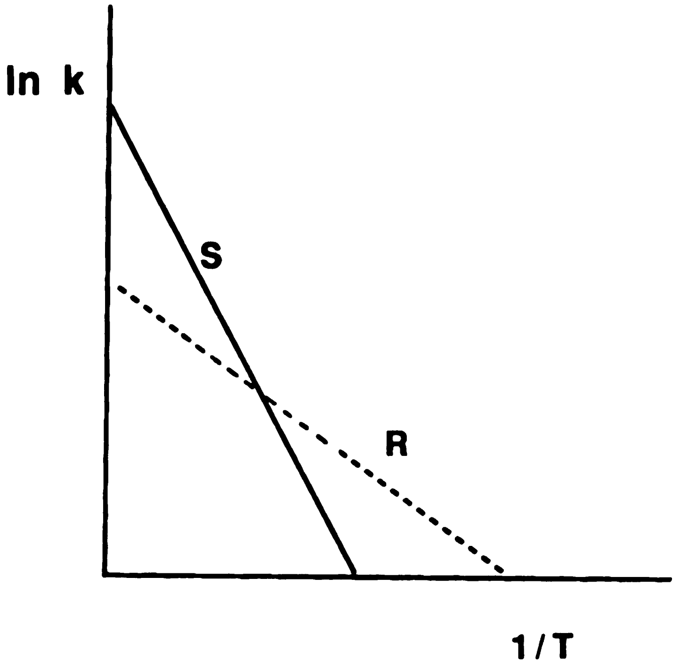
[b] The reaction was monitored by TLC until no trace of the starting reagent (chalcone) was present.

[c] Enantiomeric excess was determined by ^1H NMR (250 M Hz) in the presence of $Eu(hfc)_3$ as chiral shift reagent.

Figure 29. The hypothesis of the dependence of the reaction rate on the temperature A) Epoxidation of chalcone by F151AA B) Epoxidation of chalcone by 151AA



(A)



(B)

Table 30 Dependence of Enantiomeric Excess on the Polarity of Organic Solvent for Asymmetric Epoxidation of Chalcone[a]

Sample Number	Organic Solvent	Reaction Time, hr	Chemical Conversion, % [b]	Optical Yield, % [c]	
F151AA	CCl_4	20	100.0	46.7	α–R, β–S
F151AA	C_6H_6	20	100.0	27.9	α–R, β–S
F151AA	THF	20	100.0	8.2	α–R, β–S
151AA	CCl_4	102	100.0	25.3	α–S, β–R
151AA	C_6H_6	102	100.0	21.0	α–S, β–R

a Remaining reaction conditions : 0.48 mmole chalcone in 3 ml organic solvent: 30% H_2O_2 1.5ml and 12% NaOH 1.5 ml; 25°C; 0.2 mmole homoionic organoclay.

b The reaction was monitored by TLC until no trace of the starting reagent (chalcone) was present.

c Enantiomeric excess was determined by ^1H NMR (250 M Hz) in the presence of $Eu(hfc)_3$ as chiral shift reagent.

Table 31 Dependence of Enantiomeric Excess on the Concentration of Substrates and Volume Ratio of Aqueous and Organic Phase for Asymmetric Epoxidation of Chalcone with Clay-Supported Chiral Catalysts[a]

Sample Number	H_2O_2 30% ml	NaOH 12% ml	Chalcone mmole	Reaction Time, hr	Chemical Conversion, %, [b]	Optical Yield, %, [c]
F151AA	1.5	1.5	0.48	20	100.0	27.9 α–R, β–S
F151AA	1.5	1.5	0.96	44	100.0	29.1 α–R, β–S
F151AA	1.5	1.5	1.92	102	100.0	29.6 α–R, β–S
F151AA	1.5	1.5	0.96	44	100.0	29.1 α–R, β–S
F151AA	2.5	2.5	0.96	64	100.0	20.8 α–R, β–S
F151AA	3.5	3.5	0.96	102	100.0	15.4 α–R, β–S

[a] Remaining reaction conditions: 3.0 ml benzene; 0.2 mmole homoionic organoclay;25°C.

[b] The reaction was monitored by TLC until no trace of the starting reagent was present.

[c] Enantiomeric excess was determined by ^{1}H NMR (250 M Hz) in the presence of $Eu(hfc)_3$ as chiral shift reagent.

CHAPTER IV

RECOMMENDATIONS

Although in this study we have successful translated solution reactions into a triphase organoclay system, there are a few studies worthy of exploring in the future.

Several parameters which control the efficiency of the organoclays in nucleophilic substitution remain to be studied : 1) the dependence of the catalytic activity on the swelling properties of the organoclay in various organic solvents. 2) the dependence of the catalytic properties on the volume ratio of aqueous and organic phases. Preparation of a new series of organoclays by intercalation of crown ethers or cryptands in the clay may be worthwhile to attempt. In addition to the reactions that were investigated in this study, the organoclays can emerge as a broadly useful tools in other organic synthesis : 1) alkylation and condensation reactions 2) Ylide-mediated reactions 3) miscellansous reactions.

The investigations of organo-layered compounds as triphase catalysts have just been initiated. The catalytic properties and mechanisms of organo-layered compounds remain obscure. However, this technique can be understood better by synthesis of various organo-layered compounds with different crystallinity and molecular structure of the intercalated onium ion. The mechanisms of catalysis of organo-layered compounds can be investigated by examining the parameters that control the efficiency of the organoclay catalysts (e.g., the structure of intercalated onium cations, the concentration of substrates and catalysts. the degree of crystallinity of the layered compounds and the polarity of organic solvent). Furthermore, the intercalation of chiral catalysts in the layered compounds perhaps can be developed into other types of triphase chiral catalysts.

It is evident that the clay-supported chiral catalysts are superior to corresponding chiral catalysts and polymer-supported chiral catalysts. Attempts to prepare a new series of clay-supported chiral catalysts by intercalating the (+) n-benzyl quinidium cation or chiral crown ether complexes (125) on the clay is worthwhile. For the borohydride reduction the mechanism can be understood better by further examinations of the dependence of catalytic activity and the stereoselectivity of the reaction on 1) the volume ratio of aqueous and organic phases; 2) the method of mixing the reagents; 3) the alkyl chain length of ketone; 4) the swelling of clay-supported chiral catalysts in various organic solvents; and 5) temperature. The epoxidation of chalcones, catalyzed by organoclays can be expanded into the epoxidation of electron-poor olefins (e.g., chalcones, quinones and cyclohexenones) (68, 69, 77, 78, 81-83). The catalytic activity and the stereoselectivity of the reaction might be improved by using t-butyl hydroperoxide or 28% sodium hypochlorite instead of hydrogen peroxide. Other parameters that might affect the catalytic activity and the stereoselectivity of the system are : 1) the method of mixing the reagents; 2) the swelling of clay-supported chiral catalysts in various organic solvents; 3) the molecular structure of the organic substrate; and 4) temperature.

In addition to the borohydride reduction and epoxidation of electron-poor olelfins, several successful application of chiral phase transfer catalysts in asymmetric induction have been investigated : Michael reactions (34, 63, 73-76), 1,4-thiol and thiolacetate additions (34, 63, 75), selenophenol addition reaction (34, 63, 151), 2,2-cycloaddition reaction (34, 64, 76, 150) and 1,2-additions (34, 63, 151). From our previous studies, we can also expect that those reactions may achieved high stereoselectivities by utilizing the clay-supported chiral catalysts.

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