Alkylation of Salicylic Acids

by

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Abstract

The work described in this thesis has been directed at the development of a novel synthetic route to alkylsalicylic acids. Associated reactions have also been studied. The primary aim has been the synthesising of alkylsalicylic acids possessing an alkyl chain containing more than eight carbon atoms. In addition, a limited study has also been carried out into the sulfurisation of alkylphenols. Both the alkylsalicylic acids and the sulfurised alkylphenols are used as oil additives. They both act as detergents, keeping an engine clean and neutralising any acids formed in the engine as a result of oxidation processes.

Chapter 1 contains a general introduction to oil additives, principally the overbased detergents, and an introduction to Friedel-Crafts chemistry, which is the basic reaction employed in the alkylation of salicylic acid. Chapter 2 introduces the alkylation of salicylic acid employing concentrated sulfuric acid as the catalyst, and using simple model compounds to demonstrate the feasibility of the approach. The effect of varying the alkylating substrate to produce an alkylsalicylic acid with an alkyl chain containing at least eight carbon atoms is explored in Chapter 3.

Optimization of the alkylation reaction and the effect of altering a number of the reaction parameters (e.g. temperature, catalyst and reaction duration) on the yield and product distribution for a range of alkylating substrates is set out in Chapter 4. The work contained in Chapter 5 concentrates on the synthesis and rearrangement of the esters of salicylic acid and investigates the possibility that the esters are intermediates in the alkylation reaction. Chapter 6 is concerned with the industrial implications of the alkylation of salicylic acid. It concentrates in particular on the synthesis using industrially available alkenes and the scale-up of the reaction.

An insight into the sulfurisation of alkylphenols, and the attempted identification of products formed in the industrial process, can be found in Chapter 7. Finally, the experimental details for Chapters 2 to 7 are contained in Chapter 8.

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Finally, a heart felt thanks must go to my Mum and Dad, and especially Caroline, for their continual help, support and belief in me throughout the course of this thesis.

Abbreviations

br	broad (NMR)
CI	Chemical Ionisation
d	doublet (NMR)
dd	doublet of doublets (NMR)
EI	Electron Impact
FID	Flame Ionisation Detector
GC	Gas Chromatography
GC/MS	Gas Chromatography/Mass Specrometry
HPLC	High Performance Liquid Chromatography
λ_{max}	absorption maximum
m	multiplet (NMR)
m-	meta
NMR	Nuclear Magnetic Resonance
p-	para
PIB	Polyisobutene
ppm	parts per million
psi	pounds per square inch
q	quartet (NMR)
s	singlet (NMR)
SAP	Sulfurised AlkylPhenol
SIMS	Specific Ion Monitoring
t	triplet (NMR)
TBN	Total Base Number
TEBAB	triethylbenzylammonium bromide)
TLC	Thin Layer Chromatography
TMS	Tetramethylsilane
VTPMS	Variable temperature probe MS
ZDDP	Zinc dialkyl (or diaryl) dithiophosphate

Chapter 1

Introduction

1. Introduction.

The composition of engine oils is becoming increasingly more complex as the demands placed on the lubricants become more severe. The function of an oil inside an engine is to accomplish the following seven tasks: to minimise friction; to minimise abrasive wear; to act as a coolant to the engine, to scavenge the products of combustion; to provide a gas seal between metal components, to prevent corrosion and corrosive wear and, finally, to minimise deposits[1]. To meet these demands has necessitated the use of a range of additives. These additives have contributed in a major way to the improvements of lubricants in the second half of the 20th century[2]. No single compound meets all the requirements demanded of an engine oil, though some are capable of performing a number of functions[3].

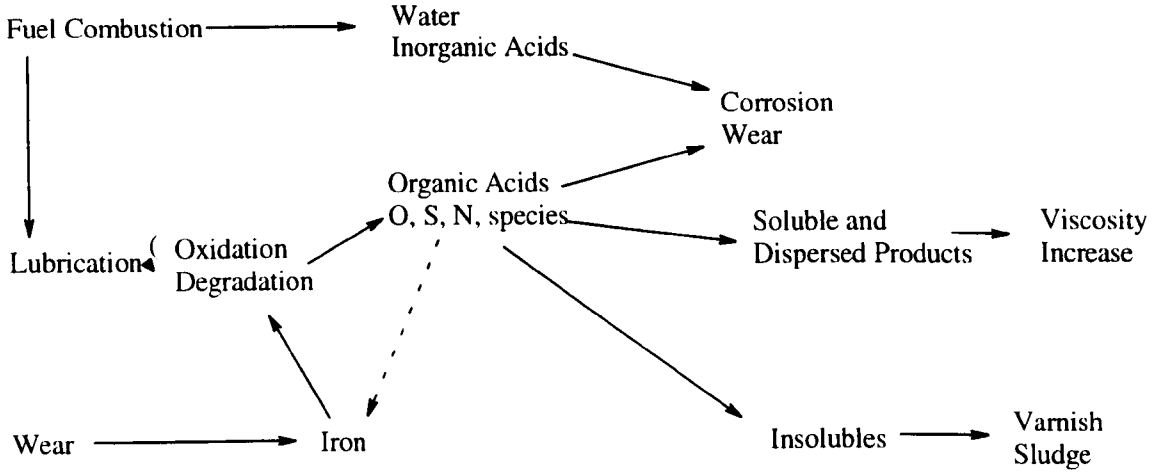
One of the most demanding uses of an oil is in marine engines. The engine will typically be operating continuously for several weeks and so the oil has to accomplish its tasks over extended periods without being changed. The sheer size is a problem, with cylinder diameters of one metre being common. (Compare this with automotive engines that have cylinder bores of a few centimetres.) More importantly, though, is the composition of the fuel used, which is generally of a very low grade. The quality of the fuel has been declining in recent years, as the drive to maximise the yield of premium products from crude oil has resulted in heavier residues with poorer combustion properties and more impurities. These residues are chosen simply because of their very low cost. Improved engine design and lubricant design has been used to combat this decline. In general, a marine engine fuel contains at least 4% sulfur and carbon residues of up to 22% by weight. In the following sections the composition of a complete oil package will be outlined, with a general description of the most common additives and their roles. The particular problems associated with low grade high sulfur content fuels and the necessary additives will be discussed in more detail.

1.1. The Problems of Internal Combustion Engines.

The inside of an internal combustion engine is a very hostile environment. The engine has to cope with high pressures (150 bar), high temperatures (200 °C) and chemical

attack by fuel combustion products (blow-by). These combustion products are corrosive to the inside of the engine and also cause degradation of the lubricating oil. To minimise the cause and effect of this degradation, additives are used, without which a modern engine would soon cease to function. Figure 1.1 is a schematic diagram of the overall degradation processes that take place.

Figure 1.1. The degradation pathways and products of an internal combustion engine.



The formation of acids, predominantly sulfuric acid, is more likely to occur in marine engines because of the high sulfur content (typically > 4% in marine diesel fuels but < 1% in automotive diesel fuels). The acidity in the lubricant can lead to corrosive wear, the rusting of critical moving parts, and the degradation of the oil to give insoluble products. An additive to neutralise these acids is therefore of especial important in marine engines. Other disadvantages, apart from those arising from acid products that corrode the metal surfaces, include the formation of insoluble particles in the oil which tend to obstruct the lubrication galleries. The deposition of lacquers and coke on the pistons can cause overheating through the heat insulating effect of the deposits and, finally, the effect of deposits on the piston rings reduces their ability to act as seals. If these problems are not resolved they will cause a progressive deterioration of the engine's performance and shorten the life of the engine.

1.2. Composition of an Engine Oil.

The composition of an oil package depends greatly on the end use of the oil. An oil for marine diesel engine use will differ in composition from that of an oil used in an automotive engine. The exact composition of marine engine oils appears not to have been disclosed to the public by the manufacturers but an automotive engine oil typically has the following composition by weight[4]:-

71.5-96.2%	Lubricating oil
2-10%	Overbased detergents
1-9%	Ashless dispersants
0.1-3.0%	Anti-wear additives
up to 5%	Viscosity index (VI) improvers
0.1-2.0%	Anti-oxidants
0.1-3.0%	Friction Modifiers
2-15 ppm	Foam inhibitors
0.5-3.0%	Anti-rust/corrosion inhibitors

In contrast marine oils can contain up to 20 - 25% of overbased detergents. Typical properties of marine diesel engine lubricants are viscosity grade SAE 50 (Society of Automotive Engineers), viscosity (cSt [centistokes]) at 40°C of 218, viscosity (cSt) at 100°C of 19.0 [this compares with an automotive oil, SAE 15W, having a viscosity at 100°C of 5.6 cSt][5] and TBN (Total Base Number) of 70-100.[6]

1.3. The Chemical Nature of Additives and Their Role in an Engine Oil.

In general additives can be divided into two classes; additives that consist of a polar end group and a hydrocarbon tail, as illustrated in Figure 1.2 and those additives that do not have a polar end group and a hydrocarbon tail.

Figure 1.2. A typical additive with a polar end group and a hydrocarbon tail.

Hydrocarbon Tail
Oleophilic Group
Solublizer

Polar Head

1.3.1. Lubricating Oils.

Lubricating oils can either be a mineral oil derived directly from crude oil or less commonly, synthetic oils such as poly-α-olefins, alkylated aromatics, polybutenes, aliphatic diesters, polyesters, polyalkyleneglycol phosphate esters[6]. A more detailed insight into the composition of the lubricating oils can be found in 'Chemistry and Technology of Lubricants'[5].

1.3.2. Overbased Detergents.

Overbased detergents are alkali metal salts of surfactants and are used to neutralise the acids that are formed in the engine. A more detailed insight into this class of additives will be included in the following sections as this thesis is concerned primarily with the synthesis of some overbased detergents. This type of additive belongs to the class that consists of a polar head group attached to a large hydrocarbon chain.

1.3.3. Dispersants.

Prior to 1955, the additive used for the purpose of keeping the engine clean was the detergent. The detergent did a good job as long as the engine was not subject to excessive low-temperature, short-distance or stop-and-go driving which promote the formation of sludge in the engine. To keep the engine clean a new type of additive the non-metallic or ashless cleaning dispersant was added to the oil package. The structure of an ashless dispersant is very similar to that of the detergents in that the dispersant has a hydrocarbon or oleophilic group which enables the dispersant to be fully soluble in the base oil. The polar head groups interact with the polar sludge whilst the hydrocarbon groups provide the solubilizing action which maintains the potentially harmful debris in suspension in the oil.

Figure 1.3 shows a stylized structure of how the dispersant interacts with sludge. There are four common types of ashless dispersants: succinate esters, succinimides, Mannich types and phosphorus types. Figure 1.4 illustrates the general syntheses for three of the four common types of dispersants

Figures 1.3. A stylized structure of how the dispersant interacts with sludge.

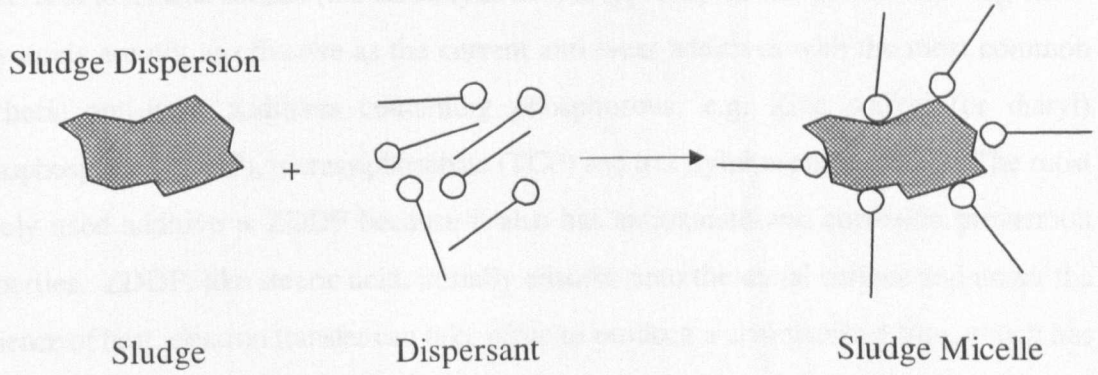
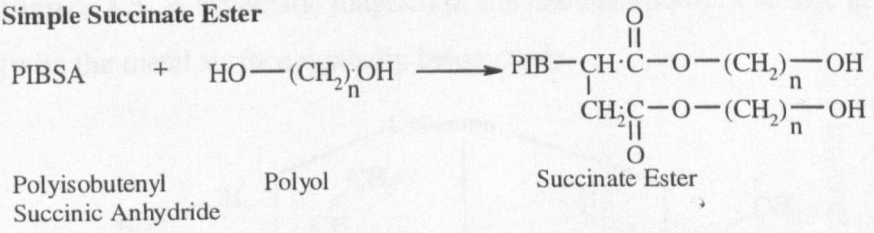
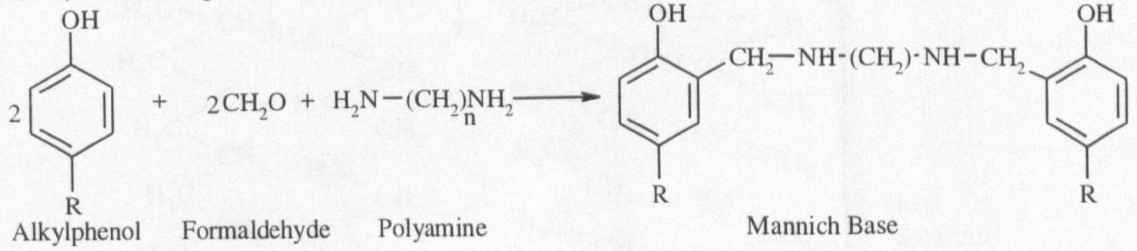


Figure 1.4. General syntheses for the formation of the four common types of dispersants.

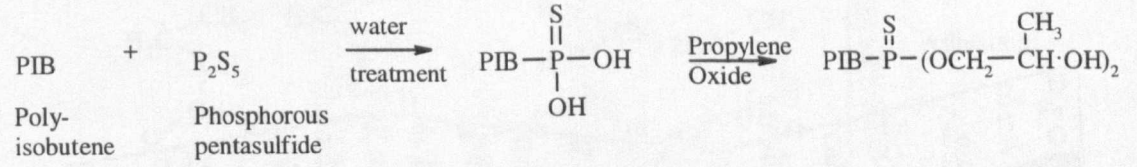
Simple Succinate Ester



Mannich Base Dispersant



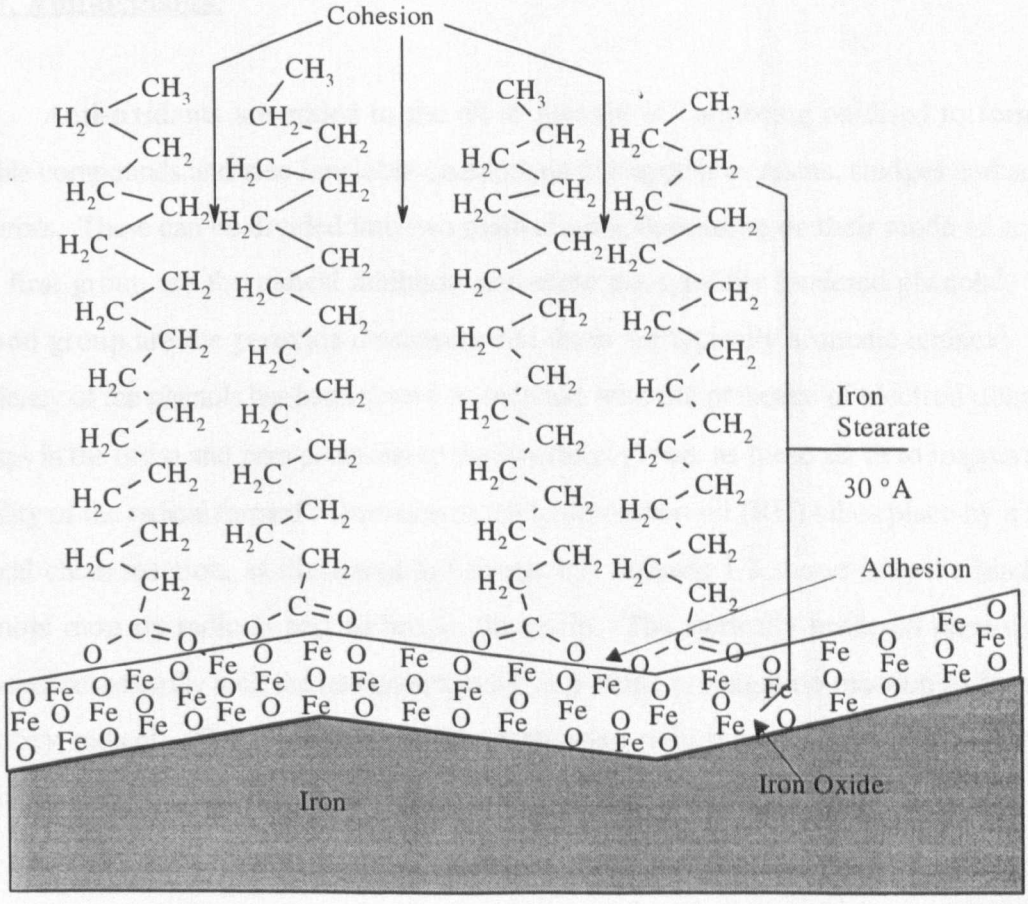
Phosphorous Dispersant



1.3.4. Anti-Wear Additives.

Anti-wear additives also consist of a polar end group and a large hydrocarbon chain. Early anti-wear additives consisted of long-chain fatty acids, such as stearic or palmitic acid. The hydrocarbon tail will orientate itself perpendicular to the surface and thus create a thick film to protect the moving parts. Figure 1.5 is a schematic diagram of the chemisorption of stearic acid to a metal surface (the carboxylic acid is typically stearic acid). The long-chain fatty acids are not as effective as the current anti-wear additives with the most common synthetic anti-wear additives containing phosphorous, e.g. Zinc dialkyl (or diaryl) dithiophosphate (ZDDP), tricresylphosphate (TCP) and trixylylphosphate (TXP). The most widely used additive is ZDDP because it also has antioxidant and corrosion prevention properties. ZDDP, like stearic acid, initially adsorbs onto the metal surface and under the influence of heat, electron transfer can take place to produce a chemisorbed film, which has much better anti-wear characteristics.

Figure 1.5. A schematic diagram of the chemisorption of stearic acid to a metal surface (with the metal surface typically being steel)



1.3.5. Friction Modifiers.

Friction modifiers also consist of a hydrocarbon tail attached to a polar head group. This polar head group can be a carboxylic acid function, a phosphoric or phosphonic acid functions, or a nitrogen containing function, such as amines, amides and imines and all their derivatives. They work in a very similar way to the anti-wear additives by adsorption onto the metal surface, with the hydrocarbon tail being perpendicular to the surface.

1.3.6. Viscosity Index (VI) Improvers.

Viscosity index improvers are high molecular weight polymers, e.g. ethylene-propylene copolymer or polyisobutene (PIB) and are used to maintain the viscosity of the oil over a wide temperature range. As the temperature increases, and the viscosity of the hydrocarbon components decreases, the polymer molecules unravel, increasing the viscosity of the oil and thus decreasing the overall change of viscosity with temperature.

1.3.7. Anti-oxidants.

Anti-oxidants are added to the oil to prevent it from being oxidised to form oil soluble compounds and also insoluble compounds that appear as resins, sludges and acidic materials. These can be divided into two main classes, depending on their mode of action. The first group are the radical inhibitors and these are typically hindered phenols[7]. The second group are the peroxide destroyers and these are typically aromatic amines[8]. The efficiency of the phenols has been shown to increase with the presence of electron donating groups in the ortho and para positions to the hydroxyl group, as these serve to improve the stability of the radical formed[9]. Oxidation of the hydrocarbon oil (RH) takes place by a free-radical chain reaction, as illustrated in Scheme 1.1. Scheme 1.2 shows how the hindered phenols mop up radicals and so breaks the chain. The sterically hindered phenols can compete successfully with the rate determining step of the propagation reaction to form the phenoxy radical. The resonance stabilized phenoxy radical preferentially scavenges an additional peroxy radical to form a cyclohexadienone peroxide.

Scheme 1.1

Initiation:

$$RH + O_2 \longrightarrow HO_2^{\cdot} + R^{\cdot} \quad (1)$$

Propagation:

$$R^{\cdot} + O_2 \longrightarrow RO_2^{\cdot} \quad (2)$$

$$RO_2^{\cdot} + RH \longrightarrow ROOH + R^{\cdot} \quad (3)$$

$$ROOH \longrightarrow RO^{\cdot} + {}^{\cdot}OH \quad (4)$$

$$RO^{\cdot} + RH \longrightarrow ROH + R^{\cdot} \quad (5)$$

$${}^{\cdot}OH + RH \longrightarrow H_2O + R^{\cdot} \quad (6)$$

Termination:

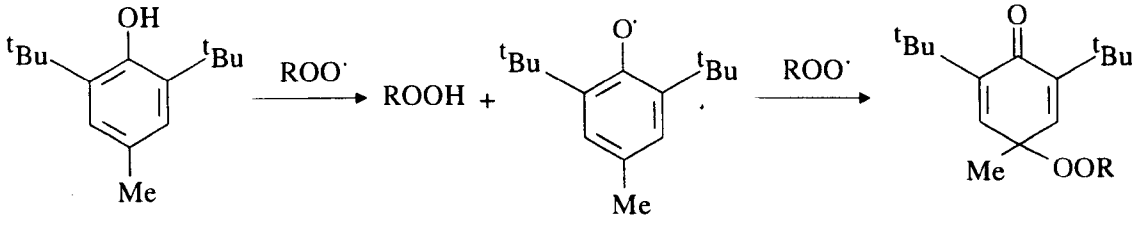
$$2HO_2^{\cdot} \longrightarrow H_2O_2 + O_2 \quad (7)$$

$$2RO_2^{\cdot} \longrightarrow ROOR + O_2 \quad (8)$$

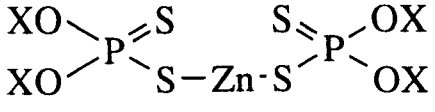
$$RO_2^{\cdot} + R^{\cdot} \longrightarrow ROOR \quad (9)$$

$$2R^{\cdot} \longrightarrow R{-}R \quad (10)$$

Scheme 1.2



An example of the second class of anti-oxidants, the peroxide destroyers, is zinc dialkyl (or diaryl) dithiophosphate (ZDDP) [1], which, as mentioned previously is also used as an anti-wear and corrosion prevention additive.



1

Zinc Dithiophosphate ZDDP

X can be alkyl, aryl or a combination of the two.

1.3.8. Foam Inhibitors.

These are added to the oil package to prevent the formation of foams, which can seriously impair the effective lubrication of an engine by starving it of the lubricant or by blocking the oil ducts. However, the exact mechanism of their action is not understood. They are typically made from silicone fluids.

1.4. Detergents.

As this thesis concentrates on the synthesis of overbased detergents, these will now be discussed in more detail. In marine engines, which use a low grade, high sulfur content fuel, the detergents serve primarily as acid-neutralising additives. However, as mentioned earlier, some additives perform a number of tasks in the engine, and the detergents do more than just neutralise the acids formed. They help to maintain engine cleanliness by keeping the insoluble particles suspended in the oil and thus prevent them from coagulating. They help as anti-oxidants and anti-rust additives by forming a protective layer on the engine metal surfaces which discourages the deposition of these particles. Surface protection is the result of physical adsorption onto the metal surfaces. In cases where a detergent is added specifically to prevent the deposition of insoluble particles, the detergent is known as a 'black-paint' additive. The term derives from the layer of insoluble material or 'black paint' which can occur on the metal parts. Finally, the detergents help maintain the viscosity of the oil. These other functions result from the chemical nature of the detergents.

An effective acid neutralising additive should have the following features;

1) It should be a strong base.
2) It should be stable even after reacting with the acid. There is no point in having an additive that after neutralisation breaks up to cause potential harm to the engine.
3) It should be a fluid concentrate with a high base number, so that when it is mixed with the oil it will have the capacity to neutralise a great deal of acid.

Colloidal dispersions of inorganic carbonates can fulfil all these requirements, calcium carbonate being the most commonly used one[10]. Sodium and magnesium carbonates are used to a much lesser extent and all three have replaced barium carbonate which posed problems of ash formation and toxicity.

The hydrocarbon tail (normally of at least eight carbon atoms) of the detergent is the

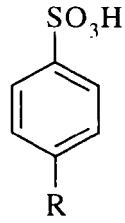
portion of the molecule that acts as the oil solubilizer, so that the whole molecule remains in the oil. The other part of the detergent is the polar head group, to which is complexed the metal carbonate. There are 5 main classes of detergents; sulfonates, phenates, salicylates, phosphonates and, a relatively new class of surfactants calixarenes (Figure 1.6). The calixarenes are of some interest chemically; a more detailed description of the calixarenes is included in Chapter 7.

To produce an overbased detergent requires the addition of the metal carbonate in stoichiometric excess. The resulting overbased detergent has the structure of an inverse micelle with the carbonate in the centre 'core' stabilised by an outer alkyl/aryl 'shell' which facilitates oil solubility[11]. The structure and shape of the micelle has been, and is currently being, investigated[12]. Figure 1.7 illustrates the colloidal structure of an overbased sulfurised phenate, with an inner core of calcium carbonate.

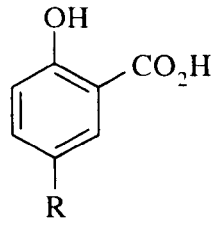
The degree of overbasing, and the strength as a base is measured by its total base number (TBN). The TBN is calculated using a standard industrial method which determines the basic components by titration with perchloric acid in glacial acetic acid[13]. The base number calculated is defined by the quantity of perchloric acid, expressed in terms of the equivalent number of mg of potassium hydroxide that are required to titrate 1 g of the sample dissolved in the specified solvent to a well defined inflection point specified by the test method. The range of values for the TBN of typical overbased detergents, can be seen in Table 1. The TBN of the overbased detergent varies a great deal depending on the application it is used for, in locomotive diesel engines[14] an additive with a TBN of about ten is used. In marine engines a high TBN (250-400) mixture is added for neutralisation purposes and a lower TBN (5-25) mixture is also added to maintain engine cleanliness and provide additional protection against rust and corrosion.

Figure 1.6. The five classes of surfactants that are used as detergents. In some instances the calixarenes[15,16] are grouped in with the phenates because they are both derived from alkylphenols.

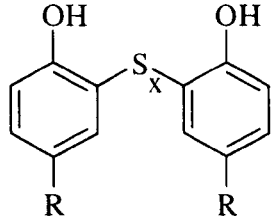
Alkylsulfonate



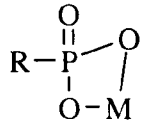
Alkylsalicylic acid



Sulfurised phenate



Phosphonate



Calixarene

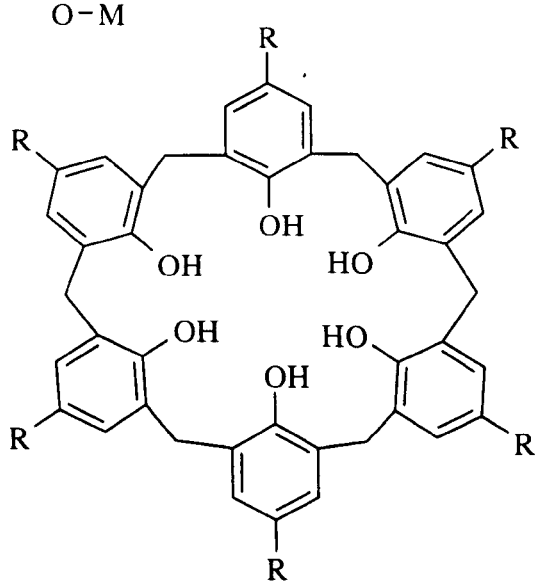


Figure 1.7. The structure of the overbased sulfurised alkylphenols. The size of the inner core of calcium carbonate is dependent on the TBN of the sample with a 150 TBN sample having the diameter of the calcium carbonate core about 0.59 nm and a 300 TBN sample having the diameter of the calcium carbonate core about 1.25 nm.[17] During the synthesis of this detergent ethylene glycol is added and this is incorporated into the inner shell. The role of the ethylene glycol is not fully understood, but is thought to help in solubilizing the reactants.

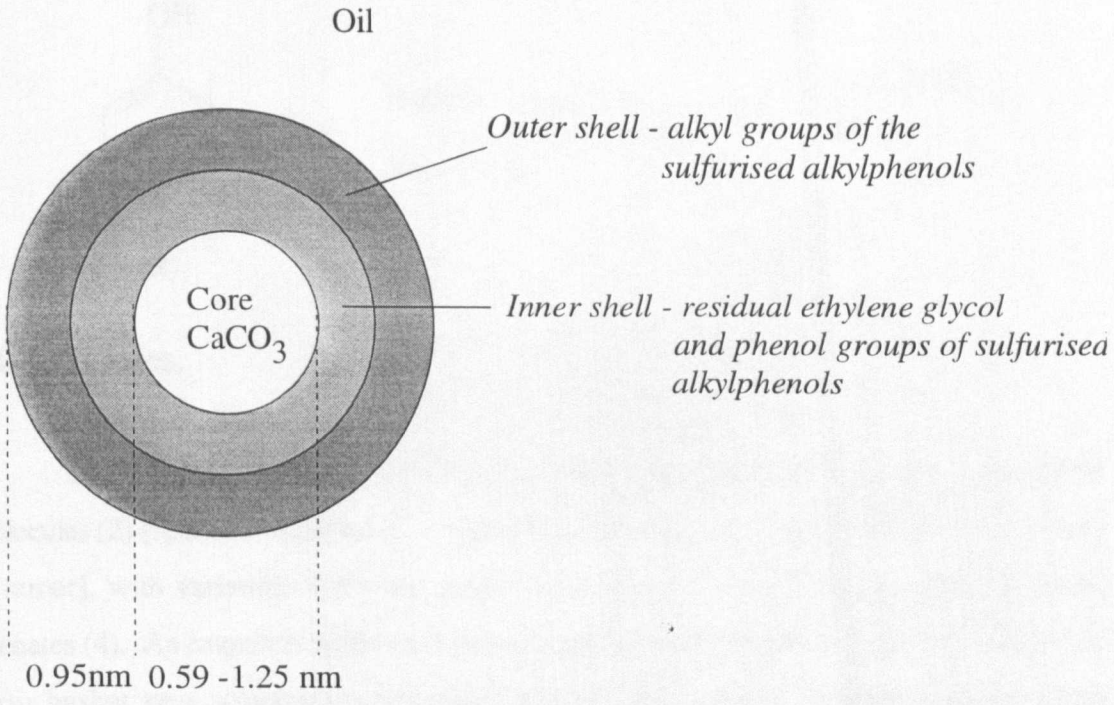


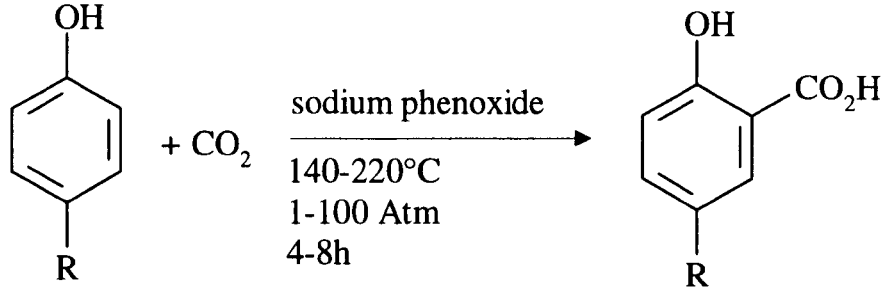
Table 1.1 The range of typical detergent lubricant additives.

	Range		
	Sulfonates	Phenates	Salicylates
TBN	0-500	50-400	50-400
Metal cation	Ca, Mg, Na, Ba	Ca, Ba, Mg	Ca, Mg
Molecular weight:			
	375-700	160-600	250-1000
Sulfur, %	0.5-4.0	0-4	0

1.4.1. Salicylates.

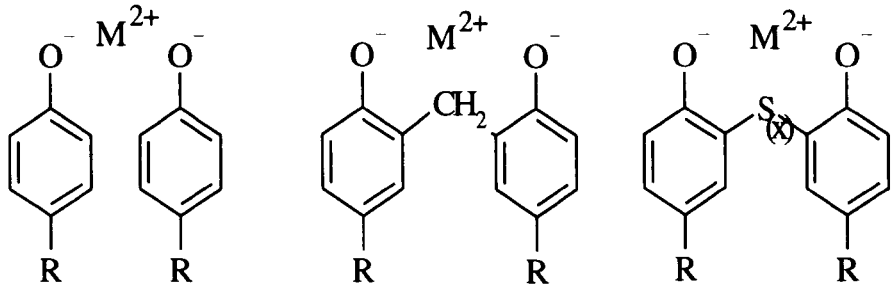
Salicylates are currently produced by the carboxylation of alkylphenols, using the Kolbe-Schmidt route[18-22], which requires the use of high temperatures and pressures, (Scheme 1.3). The alkylphenol is typically a C_{12} alkylphenol produced by alkylating phenol with propylene tetramer using one of a range of catalysts.

Scheme 1.3.



1.4.2. Phenates.

The simplest phenate consists of a metal salt complexed to two alkylphenol molecules (**2**) [again the alkylphenol is typically a C_{12} alkylphenol produced from propylene tetramer], with variations including methylene coupled phenates (**3**) and sulfur coupled phenates (**4**). An extension of the methylene coupled phenates are the calixarenes which can form basket type structures, comprising of methylene coupled alkylphenols; the metal carbonate core is held inside two of the baskets. The exact conformation of the calixarene/metal carbonate structure is currently under investigation.



2 **3** **4**

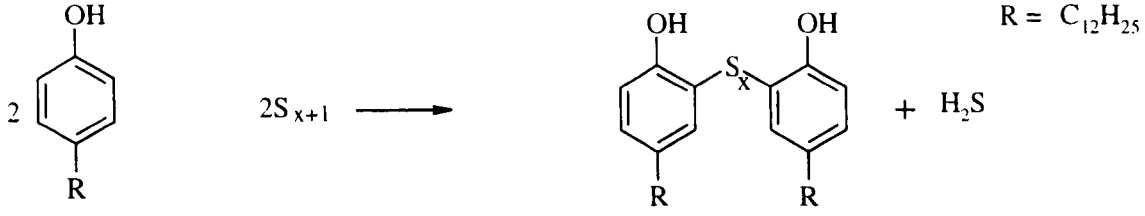
Normal Phenate **Methylene Coupled Phenate** **Sulfurised Phenate**

The most commonly used phenate is the sulfurised phenate because the sulfurisation process appears to lower the corrositivity of the oil during use, towards engine and

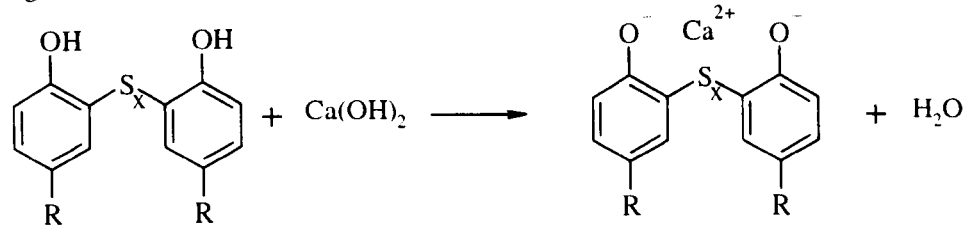
particularly the bearing metals and the sulfurised phenates also improve oxidation stability. The synthesis of the sulfurised phenates is shown in Scheme 1.4.

Scheme 1.4. The three stages in the manufacture of overbased sulfurised alkylphenols. The addition of extra calcium carbonate and carbon dioxide is to increase the TBN of the end product.

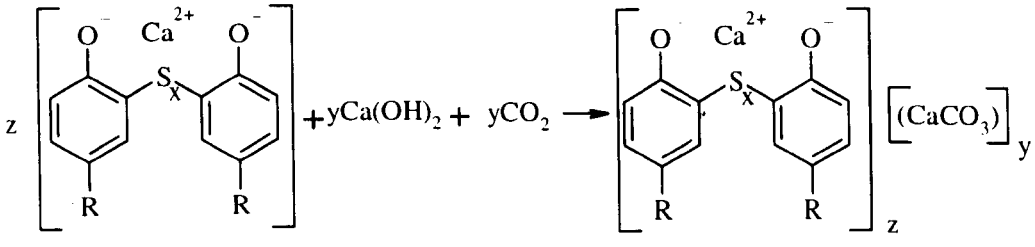
Stage 1 Sulfurisation



Stage 2 Neutralisation



Stage 3 Overbasing



1.4.3. Sulfonates and Phosphonates.

Two types of sulfonate substrates have been developed; petroleum (natural) sulfonates and synthetic sulfonates[23]. These two types of sulfonates can then be divided further into neutral or overbased sulfonates. One advantage of the basic sulfonates is their ability to neutralize acidic compounds. The natural sulfonates are a by-product in the manufacture of white oil. This process involves mixing the mineral oil with sulfuric acid to form the 'white' oil plus a sulfonic acid mixture that, when treated with sodium hydroxide, yields two different types of soaps. After the separation of the sludge, the mahogany acids (so named because of their reddish colour) are generally recovered from the oil in the form

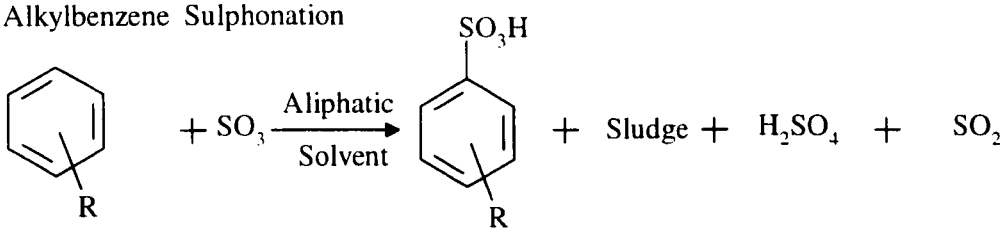
of alkali salts which are usually produced by the addition of sodium carbonate or sodium hydroxide followed by the extraction of the salt with a solvent. The mahogany acid soaps are sodium sulfonates or soaps which were the starting material for the original lubricating oil additives. The mahogany acid soaps are oil soluble.

The formation of other metal soaps can be achieved in one of two ways; the mahogany acid can be neutralised with another metal hydroxide to give the corresponding metal salt or the sodium salt can be converted to other metal salts by means of a metathesis reaction with a metal chloride.

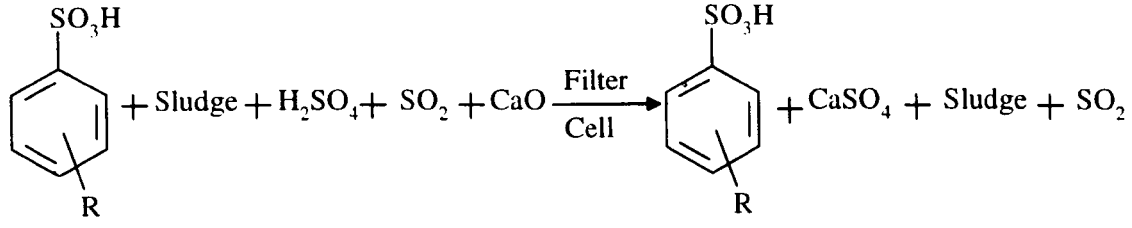
The synthetic sulfonates are prepared from a variety of aromatic substrates. An example of such a synthesis is set out in Scheme 1.5.[6,24]

Scheme 1.5

Alkylbenzene Sulphonation



Purification of the Sulphonic Acid



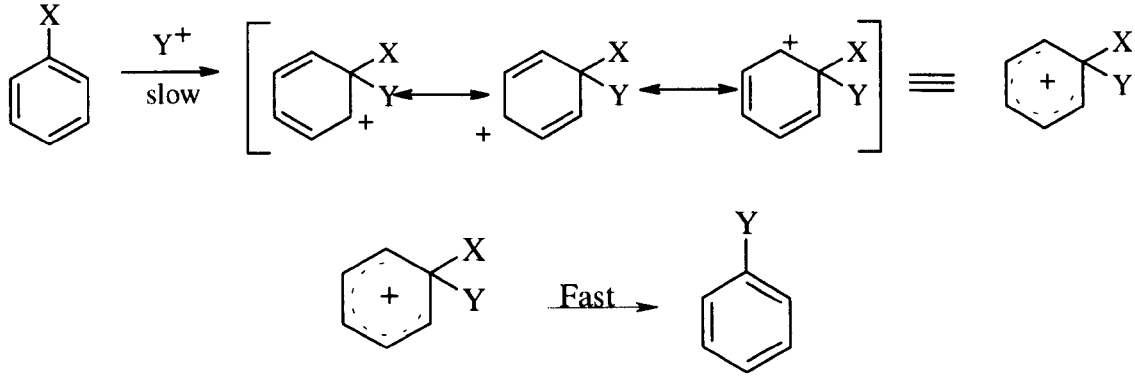
The phosphonates are prepared in the same general manner as the overbased sulfonates, but their use as overbased detergents is minimal.

A wide range of detergents are used for a number of specific purposes with many consisting of an alkyl group joined to an aromatic ring. Consequently the alkylation of aromatic rings is of major importance, the next section will discuss in detail the alkylation of aromatic rings.

1.5. Alkylation of Aromatic Rings.

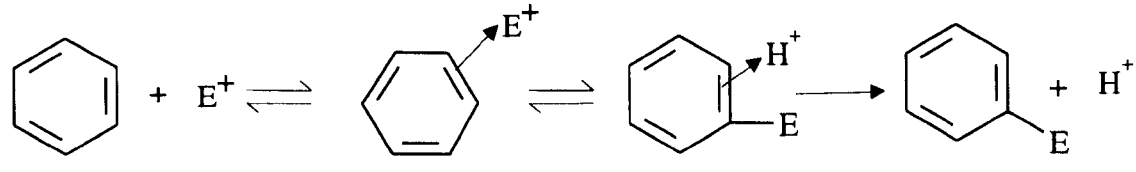
One of the most studied of all organic reactions is electrophilic aromatic substitution. As well as being important for alkylation of aromatic rings, electrophilic aromatic substitution is also very important to the dye industry (sulfonation and nitration of aromatic rings), the pesticide industry (halogenation of aromatic rings) and the explosives industry (nitration of aromatic rings). The majority of electrophilic aromatic substitution reactions proceed by a single general mechanism which involves the intermediacy of an arenium ion. The electrophile attacks in the first step, giving rise to the positively charged intermediate and in the second step a leaving group, usually a proton, is lost as shown in Scheme 1.6.

Scheme 1.6.



Generally, the first step is the slow rate determining one; the electrophile need not bear a full positive charge though obviously some positive character is required. A π complex has been suggested by Dewar[25] to play an important role in electrophilic aromatic substitution. His variant of the mechanism is shown in Scheme 1.7 and is generally favoured by a number of people[26,27,28]. Stable solutions of π complexes (e.g. with Br_2, Ag^+ or HCl) can be formed at will. Olah comments that either the σ or π complex dominates depending on the nucleophilicity of the aromatic ring and/or whether the electrophile is weak or strong[29].

Scheme 1.7.

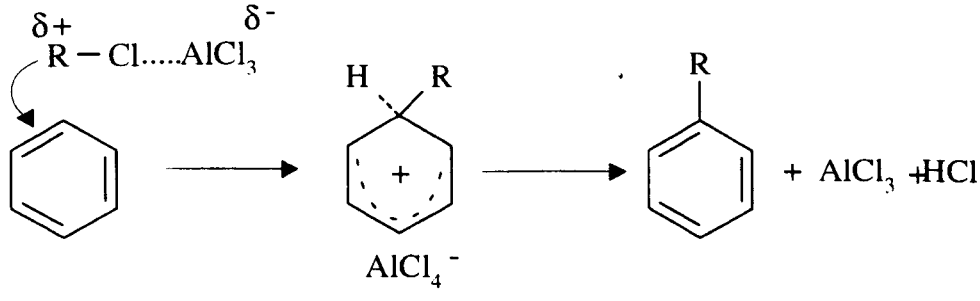


Friedel Crafts type alkylations with which much of this thesis is concerned are assumed to involve solely the σ complex and not to involve the π complex. The Friedel Crafts type alkylations are discussed in the following sections.

1.5.1. Introduction to Friedel-Crafts Alkylations.

The first Friedel-Crafts alkylation reaction was carried out by Charles Friedel and James Mason Craft in 1877, when they reacted benzene with "amyl chloride" in the presence of aluminium chloride to produce 'amylbezene'. Early work, on the alkylation of aromatics involved the use of haloalkanes. The carbon atom of the alkyl halide is electrophilic, but rarely is it sufficiently so as to bring about the substitution of the aromatic substrate. To increase the electrophilic nature of the carbon atom the presence of a Lewis acid catalyst, such as $AlCl_3$, is required. The general mechanism for the alkylation of an aromatic, using an alkyl halide, forming a σ complex, is illustrated in Scheme 1.8. The attacking electrophile is a polarised complex, the degree of polarisation in a particular case depends on both R and Hal in the R-Hal and the Lewis acid employed.

Scheme 1.8.



Friedel-Crafts alkylations are frequently complicated by the occurrence of side reactions, such as reorientation, disproportionation, dealkylation, fragmentation, hydride transfer and skeletal rearrangements in the side chain. The occurrence and degree of such complicating reactions are determined mostly by the strength of the catalyst employed and/or the experimental conditions. A great deal of work has been carried out into these side reactions, but since Lewis acids have not been used as catalysts in this thesis they will not be discussed further[30,31,32]. The nature of both the aromatic substrate and the alkylating species can have a major impact on the products and their distribution. The effects of the aromatic substrate, alkylating species and the nature of the side reactions will be discussed

in the following sections with emphasis being placed on the areas of particular relevance to the work to be described in this thesis.

1.5.2. Aromatic Substrate.

When an electrophilic substitution reaction is performed on a monosubstituted benzene the new group may be directed to the ortho, meta or para position and reaction may proceed faster or slower than benzene itself. In general, if a deactivating electron withdrawing group is present, alkylation predominantly occurs in the meta position. The orientation and reactivity effects of each group can be explained on the basis of resonance and field effects on the stability of the intermediate arenium ion. Usually the product from these reactions is kinetically and not thermodynamically controlled. Some of the reactions are irreversible whilst others are stopped well before equilibrium is reached. Therefore, which of the three possible positions is attacked is dependent on the activation energy necessary to form each of the appropriate intermediates and not on the thermodynamic stability of the products.

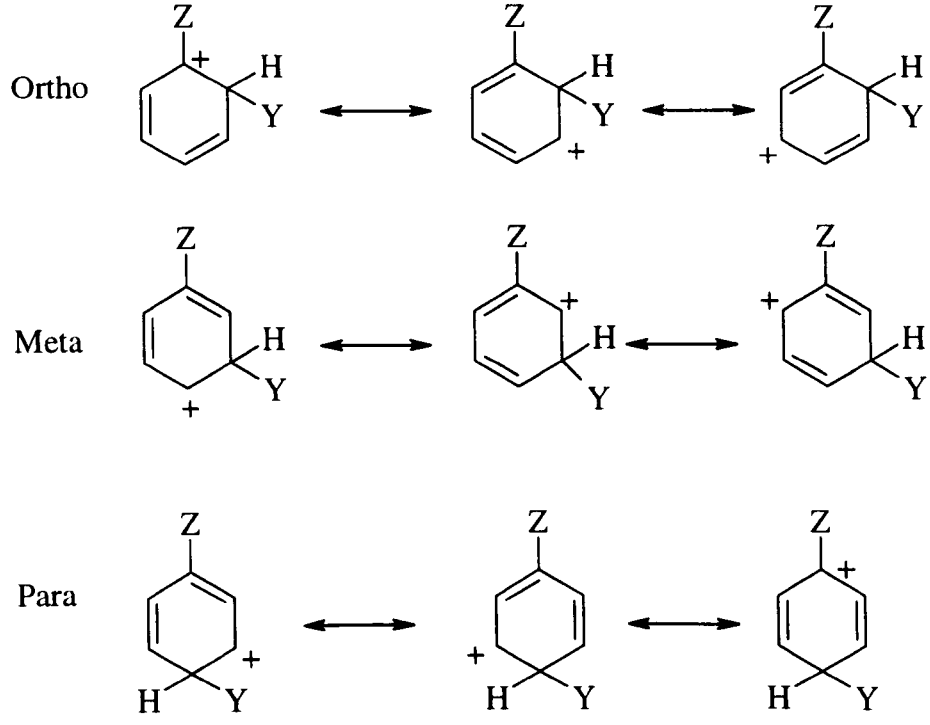
To predict the orientation effects of substituents the relative stabilities of the arenium ions need to be considered. Figure 1.7 shows the three possible resonance stabilised ions resulting from the ortho, meta and para positions.

One might expect that any group Z that has an electron donating effect would stabilize all three ions relative to the phenonium ion (Z=H), but electron-withdrawing groups, which increase the positive charge on the ring, should destabilize them. Only the ortho and para arenium ions have the positive charge on the carbon next to the group Z. The meta one does not. Therefore, electron donating groups will stabilize in particular the ortho and para isomers and consequently they tend to be ortho-para directing. The opposite is true of electron withdrawing groups, which destabilize mostly the ortho and para forms, are deactivating and meta directing.

This argument, however, does not take into account the mesomeric effect of the substituents. If a substituent contains an unshared pair of electrons next to the ring (e.g. NR_2, OH, OR, OCOR) the +M effect will stabilize further intermediates from attack at the ortho and para positions resulting in an enhanced ortho para directing effect. The converse is true for groups (e.g. NO_2, CO_2H) that the atom bonded to the aromatic ring has no

unshared pair of electrons and carries a positive or partial positive charge. These groups are meta-directing and deactivating.

Figure 1.7. The three possible ions from substitution in the ortho, meta and para positions.



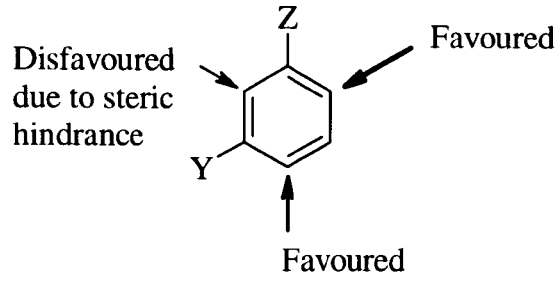
It is possible to predict the product distribution of benzene rings containing more than one substituent based on the basis of three simple rules:

1) If a strongly activating group competes with a weaker one or a deactivating group, the former controls the isomer distribution. The following groups are arranged in decreasing control over the orientation: NH_2, OH, NR_2, O^- > OR, OCOR> R, Ar > halogen > meta-directing.

2) All other things being equal, a third group is least likely to enter between two groups next to each other. This is due to steric hindrance and increases in importance with the size of both the groups on the ring and the attacking species.

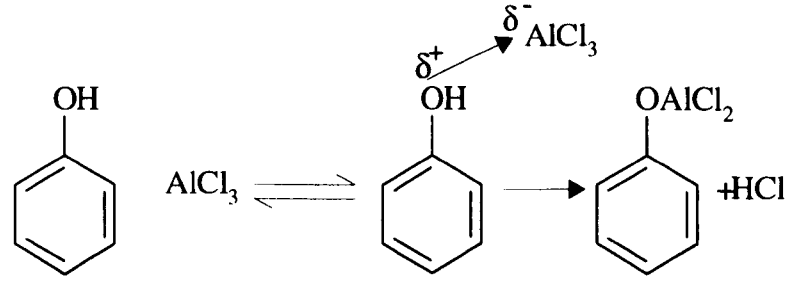
3) With 1,3-disubstitution, one group being ortho, para-directing (X) and the other meta-directing (Y) the incoming group goes primarily ortho to the meta-directing group. Figure 1.8. illustrates the favoured sites of attack for a 1,3-disubstitution.

Figure 1.8. The favoured sites of attack for a 1,3-disubstituted aromatic containing one meta-directing group and one ortho, para-directing group.



When nucleophilic groups, such as OH, OR, NH_2 are present problems are experienced with the Friedel-Crafts alkylation of the Lewis acid required, as the catalyst coordinates with the nucleophilic groups, as illustrated in Scheme 1.9. This problem is overcome by the use of an excess of the Lewis acid catalyst. Consequently, other catalysts tend to be used to alkylate aromatic rings in place of Lewis acids when such nucleophilic groups are present and the use of these alternative catalysts will be discussed in later sections.

Scheme 1.9.



1.6. Acylation.

The initial work by Friedel and Crafts, as well as demonstrating that they could alkylate aromatic rings, showed that acylation took place as well. The alkylation of aromatic compounds, as has been commented previously, can be achieved by acylation followed by reduction but this procedure is generally disfavoured industrially because it is a two stage process. Friedel-Crafts acylation is one of the most important methods for the preparation of aryl ketones, with not only acyl halides but also carboxylic acids, anhydrides and ketenes

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1.7.1. Catalysts.

The most commonly used catalyst to form carbocations are the proton acids. Their activity is measured by their ability to protonate a suitable substrate (forming a carbocation) or abstract a hydride ion. Sulfuric acid is the most commonly used proton acid because of its low cost, other strong proton acids include anhydrous hydrogen fluoride, phosphoric acid, polyphosphoric acid, and p-toluenesulfonic acid.

The acidity of the proton acids and the supported acids (solid acids) are quoted in terms of the Hammett acidity function, H_o. The acidity function H_o is a measure of the tendency of the medium to protonate a base B and it may be defined by the equation 1.12

$$H_o = pK_{BH^+} - \log \frac{[BH^+]}{[B]} \qquad 1.12$$

For very dilute solutions of acid H_o is equal to pH since $K_{BH^+} = [B][H^+]/[BH^+]$. The H_o values for water/sulfuric acid system are shown in Table 1.2, and Table 1.3 shows the H_o values for a variety of other acid catalysts.

Table 1.2. H_o values for a water/sulfuric acid system[33].

$\%H_2SO_4$	$-H_o$	$\%H_2SO_4$	$-H_o$
10	0.31	85	7.66
20	1.01	90	8.27
30	1.72	95	8.86
40	2.41	96	8.98
50	3.38	97	9.14
60	4.46	98	9.36
70	5.65	99	9.74
80	6.97	100	11.01

Table 1.3 H_o values for a variety of other acid catalysts.

Catalyst	$-H_o$
Fulcat	≈ 0.8[34]
Amberlyst-15	≈ 2[35,36]
Nafion-H	11-13[37]
Phosphoric Acid 88%	4.0[32]
Phosphoric Acid 100%	5.25[32]
Trifluoromethanesulfonic Acid	14.2[38,39]
$HSbF_6$	15.2[36,37]

There are problems associated with using proton acids as catalysts. The major problem involves the formation and subsequent rearrangement of the carbocation intermediate. The rearrangement of carbocation intermediates, which is a general problem will be discussed in a latter section. However, there are specific problems associated with using sulfuric acid which centre on undesirable side reactions resulting from its oxidising, dehydrating properties and its sulfonating ability. When sulfuric acid is used to catalyse the alkylation of aromatic with alkenes, four competing reactions can take place, Scheme 1.10:

1) Protonation of the alkene followed by alkylation of the aromatic substrate by the carbocation.
2) Polymerization of the alkene.
3) Addition of the alkene to the sulfuric acid to form the ester (the sulfuric acid is acting as a weak nucleophile).
4) Sulfonation of the aromatic ring (This requires concentrated sulfuric acid and/or elevated temperatures).

By varying the acid concentration and temperature any one of these four competing reactions can be made dominant.

Currently the greatest interest in Friedel-Crafts catalysts is in environmentally friendly supported catalysts[40]. These generally consist of a clay or resin impregnated with for example, sulfuric acid or zinc chloride[41]. Fulcat, a catalyst that is used industrially to alkylate phenol, is composed of Fullers' Earth, an aluminium poor montmorillonite clay, impregnated with sulfuric acid. An illustration of a solid acid catalyst is illustrated in Figure 1.8. The exact details vary with the type of supported acid catalyst but typically the sulfuric

acid is bonded within the holes of the support and the other reagents diffuse into the holes of the support and the desired reaction takes place at these sites.

Scheme 1.10.

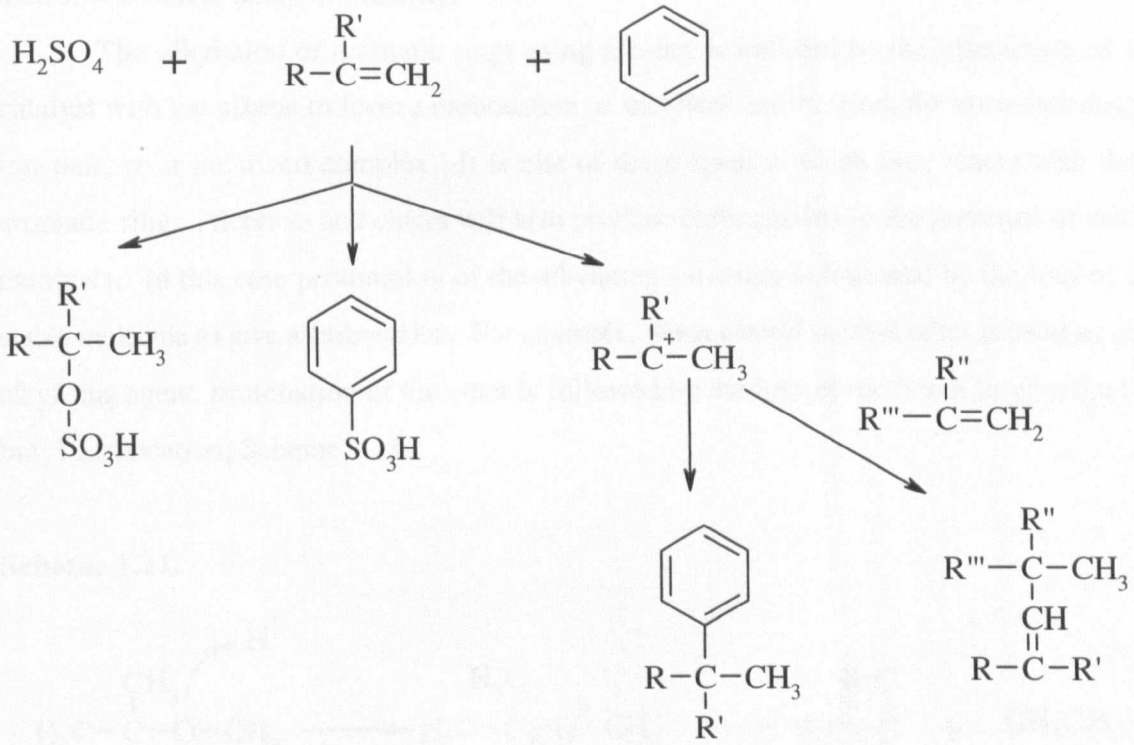
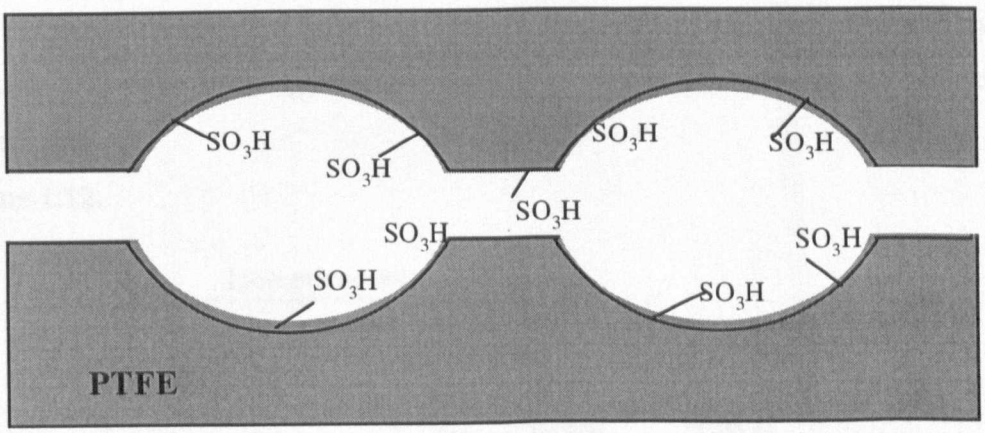


Figure 1.8. An illustration of a perfluorinated resinsulfonic acid similar to Nafion-H.[42]



1.7.2. Alkylating Agents.

A whole range of alkylating agents can be used to alkylate aromatic rings. For a detailed review of the complete range of alkylating agents see "Friedel-Crafts and Related

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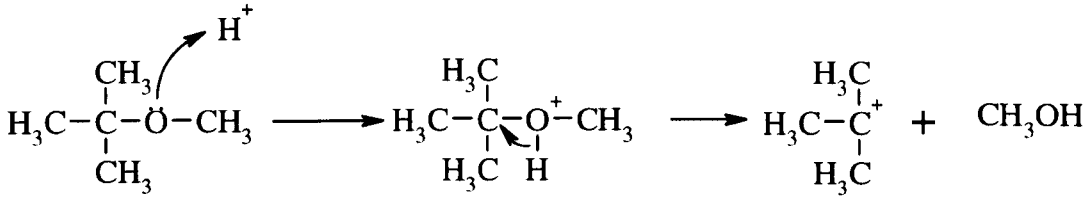
Reactions" by G. A. Olah[43]. Frequently used alkylating agents include alkyl halides, alcohols, alkenes, ethers, acyl halides and anhydrides. Of all the possible alkylating agents used, three are of particular importance to the work to be discussed; alkenes, ethers and alcohols. The most commonly used alkylating agents industrially are alkenes, because of their low cost and ready availability.

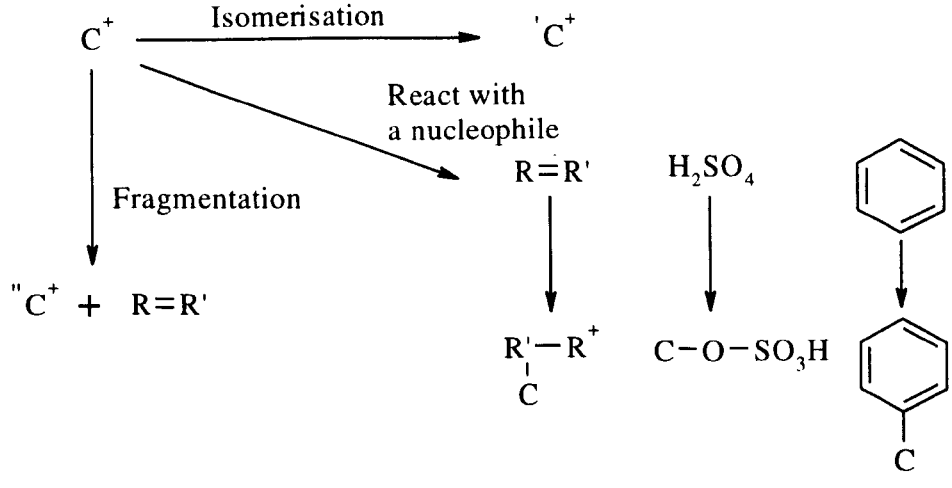
The alkylation of aromatic rings using alkenes is initiated by the interaction of a catalyst with the alkene to form a carbocation or incipient carbocation, the corresponding ion pair, or a polarized complex. It is one of these species which then reacts with the aromatic ring. Alcohols and ethers will also produce carbocations in the presence of acid catalysts. In this case protonation of the alkylating substrate is followed by the loss of a stable molecule to give a carbocation. For example, when t-butyl methyl ether is used as an alkylating agent, protonation of the ether is followed by the loss of methanol to give the t-butyl carbocation, Scheme 1.11.

Scheme 1.11.



Once the carbocation is formed it can undergo a number of reactions as illustrated in Scheme 1.12. The following sections discuss these various reactions that the carbocations can undergo.

Scheme 1.12.



1.7.3. Stability and Rearrangement of Carbocations.

When benzene is alkylated with 1-dodecene the complete range of secondary phenyl dodecanes results[44]. The distribution of these products is shown in Table 1.4.

Table 1.4. The distribution of products when benzene is alkylated by 1-dodecene in the presence of a variety of catalysts.

Ratio of Isomers	Catalyst		
	HF	$AlCl_3$	H_2SO_4
1-phenyldodecane	0	0	0
2-phenyldodecane	20	32	41
3-phenyldodecane	17	22	20
4-phenyldodecane	16	16	13
5-phenyldodecane	23	15	13
6-phenyldodecane	24	15	13

The absence of the 1-phenyl isomer is attributed to the instability of the primary carbocation, which rearranges, if it is formed at all, to give the more stable secondary carbocation. However, it would have been expected for the secondary carbocations to also rearrange to give the more stable tertiary carbocations and consequently the tertiary dodecylphenol, but none were reported.

The general order of stability of carbocations is tertiary > secondary > primary. The order results from the fact that increasing substitution of the cationic carbon atom by electron donating groups leads to increasing substitution of the positive charge by inductive effects. The relative stability of a few alkylcarbocations in the gas phase are given in Table 1.5[45].

Typically the primary carbocations are 60-70 kJ mol^{-1} less stable than the secondary 2-butyl cation, whilst the later are another 67 kJ mol^{-1} less stable than the tertiary butyl cation. However, the values quoted in Table 1.5 are based upon energies in the gas phase and as such can give only qualitative information on likely factors in solution.

Table 1.5. The relative stabilities of a few alkylcarbocations in the gas phase.

Carbocation	ΔH^{oa} (kJ mol^{-1})
1-Butyl cation	+138
2-methyl-1-propyl cation	+130
2-Butyl cation	+67
2-Methyl-2-propyl cation	0
2-Methyl-2-butyl cation	-12
2-Methyl-2-pentyl cation	-19
2-Methyl-3-pentyl cation	-19
2,3-Dimethyl-2-butyl cation	-21

The stabilizing effect of an alkyl substituent depends partly on the number of C-C bonds in the β position to the positively charged carbon atom but this stabilizing effect is small when compared with the difference in stabilization on going from a primary to secondary to tertiary carbocation.

1.7.3.1 Carbocation Rearrangements.

Once a carbocation is formed it is generally much more prone to undergo rearrangements than carbanions, radicals and other short lived intermediates. These rearrangements can be subdivided into two categories; isomerization and fragmentation. The rate of isomerization is generally always faster than that of fragmentation. The 1,2-alkyl and 1,2-hydride shifts are amongst the fastest reactions known in organic chemistry[46].

The simplest isomerization of a carbocation is a 1,2-hydride shift and can occur very rapidly. As has been commented on previously when 1-dodecene is used to alkylate phenol the complete range of secondary alkylphenolsis obtained as a result of the 1,2-hydride shifts on the initial carbocation. In effect the positive charge is moving freely up and down the alkyl chain. It is of course not possible to distinguish between various carbocations formed via 1,3-, 1,4- or 1,5-hydride shifts and a rapid sequence of 1,2-hydride shifts. The activation energy for the isomerization of a secondary to a tertiary carbocation in the liquid phase has been found to be at least 93 kJ mol^{-1} and going from tertiary to primary carbocations is at

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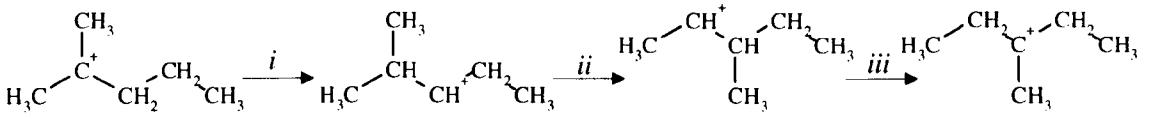
[a] The values quoted are the enthalpies of formation of the carbocations from the alkyl chlorides, relative to the 2-methyl-2-chloropropane.

least 139 kJ mol^{-1}.[47]

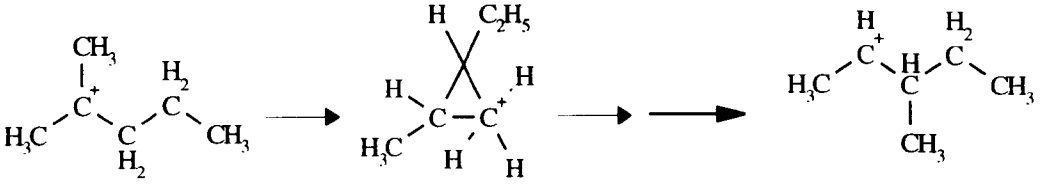
An example of an isomerization to give another tertiary carbocation is shown in Scheme 1.13. It consists of (*i*) a 1,2-hydride shift followed by (*ii*) a 1,2-methyl shift and finally (*iii*) another 1,2-hydride shift to restore the teriary carbocation.

Scheme 1.13.



It is generally accepted that the 1,2-methyl shift occurs via cyclization of the alkyl carbocation into a substituted corner protonated cyclopropane (CPCP) intermediate structure followed by reopening in the latter ion, as illustrated in Scheme 1.14. The CPCP intermediate has been trapped using super acids.

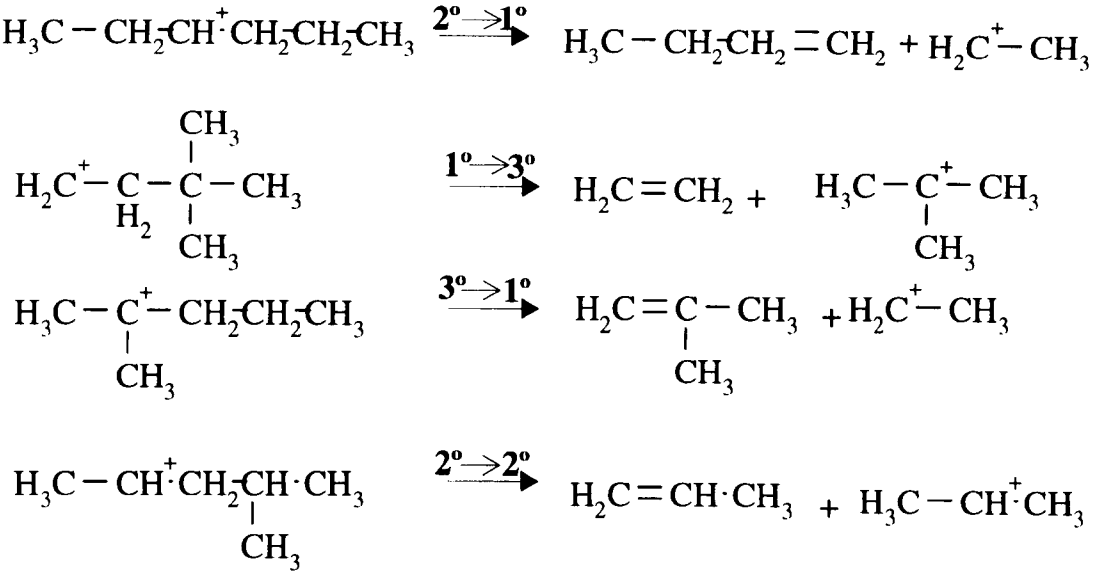
Scheme 1.14.



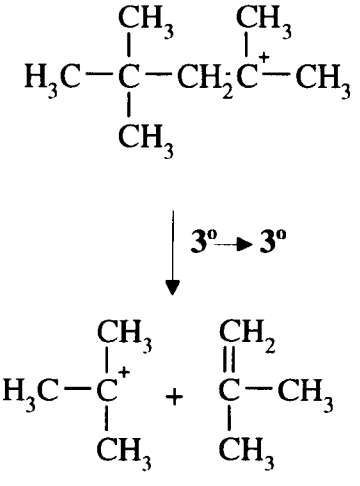
Besides rearrangements the carbocations can also undergo fragmentation reactions and these occur via carbon-carbon bond cleavage in the beta position, to form a free alkene and a smaller carbocation. Some of the possible modes of β scission for a C_6 carbocation are illustrated in Figure 1.9, showing a secondary to tertiary, a primary to tertiary and a secondary to secondary carbocation cleavage.

The most favoured modes of β scission involve the formation of a more stable carbocation or one that is at least as stable. For example, primary to secondary β scission is favoured as is secondary to secondary. The most energetically favourable mode of β scission is the tertiary to tertiary mode. This is especially important when the 2,4,4-trimethyl-2-pentyl carbocation is formed, as illustrated in Scheme 1.15. Again in general the rate of isomerization is much faster than that of fragmentation.

Figure 1.9. Some of the various modes of β scission for a C_6 carbocation.



Scheme 1.15.



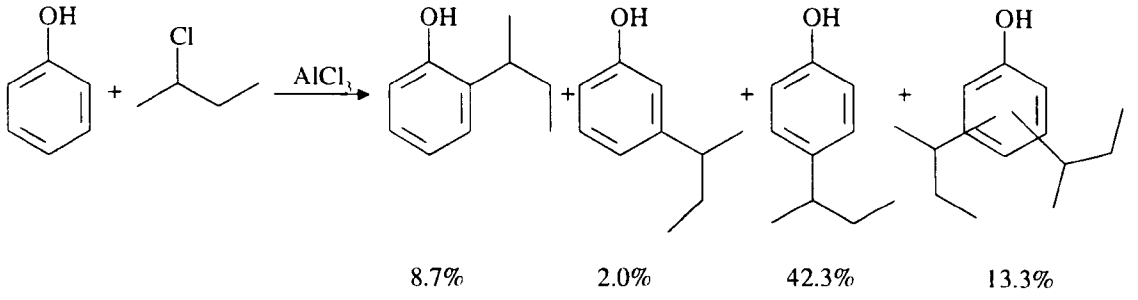
1.8. Complications with Electrophilic Aromatic Substitution Reactions.

1.8.1. Polyalkylations.

The first alkylation of an aromatic ring frequently is followed by further alkylations. This is because the electron donating effect of the first alkyl group makes the first product more reactive to electrophiles than was the starting material. When phenol is alkylated by 1-chloro-2-methylpropane and aluminium chloride[48], a high proportion of the disubstituted product remains, as illustrated in Scheme 1.16. The values quoted are the yields in mole

percent. The unreacted phenol accounting for the remaining material.

Scheme 1.16.



Polyalkylation can be overcome by employing an excess of the aromatic substrate and then removing the unreacted aromatic substrate after the reaction, which is obviously not really desirable. Polyalkylation is not the only characteristic associated with the alkyl group in Friedel-Crafts alkylations. The alkyl group can be transfered from one aromatic ring to another (transalkylation) by the catalytic effect of a range of catalysts. Dealkylation, rearrangement and fragmentation of the alkyl group whilst it is bonded to the aromatic ring can also occur. These characteristics will be discussed in more detail in the following sections. Fragmentation and rearrangement of the alkyl group whilst it is not bonded to the aromatic ring has already been discussed in previous sections.

Steric factors can also play an important role in alkylation reactions. The size of the substituent on the aromatic ring or the size of the alkylating group can restrict or even prevent the alkylation. As demonstrated by Friedman et al.[49] p-xylene will be alkylated by straight chain alkenes, alcohols and alkyl halides but always resists alkylation by the corresponding branched-chain isomers.

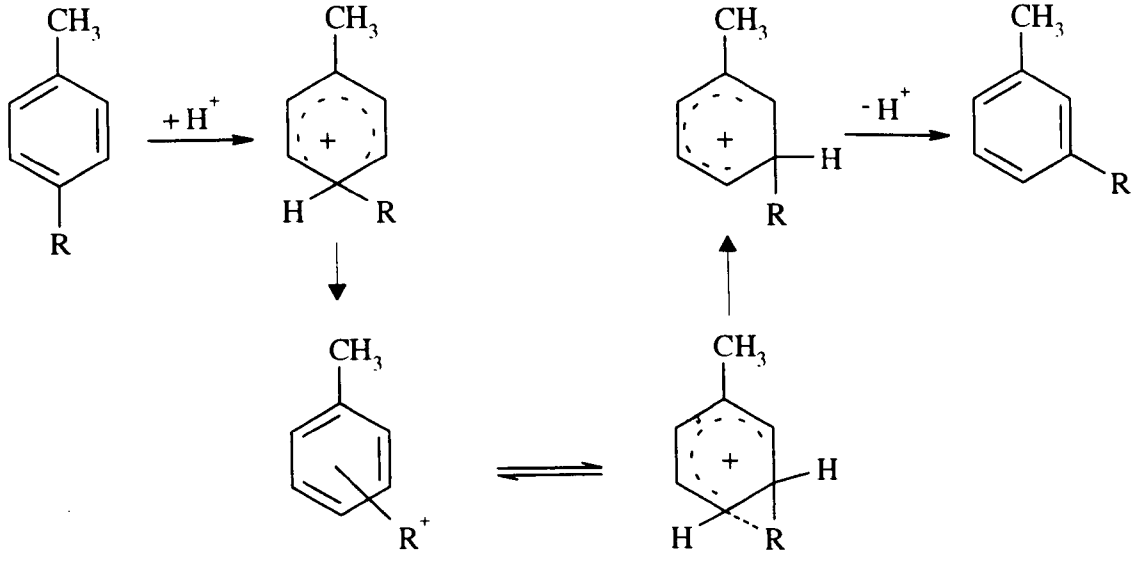
1.8.2. Dealkylation, Transalkylation and Fragmentation.

Dealkylation is really the reverse stage of the Friedel-Crafts alkylation[50]. However, under ordinary alkylating conditions the thermodynamic equilibrium is so far on the side of alkylation that the reaction is irreversible for all practical purposes. To produce dealkylation of an alkylbenzene requires forcing conditions which usually lead to other reactions as well, such as disproportionation, rearrangement of the side chain and fragmentation. In general the rates of dealkylation are in the order tertiary alkylbenzene > secondary alkylbenzene > primary alkylbenzene[51]. Fragmentation of the alkyl chain involves producing an alkane with

fewer carbon atoms than the original hydrocarbon.

In general alkyl groups containing two or more carbon atoms are readily transferred from one position to another (intra- and inter-molecular rearrangement). In the movement of alkyl groups around a ring or from one ring to another the first step is the addition of a proton at the ring carbon atom to form a σ complex. The alkyl group being less firmly held can then move intra-molecularly by a 1,2-shift (isomerization) or be detached completely as a carbocation capable of reacting with another ring. An example of an intra-molecular 1,2-shift mechanism is shown in Scheme 1.17. The alkyl group of the aromatic σ-complex bridges two adjacent aromatic carbons and then swings over to its final position. Loss of a proton yields the product.

Scheme 1.17.

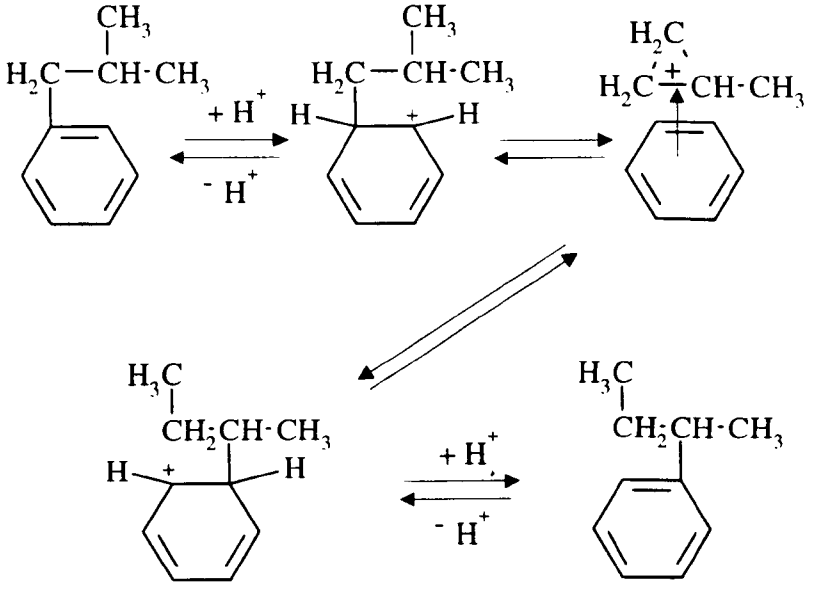


1.8.3. Rearrangement of the Alkyl Chain.

Rearrangement in the alkyl chain can also occur either via an intra- or an inter-molecular process. In general, the two routes are competing and the orientation of the alkylchain dictates which is the dominant route. Allen and co-workers concluded that the isomerization of ethyltoluene is more than 84% intra-molecular and less than 16% inter-molecular[52] but this depends on the conditions employed. The inter-molecular rearrangement consists of three stages; dealkylation, rearrangement of the carbocation and then realkylation.

An intra-molecular rearrangement has been postulated when either sec-butylbenzene or isobutylbenzene is heated in the presence of wet-aluminium chloride. The product mixture has been found to contain these two isomeric hydrocarbons in an equilibrium ratio of 0.5, with only a negligible amount of t-butylbenzene[53]. The proposed mechanism involves a methylbridged π-complex intermediate, as illustrated in Scheme 1.18. If appreciable amounts of t-butylbenzene had been produced, then the rearrangement could be thought of as dealkylation followed by rearrangement of the carbocation: the rearrangement of the carbocation would be expected to yield the more stable t-butyl cation and, consequently, the t-butylbenzene[54].

Scheme 1.18.



The composition of the side chain can play an important role in the rearrangement of the alkyl group. When pentylbenzenes are heated in the presence of wet aluminium chloride, the resulting products depend on the structure of the starting material. t-Pentylbenzene was rapidly isomerized to (1,2-dimethylpropyl)benzene and the latter was more slowly isomerized to neopentylbenzene, which is very resistant toward rearrangement. (1-methylbutyl) and (1-ethylpropyl)benzene are rapidly interconverted and both are more slowly isomerized to (2-methylbutyl)benzene. Isopentylbenzene was not isomerized under the conditions employed and n-pentylbenzene underwent only 9% rearrangement[55].

1.9. Summary of Key Aspects of Aromatic Alkylations.

The key points associated with the alkylation reactions discussed above can be summarised as follows:

1) Aromatic alkylations are frequently complicated by the involvement of side reactions such as dealkylation, disproportionation, reorientation, fragmentation and skeletal rearrangement of the alkyl chain.

2) Rearrangement of the alkyl chain can occur prior to, during and after alkylation.

3) Alkylations using linear alkenes and linear secondary alcohols or ethers yield all of the theoretically possible isomeric sec-alkylaromatics.

4) Alkylations using linear alkenes and linear secondary alcohols or ethers are thermodynamically controlled when strong acids such as $AlBr_3$, $AlCl_3$ or $HF\text{-}BF_3$ are used, giving the same distribution of products regardless of the position of the double bond in the alkene.

5) Kinetically controlled alkylations occur when "weak" acids (compared to super acids) such as HF, H_2SO_4 are used. The distribution of various isomers shows varying degrees of dependence on factors such as chain length, location of the double bond in the chain, nucleophilicity of the arene, type of catalyst and solvent, ratio of reactants, temperature and homogeneity of the reaction medium[56].

1.10. Sulfur Chemistry.

Industrially, sulfur is a very important compound with early usage involving, primarily, the formation of gunpowder. Recently there has been an increased interest in the application of elemental sulfur to many different fields of chemistry. Currently its uses can be divided into those that involve sulfuric acid and those that do not[57].

1.10.1. Reactions of Sulfur.

Reactions involving elemental sulfur have the potential to be very complex as there are several forms and oxidation states in which sulfur can exist. On heating of elemental sulfur a homolytic scission is assumed to take place, predominately leading to linear sulfur

biradicals and cyclic sulfur molecules other than S_8. Radicals have been detected above 180°C and depending on the reaction conditions, sulfur can also be present as S_x^- or S_x^+, although the later is more unusual.

Elemental sulfur, either alone or in the presence of a base will bring about the oxidation of organic compounds. Generally alkenes are much more reactive than alkanes. Sulfur only reacts with alkanes at elevated temperatures, dehydrogenation reactions occurring above 150°C with the production of H_2S to give alkenes. The main reaction with the more reactive alkenes is further dehydrogenation, followed by dimerisation, cyclisation or aromatisation.

The exact nature of these possible sulfur reactions are discussed, in more detail in Chapter 7, which is concerned with the sulfurisation of alkylphenols.

1.11. Aims.

The work detailed in this thesis is concerned with synthetic routes to marine oil additives, primarily the overbased detergents. Two classes of overbased detergents that have been investigated are the alkylsalicylic acids and the sulfurised phenates. The current synthetic route to alkylsalicylic acids is via the Kolbe-Schmitt route, which involves the use of high temperatures and pressures. This makes the process both expensive to operate and costly to build a chemical plant able to cope with the reaction conditions. Consequently, the investigation of the alkylsalicylic acids centred on the identification and development of an alternative synthetic route.

The work involving the sulfurised phenates was aimed at investigating the sulfurisation step in the formation of the sulfurised phenate overbased detergents. The major concern here was to try and ascertain the composition and distribution of products formed when alkylphenols are sulfurised. To achieve this, the synthesis and characterisation of simple sulfurised phenate compounds was attempted.

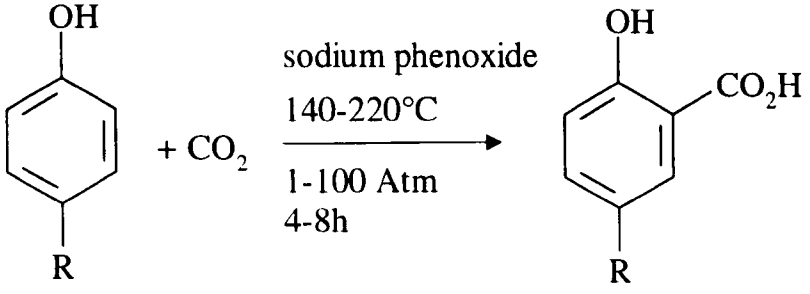
Chapter 2

The Alkylation of Salicylic Acid

2. Introduction.

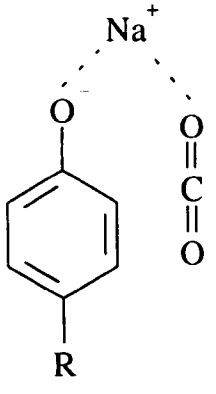
As noted in the previous chapter, alkylsalicylic acids find widespread use as additives in lubricating oils whilst the smaller alkylsalicylic acids, such as 5-t-butylsalicylic acid and 3,5-di-t-butylsalicylic acid, can be used as anti-oxidants in the food industry. The current approach to the synthesis of these acids is via the Kolbe-Schmitt route. This involves the use of high temperatures and pressures to carboxylate alkylphenols, as illustrated in Scheme 2.1.

Scheme 2.1



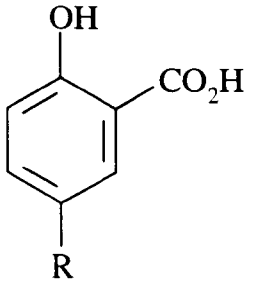
It is suggested that the formation of a complex between the reactants makes the carbon of the carbon dioxide more positive and places it in a good position to attack the ring, as illustrated in Scheme 2.2.

Scheme 2.2



The Kolbe-Schmitt route suffers from a number of potential drawbacks. Firstly, pure p-alkylphenols are expensive (when R is large) since alkylation of phenol invariably produces a mixture of ortho and para isomers separation of which is difficult. If the mixed alkylphenols are used without separation on carboxylation both the 5-alkyl-4-hydroxy benzoic acid (**5**) and the 5-alkyl-2-hydroxy benzoic acid (**6**) will be obtained. The work

contained in chapter 6 confirms the presence of both 5-alkyl-4-hydroxy benzoic acid and the 5-alkyl-2-hydroxy benzoic acid in a sample of industrially relevant alkylsalicylic acids.



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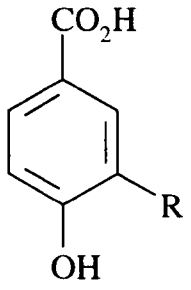

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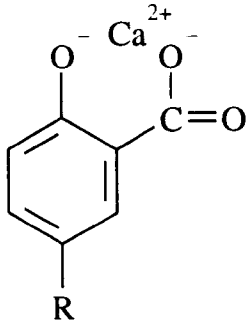
Having the alkyl group ortho rather than para to the hydroxyl group on the aromatic ring possibly reduces the effectiveness of the final additive in preventing engine wear or black paint deposition. Only the 5-alkyl-2-hydroxybenzoic acid can complex a metal salt between both the hydroxyl and carboxylic acid groups (**7**).



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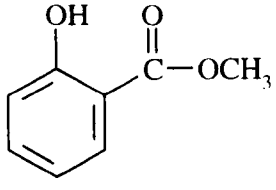
The other major problem associated with the Kolbe-Schmitt route is the use of high temperatures and pressures. This is both expensive in terms of running costs and in the equipment required to cope with the severe conditions. A synthesis of alkylsalicylic acids which uses much milder conditions has obvious advantages. As a result recent interest has been shown in developing new routes to alkylsalicylic acids[58,59,60]. In particular, studies have been carried out into the potential alkylation of salicylic acid and methyl salicylate, using a variety of substrates and catalysts. The initial route chosen for the alkylation of sulfuric acid was one based on an Elf patent which describes the alkylation of salicylic acid using tertiary ethers, primarily tertiary methyl ethers, and using concentrated sulfuric acid as the catalyst.

2.1. Synthesis of 5-t-Butyl Salicylic Acid.

Following the work outlined in the Elf patent, the simplest tertiary ether, t-butyl methyl ether, was initially used to alkylate salicylic acid. The reaction was carried out at 60°C in 80% H_2SO_4 (by volume). After three hours the reaction was stopped by the addition of water, which precipitated a creamy/white powder. If this precipitate was entirely 5-t-butylsalicylic acid the conversion obtained would correspond to 70%.

Analysis of the methylated product mixture[b] by Gas Chromatography (GC) showed the presence of three species, which were identified from their mass spectra as methyl salicylate (**8**), methyl 5-t-butylsalicylate (**9**) and methyl 3,5-di-t-butylsalicylate (**10**). Based on uncalibrated GC peak areas the methyl 5-t-butylsalicylate accounted for 96% of the mixture, whilst the remaining 4% was split equally between the salicylic acid and the 3,5-di-t-butylsalicylic acid. The presence of methyl salicylate was confirmed by comparing the retention time of an authentic sample of methyl salicylate. The ^1H nmr of the product mixture before methylation confirmed that the 5-t-butyl and not the 3-t-butyl salicylic acid was the major product.

5-t-butyl salicylic acid δ_H (270MHz ; CDCl3) 7.92(d, J=2.5Hz, 1H, ArH ortho to acid), 7.58(1H, dd, J=2.5 and 8.7Hz, 1H, ArH para to acid), 6.94(d, J=7.7Hz, 1H, ArH meta to acid), 1.32(9H, s).



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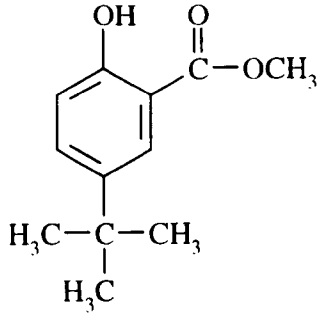

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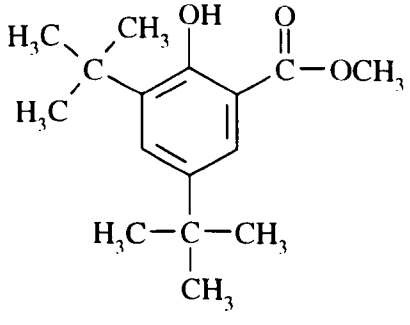

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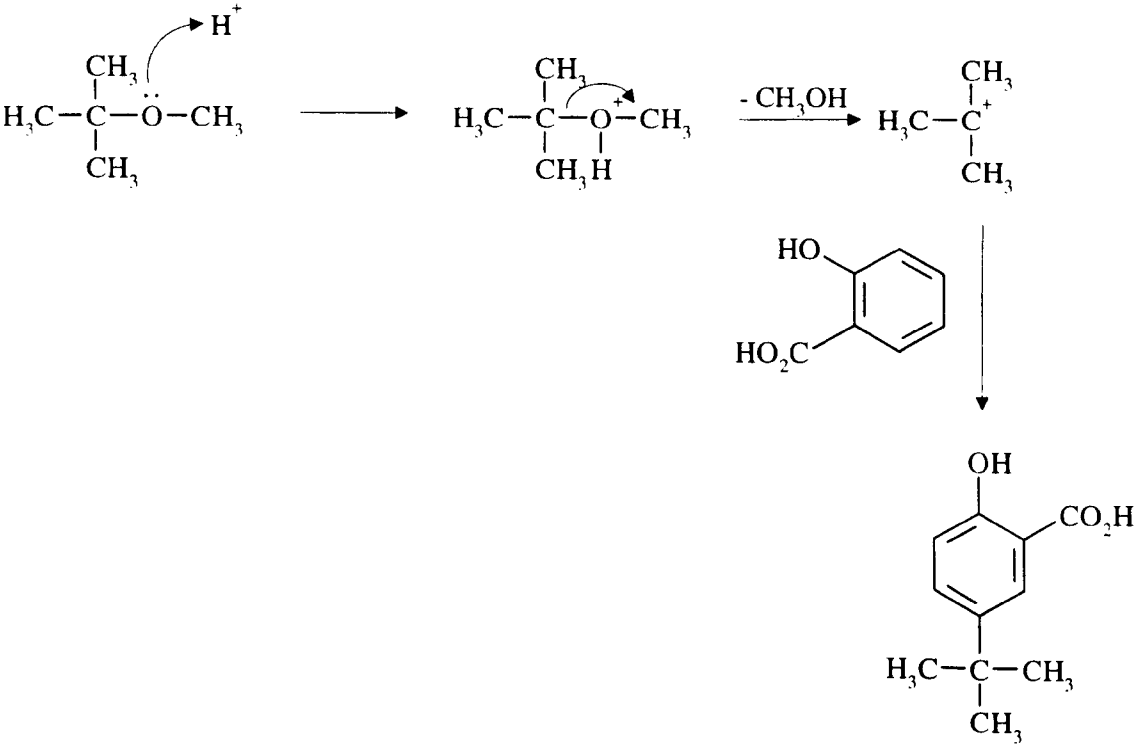
The most obvious mechanism for the formation of the 5-t-butylsalicylic acid, is illustrated in Scheme 2.3, involving the protonation of the ether and the subsequent loss of methanol to give the t-butyl carbocation. This carbocation then attacks the aromatic ring to give the 5-t-butylsalicylic acid. Reaction at the 3-position will be disfavoured because of

[b] See Section 2.4 for the method of methylation of the reaction products.

the steric hindrance between the t-butyl carbocation and the hydroxyl group. The possibility of the carbocation attacking the hydroxyl group or the carboxylate group to form the ether and ester, respectively, of salicylic acid will be discussed in more detail in Chapter 5.

Scheme 2.3



Given the limited range of ethers available commercially, an ether is not the most attractive reagent. Alcohols would be more accessible reagents and might be expected to behave in a similar manner. However, using the alcohol instead of the methyl ether results in the loss of water rather than methanol. The formation of water in the reaction will dilute the acid catalyst concentration by about 4%. Reuse of the catalyst might now become problematical as the yield from the alklation using the lower acid concentration would drop quite rapidly. The effect of varying the acid concentration will be discussed in more detail in Chapter 4.

The alkylation of salicylic acid using t-butanol instead of the t-butyl methyl ether was successfully achieved but in slightly lower accountabilities (65%) and in a lower purity (90%). Contained in Table 2.1 are the percentage yields and purities of the alkylation reactions using t-butyl methyl ether, t-butanol and n-butyl methyl ether[c]. A similar mechanism for the alkylation would obviously apply as is shown in Scheme 2.4.

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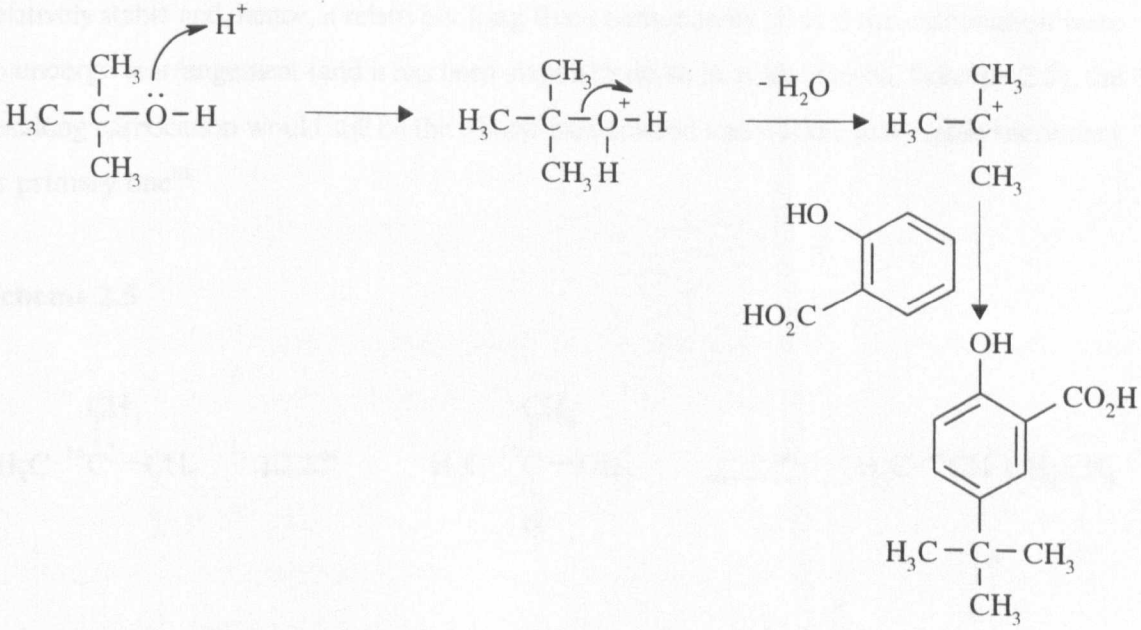
[c] See Section 2.2 for the full details concerning the alkylation using n-butyl methyl ether.

Scheme 2.4



Another alternative to an ether as a source of a carbocation is an alkene. The logical choice to produce a t-butyl carbocation from an alkene, would be to use iso-butene. However, the reaction between iso-butene and salicylic acid was not carried out because of the difficulties of handling a gas in a qualitative manner. The reactions between salicylic acid and longer chain alkenes will be discussed in the next chapter.

Table 2.1. The accountabilty and the purity of the products when salicylic acid is alkylated with t-butyl methyl ether, t-butanol and n-butyl methyl ether

Alkylating Agent	Accountability %[d]	Purity %[e]	Overall yield[f]
t-butyl methyl ether	70%	96%	67%
t-butanol	65%	90%	59%
n-butyl methyl ether	75%	0, salicylic acid recovered	0%

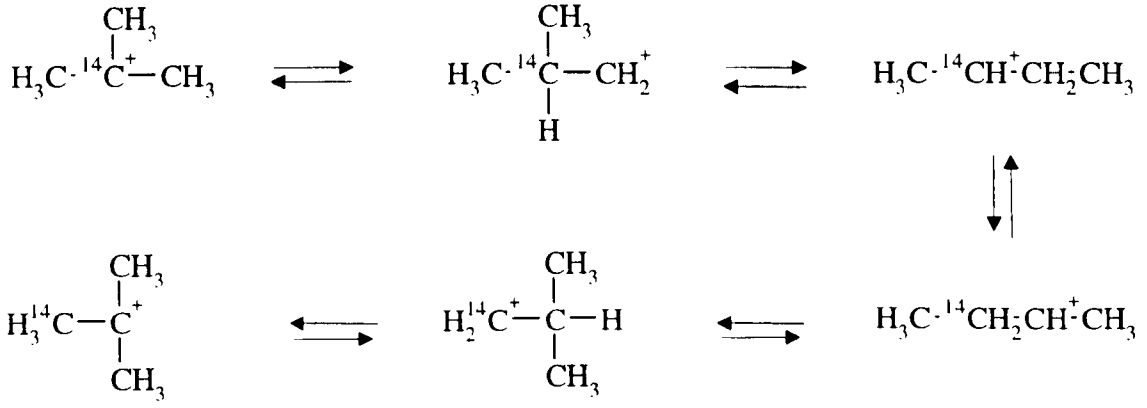
[d] The accountability is calculated by dividing the mass of product obtained by the theoretical yield of the mono alkylated salicylic acid

[e] The purity of the product is calculated on the percentage of 5-alkylsalicylic acid in the product mixture, based on uncalibrated GC peak areas

[f] The overall yield of the 5-alkylsalicylic acid calculated by multiplying the yield by purity.

There are a number of advantages in forming the t-butyl carbocation. It is a relatively stable and, hence, a relatively long lived carbocation. But if the carbocation were to undergo rearrangement (and it has been shown to do so in acidic media, Scheme 2.5), the resulting carbocation would still be the t-butyl carbocation and not the less stable secondary or primary one[61].

Scheme 2.5



2.2. Synthesis of 5-n-Butyl Salicylic Acid.

Since tertiary ethers are not as readily available as primary ethers, alkylating salicylic acid with a primary ether would have advantages. The synthesis of 5-n-butyl salicylic acid was attempted using n-butyl methyl ether in the presence of 80% sulfuric acid at 60°C for three hours. Unfortunately, after working up the reaction only salicylic acid could be detected (as the methyl ester) by GC. However, there was not complete recovery of the salicylic acid, so a side reaction must be taking place. An explanation for the lack of reaction of the n-butyl methyl ether lies in the instability of the carbocation that would be formed on protonation of the ether. On protonation of the n-butyl methyl ether, it is unlikely that it would be energetically favourable to lose methanol and thus form the n-butyl carbocation. This compares with the more energetically favourable reaction, involving a lower activation energy, of losing methanol to form the t-butylcarbocation when the tertiary ether is used.

As reported by Streitwieser et al. when n-alkyl ethers or alcohols are used to alkylate aromatic rings, the major products are the secondary alkylaromatics with either no primary

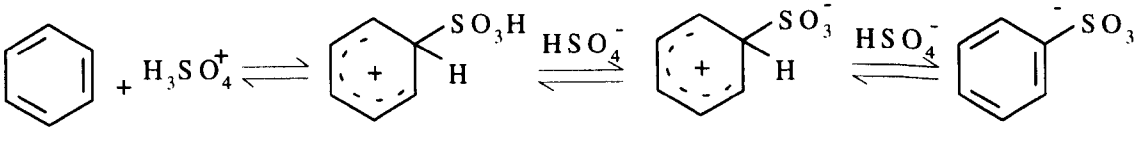
As reported by Streitwieser et al. when n-alkyl ethers or alcohols are used to alkylate aromatic rings, the major products are the secondary alkylaromatics with either no primary alkylaromatics or only traces of them in the product mixture[62]. If alkylation is to occur with the n-alkyl ethers or alcohols, more forcing conditions are generally required than when secondary or tertiary ethers and alcohols are used[63]. The effect of using more forcing conditions, such as higher temperatures and/ or increased catalyst strength will be discussed in a later chapter.

Another factor involved in the alkylation with n-alkyl ethers and alcohols is the size of the alkyl group, the larger the alkyl group the easier alkylation is to achieve and the higher the yields in other systems[64,65]. To confirm if this general rule applies to the alkylation of salicylic acid, salicylic acid was alkylated with longer chain primary alcohols and the results from those reactions, along with those from related ethers and alkenes will be discussed in the following chapter.

2.3. Side Reactions in the Alkylation of Salicylic Acid.

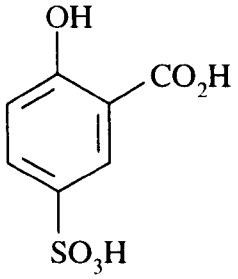
When salicylic acid is alkylated with sulfuric acid as the catalyst a large proportion of the starting material, especially the salicylic acid, is unaccounted for. Since sulfonation of aromatic rings by sulfuric acid is well documented[66] it is possible that a postulated by-product is the 5-sulfosalicylic acid (Scheme 2.6). As the usual work up of the alkylation reaction is the addition of water, the 5-sulfosalicylic acid would not be observed because it is very hydrophilic.

Scheme 2.6.



To ascertain if sulfosalicylic acid was formed as a by-product in the reaction, salicylic acid was heated at 60°C for three hours in the presence of 80% sulfuric acid. Extraction of the very hydrophilic sulfosalicylic acid from the sulfuric acid required the formation of the sodium salt. The synthesis of the sodium salt was achieved by adding sodium chloride to the hot aqueous product mixture, and the hot product mixture was then filtered, with the

preparation of the sodium salt, it was converted back to the acid and analysed by nuclear magnetic resonance spectroscopy (nmr). The nmr spectra was compared with that of an authentic sample of 5-sulfosalicylic acid and appeared to be identical.



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The effect of acid concentration and reaction temperature has shown to be critical to the sulfonation of salicylic acid and will be discussed in Chapter 4. When p-xylene was sulfonated using sulfuric acid, Kaandorp et al.[67] found that increasing the reaction temperature from 5°C to 35°C produced in excess of a fifty fold increase in the rate of sulfonation. On increasing the acid concentration from 72% to 89% about a fifty thousand fold increase in the rate of sulfonation was observed. The effect of acid concentration employed when salicylic acid is alkylated will be discussed in more detail in a later chapter.

2.4. Analysis of the Alkylsalicylic Acids.

The analysis of the alkylsalicylic acids was performed by gas chromatography (GC), gas chromatography/mass spectrometry (GC/MS) and by ^{1}H and ^{13}C nuclear magnetic resonance. To allow GC and GC/MS analysis to be performed on the alkylsalicylic acid required the conversion of the carboxylic acid to the ester. Converting the acid to the ester would lower the volatility of the alkylsalicylic acids, enhancing their ease of elution from the GC column. This was especially important with the longer alkyl chain salicylic acids. GC analysis was performed using an Econocap SE-30 capillary column.

A number of methods can be used to convert the acid to the ester[68,69]. Two of the most common ways are the refluxing of the alkylsalicylic acid in methanol in the presence of concentrated sulfuric acid[70] and reacting the alkylsalicylic acid with diazomethane[71,72]. Using diazomethane to methylate the alkylsalicylic acids has a number of advantages over other routes. These advantages include the ability to rapidly carry out the reaction at room

Using diazomethane to methylate the alkylsalicylic acids has a number of advantages over other routes. These advantages include the ability to rapidly carry out the reaction at room temperature on a large number of samples in 100% yield.

Experiments were undertaken to confirm that when the salicylic acid was methylated, the methyl ester was the only product formed, and that the methyl-(2-methoxy) benzoate was not formed as well. To samples of salicylic acid and methyl salicylate in dichloromethane was added an excess of diazomethane. The samples were shaken to complete any possible reaction and the products were anlaysed by GC. In both cases, the only product observed was methylsalicylate. A sample of 2-methoxybenzoic acid when reacted with diazomethane did give the methyl-(2-methoxy) benzoate.

Chapter 3

The Alkylation of Salicylic Acid Using Higher Molecular Weight Alkylating Substrates

3. Introduction.

The work described in Chapter 2 demonstrated that the alkylation of salicylic acid can be accomplished in high yields and purities when simple alkylating agents, such as t-butyl methyl ether, are employed. However, oil additives require an alkyl chain of at least eight carbon atoms to facilitate oil solubility. In order to establish whether the alkylation of salicylic acid is a general phenomenon the study was extended to longer alkyl chain ethers and alcohols. The use of alkenes as alkylating agents will also be discussed since the longer alkenes are liquids, and will be easier to handle than gases (e.g. isobutene). For industrial processes alkenes are likely to be more attractive because of their low cost and ready availability. There is one difference between alkenes and the ethers and alcohols, in that only secondary and tertiary carbocations can be formed initially from alkenes, whereas the production of primary carbocations is confined solely to appropriate ethers or alcohols (with the obvious exception of ethene). This chapter is divided into sections describing the alkylation of salicylic acid using the three categories of alkylating agents, namely ethers, alcohols and alkenes. The sections covering the alcohols and alkenes are subdivided further into tertiary alkylating agents and secondary agents (and in the case of the alcohols, primary alkylating agents as well). The effect of varying the reaction conditions will be discussed in Chapter 4.

Analysis of the products was performed by GC and GC/MS, after the products had first been methylated by reaction with diazomethane. The products were identified from their fragmentation patterns on mass spectrometry and by comparing retention times with those of authentic samples if these were available. In some cases ^{1}H and ^{13}C nmr spectroscopy were also employed.

3.1. Alkylation Using Long Chain Ethers.

In an attempt to see whether the excellent results obtained with the t-butyl methyl ether system could be replicated using more complex ethers, reactions were carried out using longer chain tertiary alkyl methyl ethers. A C_{12} chain tertiary ether was chosen because of the industrial importance of an alkylsalicylic acid containing a chain of this length. Long chain tertiary alkyl methyl ethers are not readily available, and so 2-methoxy-

2-methylundecane was synthesised from 2-methyl-1-undecene using mercury (II) acetate[73], followed by treatment of the adduct with borohydride.

The synthesis of the tertiary ether produced an interesting result. As well as the expected 2-methoxy-2-methylundecane (84%) there was present, beside unreacted 2-methyl-1-undecene (5%), the primary ether 1-methoxy-2-methylundecane (11%) [the figures in brackets correspond to the percentage of each compound in the product mixture based on GC areas]. Oxymercuration of monosubstituted alkenes is thought to be regioselective, with the intermediate undergoing nucleophilic attack at the most substituted carbon. This is perhaps surprising since the bromonium ion produced in the electrophilic bromination reaction is attacked relatively unselectively at both carbons. It seems the same problem can arise in mercury (II) additions.

Due to the difficulty in separating the two ethers, the mixture containing the 2-methoxy-2-methylundecane and the 1-methoxy-2-methylundecane was reacted with salicylic acid under the standard alkylating conditions of 80% sulfuric acid at 60°C for three hours. [In order to conserve the starting material the reaction was carried out on a smaller scale employing 0.01 moles of alkylating agent and salicylic acid]. However, on addition of water no precipitate was formed, as was the case with the t-butyl methyl ether. Instead what appeared to be an immiscible organic layer was formed. This organic layer was removed by extraction with diethyl ether and 1.28g of product was recovered.

The product mixture was analysed, after methylation, by both GC and GC/MS . A much wider range of products was observed than had been noted in previous cases, as can be seen from the gas chromatographic trace in Figure 3.1. The seven major products were identified by the comparison of retention times and mass spectra with authentic samples if they were available. In other instances they were identified solely from their mass spectra. The products are believed to be;

Peak 1: methyl salicylate (**8**) (from unreacted starting material); 15%[a] (13% by mass)[b]

Peak 2: methyl 5-t-butyl salicylate (**9**); <1% (0.5% by mass)

Peak 3: An unidentified product; 11%

---

[a] The value corresponds to the percentage of the compound in the product mixture, based on uncalibrated GC areas.

[b] The value in brackets takes into account the response factor of the GC towards different compounds. A full explanation on the use of correction factors in GC calibration is given in section 3.5.

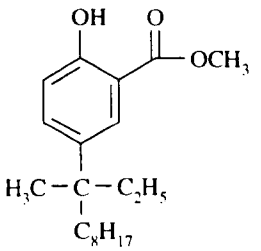
Peak 4: methyl 5-(1-methyl-1-ethylnonyl)salicylate (**12**); 3%

Peak 5: methyl 5-(1,1-dimethylnonyl)salicylate (**13**) (t-undecyl)[c]; 3%

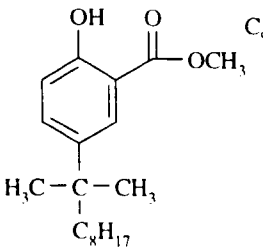
Peak 6: methyl 3-(1,1-dimethyldecyl)salicylate (**14**) (t-dodecyl); 5%

Peak 7: methyl 5-(1,1-dimethyldecyl)salicylate (**15**) (t-dodecyl); 55%

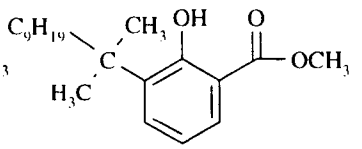
Structures 12-15



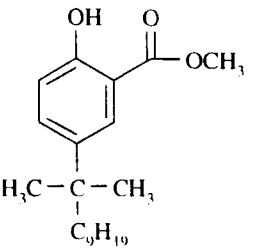
12



13

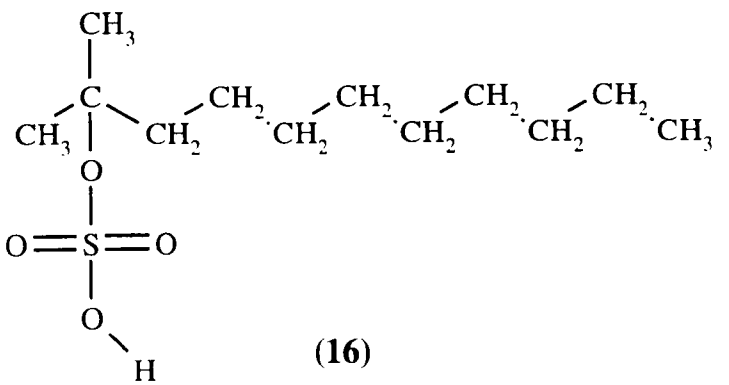


14



15

The unidentified product is suspected to be the dodecyl sulfate (**16**), though this does need confirming. In the presence of concentrated sulfuric acid the ether could be converted to either the alcohol or the alkene which could then be attacked further by the sulfuric acid to form the alkyl sulfate[74]: alternatively direct substitution might occur. The presence of the alkylsulfate esters will be discussed further in later sections.



(16)

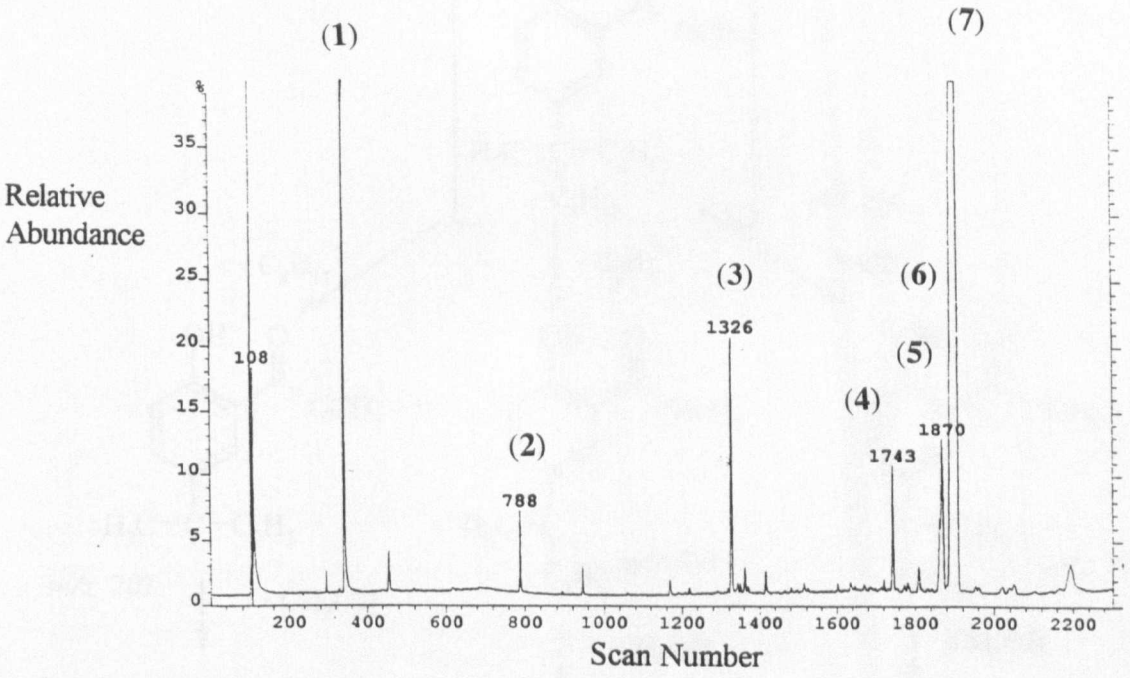
The crude product obtained in this way gave only a moderate (40%) accountability of the alkylsalicylic acid.

$$\text{Accountability} = \frac{\text{Actual Weight of Crude Product}}{\text{Theoretical Weight of Product}} \times 100\% \qquad \textbf{(3.1)}$$

[c] The t-undecylsalicylic acid was identified solely from its mass spectrum the C_9 chain might not have been a linear one as suggested. Further explanation of the assignment of structures is given in section 3.3.

This 40% accountability is much lower than the 70% accountability obtained when t-butyl methyl ether was employed as the alkylating agent. However, the formation of the major product (**15**), can be rationalised through the same mechanism as that suggested when t-butyl methyl ether was used as the substrate, i.e. protonation of the ether, loss of methanol to give a tertiary carbocation and electrophilic substitution of the aromatic ring. The origin of the extra products is discussed in a subsequent section (3.3).

Figure 3.1. The GC trace (obtained from a GC/MS run) of the products from the alkylation of salicylic acid by 2-methoxy-2-methylundecane.



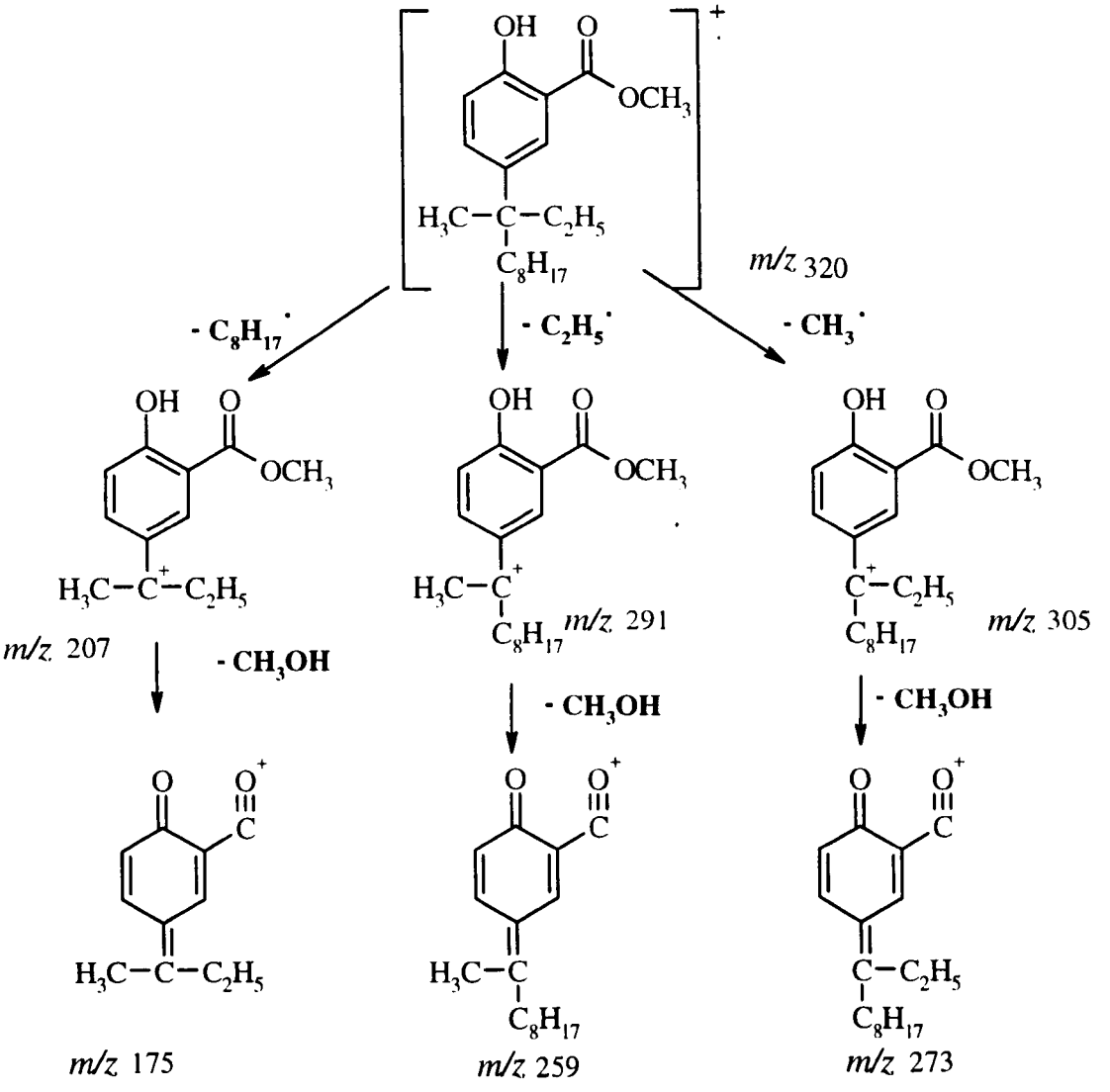
3.2. Identification of the Products by GC and GC/MS.

The identification of the products from the alkylation reactions is based, primarily, on the mass spectrum of each component. The methyl esters of alkylated salicylic acids could be identified largely on the basis of their fragmentation patterns. All show molecular ions and fragment typically by loss of an alkyl radical from the benzylic position of the alkyl side chain. The resultant even electron fragment decomposes further by loss of methanol indicating the ortho relationship of the methyl ester to the hydroxyl group. A minor fragmentation route from the molecular ion is loss of a methoxy radical followed by the loss

of CO, the typical fragmentation of methyl esters.

In instances where there is a choice of alkyl groups which can be lost from the benzylic site, e.g. for compound **12**, the larger group, giving the more stable radical, is the one preferentially lost, though in practice all possible routes are seen (Scheme 3.1). In the case of **12,** whose mass spectrum is shown in Figure 3.2, loss of an octyl species dominates. Less intense ions are seen corresponding to initial loss of an ethyl radical whilst ions due to loss of a methyl radical are very weak.

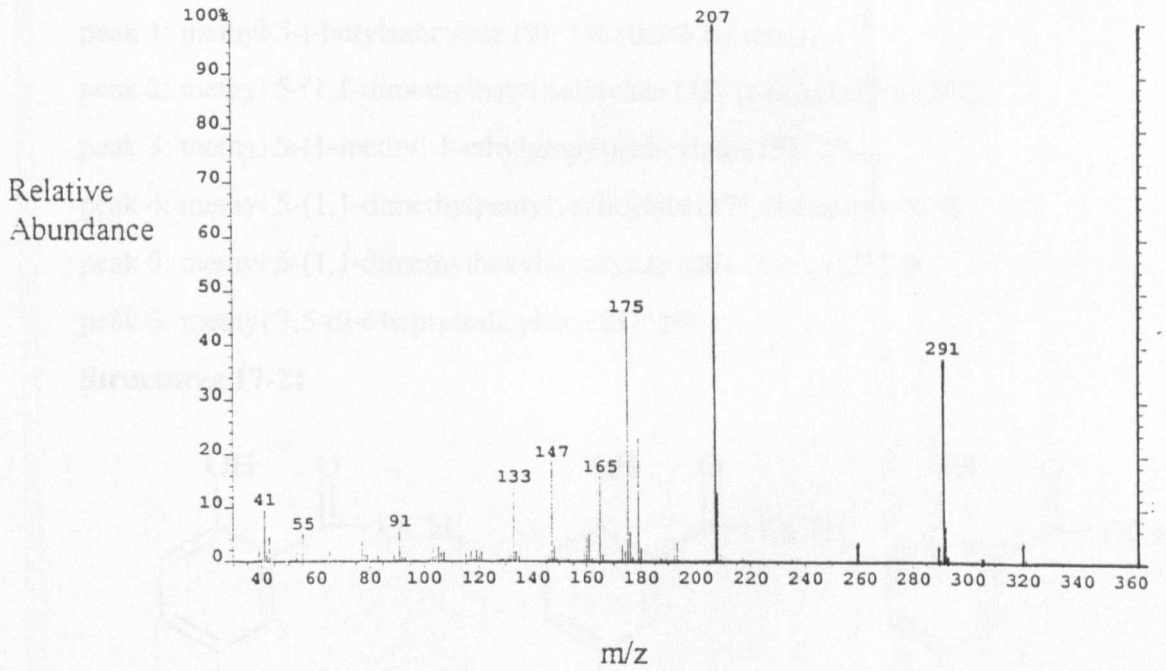
Scheme 3.1.



However, from the fragmentation pattern it is not possible to obtain information on whether the alkyl group lost initially is linear or branched. As a generalisation the alkyl chain is assumed to be linear if the alkylsalicylic acid formed is derived directly from the

initial alkylating agent.

Figure 3.2. The mass spectrum of methyl 5-(1-methyl-1-ethylnonyl)salicylate (**12**)



3.3. Alkylation Using Long Chain Alcohols.

Following the successful alkylation of salicylic acid using 2-methoxy-2-methylundecane, the logical step was to attempt the alkylation using a long alkyl chain alcohol, since in general, alcohols are more readily available than ethers. The section on the alkylation of salicylic acid is split in two: Firstly, alkylations using tertiary alcohols, such as 2-methyl-2-hexanol, are discussed. This is followed by a section on the use of primary and secondary alcohols such as 1- and 2-hexanol.

3.3.1 Alkylation Using Tertiary Alcohols.

3.3.1.1. 2-Methyl-2-hexanol.

A readily available tertiary alcohol, 2-methyl-2-hexanol was used to alkylate salicylic acid under the standard alkylating conditions (heating with 80% sulfuric acid, at 60°C, for three hours). On addition of water to the product mixture a purple precipitate was formed in reasonable accountability (68% based on the assumption that all the product should be

the C_7 alkylsalicylic acid). Analysis by GC and GC/MS following methylation revealed a number of compounds, as can be seen in Figure 3.3, each one of which was identified from its mass spectrum. The major product, peak 4, proved to be methyl 5-(1,1-dimethylpentyl) salicylate (**17**) (t-heptyl) which accounted for 80% of the product mixture. The remaining significant products appeared to be:

peak 1: methyl 5-t-butylsalicylate (**9**); 1% (0.5% by mass)

peak 2: methyl 5-(1,1-dimethylbutyl)salicylate (**18**) (t-hexyl); 3% (2%)

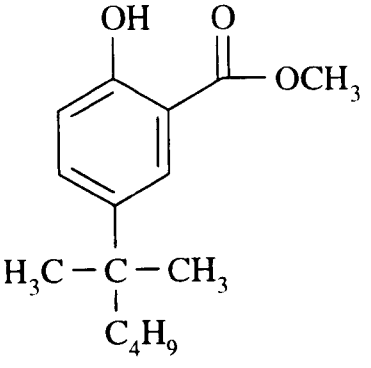
peak 3: methyl 5-(1-methyl-1-ethylpropyl)salicylate (**19**); 2%

peak 4: methyl 5-(1,1-dimethylpentyl) salicylate (**17**) (t-heptyl); 80%

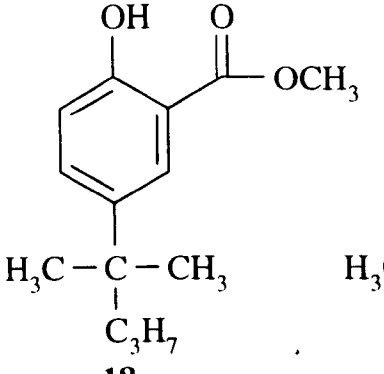
peak 5: methyl 5-(1,1-dimethylhexyl)salicylate (**20**) (t-octyl)[d]; 3%

peak 6: methyl 3,5-di-t-heptylsalicylate (**21**); 2%

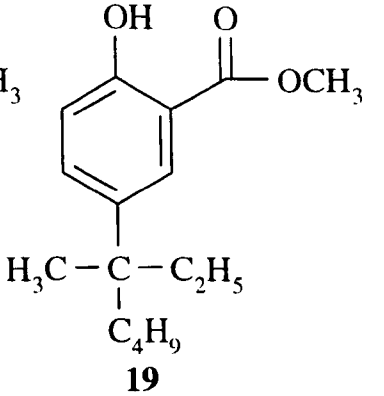
Structures 17-21



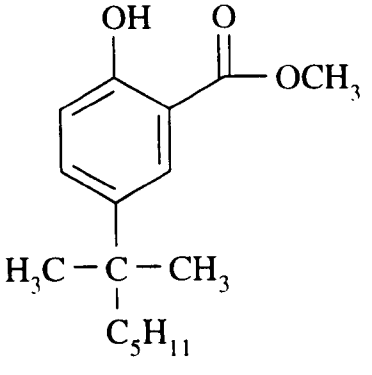
17



18



19



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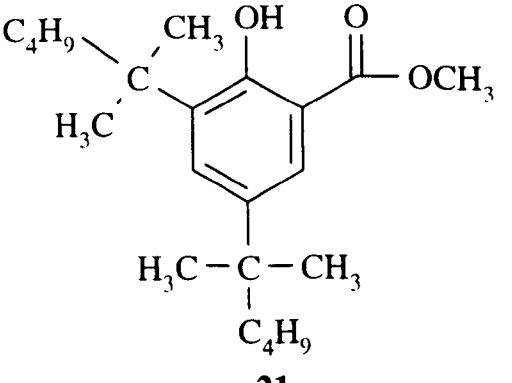
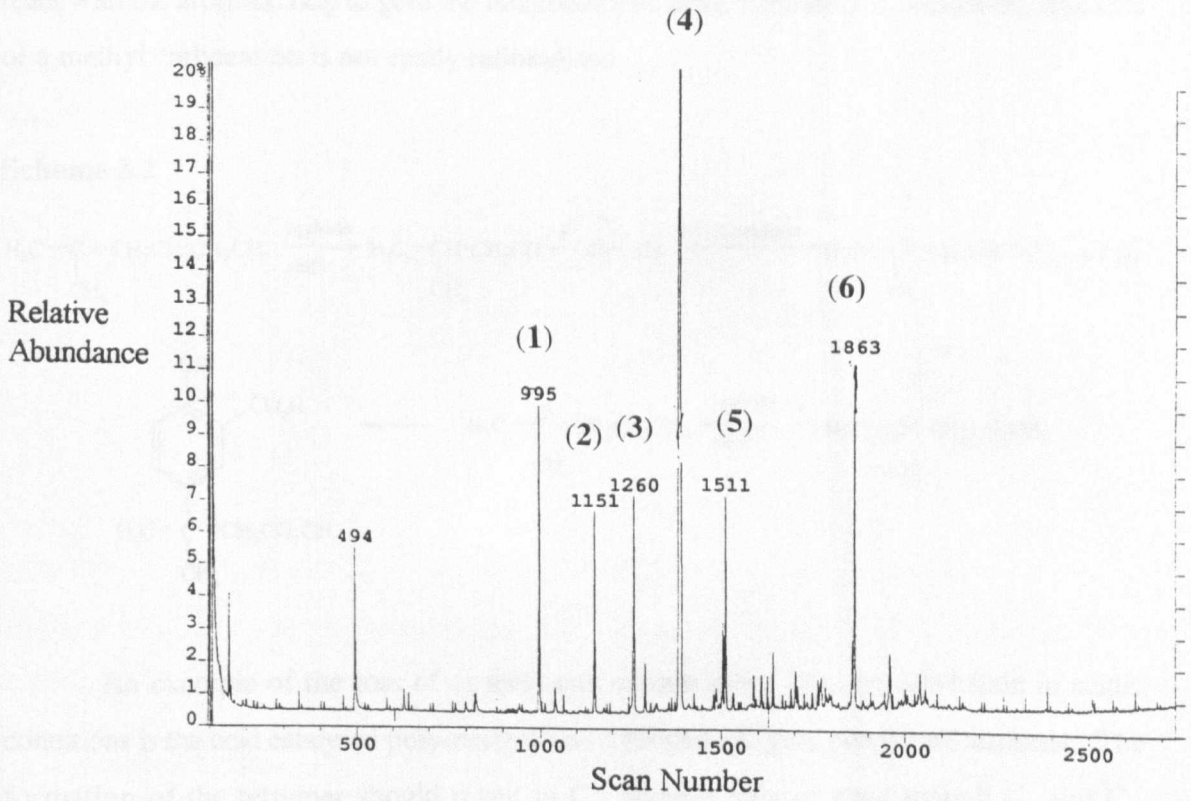


21

[d] The assignment of t-octyl group is speculative: It is likely that the chain is highly branched and not linear. This view is based on the assumed method of formation of the octylsalicylic acid.

Figure 3.3. The GC trace (obtained from a GC/MS run) of the product from the alkylation of salicylic acid by 2-methyl-2-hexanol, under standard conditions.

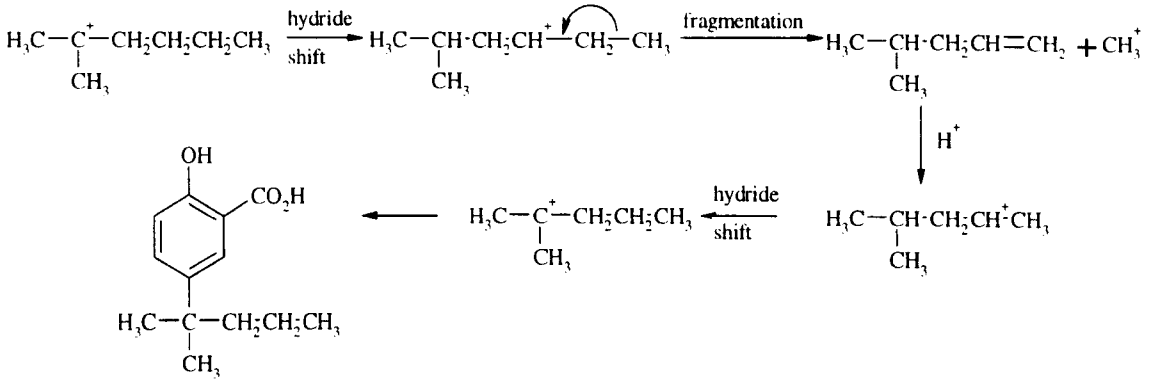


The formation of both the 5-t-heptyl and the 3,5-di-t-heptylsalicylic acids is to be expected since these two compounds are formed by the attack of the t-heptyl carbocation on the aromatic ring to give first one and then the other compound. The formation of the other alkylsalicylic acids containing a fewer or greater number of carbon atoms than the starting material cannot be rationalised as easily. Analysis of the starting material showed that impurities in it could not be responsible for these other compounds. Instead, to form these other compounds, the t-heptyl carbocation must undergo a series of reactions to give both shortened and lengthened alkyl chains. As was commented on in Chapter 1, once a carbocation is formed it can readily isomerize to give a wide range of carbocations. However, there is the entropic factor to consider in the isomerization of the carbocations in that going from the stable tertiary carbocation to the less stable secondary and primary carbocations is energetically disfavoured.

The carbocations also have the potential to fragment to give an alkene and a smaller carbocation. This alkene can either be protonated or attacked by another carbocation to give a carbocation of increased size. The most probable route to form the hexylsalicylic acid

from the initial t-heptyl carbocation would require the loss of a methyl carbocation to give the C_6 alkene, which would then be protonated to give a C_6 carbocation which will then react with the aromatic ring to give the hexylsalicylic acid, Scheme 3.2. However, this loss of a methyl carbocation is not easily rationalised.

Scheme 3.2



An example of the loss of at least one carbon atom from an alkylchain in acidic conditions is the acid catalysed polymerization of propene to give propylene tetramer. The formation of the tetramer should result in C_{12} alkenes only or even though C_9 and C_{15} alkenes might be expected to be impurities. Instead a number of C_{10} and C_{11} alkenes are formed as well. These smaller alkenes must be formed by the loss of one or two carbon atoms from the carbocation intermediates. In all cases the alkyl chains are highly branched. The propylene tetramer does not contain one double bond but consists of a mixture of alkenes, dienes and trienes.

To form the C_8 alkylsalicylic acid involves the addition of for example the methyl carbocation to the C_7 alkene to give a C_8 carbocation, with a branched chain. The C_8 carbocation can then attack the aromatic ring to give the octylsalicylic acid, Scheme 3.3.

All the other products from the alkylation reactions not involving simple isomerization can be formed from a carbocation undergoing one of three reactions; isomerization, fragmentation and combination with an alkene to give another carbocation. At any point the cycle can be broken when the carbocation attacks the aromatic ring. Figure 3.4 shows all these possible reactions that can give rise to the various products. It is therefore very likely that any of the unexpected products will not have long linear chains but they will be highly branched and will tend towards tertiary species.

Scheme 3.3.

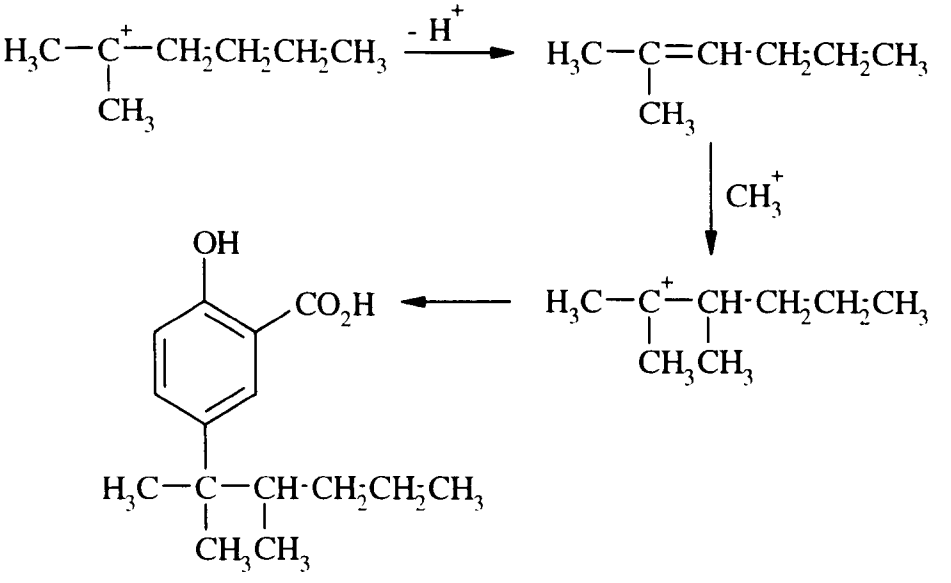
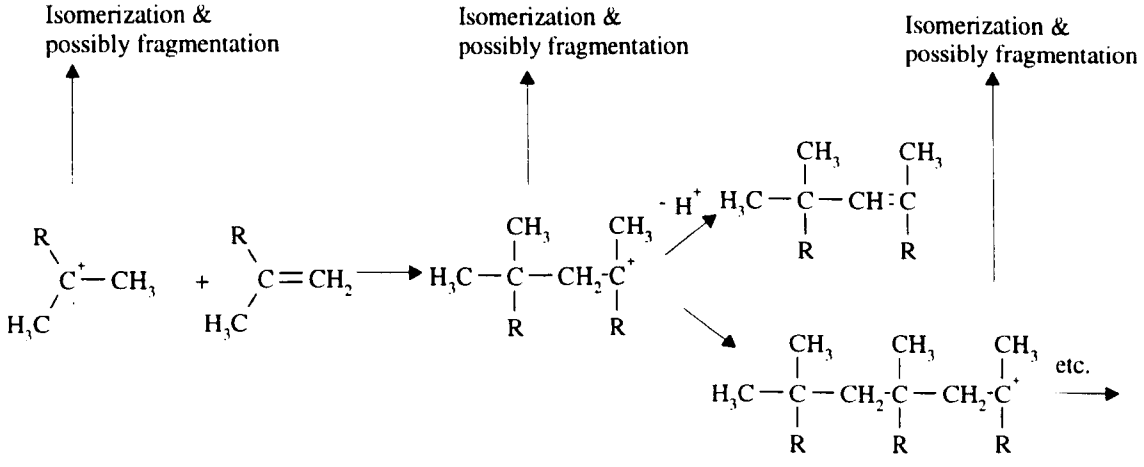


Figure 3.4. The various reactions that can take place when the initial carbocation has fragmented to give a smaller carbocation and an alkene.



3.3.1.2. 2-Methyl-2-undecanol.

A tertiary alcohol with a longer alkyl chain was not readily available and so 2-methyl-2-undecanol was synthesised from 2-methyl-1-undecene, using a very similar approach of that used to synthesis the 2-methoxy-2-methylundecane. Again an unexpected product, the primary alcohol 2-methyl-1-undecanol, was formed. In addition, the product was contaminated by a small amount of unreacted starting material which proved difficult to separate. This mixture containing 2-methyl-2-undecanol (93%), 2-methyl-1-undecanol (3%) and 2-methyl-1-undecene (3%) [the value in brackets corresponds to the percentage

of each compound in the product mixture, based on GC peak areas] was then used under the standard alkylation reaction conditions (again on a small scale) and produced, as expected, a similar product distribution to that obtained when the corresponding ether (2-methoxy-2-methylundecane) was employed. Analysis of the product mixture by GC/MS, showed that the major product was again the 5-t-dodecylsalicylic acid (**15**). A higher accountability was obtained with the alcohol (78%) compared to the corresponding ether (40%) but the purity of the 5-t-dodecylsalicylic acid obtained was lower with the alcohol than the ether (26% and 55% respectively). These values assume that all the products formed during the alkylation reaction are eluted through the GC and any high molecular weight, low volatility compounds are not formed. The other significant products observed were;

methyl salicylate (unreacted starting material) (**8**); (5%)

an unidentified product; (17%)

a number of higher alkenes ($C_{24}H_{48}$); (29% in total)

The unidentified product is again suspected, from what little information can be obtained from its mass spectrum, to be the dodecyl sulfate (**16**). This is based on the evidence of previous studies in which alkenes were reacted in the presence of concentrated sulfuric acid[75,76] to give the sulfate esters as the major products. In this case the alcohol can either be dehydrated by the sulfuric acid to form the alkene, which can then be attacked by the sulfuric acid to form, alternatively, the alkyl sulfate, or alternatively the alcohol might be converted directly to the alkyl sulfate ester.

For the first time there is evidence for the formation of higher alkenes. These are likely to be formed formed by a C_{12} alkene being attacked electrophilicly by a C_{12} carbocation and subsequent loss of a proton gives the higher alkene. The reason as to why the higher alkenes are not observed when smaller alkylating species are employed is thought to involve the miscibility of the alkylating agents in the concentrated sulfuric acid. The larger alkylating agents will be less miscible in the concentrated sulfuric acid than the smaller alkylating agents, so they will have less chance of reacting with the salicylic acid to produce the alkylsalicylic acids and more chance of reacting with alkenes to form the higher molecular weight alkenes .

3.3.1.3. Summary of the Results Using Tertiary Ethers and Alcohols

The accountabilities and purities of the products obtained when salicylic acid was

alkylated by tertiary ethers and alcohols are presented in Table 3.1. As can be seen from these results there is quite a marked difference in the accountabilities and purities when the corresponding large ethers and alcohols are used. However, the overall accountability for the two products is very similar, indicating that there is no real difference between using an ether or an alcohol. However, the reason for the differences in the individual accountabilities and the purities of products when the alcohol and ether are used are not clearly understood.

Table 3.1. The results from the alkylation reactions using hindered ethers and alcohols.

Alkylating Agent	Accountability %	Purity %	Overall Yield[e]
2-methoxy-2-methylundecane	40%	55%	22%
2-methyl-2-hexanol	68%	80%	54%
2-methyl-2-undecanol	78%	26%	20%

3.3.2. Alkylations Using Primary and Secondary Alcohols.

Further experiments into the alkylation of salicylic acid were carried out by replacing the tertiary alcohol with either a primary or a secondary alcohol. Primary and secondary carbocations would be expected to be formed on protonation of the primary and secondary alcohols and these would be expected to rearrange rapidly via simple 1,2-hydride shifts to give the complete range of secondary carbocations. Rearrangement is also likely to give the even more stable tertiary carbocations though alkyl migration would have to occur as well.

3.3.2.1. 1-, 2- and 3-Hexanols.

A study of the potential to introduce secondary or primary alkyl groups onto the salicylic acid ring was undertaken, with 1-,2- and 3-hexanols chosen as models. Alkylating salicylic acid under standard reaction conditions with 1-, 2- and 3-hexanol gave similar accountabilities of products from all three alcohols (60, 63 and 51% respectively). Analysis

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[e] The overall yield of the 5-alkylsalicylic acid calculated by multiplying the accountability by purity. Though this value is not the isolable yield it is a guide as to the potential recoverability.

by GC and GC/MS showed that the product distributions from the three reactions were also similar. The GC/MS trace of products derived from 3-hexanol can be taken as typical for both 3- and 2-hexanol, Figure 3.6. A slightly different product distribution is observed when 1-hexanol is used as the alkylating agent. If any difference was to be expected between the three alcohols then it would be expected between the 1-hexanol and the 2- and 3-hexanols, with the difference being due to the formation of a primary carbocation which would have an effect on the subsequent isomerizations and fragmentations giving rise to a different product distribution. Table 3.2 shows the distribution of the various hexylsalicylic acids when the three hexanols are used as the alkylating agents. A much wider range of products is obtained when 3-hexanol is used as the substrate instead of 2-methyl-2-hexanol. The products from the reaction were identified as;

peak 1: methyl salicylate (**8**); 4%

peak 2: methyl 5-t-butylsalicylate (**9**); 1%

peak 3: methyl 5-t-pentylsalicylate (**22**);1%

peak 4: methyl 5-t-hexylsalicylate (**18**); 13%

peak 5: methyl 5-(1-ethylbutyl)salicylate [3'-hexyl](**23**); 16%

peak 6: methyl 3-(1-ethylbutyl)salicylate [3'-hexyl[f]](**24**); 2%

peak 7: methyl 3-(1-methylpentyl)salicylate [2'-hexyl](**25**); 8%

peak 8: methyl 5-(1-methylpentyl)salicylate [2'-hexyl](**26**); 19%

peak 9: methyl 3,5-dihexylsalicylates (**27**); 34%

Table 3.2 The distribution of the various hexylsalicylic acids when 1-, 2- and 3-hexanol are used as alkylating agents.

	1-hexanol	2-hexanol	3-hexanol
methyl 5-(3'-hexyl)salicylate (**23**)	8%	17%	16%
methyl 5-(2'-hexyl)salicylate (**26**)	16%	19%	19%
methyl 5-t-hexylsalicylate (**18**)	14%	13%	13%
methyl 3-(3'-hexyl)salicylate (**24**)	6%	4%	2%
methyl 3-(2'-hexyl)salicylate (**25**)	0%	6%	8%

[f] The ' ' in the 3'-hexyl signifies that the 3 position on the hexyl chain is bonded to the aromatic ring and not the hexyl chain is bonded to the 3-position on the aromatic ring.

Structures 22-27

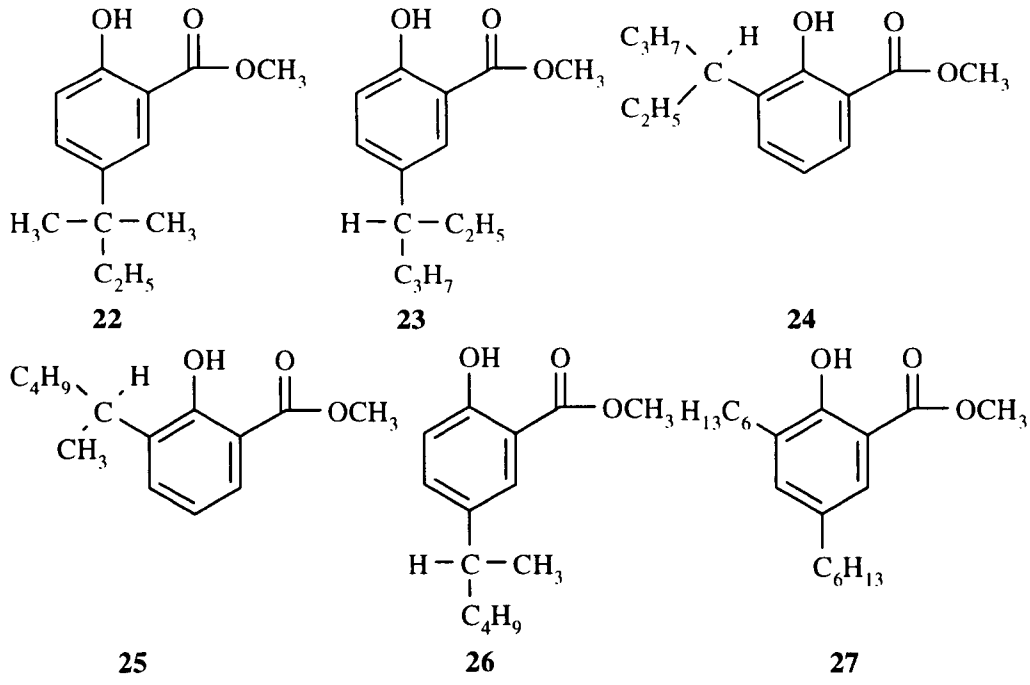


Figure 3.6 shows how the various hexyl isomers were identified from their mass spectral fragmentation pathways. None of the products from the alkylation reactions using the hexanols are unexpected, they can all be rationalised on the basis of the isomerization of the initial carbocation to give the 1-ethyl-1-butyl (3'-hexyl), 1-methyl-1-pentyl (2'-hexyl) and 1,1-dimethylbutyl (t-hexyl) cations. The isomerization of the initial carbocation to give the other carbocations is illustrated in Scheme 3.4. The three carbocations, t-, 2'- and 3'-hexyl, can then attack the ring to give the complete range of products shown.

Scheme 3.4.

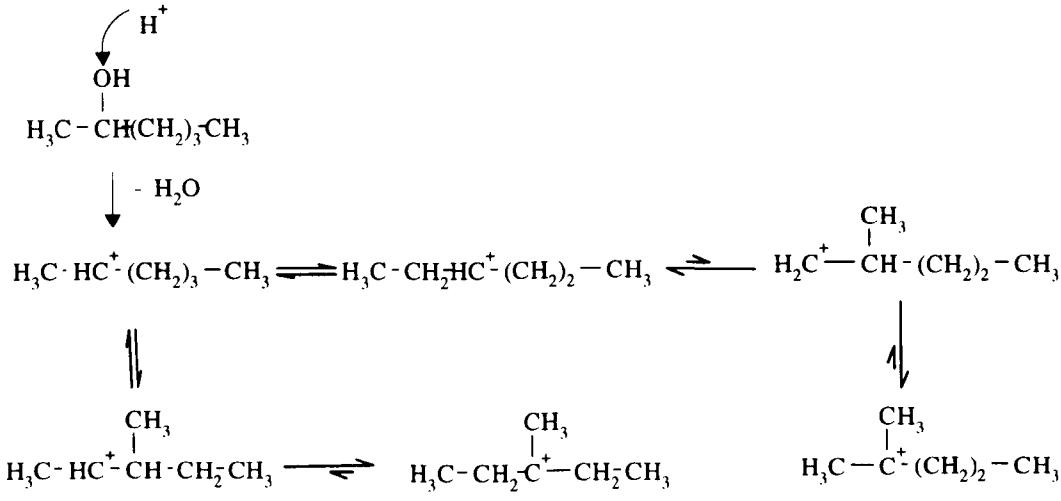
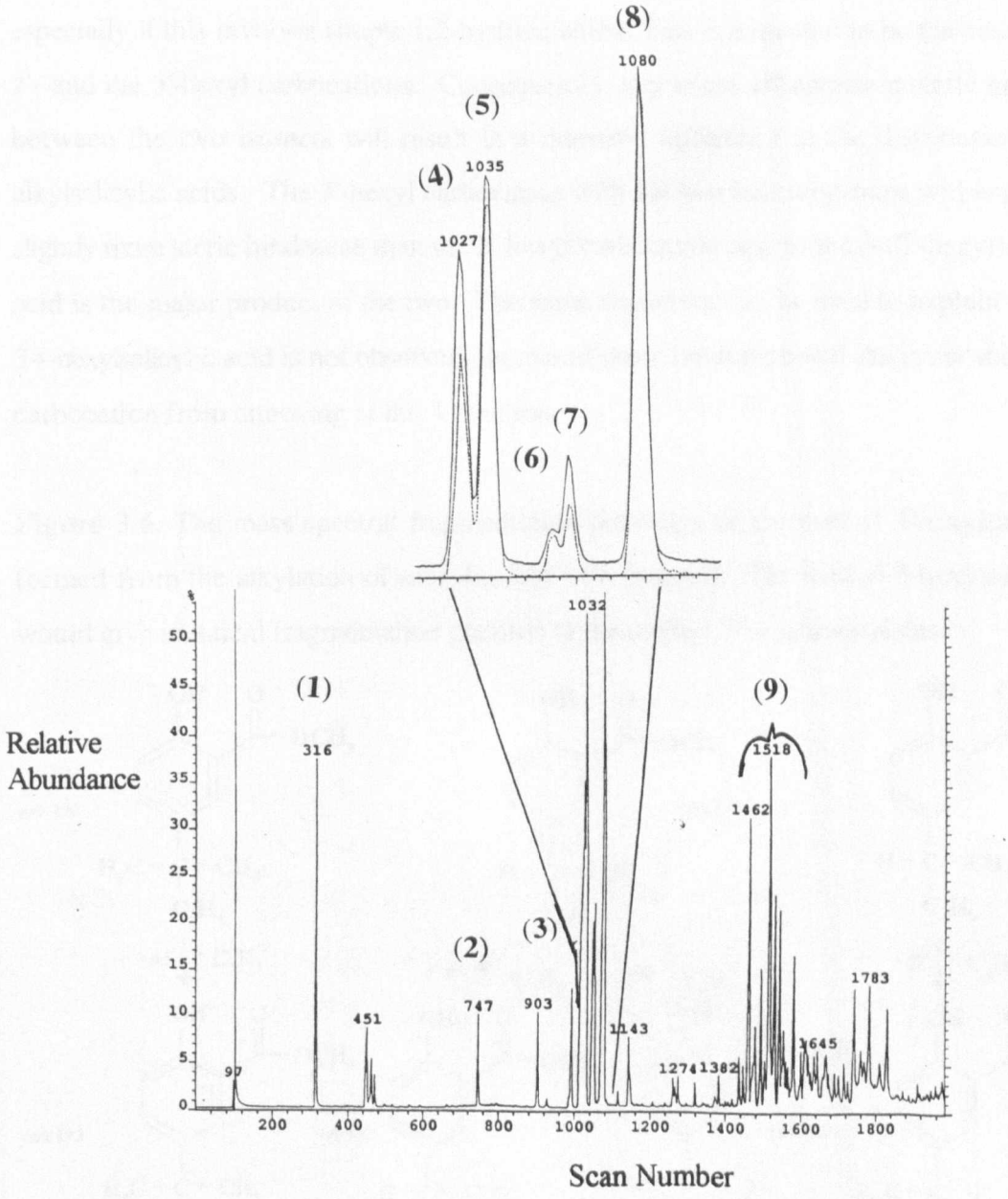


Figure 3.5. The GC trace (obtained from a GC/MS run) of the products from the alkylation of salicylic acid by 3-hexanol[g].

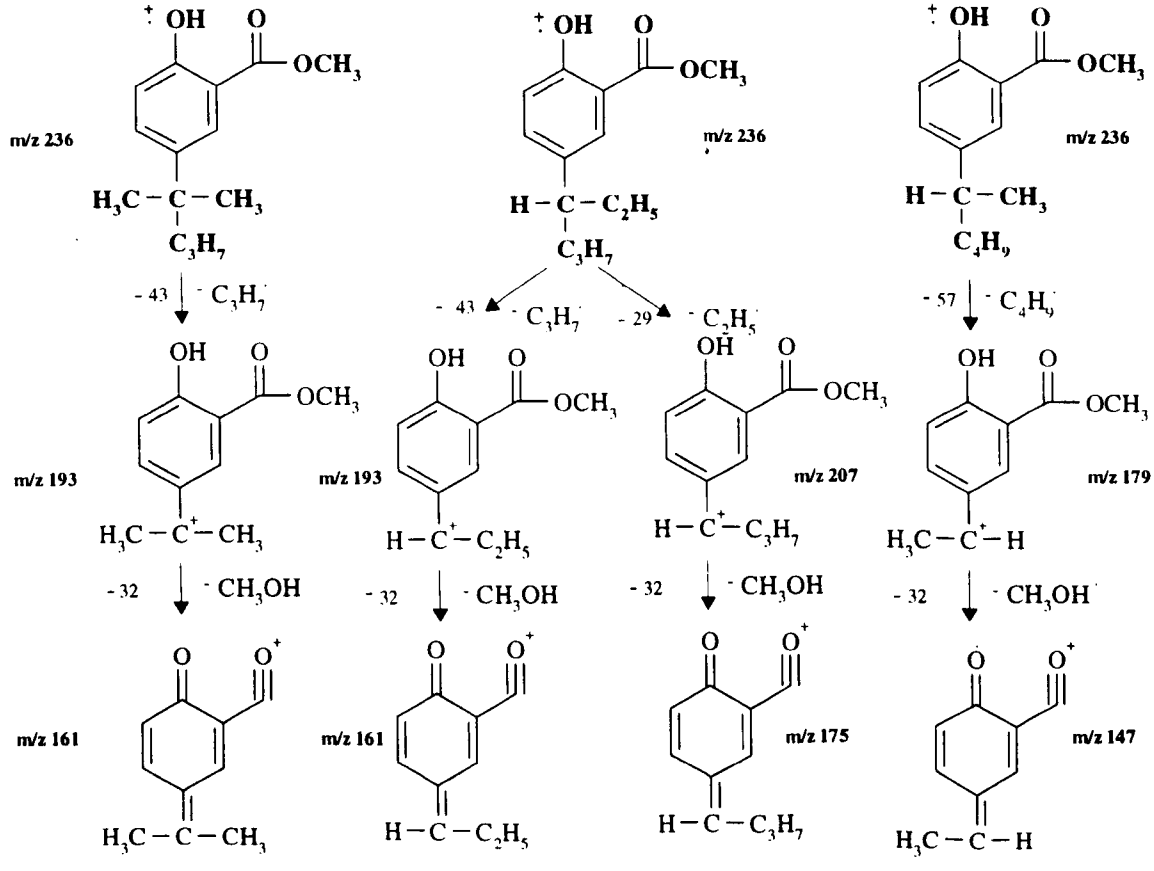


There is one unexpected discrepancy in the results. When comparing the distribution of the 2'- and 3'-hexylsalicylic acids it would be expected that the 2'- and the 3'-hexyl carbocations should show very similar reactivities. This is the case when attack is in the 5-position on the aromatic ring, with an approximate 1:1 distribution between the 2'- and the

[g] The GC traces presented in this thesis are taken from the mass spectrometer and are constructed from individual scans by the spectrometer, taken typically every second. Scan number refers to the number of the spectrum providing that point on the trace.

3'-hexylsalicylic acids being observed. However, when it comes to attack at the 3-position, a 1:1 distribution of the 2'- and the 3'-hexylsalicylic acids is not found. The reason for this involves the steric hindrance between the hexyl group and the hydroxyl group. Literature evidence already presented in this thesis shows that carbocations rapidly isomerize, especially if this involves simple 1,2-hydride shifts. This is expected to be the case for the 2'- and the 3'-hexyl carbocations. Consequently, any slight difference in steric hindrance between the two isomers will result in a dramatic difference in the distribution of the alkylsalicylic acids. The 3'-hexyl carbocation with the two bulkier groups will experience slightly more steric hindrance than the 2'-hexyl carbocation and so the 3-(2'-hexyl)salicylic acid is the major product of the two. The same reasoning can be used to explain why the 3-t-hexylsalicylic acid is not observed, increased steric hindrance will disfavour the t-hexyl carbocation from attacking at the 3-position.

Figure 3.6. The mass spectral fragmentation pathways of the methyl 5-hexylsalicylates formed from the alkylation of salicylic acid with hexanol. The methyl 3-hexylsalicylates would give identical fragmentation patterns to the methyl 5-hexylsalicylates.



There is no evidence for any primary alkyl groups attached to the salicylic acid in the product mixture, only secondary and tertiary alkylsalicylic acids are found. Any primary carbocations that are formed must isomerize rapidly to the more stable secondary and tertiary species.

The GC/MS analysis shows that there are a number of 3,5-dihexylsalicylic acids but there is insufficient evidence for the presence of all nine of the dihexylsalicylic acids that could have been formed from the combination of the t-,2'- and 3'-hexyl carbocations. However, it will not be surprising that at least two of the 3,5-dihexylsalicylic acid will be eluted from the GC at the same time so the formation of all nine 3,5-dihexylsalicylic acids cannot be dismissed immediately. One of the problems in assigning structures to the 3,5-dihexylsalicylic acids is the fact that only one substituent can be accurately identified from the mass spectrum. Once the first alkyl group has fragmented in the mass spectrometer, subsequent fragmentation has to involve the loss of a neutral molecule (e.g. methanol) and so information on the other alkyl substituent cannot be ascertained. However, based on the results from the monoalkylated salicylic acids, it is unlikely that the three dihexylsalicylic acids will contain the 3-t-hexyl-5-hexylsalicylic acids because of the fact that 3-t-hexylsalicylic acid was not observed.

3.3.2.2. 2-Octanol.

Repeating the alkylation reaction using 2-octanol as the substrate under the same conditions again gave the complete range of secondary octylsalicylic acids as well as substantial amounts of the tertiary octylsalicylic acid and dialkylated products. The significant species, identified by GC/MS, present in the product mixture are:

methyl salicylate (**8**); 55%

methyl 5-t-butylsalicylate (**9**); 3%

methyl 5-(1-methylheptyl)salicylate [2'-octyl](**28**); 5%

methyl 5-(1-ethylhexyl)salicylate [3'-octyl](**29**); 5%

methyl 5-(-1-propylpentyl)salicylate [4'-octyl](**30**); 5%

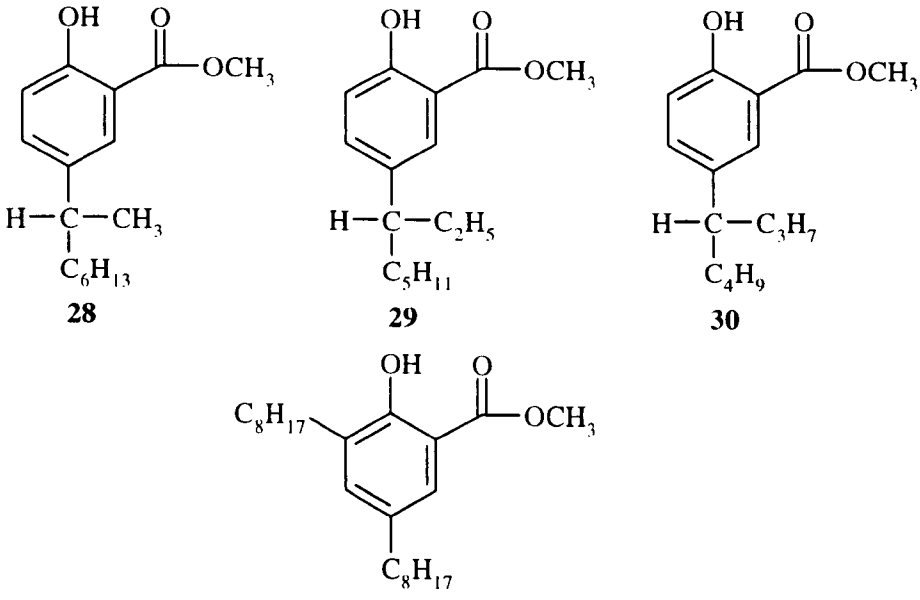
methyl 5-t-octylsalicylate (**20**); 6%

methyl 3,5-dioctylsalicylate (**31**); 10%

3-octyl-2-hydroxy-5-methoxysulfonyl-benzoic acid methyl ester (**32**); 2%

5-octyl-2-methoxy-3-methoxysulfonyl-benzoic acid methyl ester (**33**); 1%

Structures 28-31



Again all the products can be rationalised on the basis of the isomerization of the initial carbocation giving the complete range of secondary carbocations and some tertiary ones. However the accountability (40%) and the purity (21%[h]) of the octylsalicylic acids are substantially lower than when hexanol is used as the alkylating agent. Also, a very high proportion of starting material (55%) remains. As was the case when hexanol was used as the alkylating agent, the 3,5-dialkylsalicylic acids consisted of a number of isomers, consistent with the combination of all the monoalkylated isomers. In the case of octanol these were the 2'-,3'-, 4'- and t-octylsalicylic acids.

For the first time there was now evidence for the existence, based only on their mass spectra, of small amounts of two methylated alkyl-sulfo-salicylic acid products. It is suggested that these are the 3-octyl-2-hydroxy-5-methoxysulfonyl-benzoic acid methyl ester (**32**) and the 5-octyl-2-methoxy-3-methoxysulfonyl-benzoic acid methyl ester (**33**). The formation of these two compounds depends, primarily, on the order of attack of the alkyl group and the sulfonate group. Attack will predominantly occur at the 5-position on the aromatic ring because of the reduced steric hindrance there compared to attack at the 3-position. So to form the 5-octyl-2-hydroxyl-3-sulfonyl-benzoic acid, alkylation is almost certainly followed by sulfonation and vice versa for the formation of the 3-octyl-2-hydroxy-

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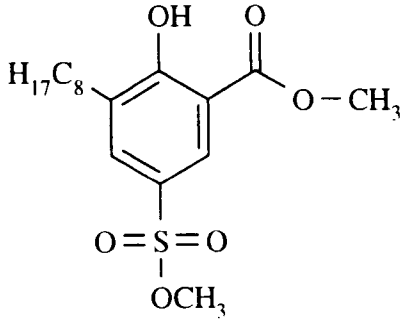
[h] 21% of the product mixture consisted of methyl 5-(1-methylheptyl)salicylate (**28**), methyl 5-(1-ethylhexyl)salicylate (**29**), methyl 5-(-1-propylpentyl)salicylate (**30**) and methyl 5-t-octylsalicylate (**20**).

5-sulfonyl-benzoic acid (both substituents activate the ring favouring the introduction of a further substitutent. The reason why the hydroxyl group is methylated in the 5-octyl-2-methoxy-3-methoxysulfonyl-benzoic acid methyl ester is because of the acidity of the hydroxyl proton. Hydrogen bonding between the sulfonate group and the hydroxyl group would make the hydroxyl proton somewhat more acidic than if the sulfonate group was distant from the hydroxyl group. The increased acidity of the hydroxyl proton would enable it to be methylated by diazomethane (diazomethane is not very selective and will methylate any acidic protons)[i].

Structures 32 and 33



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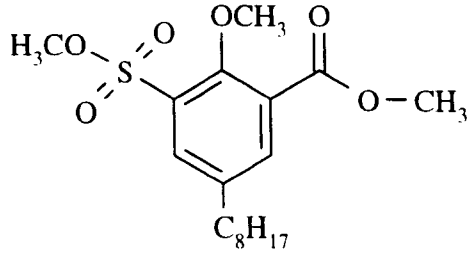

33

As has been commented on previously, the competitive sulfonation of the aromatic ring can have a dramatic effect on the accountability of alkylsalicylic acid. Because of its very hydrophilic nature a simple of 5-sulfosalicylic acid will not precipitate out of solution on the addition of water: nor can it be extracted into an organic solvent. However, the addition of an alkyl chain has the effect of increasing the solubility of the compound in organic solvents and a part at least is now extractable from water. The length of the alkyl chain is obviously going to be of importance since the size will control the hydrophilicity of the molecule. Once in the organic solvent it can easily be methylated and then detected by GC/MS. This may be why no sulfonated products were observed with the shorter chain systems described earlier.

As can be seen from these results there is a great deal more dialkylation than when the tertiary ethers and alcohols were used. The greater proportion of secondary dialkylated products are due to reduced steric hindrance of the secondary carbocation attacking in the

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[i] Previously, in chapter 2, it was commented that only the carboxylic acid proton of salicylic acid would be methylated by diazomethane and the hydroxyl proton would not be methylated.

3-position compared to the bulkier tertiary carbocations. The electron donating effect of the first alkyl substituent will also help to promote somewhat the second substitution.

Table 3.3. The results from the alkylation reactions using primary and secondary alcohols.

Alkylating Agent	Accountability %	Purity %	Overall Yield
1-hexanol	60%	40% + (20%di)	24%
2-hexanol	63%	59% + (34%di)	37%
3-hexanol	51%	58% + (34%di)	30%
2-octanol	40%	21% + (10%di)	8%

3.4. Alkylations Using Long Alkyl Chain Alkenes.

As commented on in previous chapters, alkenes are a favoured feedstock for industrial processes because of their low cost and general availability. Consequently the alkylation of salicylic acid using alkenes would have significant advantages. Alkenes would have another advantage in comparison to alcohols, assuming a similar mechanism, since on protonation of the alkylating agent no water will be formed which would dilute the acid concentration. The following section covering the alkylation of salicylic acid by alkenes, is split into two parts. The first part covers studies using tertiary alkenes whilst the second covers reactions which employed secondary alkenes.

3.4.1. Tertiary Alkenes.

The initial study carried out using alkenes involved, on protonation, the formation of tertiary carbocations. A number of suitable alkenes are available and a selection of these were used to alkylate salicylic acid. If the same mechanism is involved in the alkylation of salicylic acid by tertiary alkenes, as was the case with the tertiary alcohols and ethers, the major product would be expected to be the 5-t-alkylsalicylic acid.

3.4.1.1. 2-Methyl-1-pentene.

Reacting salicylic acid with 2-methyl-1-pentene under the standard conditions gave

a low accountability (27%) and a somewhat unexpected product distribution. Analysis by GC/MS identified the following compounds in the reaction mixture;

peak 1: methyl salicylate (**8**); 13%

peak 2: methyl 5-t-butylsalicylate (**9**); 20%

peak 3: methyl 5-t-pentylsalicylate (**22**); 2%

peak 4: methyl 5-(1-ethylbutyl)salicylate (**25**); 1%

peak 5: methyl 5-t-hexylsalicylate (**18**); 3%

peak 6: methyl 3,5-di-t-butylsalicylate (**11**); 2%

As can be seen from the results, the major component in the reaction mixture is the 5-t-butylsalicylic acid. This compound, and the others, can be again rationalised on the basis of the isomerization and fragmentation of the initially formed carbocation. In this specific case, fragmentation of the carbocation is favoured, resulting in the formation of the t-butylcarbocation. As will be discussed in the next chapter, there is a reason for this disappointing result and a much higher accountability and purity can be obtained on lowering the reaction temperature.

3.4.1.2. 2-Methyl-1-undecene.

Increasing the size of the alkylchain further by using 2-methyl-1-undecene gave a high accountability (76%) and purity (87%) of the desired 5-t-dodecylsalicylic acid. The GC/MS trace of the product mixture is illustrated in Figure 3.7. The other major species, identified by GC/MS, amongst the many peaks in the product mixture are;

peak 1: 2-methyl-1-undecene; 1%

peak 2: methyl salicylate (**8**); 5%

peak 3: methyl 5-t-butylsalicylate (**9**); <1%

peak 4: methyl 5-t-pentylsalicylate (**22**); <1%

peak 5: An unidentified product; 2%

peak 6: Alkene dimer ($C_{24}H_{48}$); 1%

peak 7: methyl 3-t-dodecylsalicylate; 3%

peak 8: methyl 5-t-dodecylsalicylate (**15**); 87%

The one peak that has not been fully identified by its mass spectrum it is again believed to be the alkyl sulfate. The retention times on the GC of the unidentified product from this reaction and the unidentified products from the reactions using 2-methoxy-2-methylundecane and 2-hydroxy-2-methylundecane are the same, within experimental error.

The alkene presumably reacts directly with the sulfuric acid to form the sulfonate ester (**16**). It is possible that all the alkylating agents are sulfated, but the actual detection of these species depends on the length of the alkyl chain. The longer the alkyl chain the lower the solubility of the alkyl sulfate in water and the more easily it can be extracted. Consequently, when a small alkylating agent, such as t-butanol is used, the t-butyl sulfate will still remain in the aqueous sulfuric acid along with any sulfosalicylic acid. As the alkyl chain is increased to 2-methyl-2-undecanol the dodecyl sulfate is now more soluble in an organic solvent and will be extracted and thus detected.

Again the presence of the alkene dimer and a much smaller amount of the alkene trimer is observed. (GC suggests that only one major isomer of the alkene dimer is present. This differs from the previous results involving the corresponding alcohol and ether which resulted in a number of higher alkenes) The polymerization of the alkene was not totally unexpected since the polymerization of alkenes in acidic media is well documented[77]. It is also possible that the tetramer and higher polymers are formed but because of their low volatility they are not being eluted from the GC. Figure 3.8 shows the alkene polymerization reaction.

Figure 3.7. The GC trace (obtained from a GC/MS run) of the product mixture, when 2-methyl-1-undecene was used to alkylate salicylic acid under standard conditions.

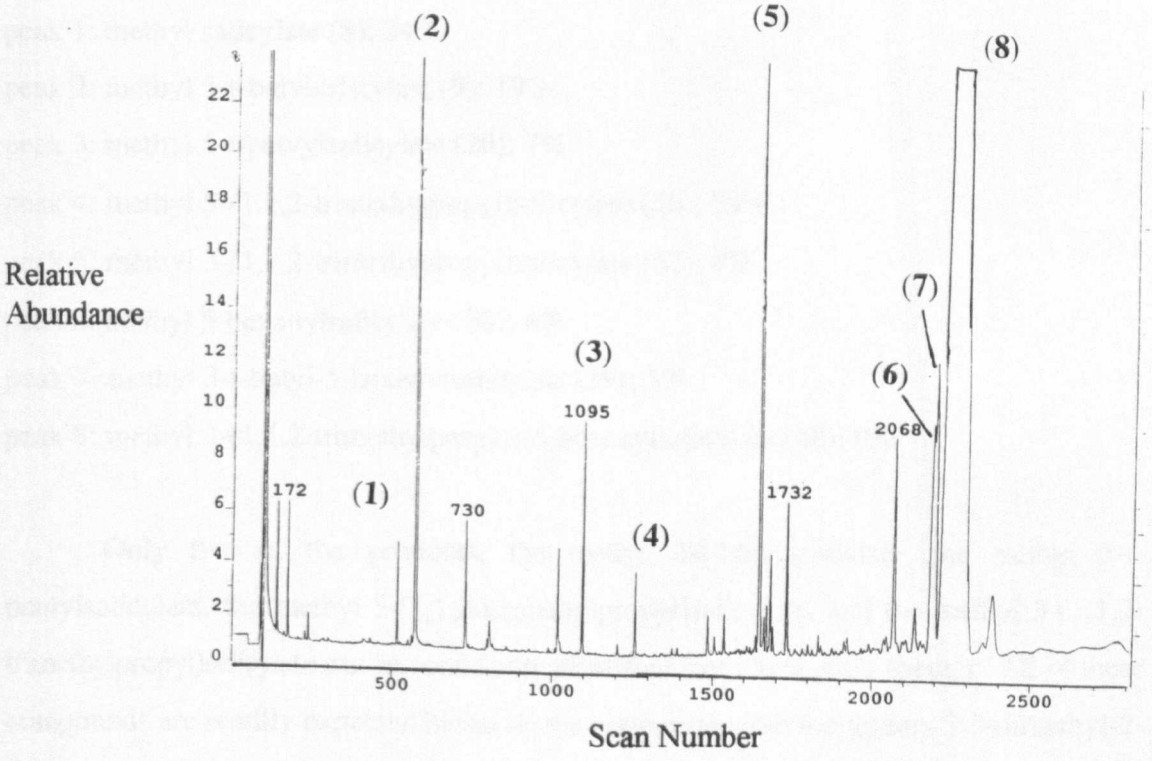
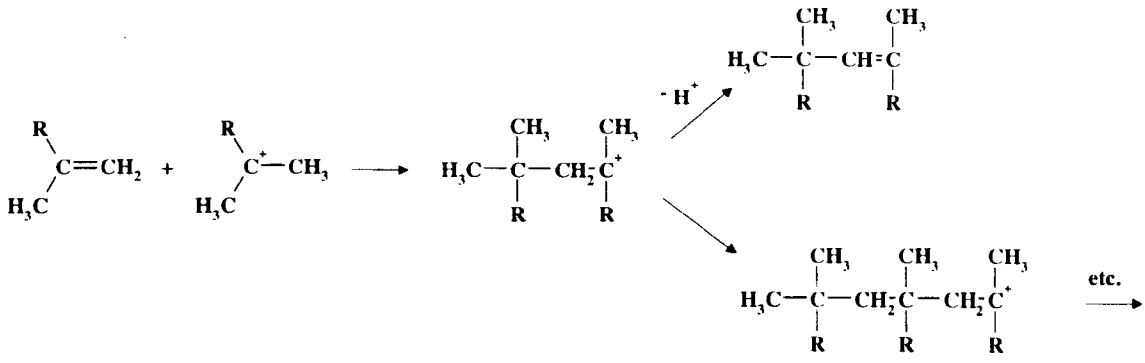


Figure 3.8. The alkene polymerization reaction.



3.4.1.3. 3,3-Dimethyl-1-butene.

In an attempt to mimic the conditions that would be faced when alkylating salicylic acid with commercially available alkenes, such as propylene tetramer, even more hindered alkenes were employed as substrates in the reaction. The aim was to ascertain if the initially formed carbocation would rearrange and how the increased substitution would affect this.

Alkylating salicylic acid with 3,3-dimethyl-1-butene under standard alkylating conditions gave alkylsalicylic acids in high accountabilities but, as can be seen from the GC/MS trace in Figure 3.11, a wide range of products were formed. The more significant of these products have been identified, in some cases very tentatively, from their mass spectra, as;

peak 1: methyl salicylate (**8**); 24%

peak 2: methyl 5-t-butylsalicylate (**9**); 19%

peak 3: methyl 5-t-pentylsalicylate (**20**); 7%

peak 4: methyl 5-(1,1,2-trimethypropyl)salicylate (**36**); 29%

peak 5: methyl 3-(1,1,2-trimethypropyl)salicylate (**37**); 4%

peak 6: methyl 5-hexenylsalicylate (**38**); 4%

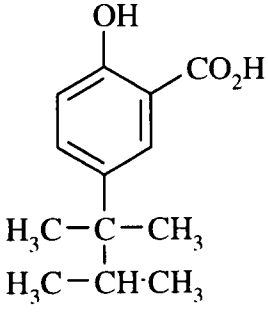
peak 7: methyl 3-t-butyl-5-hexenylsalicylate (**39**); 3%

peak 8: methyl 3-(1,1,2-trimethylpropyl)-5-hexenylsalicylate (**40**); 9%

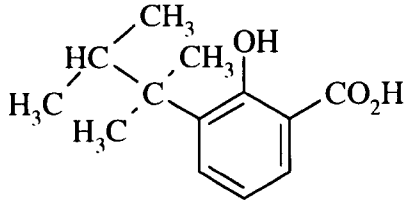
Only five of the products, the methyl 5-t-butylsalicylate, the methyl 5-t-pentylsalicylate, the methyl 5-(1,1,2-trimethylpropyl)salicylate, and the methyl 3-(1,1,2-trimethylpropyl)salicylate can be confidently identified from their mass spectra. All of these compounds are readily expected based on the assumption that the tertiary 3,3-dimethyl-2-

butyl carbocation will be formed from the alkene and then react with the salicylic acid to give both the 3- and the 5-(1,1,2-trimethylpropyl)salicylic acid. The initial carbocation would also be expected to fragment easily to give the t-butyl and, less likely, the t-pentyl carbocation and from this the 5-t-butyl and 5-t-pentylsalicylic acids respectively would be formed. There is no explanation as to why alkenylsalicylic acids are formed. The fact remains that with the alkylation of salicylic acid using 3,3-dimethyl-1-butene unsaturated products are formed and there is no evidence for any unsaturated products in any other systems. However, the formation of the remaining products cannot be rationalised as easily. The unexpected unsaturated 5-hexenylsalicylic acid may be an alicyclic system.

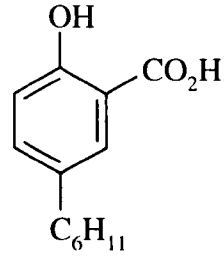
Structures 36-40



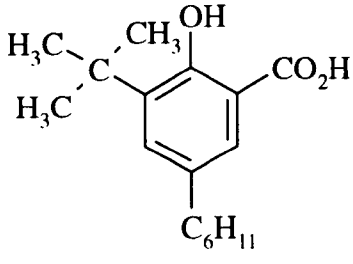
(36)



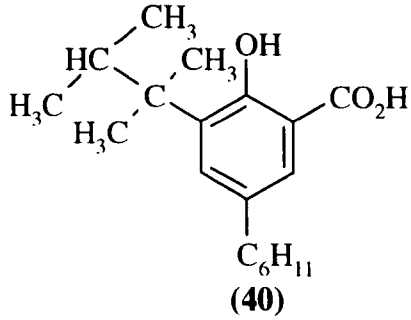
(37)



(38)



(39)



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Scheme 3.4.

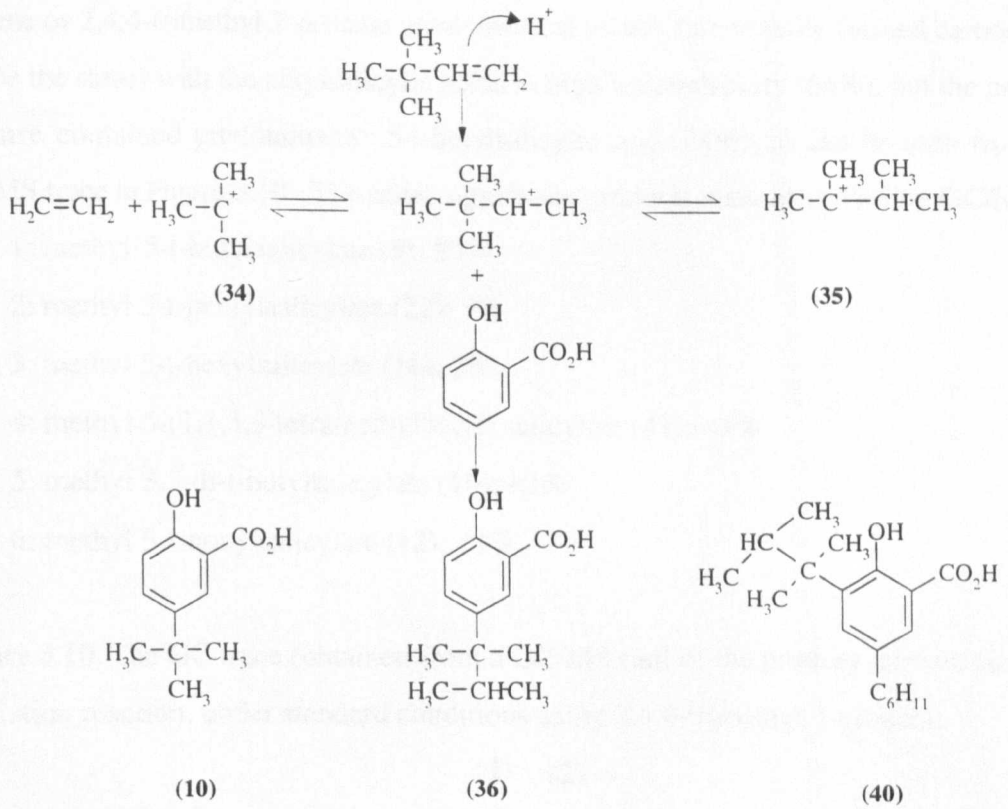
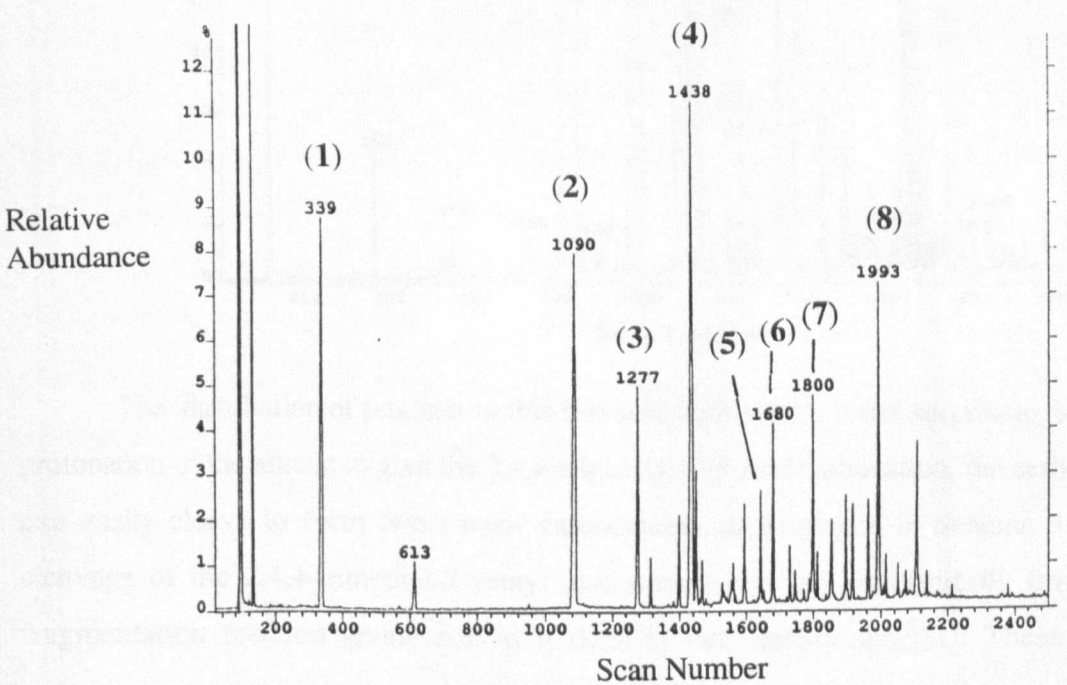


Figure 3.9. The GC trace (obtained from a GC/MS run) of the product mixture from the alkylation reaction, under standard conditions using 3,3-dimethyl-1-butene.



3.4.1.4. 2,4,4-Trimethylpentenes.

Alkylating salicylic acid under the standard conditions with either 2,4,4-trimethyl-1-pentene or 2,4,4-trimethyl-2-pentene gave identical results (the initially formed carbocation will be the same) with the alkylsalicylic acids in high accountability (66%), but the product mixture contained predominantly 5-t-butylsalicylic acid (84%), as can be seen from the GC/MS trace in Figure 3.10. The other significant products were identified by GC/MS as;

peak 1: methyl-5-t-butylsalicylate (**9**); 84%

peak 2: methyl 5-t-pentylsalicylate (**22**); 9%

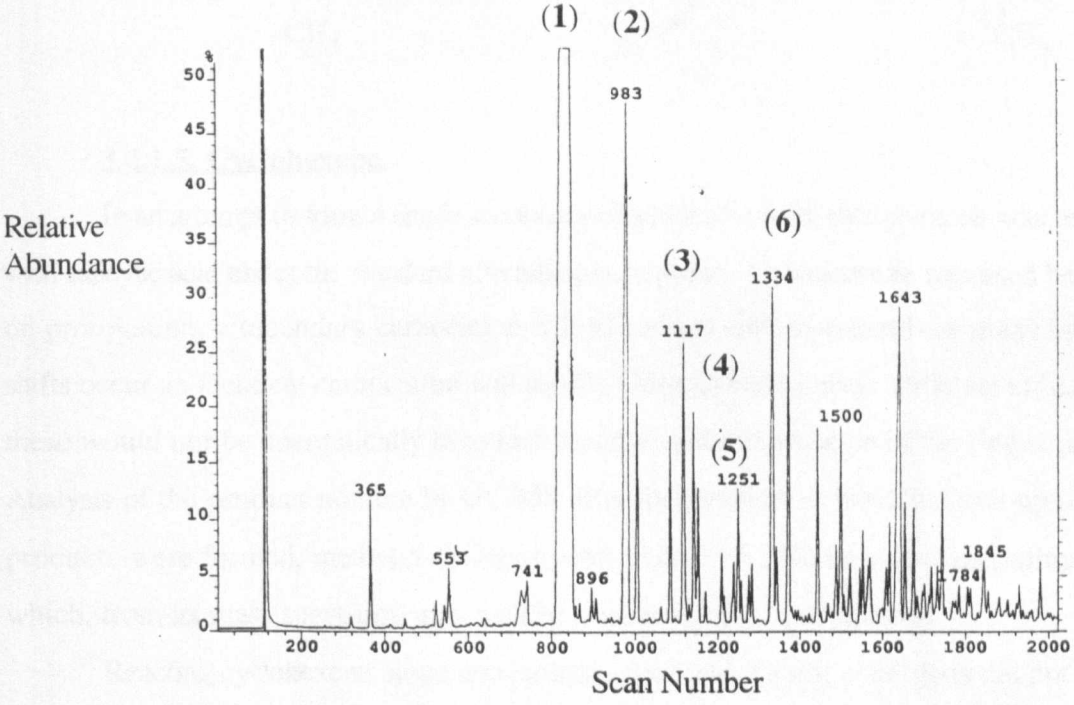
peak 3: methyl 5-t-hexylsalicylate (**16**); 2%

peak 4: methyl 5-(1,1,3,3-tetramethylbutyl) salicylate (**41**); <1%

peak 5: methyl 3,5-di-t-butylsalicylate (**10**); <1%

peak 6: methyl 5-t-nonylsalicylate (**12**); <1%

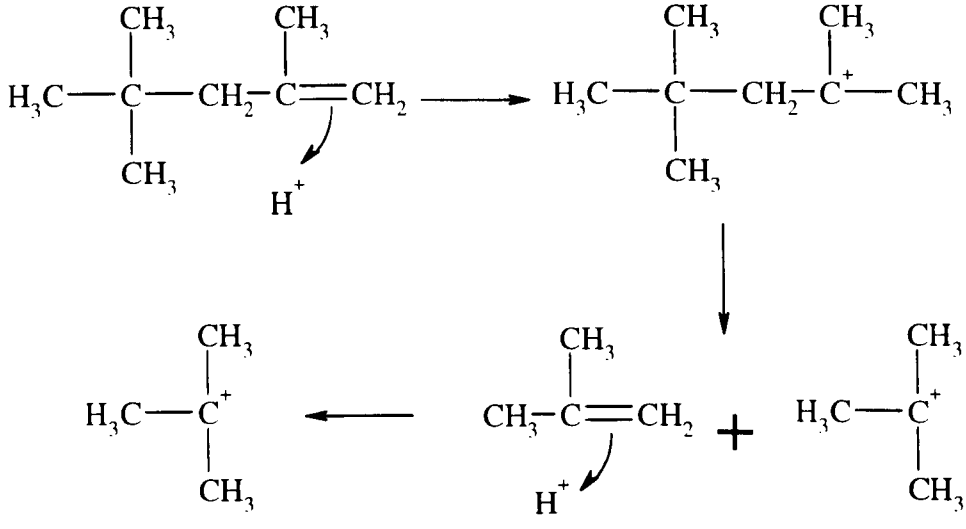
Figure 3.10. The GC trace (obtained from a GC/MS run) of the product mixture from the alkylation reaction, under standard conditions using 2,4,4-trimethyl-1-pentene.



The distribution of products at this elevated temperature is not surprising, since on protonation of the alkene to give the 2,4,4-trimethyl-2-pentyl carbocation, the carbocation can easily cleave to form two t-butyl carbocations, as illustrated in Scheme 3.5. The cleavage of the 2,4,4-trimethyl-2-pentyl carbocation is a very energetically favourable fragmentation reaction giving rise as it does to two tertiary species. These t-butyl

carbocations can then react with the salicylic acid to give the major product the 5-t-butylsalicylic acid. The remaining products arise from the isomerization of the initial carbocation and then subsequent fragmentation to give the smaller chain length alkylsalicylic acids. The 5-t-nonylsalicylic acid is likely to arise from the combination of the 2,4,4-trimethylpentene and a methyl carbocation to give the C_9 alkylsalicylic acid.

Scheme 3.5.

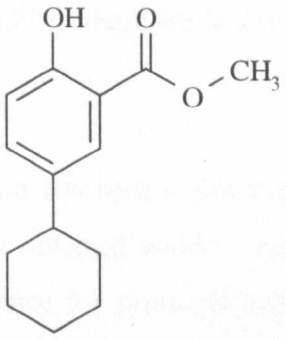


3.4.1.5. Cyclohexene.

In an attempt to form a single secondary alkylsalicylic acid, cyclohexene was reacted with salicylic acid under the standard alkylating conditions. Cyclohexene was used because on protonation, a secondary carbocation will be formed and no matter how many hydride shifts occur an identical carbocation will result. Corresponding alkyl shifts are unlikely as these would not be energetically favoured because of destabilisation of the ring structure. Analysis of the product mixture by GC/MS after methylation showed that two significant products were formed, methyl 5-cyclohexylsalicylate 33% (**42**) and a second component which, from its mass spectrum, may well be a tetracyclohexyl compound.

Reacting cyclohexene alone with sulfuric acid under these conditions did not result in such a high proportion of the tetracyclohexyl compound, suggesting that in some way the salicylic acid is implicated in the formation.

Structure 42



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3.4.1.6. Summary of the Results Using Tertiary Alkenes.

In Table 3.4 all the results on the alkylation of salicylic acid, which can be achieved in most cases in high accountabilities and purities, are brought together. What is evident is that the greater the degree of branching of the alkene, the more molecular reorganisation takes place largely as a result of fragmentation processes, and a wider product distribution results. The other tertiary alkenes used in this study, 2-methyl-1-pentene and 2-methyl-1-undecene, do not fragment or isomerize as easily as the more hindered alkenes, such as 2,4,4-trimethyl-1-pentene and so do not produce such a wide range of alkylsalicylic acids.

Table 3.4. The accountability and purity of the alkylsalicylic acids when hindered alkenes are used as the alkylating agents.

Alkylating Agent	Accountability %	Purity %	Overall Yield
2-methyl-1-pentene	27%	3% (**22**)	<1%
2-methyl-1-undecene	76%	87% (**15**)	66%
3,3-dimethyl-1-butene	83%	22% (**9**)	18%
2,2,4-trimethyl-1-pentene	78%	85% (**9**)	66%
cyclohexene	75%	36% (**42**)	27%

3.4.2 Alkylations Using Monosubstituted Alkenes.

In an attempt to mimic other industrially available alkenes which can contain a large

proportion of monosubstituted alkenes, the alkylation of salicylic acid was undertaken using monosubstituted alkenes. The results of these studies are listed below.

3.4.2.1. 1-Hexene.

Alkylating salicylic acid with 1-hexene under standard reaction conditions gave a similar product distribution to that obtained when 1- hexanol was used as the alkylating agent, except there was no evidence for products resulting from fragmentation of C_6 carbocation, such as methyl t-butyl or the methyl t-pentylsalicylates. The complete range of secondary hexylsalicylic acids were produced as well as other associated products including the t-hexylsalicylic acid. The accountability of the hexylsalicylic acid was 45% and the percentage of the product mixture consisting of the methyl hexylsalicylates was 43%. The overall distribution of products by GC/MS was as follows:

peak 1: methyl salicylate (**8**); 2%

peak 2: methyl 5-(1-ethylbutyl)salicylate [3'-hexyl](**23**); 4%

peak 3: methyl 5-(1-methylpentyl)salicylate [2'-hexyl](**24**); 9%

peak 4: methyl 5-t-hexylsalicylate (**18**); 14%

peak 5: methyl 3-(1-ethylbutyl)salicylate [3'-hexyl](**25**); 8%

peak 6: methyl 3-(1-methylpentyl)salicylate [2'-hexyl](**26**); 8%

peak 7: methyl 3,5-dihexylsalicylate (**27**); 20%

3.4.2.2. 1-Octene.

Replacing 1-hexene with 1-octene to alkylate salicylic acid under standard conditions again resulted in a similar product distribution to that obtained when 2-octanol was used to alkylate salicylic acid. The product distribution can be rationalised in the same way. The product mixture contained the complete range of secondary methyl octylsalicylates, again with the methyl t-octylsalicylate present. The accountability (92%) and purity (66%)of the octylsalicylic acids was higher than that obtained when hexene was used.

peak 1: methyl salicylate (**8**); 8%

peak 2: methyl 5-(1-methylheptyl)salicylate [2'-octyl](**28**); 12%

peak 3: methyl 5-(1-ethylhexyl)salicylate [3'-octyl](**29**); 14%

peak 4: methyl 5-(-1-propylpentyl)salicylate [4'-octyl](**30**); 13%

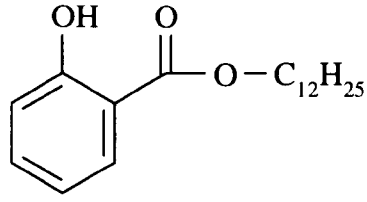
peak 5: methyl 5-t-octylsalicylate (**20**); 27%

peak 6: methyl 3,5-di-t-octylsalicylate (**31**); 9%

3.4.2.3 1-Dodecene.

Increasing the alkyl chain further by using 1-dodecene as the alkene resulted in a much lower accountability (70%) and purity (8%). The principal products are not the expected methyl dodecylsalicylates but the dodecyl salicylates (**43**).

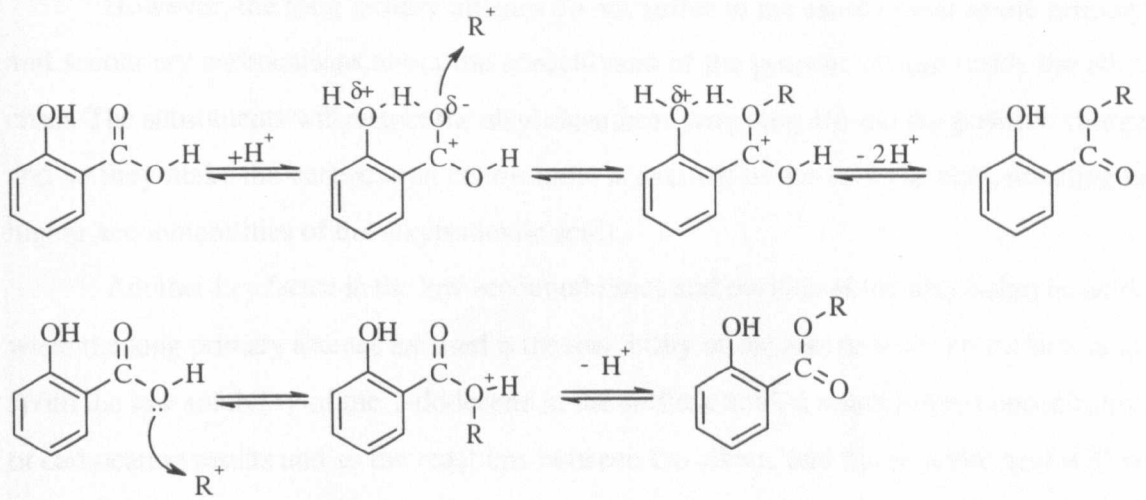
Structure 43



(43)

It is impossible to identify individually the distribution of the various dodecyl salicylates because they have near identical mass spectra. It has always been suggested that the esters and the ethers should be formed in this system. This is because of the nucleophilic nature of both the hydroxyl, but more importantly, the carboxylic acid group. Previous studies at York[78] and other literature evidence[79] into the alkylation of phenol using alkenes and solid acid catalysts have shown that the ether is the kinetically favoured product and is formed initially. However, it quickly disappears to form the alkylphenol as the reaction progresses. Two plausible mechanisms for the formation of the dodecyl esters are shown in Scheme 3.7. The first mechanism involves the protonation of the acid, forming a carbocation, which makes the oxygens lone pair of electrons a better nucleophile. This nucleophile then attacks the alkyl carbocation and subsequent loss of two protons gives the alkyl salicylate. The second mechanism involves the acid acting as a nucleophile attacking the carbocation. The formation of the esters of salicylic acid will be discussed in more detail in the following two chapters. The reason why only 1-dodecene produces the esters of salicylic acid may be due to the structural conformation of both the dodecyl carbocations and the dodecyl salicylate, as well as the relative stability of the dodecyl carbocations. A more detailed discussion as to why the dodecyl salicylate is formed in preference to the dodecyl salicylic acid is included in the next chapter.

Scheme 3.7.



As can be seen from the results in Table 3.5, as the alkylating agent increases in length, the purity of the alkylsalicylic acids drops.

Table 3.5. The accountability and purity of the alkylsalicylic acids when monosubstituted alkenes are used as the alkylating agents.

Alkylating Agent	Accountability %	Purity %	Overall Yield
1-hexene[j]	45%	43%	19%
1-octene	92%	66%	61%
1-dodecene	70%	8%[k]	6%

This drop in purity of the products may be due to the orientation of the carbocation that is formed. The reaction takes place in a two phase system with the alkylation reaction being effected at the phase boundary. As the alkyl chain becomes longer the arrangement of the alkene is no longer linear but somewhat spherical in nature, with the alkylchain wrapping around itself. On protonation of the alkene to form the carbocation, 1,2-hydride shifts will rapidly isomerize the initial secondary carbocation to the complete range of secondary carbocations. This isomerization will reduce the availability of the carbocation centre to reach the salicylic acid because it is hidden inside the spherical structure of the alkyl chain. Increasing the alkylchain length further would only make the carbocation centre

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[j] Higher accountabilities have been achieved at lower temperatures (see chapter 4).

[k] The products are the dodecyl esters of salicylic acid and not the methyl dodecylsalicylates.

even less accessible to the salicylic acid.

However, the long tertiary alkenes do not suffer to the same extent as the primary and secondary carbocations about the concealment of the positive charge inside the alkyl chain. The substituents will restrict the alkyl chain from wrapping around the positive charge and so they make the carbocation centre more accessible to the salicylic acid, resulting in higher accountabilities of the alkylsalicylic acids.

Another key factor in the low accountabilities and purities of the alkylsalicylic acids when the long primary alkenes are used is the miscibility of the alkene with the sulfuric acid. With the low solubility of the 1-dodecene in the sulfuric acid, a much lower concentration of carbocation results and so the reactions between the alkene and the salicylic acid will be much slower resulting in both lower accountabilities and purities. However, the reaction between a carbocation and an alkene is more likely to proceed, resulting in the higher alkenes. To overcome this problem, phase transfer catalysts, much longer reactions or improved agitation of the reaction mixture could be employed. These factors will be discussed in the following chapters.

As will have been noted only the larger tertiary alkylating substrates produce the alkene dimers and higher polymers but lower amounts of the 3-alkylsalicylic acids. This is partly attributed to the nucleophilicity of the alkene and the electrophilicity of the carbocation[80]. The reactivity of a tertiary alkene is greater than that of the primary or secondary alkene. The reactivity of iso-butene is 25,000 times greater than that of propene[81]. As yet there is no quantitative reactivity data for many classes of electrophiles and so there is, no electrophilicity parameter for a range of electrophiles. The electrophiles that have been studied tend to be of little use preparatively[82].

3.5. GC Calibration.

All previous results have been calculated using uncalibrated GC peak areas. To give more accurate results calibration is required as the sensitivity of the Flame Ionization Detectors (FID) response varies from compound to compound.

Production of calibration plots is typically achieved by the addition of an internal standard. The standard is a compound that cannot be formed in the reaction mixture, will not react with any of the components in the reaction mixture, and whose retention time

should be such as to be well separated from any other peak on the GC trace. The standard can either be added to the reaction mixture at the start of the reaction but more commonly a known amount is added to the product mixture just prior to the GC analysis. An internal standard which fitted all the requirements for the alkylsalicylic acids was hexamethylbenzene.

To carry out the GC calibration of the alkylsalicylic acids a known mass of the standard was added to a known mass of methyl salicylate. A number of GC runs were carried out, with the average values calculated and this enabled a calibration to be carried out using equation 3.1.

$$K = \frac{A_{std} \times m_x}{A_x \times m_{std}} \qquad \textbf{3.1}$$

K= Correction Factor

A_{std} = area of the standard from the GC trace.

A_x = area of the compound of interest on the GC trace.

m_{std} = mass of standard.

m_x = mass of compound of interest.

This calculation needs to be carried out on all the components that are found in the mixture, and this requires there to be available pure samples of each of the components in the product mixture. To use the correction factor for each component the equation is rearranged to obtain the mass of that particular component, equation 3.2. The number of moles of the particular component can be calculated and a percentage of that component in the product mixture can be calculated.

$$m_x = \frac{K \times A_x \times m_{std}}{A_{std}} \qquad \textbf{3.2}$$

A selective number of correction factors have been calculated, and are presented in Table 3.6. To obtain each correction factor required the synthesis of a pure sample of each of the components of interest. Obtaining pure samples of each component has proved the most challenging for the larger alkylsalicylic acids, especially the 5-t-dodecylsalicylic acid as these materials are not commercially available and the synthesis is not easy. So, in an attempt to produce a pure sample of the 5-t-dodecylsalicylic acid a number of purification techniques were used and these techniques are discussed in the following sections.

Table 3.6. The correction factors of various alkylsalicylic acids relative to hexamethylbenzene.

Alkylsalicylic acid	Correction factor
methyl salicylate	1.8
methyl 5-t-butylsalicylate	1.5
methyl 3,5-dit-butylsalicylate	≈3.0
methyl 5-t-hexylsalicylate	2.4

3.5.1. Purification by Thin Layer Chromatography (TLC).

The first method of purification attempted was Thin Layer Chromatography (TLC), using a variety of solvent systems, but with no success. On all the TLC's attempted, no single spot or group of spots, was obtained, in each case a single streak resulted starting from the base line (this streaking was not due to overloading of the TLC plate). However, one interesting solvent system was found that would separate the dodecylsalicylic acid from the shorter alkylsalicylic acids. This method involved adding acetonitrile to the product mixture, shaking the mixture and then removing the acetonitrile containing the shorter alkylsalicylic acids, leaving the dodecylsalicylic acid behind. This method did lead to complete purifcation. Analysing the sample by proton nmr and integrating the aromatic protons relative to the alkyl chain protons showed an excess of the alkyl protons suggesting that either dialkylated salicylic acid or alkene polymers were present.

3.5.2. Purification by High Performance Liquid Chromatography (HPLC).

High Performance Liquid Chromatography (HPLC) was used in an attempt to provide improved separation of the various components, especially the dodecylsalicylic acid from the dialkylated salicylic acid and the alkene polymers. Before carrying out the HPLC analysis the acids were converted to the methyl esters by the addition of diazomethane. To detect the methyl alkysalicylates eluting through the HPLC, a UV/VIS spectrum was run of methyl salicylate to obtain λ_{max} (the wavelength of the strongest absorption for methyl salicylate) and it was at this wavelength that the UV detector on the HPLC was set. A number of solvent systems were tried, with varying degrees of apparent success. In several

cases three major peaks, with minimal separation, were observed and the eluent containing each of these three components was collected separately. A number of repeat injections were made in order to collect enough of the separated products to perform GC, GC/MS and ^{1}H nmr analysis. Unfortunately each of the three samples gave nearly identical GC traces, showing, that the separation observed on the HPLC had not actually taken place as required.

3.5.3. Purification by Extraction.

This approach was an attempt to separate the polar alkylsalicylic acids from the non-polar alkene polymers by the addition of a base, followed by ether extraction, reacidification of the aqueous medium followed by another ether extraction. The basis of this approach, is that the alkylsalicylic acid, on the addition of a base will preferentially remain in the aqueous layer, whilst the non-polar hydrocarbon is removed in the ether extraction. On reacidification the alkylsalicylic acids will be extracted from any residual sulfuric acid or sulfosalicylic acid.

The method was as follows: To the product mixture was added approximately 40 cm^3 water and to this was added sodium hydrogen carbonate until the pH was approximately 8 (tested by full range pH indicator paper). Then an ether extraction was carried out and the remaining aqueous layer was reacidified to approximately pH 3 by the addition of, hydrochloric acid. Finally, another ether extraction was carried out.

Analysis by GC showed that after the base/acid wash there was still some residual alkene dimer and trimer and possibly higher alkene polymers. A possible explanation for this poor separation is the formation of the alkylsalicylic acids into micelles, trapping the alkene polymers inside the micelle so they are not removed by the various washings. (The alkysalicylic acids were acting as very good surfactants). There was also a problem with this method of purification, in that, after the various washings and extractions, the base ether extraction accounts for about 90% by mass of the original product mixture and this contains not just the alkene polymers but also a great deal of the alkylsalicylic acids.

3.5.4. Purification by Distillation.

The final purification method used in an attempt to purify the alkylsalicylic acids was vacuum distillation. To lower dramatically the acids' boiling points they were first

converted to the methyl esters by reacting with diazomethane. In the purification of the methyl t-dodecylsalicylate, the lower boiling methyl alkylsalicylates, methyl salicylate and 2-methyl-1-undecene ,were stripped away by distilling at 175°C and approximately 1mm Hg. This left the methyl t-dodecylsalicylates (both the 3- and methyl 5-t-dodecylsalicylates were present), the alkene dimer and any higher boiling species. To separate the t-dodecylsalicylic acid and the alkene dimer from any possible higher boiling compounds the next fraction distilled at 250°C and 1mm Hg. This fraction contained the t-dodecylsalicylic acids and the alkene dimer. To separate these three species by distillation would have required very fine control of both the temperature and the pressure because the boiling points of all three compounds are very close. Unfortunately, this very fine control of temperature and pressure was not available on the equipment used. The small difference in boiling points is demonstrated very well on the GC trace of the product mixture from the alkylation of salicylic acid using 2-methyl-1-undecene, Figure 3.7. The peaks corresponding to the methyl esters of 3- and 5-t-dodecylsalicylic acids and the alkene dimer have very similar retention times. The column used, an Econocap SE-30 capillary column, separates the components, principally by their boiling points.

By combining two methods of purification (distillation and the base/acid wash) it was hoped that just the dodecylsalicylic acid would be left, enabling GC calibration to take place. However, this did not prove to be the case. After carrying out both purification techniques, analysis by GC using uncorrected relative peak areas showed that 3% of the mixture was the alkene dimer: Based on the ^{1}H nmr evidence, the figure appeared to be 4%.

3.6. Conclusions.

The alkylation of salicylic acid can frequently be achieved in high accountabilities and purities using a variety of alkylating agents, in the presence of concentrated sulfuric acid. The proposed mechanism involves the protonation of the alkylating agent and subsequent formation of a carbocation. This carbocation can then undergo three primary reactions, isomerization, fragmentation or it can attack the aromatic ring to form, the 5-alkylsalicylic acid. Primary and secondary alkylating agents produce a mixture of mainly secondary alkylsalicylic acids, though some tertiary alkylsalicylic acids are also present. Tertiary alkylating agents produce principally,tertiary alkylsalicylic acids, but also a very small amount of secondary alkylsalicylic acids. The degree of branching of the tertiary

alkylating agent also plays a part; the more substituted the alkene the more likely the carbocation is to fragment, giving rise to smaller alkylsalicylic acids.

Another significant difference between the alkylation of salicylic acid using tertiary alkylating agents or using primary and secondary alkylating agents, is the amount of attack in the 3-position. A relatively higher proportion of attack occurs at the 3-position when a secondary carbocation is present compared to when a tertiary carbocation is present. This is thought to be due to steric hindrance. The bulkier tertiary carbocation would experience greater steric hindrance attacking the 3-position than would the less bulky secondary carbocation. The occurrence of a higher proportion of dialkylated salicylic acids, when primary and secondary alkylating agents are used is again symptomatic of to reduced steric hindrance for the secondary carbocation.

The accountabilities and purities of products formed when tertiary alkylating agents are used are generally higher than the corresponding primary and secondary alkylating agents. This will be due to the increased stability and free solubility of the initial carbocation that is formed. A tertiary carbocation because of its higher stability will be formed faster than a less stable secondary carbocation since the activation energy for formation is much lower.

Comparison of the accountability and purity of products obtained when alkenes and alcohols/ethers are used to alkylate salicylic acid shows that the alkenes are superior in performance to the corresponding alcohols (or ethers). This probably is due to the greater ease of formation of carbocations from alkenes. Alcohols and ethers require protonation followed by the loss of a neutral molecule.

The initial aim of synthesising an alkylsalicylic acid with at least a C_8 side chain has been attained, without optimizing the reaction conditions. However, the effect of altering the reaction conditions in an attempt to reduce the side reactions, will be discussed in the following chapter. Also, the formation of possible intermediates, such as the esters of salicylic acid, will be discussed in more detail in the following chapters.

Another factor that will be discussed in a subsequent chapter is the use of a commercially available alkene on a much larger scale. Also to be established is, does the behaviour of commercially available alkene agree with the model compounds? The cost of 2-methyl-1-undecene would prohibit its use to form the commercially available overbased detergent. The comparison with an industrially available alkylsalicylic acid overbased detergent will also be made.

Chapter 4

The Effect Of The Reaction Conditions On The Product Distribution From The Alkylation of Salicylic Acid

4. Introduction.

As has been indicated in previous chapters, the effect on product distribution of the alkylsalicylic acids of altering the reaction conditions can be quite marked. All the results presented so far have been obtained using standard conditions, namely heating the reactants for 3 hours at 60°C in 80% sulfuric acid (by volume). This chapter is concerned with the effects of varying some of these parameters, notably the catalyst (either changing it completely or altering its concentration), temperature and, finally, reaction duration.

4.1. The Effect of the Catalyst on the Alkylation Reaction.

Two types of acid have been used in this study to alkylate salicylic acid. The standard concentrated aqueous solutions of acids, such as sulfuric acid have been employed. Replacements for concentrated sulfuric acid have been sought. With potential alternatives associated problems occur. For instance, nitric acid is likely to bring about nitration of the salicylic acid, and hydrochloric acid is unacceptable because of the nucleophilic nature of the chloride. Acids which do not suffer from these problems, and are discussed subsequently, include orthophosphoric acid and toluenesulfonic acid.

The effect of using solid acids, such as Fulcat, as the catalyst has also been investigated. The solid acids have a number of advantages over the aqueous acids in that work up of the reaction is much simpler; the solid acids are just filtered off and can easily be recycled. Below are reported the effect of variation of catalyst on the alkylation of salicylic acid.

4.1.1. The Use of Concentrated Aqueous Solutions of Acids.

In the first part of this chapter the results in product distribution on varying the strength of the sulfuric acid employed are described. In subsequent parts are noted the changes brought about by replacing the sulfuric acid with other concentrated aqueous solutions of acids.

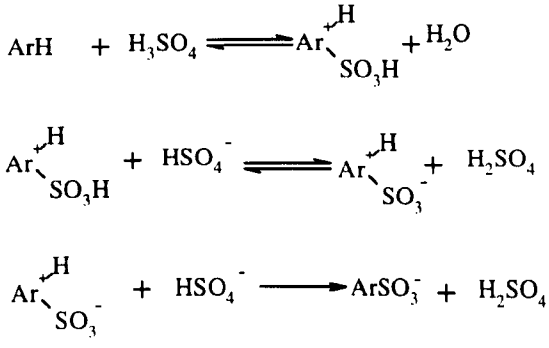
4.2.1.1. Sulfuric Acid as the Catalyst

An earlier study into the effect of sulfuric acid concentration on the course of alkylations of benzene derivatives has shown that a slight increase in acid concentration can lead to a dramatic increase in the extent of competitive sulfonation[77]. To examine this aspect of the system described in sections 3.4.1.1 and 3.4.1.2., the alkylations of salicylic acid using 2-methyl-2-hexanol and 2-methyl-1-undecene were attempted under varying acid concentrations whilst all other variables (temperature, duration etc.) were kept constant. The results are presented in Table 4.1. As can be seen the acid concentration is indeed critical. Below 70% concentration the accountability and purity of products drop dramatically. Above 85% concentration the same low recovery is observed. The drop in accountability at higher acid concentrations can be attributed to the increased rate of competitive sulfonation of the salicylic acid, forming the sulfosalicylic acid (see Chapter two for the sulfonation of salicylic acid).

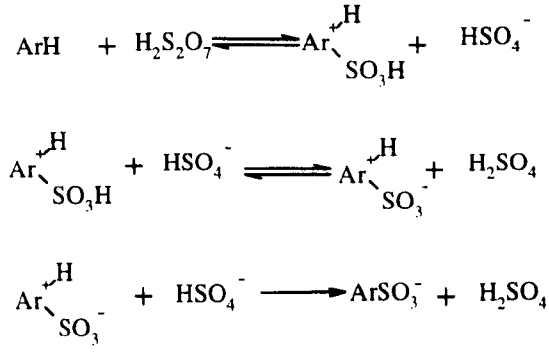
The results in Table 4.1 clearly illustrate a number of trends; as the acid concentration increases the accountability drops but the purity of the product continues to rise to a maximum and then drops. The absence of any alkylsalicylic acids indicates that either no reaction is taking place (salicylic acid is recovered) or the reaction conditions now favour competing reactions (fragmentation and isomerization of the carbenium intermediate) producing other species rather than the desired alkylsalicylic acid (low purity). When concentrated sulfuric acid is employed two different electrophiles exist, depending on the concentration (H_3SO_4 or $H_2S_2O_7$). The difference in mechanism simply involves the attack by the different electrophiles, which both give the sulfonated product, as shown in Scheme 4.1.[83]. With concentrated sulfuric acid the attacking species is thought either to be, as shown $H_2S_2O_7$ or a combination of H_2SO_4 and SO_3.

Scheme 4.1.

Dilute Acid (<80-85%)



Concentrated Acid (>80-85%)



The results also show that under identical conditions, higher accountabilities can be achieved with the larger substrate; this is likely to be due to the lower volatility of the larger substrate reducing the proportion being lost from the system by evaporation.

As has already been commented on, a 10% increase in acid concentration resulted in a fifty thousand fold increase in the rate of sulfonation[77]. The sulfosalicylic acid is not recovered from the reaction as it is very hydrophilic and is not extracted from the aqueous medium by diethyl ether (see Chapter 2). However, sulfonation is reversible and even if sulfonation is competitive with alkylation, the aromatic substrate might well be regenerated and go on to give alkylsalicylic acid, albeit more slowly than by a direct route. The classical desulfonation reaction generally requires elevated temperatures using dilute sulfuric acid concentrations, whilst sulfonation only occurs effectively with acid concentrations greater than 80%.

The product distribution when 2-methyl-2-hexanol and the 2-methyl-1-undecene were used as the alkylating agents, under standard alkylating conditions (80% sulfuric acid), can be seen in Chapter 3. With low acid concentrations, the other major compounds present in the product mixture when 2-methyl-2-hexanol was used as the alkylating agent was primarily unreacted salicylic acid. Similar observations were made when 2-methyl-1-undecene was the alkylating agent, in that the product mixture contained predominately unreacted salicylic acid. At higher acid concentrations the other major compound present in the product mixture for the 2-methyl-2-hexanol and the 2-methyl-1-undecene was again unreacted salicylic acid.

Table 4.1. The effect of sulfuric acid concentration on accountability and purity of the alkylsalicylic acids.

Alkylating Agent	Sulfuric Acid Concentration	Accountability %[a]	Purity %[b]	Overall Yield[c]
2-methyl-2-hexanol	50% H_2SO_4	98%	0%[d]	0%
2-methyl-2-hexanol	65% H_2SO_4	57%	12%	7%
2-methyl-2-hexanol	70% H_2SO_4	66%	56%	37%
2-methyl-2-hexanol	75% H_2SO_4	62%	85%	53%
2-methyl-2-hexanol	80% H_2SO_4	70%	55%	39%
2-methyl-2-hexanol	85% H_2SO_4	54%	35%	19%
2-methyl-2-hexanol	90% H_2SO_4	15%	12%	2%
2-methyl-1-undecene	65% H_2SO_4	98%	11%	11%
2-methyl-1-undecene	70% H_2SO_4	95%	27%	26%
2-methyl-1-undecene	75% H_2SO_4	80%	62%	50%
2-methyl-1-undecene	80% H_2SO_4	87%	76%	66%
2-methyl-1-undecene	85% H_2SO_4	66%	32%	21%

4.1.1.2. Orthophosphoric Acid.

In order to establish whether sulfuric acid is an essential component of the system, the sulfuric acid was replaced by orthophosphoric acid. Orthophosphoric acid was chosen because it is unlikely to react with the alkenes to form alkyl phosphates; nor can it attack the aromatic ring. The only side reaction that could take place should therefore be the

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[a] The accountability is calculated by dividing the mass of product obtained by the theoretical yield of the mono alkylated salicylic acid.

[b] The purity of the product is calculated as the percentage of 5-alkylsalicylic acid in the product mixture, based on uncalibrated GC peak areas.

[c] The overall yield of the 5-alkylsalicylic acid calculated by multiplying the accountability by purity. Though this value is not the isolable yield it is a guide as to the potential recoverability.

[d] Only unreacted starting material was recovered.

polymerization of the alkene.

When orthophosphoric acid was used in an effort to alkylate salicylic acid with 2-methyl-2-hexanol a higher accountability of product was achieved (greater than 95%) than compared to similar reactions using sulphuric acid (70%). The lower accountability with sulfuric acid is almost certainly due to the competitive side reaction of sulfonation leading to a water soluble product. However, the purity of the products obtained using orthophosphoric acid as catalyst is very low; approximately 20% of the product mixture is the desired alkylsalicylic acid, the remainder being unreacted salicylic acid. Initial reactions using 80% orthophosphoric acid at 60°C for 3 hours (standard sulfuric acid conditions) were less successful and more forcing conditions were therefore employed. The optimum result (accountability 70% and purity 22%) was obtained under the most forcing conditions of 88% orthophosphoric acid, at 110°C for 6 hours. Reactions above this temperature should have a limited affect on the reaction as the alkylating agent will still be in the vapour phase: increasing the temperature further would not be expected to be beneficial. In fact, at higher temperatures, it is likely that the alkylating agent will fragment more easily producing more volatile alkenes and carbocations which would be lost more easily from the system. Reaction time can be expected to affect the reaction as the alkylation with orthophosphoric acid appears to be much slower than using sulphuric acid. The orthophosphoric acid appears to be a less efficient catalyst for the alkylation reaction than is sulfuric acid.

A possible explanation for the lower conversion of salicylic acid to products could be the slightly lower acidity of the orthophosphoric acid when compared to the 80% sulfuric acid ($-H_o$ 4.05 and 6.97 respectively). As has been commented on, if the sulfuric acid concentration drops below 70% by volume the alkylation of salicylic acid effectively stops. This acid concentration corresponds to a $-H_o$ value of approximately 5.5, somewhat higher than that of phosphoric acid $-H_o = 4.05$. In an attempt to circumvent this problem a stronger acid with a higher $-H_o$ value was sought. Polyphosphoric acid, with a value for $-H_o$ of 5.25, although is not as high as the 80 %sulfuric acid, is the closest that fits all the other requirements.

4.1.1.3. Polyphosphoric Acid.

On attempting to alkylate salicylic acid with 2-methyl-2-hexanol using polyphosphoric acid as the catalyst, no reaction took place. This may be because of the very high viscosity of the polyphosphoric acid which prevented effective mixing of the reagents.

On separate addition of the three reagents (salicylic acid followed by polyphosphoric acid and finally 2-methyl-2-hexanol) three distinct layers were observed despite attempts at mixing. Using a stronger stirring device could have mixed the reagents together but such a piece of equipment was not available (both a magnetic flea and an overhead stirrer were used with no success). The problem of mixing meant that no further reactions were attempted using this catalyst. However, other studies have claimed that it is possible to alkylate salicylic acid with polyphosphoric acid but very forceful mixing conditions are required. Unfortunately, this result is detailed in a patent and exact experimental conditions are not given[60].

4.1.1.4. p-Toluenesulfonic Acid.

Toluenesulfonic acid is not prone to the problem of reacting with the aromatic substrate itself whilst still being a strong acid. It might, therefore, give improved yields. Since p-toluenesulfonic acid is a solid, to enable mixing of the reagents, the toluenesulfonic acid was dissolved in water (an approximate 20 mol dm^{-3} solution of p-toluenesulfonic acid in water was used). However, on using p-toluenesulfonic acid as the catalyst, salicylic acid was not alkylated, the only species detected by GC being unreacted salicylic acid and the alkylating agent 2-methyl-1-undecene.

4.1.2. Solid Acid Catalysts.

Solid acid catalysts have a number of advantages over proton acids in that they can be removed from the product mixture by simple filtration and they can then be recycled. There are currently a wide range of solid acid catalysts available for Friedel-Crafts alkylations. Of these, three solid acids were chosen for use in this study. These were Fulcat (Fullers Earth impregnated with sulfuric acid), equivalent to approximately 15% sulfuric acid, Amberlyst-15, a resin impregnated with sulfuric acid, equivalent to approximately 35% sulfuric acid, and Nafion-10, a perfluorinated resinsulfonic acid, equivalent to approximately 98% sulfuric acid.

4.1.2.1. Fulcat.

A variety of substrates were use in an attempt to alkylate salicylic acid using Fulcat as the catalyst. Initial work involved employing t-butyl methyl ether as the alkylating

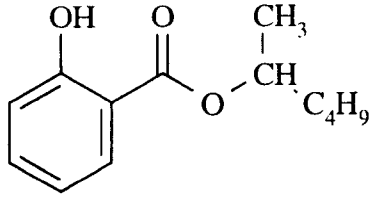
substrate as this had produced the highest accountabilities and purities of products when sulfuric acid was used. The initial reaction with t-butyl methyl ether was carried out using the standard alkylation conditions of mixing at 60°C for 3 hours employing Fulcat instead of sulfuric acid. However, under these conditions, only unreacted starting materials were recovered. Further reactions were carried out at higher temperatures and in the presence of a non-polar solvent. The addition of a non-polar solvent was an attempt to mimic the conditions employed when phenol was alkylated successfully using Fulcat as the catalyst. Under all conditions used alkylation using t-butyl methyl ether proved unsuccessful. The reaction conditions typically involved elevated temperatures (up to 100°C) in a non-polar solvent, such as toluene. The lack of alkylation may well be due to the high volatility of the ether. At the elevated temperatures it is likely that the ether would have been lost from the system.

In an attempt to prevent the loss from the system of the alkylating agent, and any possible side reactions involving the solvent, revised reaction conditions were used. These involved heating salicylic acid with one equivalent of a number of alkenes which have higher boiling points than the t-butyl methyl ether, in the presence of Fulcat at temperatures between 140 and 160°C over one hour without the presence of any solvent. At this temperature the salicylic acid will be a liquid and will therefore not require solvent to assist mixing. After one hour the reaction mixture was cooled and diethyl ether added to extract the solid product mixture from the catalyst. The catalyst was simply filtered off, the solvent removed from the filtrate and the accountability of the alkylsalicylic acid determined. In all cases the accountability varied between 70 and 95%, indicating that some of the starting material has been lost from the system (losses were greater than experimental error). The lowest accountabilities resulted using alkenes with low boiling points suggesting that they simply evaporate from the reaction system.

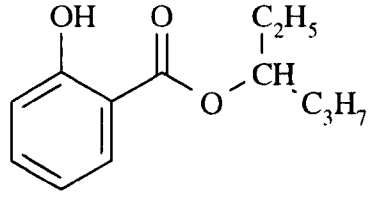
Attempt at alkylating salicylic acid with 1-hexene under the high temperature conditions for Fulcat (140-160°C for 1 hour) resulted in very little conversion of salicylic acid to products (about 1% of the product mixture was products, the rest being unreacted salicylic acid). The accountability was 70% . However, three products were detected by GC in a ratio of about 2:8:1. GC/MS analysis showed the first two products to be hexyl esters of salicylic acid. It is expected that the 1-hexene would give the 2-hexyl carbocation which could then isomerize to give the 3-hexyl carbocation. The formation of the primary 1-hexyl carbocation is not expected to be formed, so, on this basis, only products resulting

from secondary carbocations will be produced. Although the two esters could not be differentiated as they had virtually identical mass spectra, it is likely that they are the 1-methylpentyl salicylate (**44**) [2'-hexyl salicylate] and the 1-ethylbutyl salicylate (**45**) [3'-hexyl salicylate]. It is noted that a comparison of retention times with authentic samples strongly suggests that the two esters are the 2'- and 3'-hexyl salicylates. Synthesis, characterisation and identification of the esters of salicylic acid is described in Chapter 5. The remaining product was assigned the structure (**25**) [methyl 5-(1-ethylbutyl)salicylate]. If the assumption about the isomerization of initially formed secondary carbocation to the other secondary carbocation is correct, then another product, the methyl 5-(1-methyl-pentyl) salicylate would have been expected. The reason why this product is absent remains, as yet, unknown.

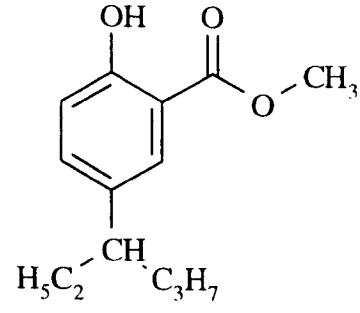
Structures 44 and 45



(44)



(45)



(25)

On using a tertiary alkene, 2-methyl-1-pentene, which has a very similar boiling point to 1-hexene, a much higher conversion of starting materials to products was observed, as can be seen from the GC/MS trace in Figure 4.1. This time the major product was the methyl 5-t-hexylsalicylate (**18**), the minor products consisting of a number of other methyl 5-hexylsalicylates and methyl dialkylsalicylates. There was no evidence for the presence of hexyl esters in this system. The product distribution as obtained by GC/MS was:

peak 1:methyl 5-t-pentylsalicylate (**22**); 4%

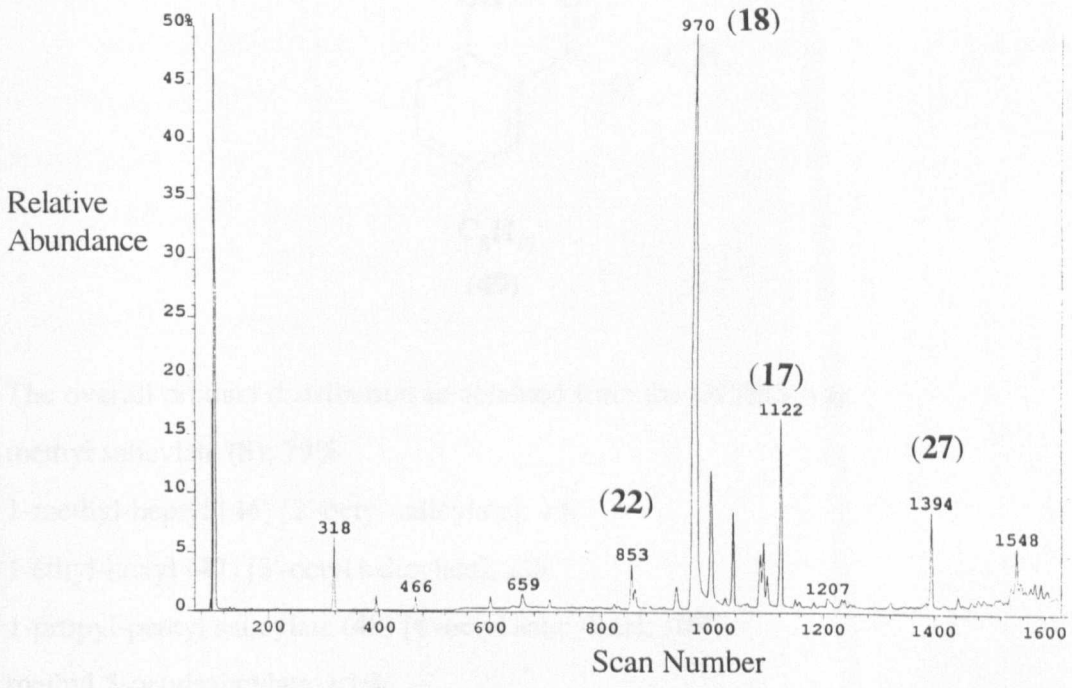
peak 2:methyl 3-t-hexylsalicylate; 2%

peak 3:methyl 5-t-hexylsalicylate (**18**); 86%

peak 4:methyl 5-t-heptylsalicylate (**17**); 5%

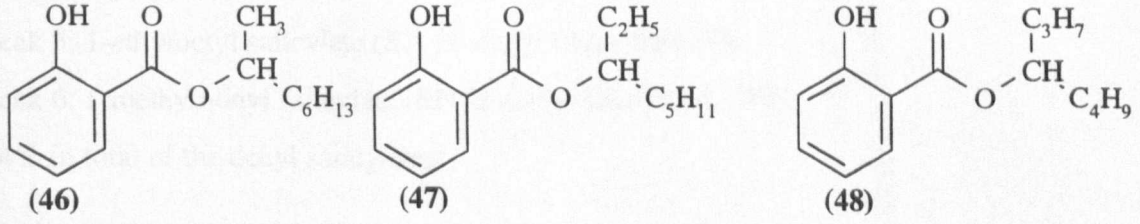
peak 5:methyl 3,5-di-t-hexylsalicylate (**27**); 3%

Figure 4.1. The GC trace (obtained from a GC/MS run) of the product mixture from the alkylation reaction using 2-methyl-1-pentene and, Fulcat as the catalyst.



Using a longer chain primary alkene, in this case 1-octene, to alkylate salicylic acid with Fulcat, under conditions identical to those employed with 1-hexene, resulted in a much higher conversion of starting materials to products (though about 80% of the product mixture is still unreacted salicylic acid). The major products were the three octyl salicylates, which each had near identical mass spectra. The three isomers (accounting for 15% of the product mixture) have been assigned, again based on the assumption that the initially formed carbocation rearranges to give the complete range of secondary carbocations, as the three secondary octyl esters, the 1-methyl-heptyl (**46**) [2'-octyl salicylate], the 1-ethyl-hexyl (**47**) [3'-octyl salicylate] and the 1-propyl-pentyl salicylate (**48**) [4'-octyl salicylate].

Structures 46-48

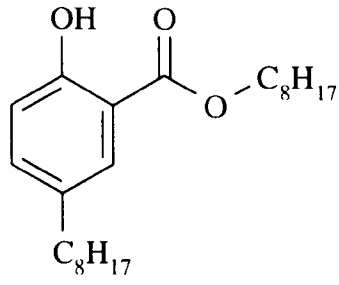


(46) **(47)** **(48)**

Also present in the product mixture, accounting for some 5% of the products, are a range of methyl octylsalicylates, including the methyl 1,1-dimethylhexyl salicylates (t-octyl) (**20**). Other very minor products included what has tentatively been identified as the octyl 5-

octylsalicylate (**49**)[<1%].

Structure 49



(49)

The overall product distribution as obtained from the GC/MS was:

methyl salicylate (**8**); 79%

1-methyl-heptyl (**46**) [2'-octyl salicylate]; 1%

1-ethyl-hexyl (**47**) [3'-octyl salicylate]; 2%

1-propyl-pentyl salicylate (**48**) [4'-octyl salicylate]; 10%

methyl 5-octylsalicylate; <1%

methyl 5-(3'-octyl)salicylate (**29**); <1%

methyl 3-(2'-octyl)salicylate; 1%

methyl 5-(2'-octyl)salicylate (**28**); 2%

octyl 5-octylsalicylate (**49**); <1%

Increasing the size of the alkene further, to 1-decene, resulted in further increased conversion of starting materials to products (about 50% of the product mixture is now salicylic acid). The product distribution obtained from the GC/MS was:

peak 1: 1-decene; 27%

peak 2: methyl salicylate (**8**); 29%

peak 3: 1-butylhexyl salicylate (**50**) [5'-decyl salicylate]; 2%

peak 4: 1-propylheptyl salicylate (**51**) [4'-decyl salicylate]; 3%

peak 5: 1-ethyloctyl salicylate (**52**) [3'-decyl salicylate]; 9%

peak 6: 1-methylnonyl salicylate (**53**) [2'-decyl salicylate]; 29%

44% in total of the decyl salicylates[e]

---

[e] The exact distribution of the decyl salicylates is not fully known. The only accurate assignment of the proportion of a given ester in the mixture is of the 4'-decyl salicylate. This was achieved by comparing retention times with an authentic sample of the 4'-decyl salicylate (see Chapter 5).

peak 7: methyl 5-(1-methylnonyl)salicylate (2'-decyl); 1%

peak 8: methyl 3-(1-methylnonyl)salicylate (2'-decyl); <1%

A similar result was observed when 1-dodecene was used, five dodecyl salicylates were observed and a very small proportion of the product mixture consisted of methyl dodecyl salicylates with one being identifiedas methyl 5-(1-methylundecyl)salicylate. The product distribution obtained from the GC/MS was:

1-dodecene; 30%

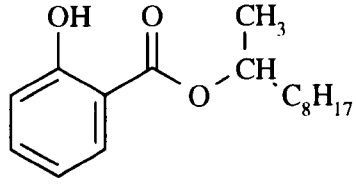
methyl salicylate (**8**); 60%

dodecyl salicylates (five isomers); 10% total

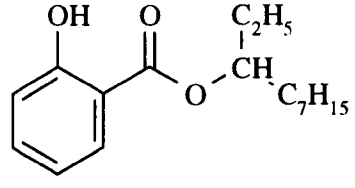
methyl 5-(1-methylundecyl)salicylate; <1%

other methyl dodecyl salicylates; <1%

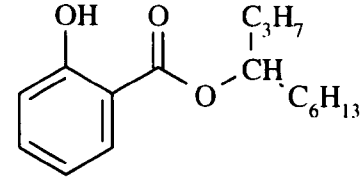
Structures 50-53



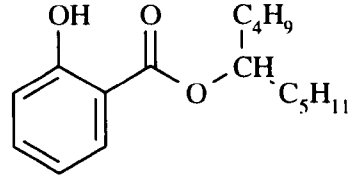
(50)



(51)



(52)



(53)

Using a branched C_{12} alkene, 2-methyl-1-undecene, at 140°C, resulted, in one major product the methyl 5-t-dodecylsalicylate (**15**) and a small amount of the alkene dimer and other methyl dodecylsalicylates. One of the methyl dodecylsalicylates would be expected to be the methyl 3-t-dodecylsalicylate and the other dodecyl species suggest rearrangement of the initially formed carbocation to either another tertiary carbocation or to a less stable secondary carbocation has taken place. No esters were observed using this alkene, in line with the observations using the other trisubstituted alkene such as, 2-methyl-1-pentene.

The results obtained using Fulcat as the catalyst differ quite significantly from those obtained when sulfuric acid is used. With sulfuric acid the lower the relative molecular mass (RMM) of the alkene the higher the accountability (the larger the mass of product recovered) and the purity. 1-Hexene gives high accountabilities and high purity of the

alkylsalicylic acid with sulfuric acid, whereas 1-dodecene gave reasonable accountabilities but very low purity of the dodecyl salicylates (standard conditions resulted in 8% of the product mixture being the dodecyl salicylates). The reverse is true when Fulcat is used, higher accountabilities and higher purities result when the larger alkenes are employed. A higher conversion of salicylic acid to alkylsalicylic acid results when 1-dodecene is used in preference to 1-hexene.

One possible explanation for this increased conversion involves the effect of temperature on the conformation of the carbocation. At low temperatures, ca. 60°C, a large secondary carbocation in a polar medium could possibly exist, structurally, effectively as a sphere, with the alkyl chain wrapping around itself. The larger the alkyl chain, the greater the chance of the positive charge being "buried" inside the sphere so reducing the availability of the carbocation centre to attack the aromatic ring. At these lower temperatures the large tertiary carbocations will be less spherical in nature, with the positive charge more easily accessible to attack the aromatic ring. However, at elevated temperatures entropic considerations would suggest that the carbocations will become less spherical and more linear in nature. This would make the positive charge on the secondary carbocations relatively more accessible. 1,2-hydride shifts will easily and rapidly move the positive charge along the chain to yield the complete range of secondary carbocations. These secondary carbocations will then attack the carboxylic acid to give the range of esters.

Another more plausible explanation to account for the increased conversion of alkenes to products using Fulcat is the reduced ability of the larger alkenes to dissolve in the sulfuric acid. At the lower temperatures, when using sulfuric acid as the catalyst, it is unlikely that the larger alkylating agents will be completely soluble or mobile in the sulfuric acid. As the temperature is increased solubility and mobility will increase. Therefore, at the lower temperatures the reactions involving the higher molecular weight substrates is more likely to take place at the phase boundary than in the body of the liquid. Reaction at the phase boundary will disfavour alkylation because there is a limited amount of surface area of the alkylating agent in contact with the salicylic acid. Instead competing reactions such as polymerization, fragmentation, isomerization will be favoured. However, when Fulcat is employed as the catalyst there should be no mixing or solubility problems and so higher purities of products should result.

One competing reaction of the alkylation of the aromatic ring of salicylic acid is the attack at the carboxylic acid function to form the esters. These appear to be formed in

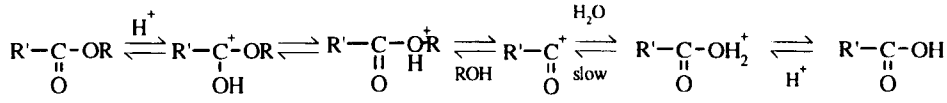
significant amounts in the Fulcat systems but only in trace quantities and under mild conditions with sulfuric acid. It appears that the ester is the kinetically controlled product whereas the alkylsalicylic acid is the thermodynamically controlled one.

Before any explanation is given as to the difference between the catalysts, a brief introduction into ester hydrolysis is appropriate. Eight mechanisms for ester hydrolysis (and formation since these are reversible reactions and must therefore have the same mechanism) have been postulated by Ingold[85]. They are classified as either 1) acid or base catalysed, 2) unimolecular or bimolecular and 3) acyl or alkyl cleavage. Since the system under investigation involves acidic conditions, only the acid catalysed mechanisms will be discussed. The four possibilities are set out in Scheme 4.2.

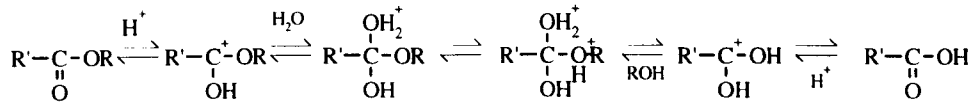
Scheme 4.2.

Type

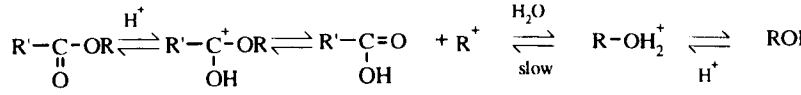
AAC1



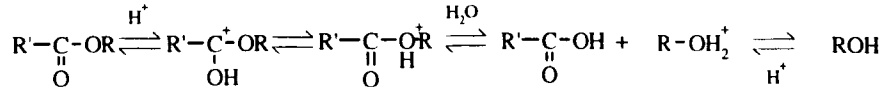
AAC2



AAL1



AAL2

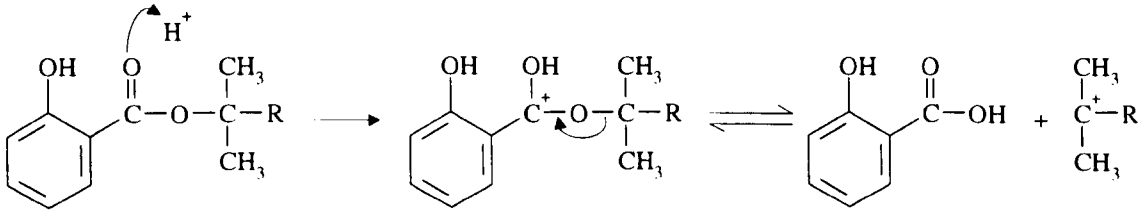


Of these four mechanism, one the AAL2, has never been observed and will not be discussed further. This now leaves three possible mechanisms. Of these the AAC1 is rarely observed, only being found when R is very bulky. Of the two remaining acid catalysed mechanisms, the AAL1 is favoured when R can form a stable carbocation and the AAC2 occurs in practically all other cases. A detailed review on ester hydrolysis can be found in "Comprehensive Chemical Kinetics"[86] and this covers in detail the various factors that affect the mechanisms.

The proposed deesterification mechanism when tertiary carbocation can be formed involves the tertiary alkyl group being lost rapidly from the ester to give the stable tertiary

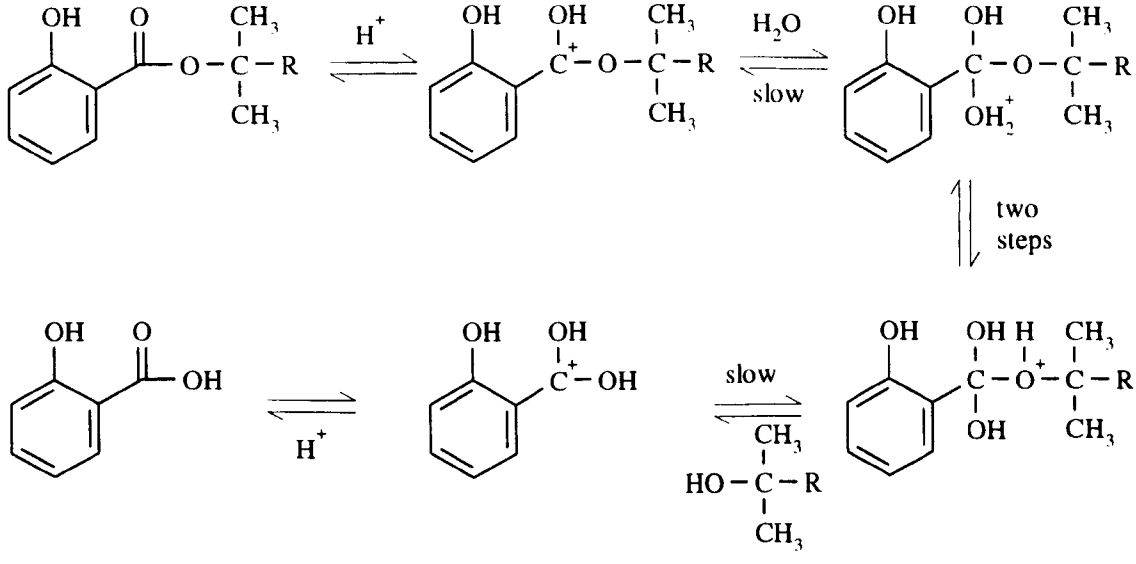
The proposed deesterification mechanism when tertiary carbocation can be formed involves the tertiary alkyl group being lost rapidly from the ester to give the stable tertiary carbocation, as shown in Scheme 4.3 (AAL1). The formation of the tertiary ester is completely reversible whereas the formation of the alkylsalicylic acid is effectively irreversible under these conditions, so the acid is the major product. This elimination of the alkyl group from the ester does not occur as readily with secondary alkyl groups because of the lower stability of the secondary carbocation which disfavours elimination.

Scheme 4.3.



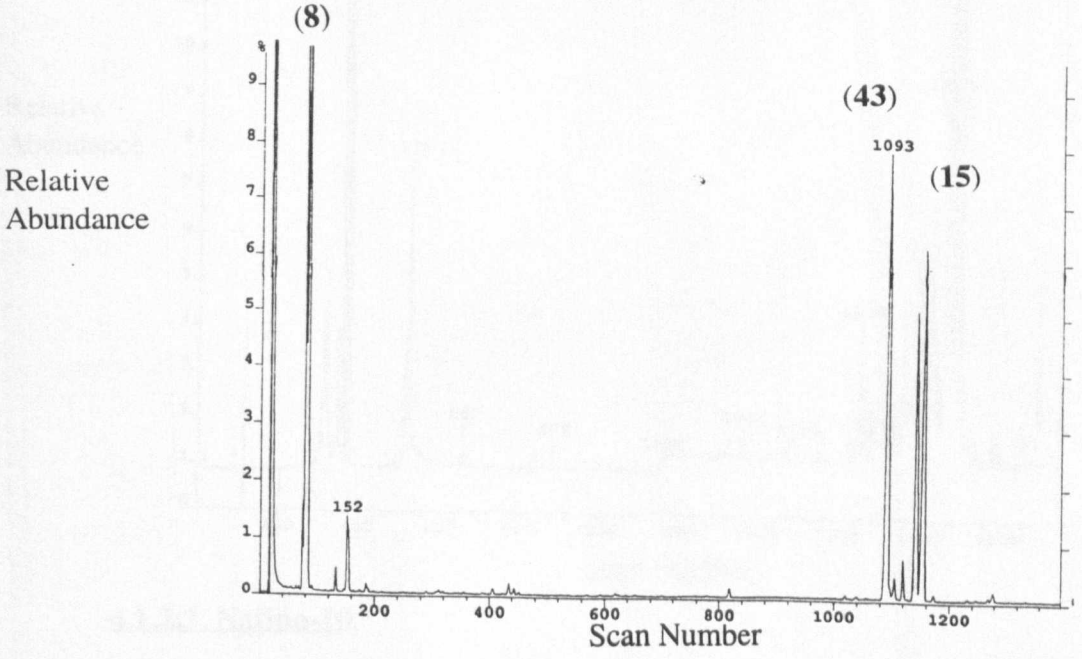
When Fulcat is used as the catalyst, there should be no water present in the reaction system. If water was present in the system, the rearrangement of the ester might well proceed via an alternative mechanism, (AAC2 [Scheme 4.4]). This would enhance the ability for a secondary alkyl group to be lost from the ester. Hydrolysis of the ester by this route should involve less differences between secondary and tertiary esters. This will be the case when sulfuric acid is the catalyst, which is probably why the formation of salicylic acid esters is typically not observed in that reaction.

Scheme 4.4.



A Fulcat catalysed reaction with 2-methyl-1-undecene at 60°C demonstrated that esters from tertiary carbocations can be formed. Small quantities of three compounds in addition to unreacted starting materials, as can be seen from the GC/MS trace (Figure 4.2). The three products which accounted for ca. 5% of the product mixture were identified from their mass spectra as the dodecyl salicylate (**43**), the alkene dimer, and the methyl 5-(1,1-dimethyldecyl) salicylate (**15**). Based on the mass spectrum it is impossible to say if the dodecyl ester was formed by the attack of the 2-methyl-2-undecyl carbocation, another tertiary carbocation, or by the attack of a secondary dodecyl carbocation formed from the rearrangement of the initially formed tertiary carbocation. However, as only a single isomer appears to be formed, it is assumed that the ester is the 1,1-dimethyldecyl salicylate (**54**). It should be noted that no water is present and carrying out the reaction at low temperature is conducive to helping the ester survive.

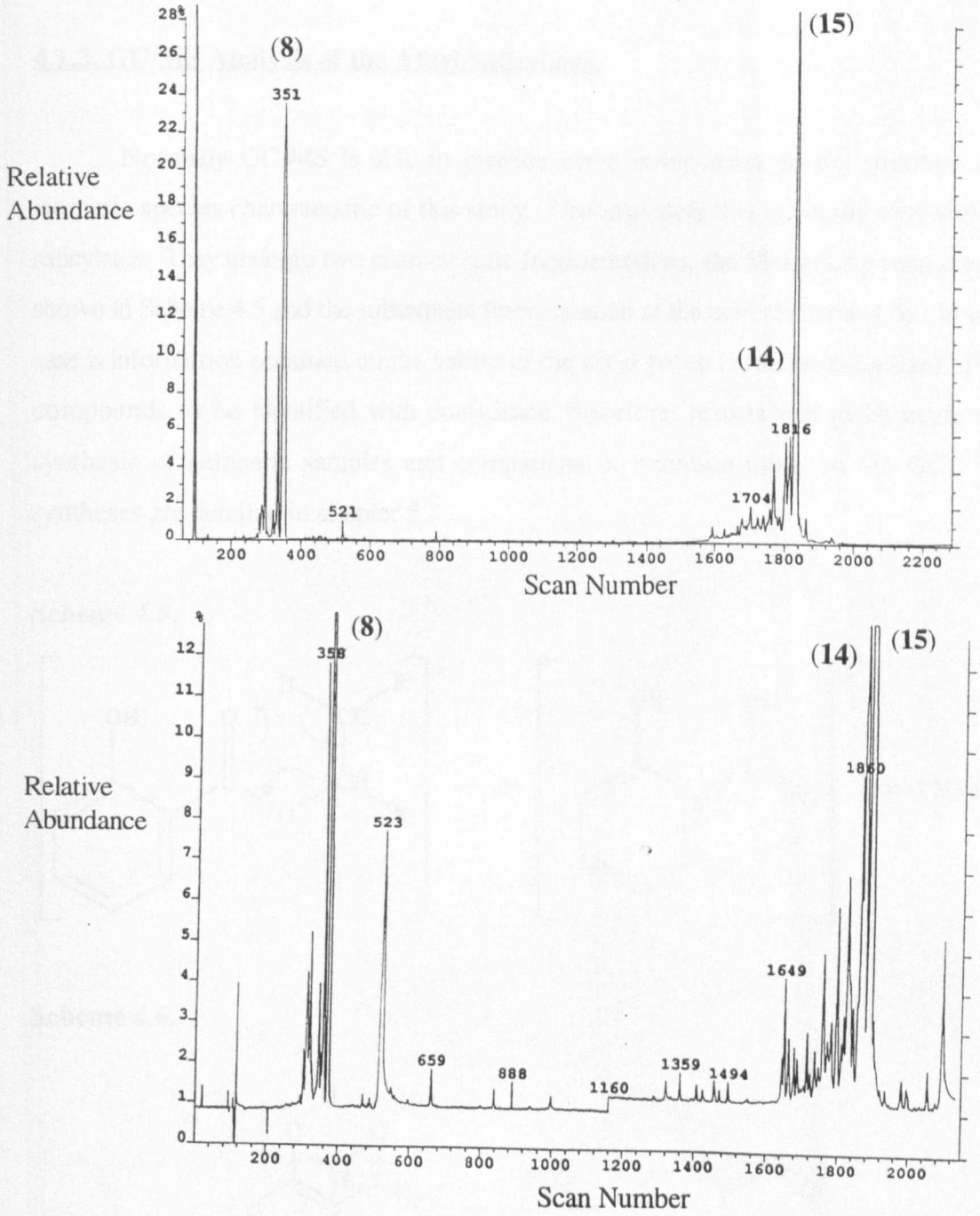
Figure 4.2. GC trace (obtained from a GC/MS run) of the product mixture from the alkylation of salicylic acid with 2-methyl-1-undecene and Fulcat at 60°C.



4.1.2.2. Amberlyst 15

Alkylating salicylic acid using Amberlyst 15 gave very similar results to those obtained when Fulcat was used (a comparison of the results when the alkylating substrate was used with either Fulcat or Amberlyst can be seen in Figure 4.3). Again, the maximum accountability obtained with using either Fulcat or Amberlyst at 140°C was 90%.

Figure 4.3. GC trace (obtained from GC/MS runs) of the product mixtures from the alkylation of salicylic acid using (a) Fulcat and (b) Amberlyst 15.



4.1.2.3. Nafion-10.

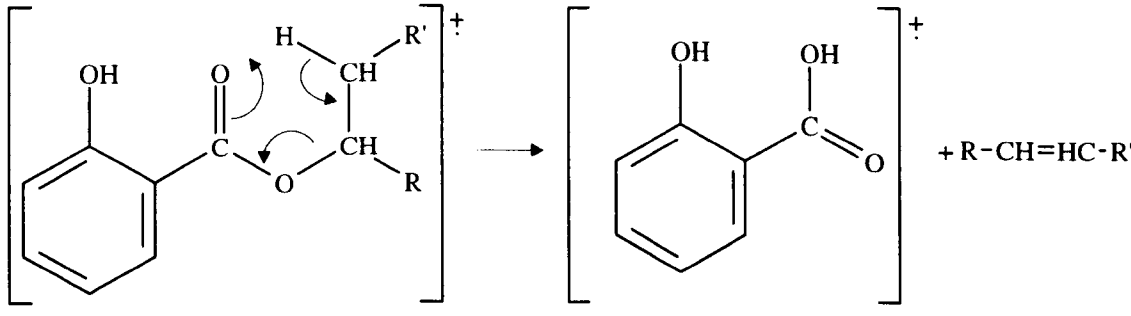
Nafion-10 is a much stronger solid acid catalyst ($-H_o$ = 11-13) and was used with t-butyl methyl ether in an attempt to alkylate salicylic acid, employing a range of temperature conditions from 60°C to 120°C, but with no success. It was thought that a stronger acid would help to promote the formation of carbocations and consequently lead to good conversion to alkylsalicylic acids. It was thought beneficial that the salicylic acid should be in the liquid rather than the solid phase. At 125°C this would not be the case. The safe

operating temperature for this catalyst was 125°C, beyond which, it begins to decompose[87], no further reactions were carried out with the larger alkylating agents.

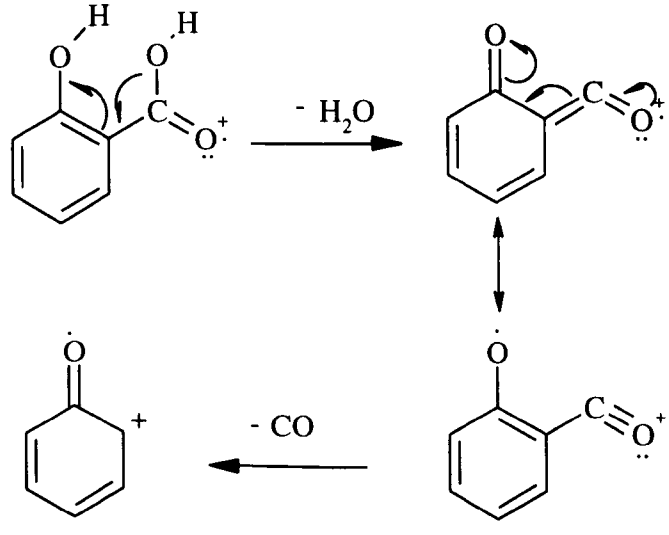
4.1.3. GC/MS Analysis of the Alkyl Salicylates.

Normally GC/MS is able to provide some information on the structure of the isomeric species characteristic of this study. Unfortunately this is not the case with alkyl salicylates. They undergo two characteristic fragmentations, the McLafferty rearrangement shown in Scheme 4.5 and the subsequent fragmentation of the acid (Scheme 4.6). In neither case is information obtained on the nature of the alkyl group (apart from its size). For the compounds to be identified with confidence, therefore, resorts had to be made to the synthesis of authentic samples and comparison of retention times on the GC. These syntheses are detailed in chapter 5.

Scheme 4.5.



Scheme 4.6.



4.2. The Effect of Temperature on the Alkylation Reaction

As has been noted previously, increasing the reaction temperature has a relatively smaller effect on the rate of sulfonation than does increasing the acid concentration[65]. It is possible that alkylating salicylic acid at lower temperatures might well give rise to a higher accountability of products and possibly less rearrangement of the initial carbocations. A study was therefore carried out into the effect of temperature on the product distribution. The results from a series of experiments at different temperatures but otherwise employing standard conditions are set out in Table 4.2. (for the secondary alkylating agents) and Table 4.3 (for tertiary alkylating agents).

Table 4.2. The effect of varying the reaction temperature on the accountability and purity of alkylation products when primary alkenes are used.

Alkylating Agent	Temperature °C	Accountability %	Purity %	Overall yield
1-hexene	20	100%	41%	41%
1-hexene	30	96%	61%	59%
1-hexene	40	95%	50%	48%
1-hexene	55	79%	57%	45%
1-hexene	60	45%	43%	19%
1-dodecene	20	91%	trace	trace
1-dodecene	55	79%	trace	trace
1-dodecene	60	70%	8%[f]	6%

As can be seen from the 1-hexene results, as the reaction temperature increases accountability falls, suggesting that some of the alkene had been lost from the system. This loss could be due to two factors; one is the loss of the alkene either by direct evaporation or more likely by fragmentation of the initial carbocation to give smaller carbocations and even more volatile alkenes which will be more readily lost from the reaction system (entropic factors would favour the fragmentation). However, the fragmentation of these primary alkenes, resulting in the formation smaller chained alkylsalicylic acids is never seen

[f] The products are the dodecyl esters of salicylic acid and not the methyl dodecyl salicylates.

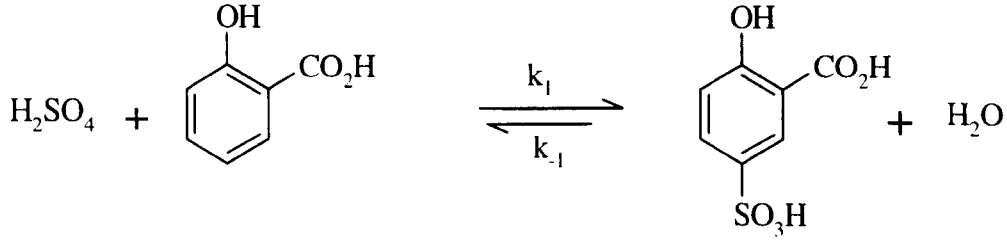
to any significant extent. The other, more likely factor, is that the salicylic acid has been sulfonated and so, on work up, some of the product is lost as the water soluble sulfosalicylic acid. The purity of the products is optimal at 30°C and falls as the temperature is increased. One possible explanation is the fragmentation of the carbocation. At elevated temperatures the fragmentation of the carbocations will occur more easily and much faster, resulting in an increased loss from the system of the hexene. Interestingly, at low temperatures, 20°C, using 1-hexene, a small percentage of the product mixture (approximately 1%) is the hexyl salicylate and not the hexylsalicylic acid.

Reacting octene at 20°C did not result in such a high accountability as when hexene was used, but on increasing the reaction temperature to 65°C, an improvement in both accountabiltiy and purity was noted. As was the case with hexene, reacting octene at 20°C produced a small amount of octyl salicylate in the product mixture (approximately 1%). The increase in the purity of the alkylsalicylic acids is thought possibly to be due to the unravelling of the alkene to a more linear structure at the elevated temperature. This would enable the carbocation centre to more easily attack the aromatic ring, increasing both the purity of alkylsalicylic acids and the accountability. The overall accountability is controlled primarily by two equilibrium reactions; the sulfonation and desulfonation of the aromatic ring (Scheme 4.7.), and the alkylation and dealkylation of the aromatic ring. Other reactions, such as the formation of alkylsulfonate esters and the alkene polymers, will also effect the accountability.

The larger alkene, 1-dodecene, behaves in a similar manner. As the temperature increases the recoverability drops. The major difference between the majority of the other reactions and those employing 1-dodecene was the formation of the dodecyl esters rather than the dodecylsalicylic acids, albeit in very low yields. The reason for the occurrence of the dodecyl salicylate is thought to be a combination of two factors; the stability of the secondary carbocation, and the size of the dodecyl chain. As has already been commented on, the ester is thought to be the kinetically controlled product which rearranges to give the alkylsalicylic acid. However, the instability of the secondary dodecyl carbocation compared to a tertiary carbocation would disfavour elimination by the AAL1 route, and because of its size it would inhibit the attack by the water molecule in the AAC2 mechanism, and so the ester is observed at the end of the reaction. The low purity is thought to involve the lower solubility of the larger alkene in the sulfuric acid which would reduce the probability of the alkene reacting with the salicylic acid.

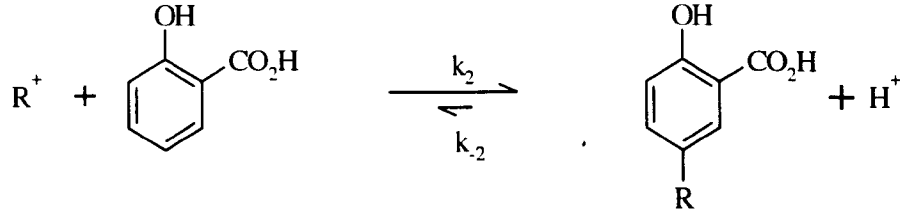
As has been commented on before, the reversibility of the sulfonation reaction depends on both temperature and acid concentration. The higher the temperature and the higher the acid concentration, the more the equilibrium is shifted to the right hand side, so in effect the reaction is irreversible. Also, as the temperature and acid concentration are increased, the overall accountability of the sulfosalicylic acid increases.

Scheme 4.7.



From the reactions undertaken ,the overall alkylation/dealkylation equilibrium lies firmly on the side of formation of the alkylsalicylic acid ($k_2 \gg k_{-2}$), with both k_2 and k_{-2} being highly dependent on the alkylating agent (Scheme 4.8). The dealkylation of salicylic acid and its implications will be discussed in more detail in the following section.

Scheme 4.8.



The effect of temperature on the accountability and purity of products obtained with tertiary alkenes can be very dramatic, as is the case with 2-methyl-1-pentene. Here there appears to be a cut off point (>40°C) at which the accountability and purity of products drops dramatically. A possible explanation for this cut off is the ease of fragmentation of the initial carbocation to form smaller carbocations which will be more easily lost from the system, resulting in both the low accountability and purity.

In comparison, this dramatic cut off is not observed when 2-methyl-1-undecene is used under the same reaction conditions because it is less likely to fragment to give the smaller carbocations which could be lost from the reaction system. The carbocations that are likely to be formed on fragmentation could be larger compared to the ones formed from 2-methyl-1-pentene and consequently will be less volatile, so they will have a greater chance of reacting before being lost from the system. The optimum overall yield for 2-methyl-1-

undecene was obtained when the reaction temperature was 60°C. Above this temperature, there is a fall in the accountability, probably because of an increased rate of sulfonation. Howeve,r the purity of the isolated products remained approximately constant, possibly because the equilibrium between the various competing reactions is reached at these temperatures. The reactions undertaken at lower temperatures resulted in lower purities of the 5-alkylsalicylic acid, possibly because of the structural configuration of the carbocation (spherical, with the carbocation centre buried inside the sphere). However, it is more likely that the lower solubility of the alkene in the sulfuric acid at the reduced temperature will result in the lower purity of products, because the carbocations will not be in close enough proximity to the salicylic acid to react.

Table 4.3. The effect of temperature on the accountability and purity of products when tertiary alkenes are used as alkylating agents.

Alkylating Agent	Temperature °C	Accountability %	Purity %	Overall yield
2-methyl-1-pentene	20	99%	55%	54%
2-methyl-1-pentene	30	88%	43%	38%
2-methyl-1-pentene	40	86%	39%	34%
2-methyl-1-pentene	60	27%	3%	1%
2-methyl-1-pentene	70	28%	4% t-butyl	-
2-methyl-1-undecene	20	98%	11%	11%
2-methyl-1-undecene	40	95%	47%	45%
2-methyl-1-undecene	50	98%	53%	52%
2-methyl-1-undecene	60	87%	76%	66%
2-methyl-1-undecene	65	89%	60%	53%
2-methyl-1-undecene	75	71%	71%	50%
2-methyl-1-undecene	90	68%	75%	51%

The effect of temperature can be even more dramatic when the more substituted alkenes are employed as substrates. This was well demonstrated when 3,3-dimethyl-1-butene, 2,4,4-trimethyl-1-pentene and 2,4,4-trimethyl-2-pentene were employed as substrates to alkylate salicylic acid.

Table 4.4. shows the product distribution when salicylic acid is alkylated at (60°C and 0°C) using 3,3-dimethyl-1-butene as the reagent. The results from the reaction at 60°C

have been detailed in Chapter 3 section 3.4.1.3. However, on lowering the temperature to 0 °C a different distribution of products is observed. The major differences probably stem from the reduced temperature resulting in less isomerization and fragmentation and a resultant higher selectivity. At the lower temperature the general rate of all the reactions would be expected to be slower, with the likely result being a higher proportion of unreacted starting materials.

A major difference in the product distribution is observed when 2,4,4-trimethylpentenes are used to alkylate salicylic acid, under similar conditions, Table 4.5. As can be clearly seen from the results at the elevated temperature a much higher proportion of methyl 5-t-butylsalicylate results. This is formed by the very favourable tertiary β-scission of the 2,4,4-trimethyl-2-pentyl carbocation to give isobutene and the t-butyl carbocation (Scheme 4.7). At the lower temperature there is a much higher proportion of di-t-butylsalicylic acid and t-nonylsalicylic acid with other higher molecular weight species also present. These are probably due to the lower solubility of the alkene at the lower temperatures, so on protonation the carbocation formed is now more likely to react with an alkene than with the salicylic acid to produce a higher molecular weight carbocation and therefore ultimately a higher molecular weight alkylsalicylic acid. The GC/MS trace of the products from the alkylation of salicylic acid at 0°C, is shown in Figure 4.4.

Table 4.4. The product distribution when salicylic acid is alkylated under standard alkylating conditions (60°C and 0°C) using 3,3-dimethyl-1-butene as the substrate[g].

Product	% at 60°C	% at 0°C
methyl salicylate (**8**)	24%	48%
methyl 5-t-butylsalicylate (**9**)	19%	9%
methyl 5-t-pentylsalicylate (**20**)	7%	3%
methyl 5-(1,1,2-trimethylpropyl)salicylate (**36**)	29%	37%
methyl 3-(1,1,2-trimethypropyl)salicylate (**37**)	4%	-
methyl 5-hexenylsalicylate (**38**)	4%	-
methyl 3-t-butyl-5-hexenylsalicylate (**39**)	3%	-
methyl 3-(1,1,2-trimethylpropyl)-5-hexenylsalicylate (**40**)	9%	2%
methyl 5-dodecylsalicylate (**15**)	-	1%

[g] See chapter 3 for the identification of these products.

Scheme 4.9.

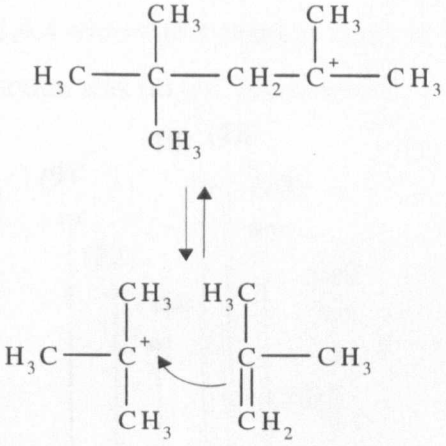
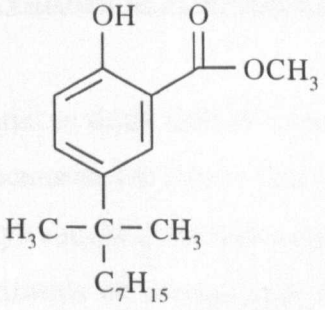


Table 4.5. The product distribution when salicylic acid is alkylated under standard alkylating conitions (60°C and 0°C) using 2,4,4-trimethyl-1-pentene as the substrate.

Product	% at 60°	% at 0°C
methyl 5-t-butylsalicylate (**9**)	84%	13%
methyl 5-t-pentylsalicylate (**22**)	9%	10%
methyl 5-t-hexyl salicylate (**16**)	2%	8%
methyl 5-t-octylsalicylate (**20**)	<1%	-
methyl 3,5-di-t-butylsalicylate (**10**)	<1%	15%
methyl 5-t-nonylsalicylate (**12**);	<1%	22%
methyl 5-(decyl)salicylate (**55**)	-	13%
methyl 5-(t-undecyl)salicylate (**14**)	-	3%
methyl 5-(t-tetradecyl)salicylate (**56**)	-	8%

Structures 55 and 56



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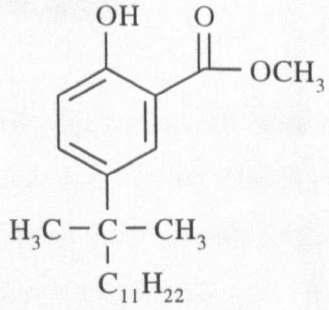
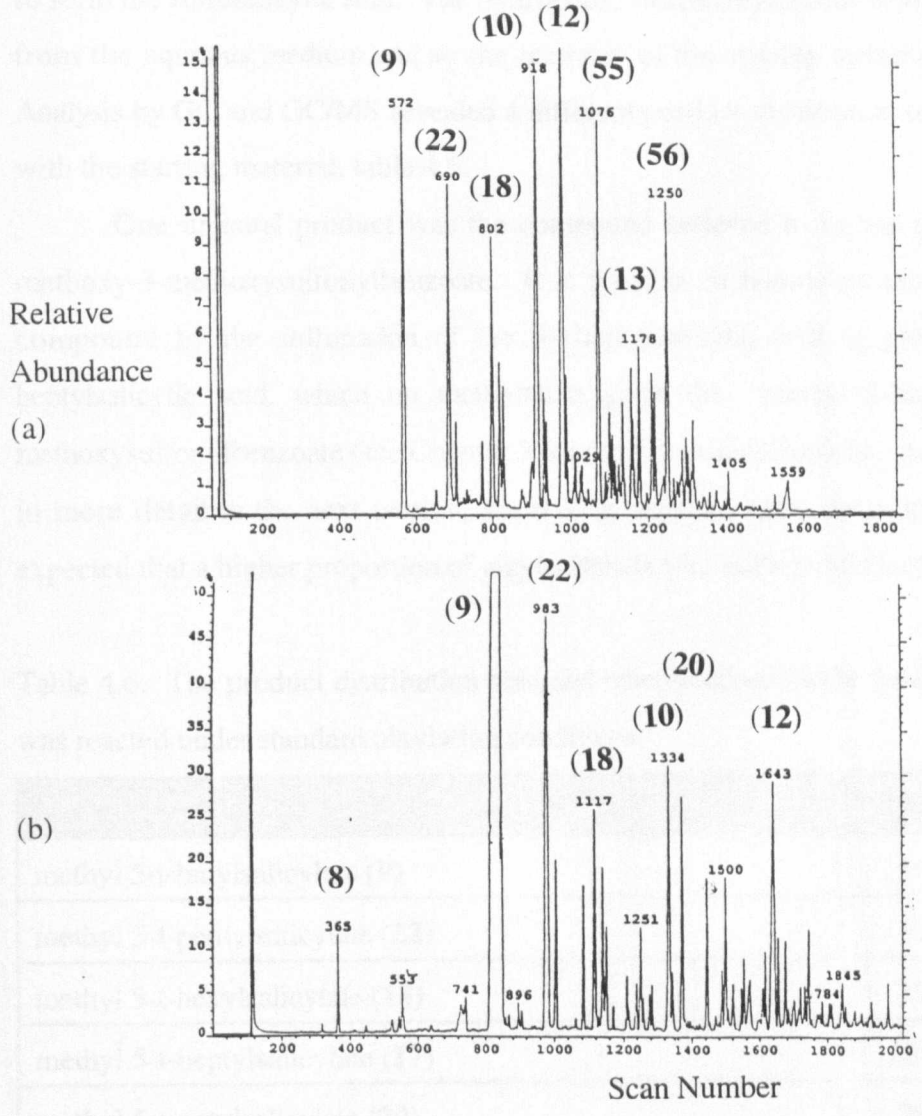


(56)

Figure 4.4. The GC trace (obtained from a GC/MS run) of the product mixture from the alkylation reaction, using 2,4,4-trimethyl-1-pentene under standard conditions, except that the temperature of the reaction was (a) 0°C and (b) 60°C.



4.3. The Dealkylation of Alkylsalicylic Acids.

The potential to dealkylate an aromatic ring has already been mentioned (Chapter one) and is well documented in Friedel-Crafts chemistry. In an attempt to ascertain whether dealkylation of alkylsalicylic acids was a significant problem under the reaction conditions, a series of experiments on alkylsalicylic acids were carried out. A sample containing predominantly 1,1-dimethylpentylsalicylic acid (t-heptyl)[h] was reacted under standard

[h] As has already been noted purifying the alkylsalicylic acids has not been very easy and so a sample containing predominately the heptylsalicylic acid was used.

alkylating conditions (stirring at 60°C for three hours in 80% sulfuric acid) to see if dealkylation did take place. On work up not all the starting material was recovered (65% recovery) suggesting that the alkylsalicylic acid had been dealkylated and then sulfonated to form the sulfosalicylic acid. The hydrophilic sulfosalicylic acid would not be extracted from the aqueous medium and so the recovery of the starting material would be lower. Analysis by GC and GC/MS revealed a different product distribution to the one obtained with the starting material, table 4.6.

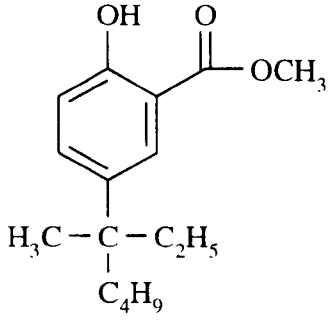
One unusual product was the compound believed to be the methyl 5-heptyl-2-methoxy-3-methoxysulfonylbenzoate. It is possible to rationalise the formation of this compound by the sulfonation of the 5-t-heptylsalicylic acid to give the 3-sulfo-5-t-heptylsalicylic acid, which on methylation gives the methyl 5-heptyl-2-methoxy-3-methoxysulfonylbenzoate (see Chapter 3 for the full rationalisation). As will be discussed in more detail in the next section, when long reaction times are employed it would be expected that a higher proportion of alkylsulfosalicylic acids would be formed.

Table 4.6. The product distribution obtained when predominately 5-t-heptylsalicylic acid was reacted under standard alkylating conditions.

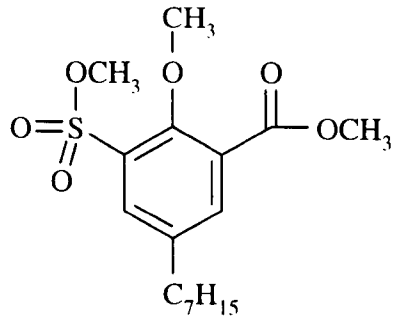
Product	% Before	% After
methyl 5-t-butylsalicylate (**9**)	1%	2%
methyl 5-t-pentylsalicylate (**22**)	1%	2%
methyl 5-t-hexylsalicylate (**18**)	2%	2%
methyl 5-t-heptylsalicylate (**17**)	65%	45%
methyl 5-t-octylsalicylate (**20**)	2%	1%
methyl 5-(1-methyl-1-ethylpentyl)salicylate (**57**)	1%	1%
methyl 5-heptyl-2-methoxy-3-methoxysulfonylbenzoate[i] (**58**)	-	37%
methyl 5-decylsalicylate (**59**)	15%	-
methyl 3,-5-diheptylsalicylate (**21**)	1%	-

[i] The methyl 5-heptyl-2-methoxy-3-methoxysulfonylbenzoate is only suspected based on its mass spectral fragmentation pattern and a knowledge of the starting material.

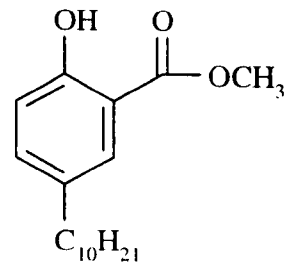
Structures 57-59



(57)



(58)



(59)

To ascertain if only dealkylation followed by realkylation occurred, or transalkylation took place, a mixture of 5-t-butylsalicylic acid and 3,5-di-t-butylsalicylic acid was reacted under standard alkylating conditions in the presence of 3-methylsalicylic acid. The distribution of the mixture containing the t-butylsalicylic acid and the di-t-butylsalicylic acid by GC (of the corresponding methyl esters) was:

salicylic acid; 2%

5-t-butylsalicylic acid; 90%

3,5-di-t-butylsalicylic acid; 8%

Recovery (25%) was low, suggesting that extensive sulfonation of at least the 3-methylsalicylic acid might have occurred. The electron donating effect of the methyl group in the 3-methylsalicylic acid would enhance somewhat electrophilic sulfonation compared to salicylic acid. Sulfonation would also be more favourable with the 3-methylsalicylic acid than the 5-t-butylsalicylic acid because of steric factors. Analysis by GC and GC/MS showed that there was some methyl 3-methyl-5-t-butylsalicylate present, confirming that either transalkylation or realkylation had occurred.

The distribution of the products after the reaction with 3-methylsalicylic acid, identified by GC/MS, was:

peak 1: methyl salicylate (**8**); 17%

peak 2: methyl 3-methylsalicylate (**60**); 34%

peak 3: methyl 5-t-butylsalicylate (**9**); 21%

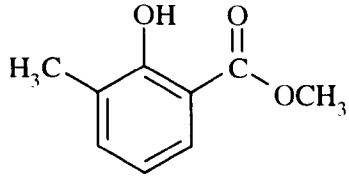
peak 4: methyl 3-methyl-5-t-butylsalicylate (**61**); 11%

peak 5: methyl 3,5-di-t-butylsalicylate (**10**); 4%

peak 6: unidentified; 7%

peak 7: unidentified; 6%

Structures 60 and 61



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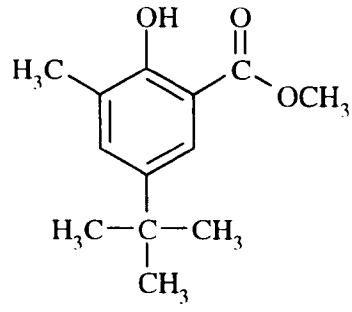

(61)

The presence of such a high proportion of methyl salicylate in the GC analysis confirms that dealkylation of alkylsalicylic acids can take place, either by the formation of a free carbocation or by direct transfer of the alkyl group to a neighbouring ring. The dealkylation reaction further complicates the analysis of the product distribution.

4.4. The Effect of Reaction Time on the Alkylation Reaction.

Of the three reaction parameters that were varied, the effect of altering the reaction time has the least impact on the accountability and purity of products when the other parameters remained constant, as can be seen from Table 4.7. The hexene results show the general trend that as the reaction time is increased the purity of the 5-alkylsalicylic acid and the 3,5-dialkylsalicylic acid increases. These results suggest that the sulfonation and alkylation equilibria do exist under the reaction conditions, with the desulfonation step likely to be faster than the dealkylation step, resulting in a higher proportion of the alkylsalicylic acids with the longer reaction times. However, the solution is not as clear cut for the 2-methyl-1-undecene results.

Table 4.7. The effect of reaction duration on the accountability and purity of products when 1-hexene and 2-methyl-1-undecene are used as substrates.

Alkylating Agent	Duration /hours	Accountability %	Purity %	Overall yield
1-hexene[j]	1.5	90%	30% 8%di[k]	27%
1-hexene	3	100%	41% 15%di	41%
1-hexene	15	96%	53% 24%di	51%
2-methyl-1-undecene[l]	2	75%	71%	53%
2-methyl-1-undecene	3	87%	76%	66%
2-methyl-1-undecene	8	73%	60%	44%
2-methyl-1-undecene	18	70%	83%	58%

Reactions involving a third alkene, 1-dodecene, were also carried out. Previously, when 1-dodecene was used as the alkylating agent the only products observed were the dodecyl salicylates. On increasing the reaction duration to 18 hours, the accountability dropped dramatically and two groups of products were observed by GC. The first of these groups was identified as the dodecylsalicylic acids whilst the other group has been tentatively identified as the alkyl sulfates. There was no evidence for any unreacted salicylic acid. The long reaction duration allows the equilibrium between the formation of the alkylsalicylic acids and the formation and subsequent conversion of the alkyl salicylates to lie firmly on the side of the alkylsalicylic acid. So now, the thermodynamically favoured product, the dodecylsalicylic acid, rather than the kinetically favoured product, the dodecyl salicylate, is formed. The alkyl sulfates arise from the reaction between the sulfuric acid and the alkene. It is not understood why the alkyl sulfates are now present in such large quantities, but one possible explanation could be due to the lower solubility of the dodecene in the sulfuric acid. The lower solubility would mean that the dodecene is less likely to react with the salicylic acid and more likely with itself. The larger alkylsulfates are less likely to be water soluble and are therefore, more likely to be observed than the smaller more water

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[j] All 1-hexene reactions carried out at 20°C.

[k]The first number corresponds to the percentage of the hexylsalicylic acids present in the product mixture and the second number corresponds to the percentage of dihexylsalicylic acids in the product mixture.

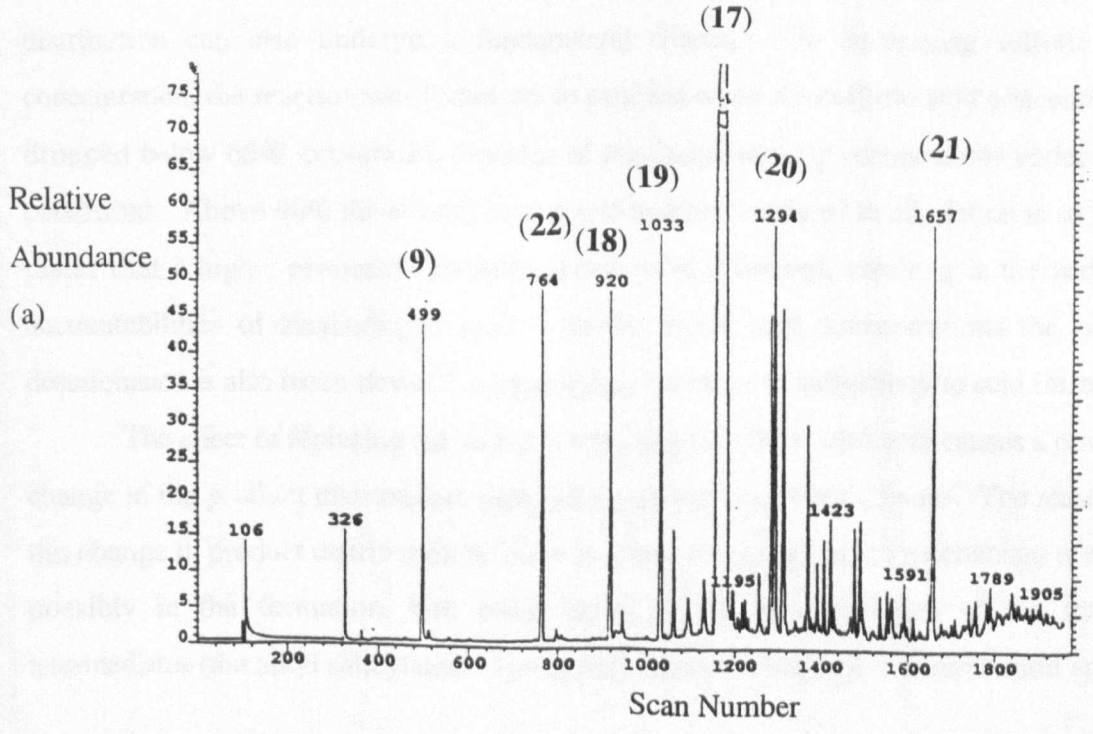
[l] All 2-methyl-1-undecene reactions carried out at 60°C.

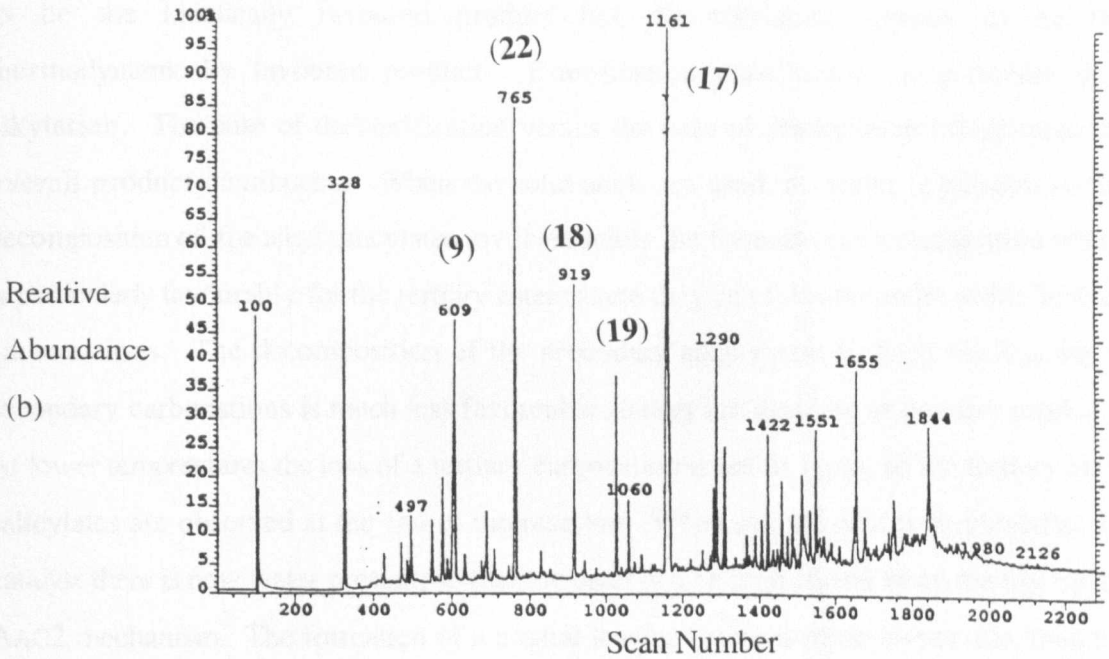
soluble ones.

There is one important point to make about the reaction duration and that is the time the salicylic acid and sulfuric acid are reacted together before the addition of the alkylating agent. Two reactions were carried out using 2-methyl-2-hexanol, salicylic acid and the sulfuric acid under identical conditions. One was left for 90 minutes before the addition of the 2-methyl-2-hexanol, whilst in the other case the alcohol was added immediately. For the reaction in which the two acids were allowed to stand for 90 minute before the addition of the alcohol, the accountability was 34% compared to 70% when the alcohol was added straight away to the sulfuric/salicylic acid mixture. This is consistent with competition between sulfonation of the aromatic ring and alkylation. Sulfonation now has a head start.

The percentage of the desired product, the 5-t-heptylsalicylic acid, in the product mixture is 20% for the reaction which had the alkylating agent added after 90 minutes compared to 47% for the reaction when the alkylating agent was added straight away. The GC/MS traces in Figure 4.5. show very clearly that the product distribution has changed quite dramatically.

Figure 4.5. The GC/MS traces of the product mixture from the alkylation of salicylic acid using 2-methyl-2-hexanol under standard alkylating conditions (a) with direct addition of the alcohol and (b) where the addition of the alcohol was delayed 90 minutes.





4.5. Conclusions.

Varying the reaction conditions has a significant effect on the accountability and purity of the alkylsalicylic acids. To achieve optimum accountabilities requires a careful balance of three parameters; catalyst (acid concentration or type employed), temperature, and duration of reaction. Altering one parameter may have a positive effect on the accountability or on the purity but seldom on both.

The most important parameter seems to be the catalyst used. The accountability when the sulfuric acid concentration is altered is particularly affected. But the product distribution can also undergo a fundamental change. On decreasing sulfuric acid concentration, the reaction was found not to proceed when the sulfuric acid concentration dropped below 65%, presumably because of the failure to form carbocations under these conditions. Above 90% the overall rate of sulfonation compared to alkylation is so much faster that a higher proportion of sulfosalicylic acid is formed, resulting in the very low accountabilities of alkylsalicylic acids. At the higher acid concentrations the rate of desulfonation is also much slower[74], compounding the effect of sulfosalicylic acid formation.

The effect of replacing the sulfuric acid catalyst with a solid acid causes a dramatic change in the product distribution, especially with the secondary alkenes. The reason for this change in product distribution is likely to involve a change in the mechanism involved possibly in the formation, but, more likely, in the decomposition of the reaction intermediates (the alkyl salicylates). Under the conditions employed esterification appears

to be the kinetically favoured product but the alkylation appears to be the thermodynamically favoured product. Esterification must occur more rapidly than alkylation. The ease of deesterification versus the ease of dealkylation will control the overall product distribution. When the solid acids are used, no water is present, so the decomposition of the alkyl salicylates involves solely the formation of a carbocation which is particularly favourably for the tertiary esters since they can form the more stable tertiary carbocations. The decomposition of the secondary alkyl esters to form the less stable secondary carbocations is much less favourable so they are detected as primary products. At lower temperatures the loss of a tertiary carbocation is not as rapid, so the tertiary alkyl salicylates are observed at the end of the reaction. When sulfuric acid is employed as the catalyst there is now water present, so that the ester can be hydrolysed more readily by the AAC2 mechanism. The formation of a neutral leaving group is more favourable, then the loss of a carbocation, so the secondary alkyl salicylates decompose back more easily to the salicylic acid and an alcohol. The overall result is that the alkylsalicylic acids are the observed products. The rearrangements of the esters of salicylic acid will be discussed in detail in the next chapter.

Altering the temperature does not have such a dramatic effect on the distribution of products as does changing the catalyst concentration. The change in accountability from varying the temperature is probably due to variation in the equilibria that are set up between the sulfonation and the alkylation reactions. At low temperatures the overall sulfonation rate is dramatically reduced, so very little sulfosalicylic acid is formed enabling a higher mass of alkylsalicylic acid to be formed. At the elevated temperatures the overall sulfonation rate is faster, resulting in more sulfosalicylic acid and, consequently, lower accountabilities of the desired product. Elevated temperatures also promote the fragmentation and isomerization of the carbocations (entropic factors), so in general the smaller alkylsalicylic acids, such as t-butylsalicylic acid, are the major products. The extent of fragmentation and isomerization depends a great deal on the alkylating agent itself. The more hindered the alkylating agent the more likely it is to fragment.

The least important parameter appears to be the reaction duration. Increasing the reaction duration promotes the formation of the dialkylated products and a very slight drop in the accountability. The effect on the accountability and the proportion of dialkylsalicylic acid is again due to the sulfonation and alkylation equilibria, primarily the reverse reaction (dealkylation and desulfonation). When salicylic acid has been alkylated once, it is slightly

more likely to be alkylated a second time because of the inductive effect of the first alkyl group slight enhancing the susceptibility of the aromatic ring to electrophilic substitution. A greater proportion of dialkylated product will mean that there is also more unreacted salicylic acid which can be sulfonated reducing the accountability.

Chapter 5

The Reactions of the Esters of Salicylic Acid

5. Introduction.

It has been suggested in earlier chapters that the esters of salicylic acid might be the kinetically preferred products in the reaction of alkenes, alcohols and ethers with salicylic acid. If esters are indeed intermediates in the reaction, then it is necessary to demonstrate that they can rearrange to alkylsalicylic acids under the reaction conditions, and that a similar distribution of products is obtained. It was first necessary to synthesise authentic samples of the esters of salicylic acid, and then to react these with 80% sulfuric acid at 60°C for 3 hours (standard alkylating conditions).

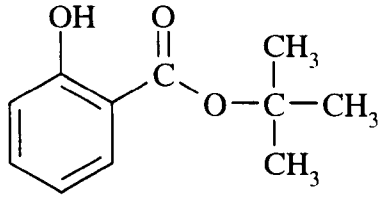
5.1. The Synthesis of the Esters of Salicylic Acid.

In theory, synthesis of the esters should be easy, but in practice, a number of problems were encountered. This was particularly the case with the tertiary alkyl salicylates because of their ease of decomposition to a tertiary carbocation and the carboxylic acid. The following sections describe the various routes employed to form the esters, and the results from their subsequent reactions are then outlined.

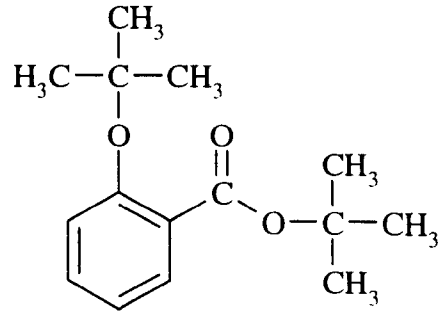
5.1.1. The Synthesis of t-Butyl Salicylate.

The simplest tertiary ester is the t-butyl ester. Such compounds are typically obtained by reacting the carboxylic acid with 2-methyl-1-propene in the presence of sulfuric acid[87], or by the reaction of the acid chloride with t-butanol[88]. However, both these types of reaction have been shown not to work with salicylic acid. An alternative literature procedure was therefore used which involved refluxing a mixture containing salicylic acid in the presence of an excess of N,N-dimethylformamide di-t-butyl acetal[89]. GC/MS analysis of the product mixture showed that two compounds were formed; the desired t-butyl salicylate (**62**) [96%] and the t-butyl 2-t-butoxybenzoate (**63**) [4%]. Whilst further purification was feasible, it was difficult to carry out on a large scale and so the mixture was used without further purification.

Structures 62 and 63.



(62)



(63)

5.1.2. The Synthesis of Primary and Secondary Alkyl Salicylates.

A number of procedures were attempted, with varying degrees of success, to produce the primary and secondary esters of salicylic acid in high purities.

5.1.2.1. Reactions of Haloalkanes with Salicylic Acid.

The first route used to synthesise the alkyl salicylates involved refluxing salicylic acid under basic conditions with a haloalkane (initially 1-bromohexane). Analysis by GC and GC/MS following methylation of the crude product mixture identified four major products as:

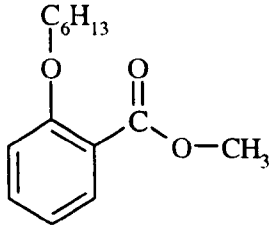
peak 1: unknown; 30%

peak 2: methyl 2-hexoxybenzoate (**64**); <1%

peak 3: hexyl salicylate (**65**); 61%

peak 4: hexyl 2-hexoxybenzoate (**66**); 7%

Structures 64-66.



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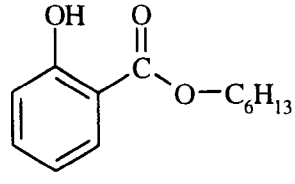
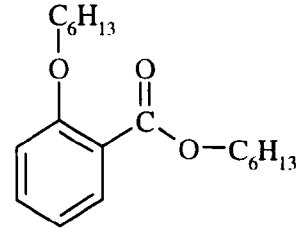


(65)



(66)

A number of purification techniques (column chromatography and acid/base washes) were employed in an attempt to separate the four components. In principle it should have been easy to separate the ester (**65**) ffrom the ether and the alkoxyester (**64** and **66**) by washing with aqueous solutions of appropriate pH, but this procedure did not work satisfactorily. It could have been that hydrogen bonding between the hydroxyl proton and the carbonyl oxygen prevented the formation of the metal salt. Given the lack of success in separating the four components, an alternative synthesis was employed.

The mass spectra of the unknown showed that it was neither the 1-bromohexane or the methyl salicylate. The mass spectra is as follows; 94 (M^+, 100%) 66(27) 65(24) 55(9) 39(21)

5.1.2.2. Esterifcation in the Presence of Methylsulfonyl Chloride.

A second procedure[90] tried involved the heating of salicylic acid in the presence of a secondary alcohol, potassium carbonate, methylsulfonyl chloride and a phase transfer catalyst. Use of 2-hexanol as the alcohol, followed by methylation of the product mixture, gave a product which, as shown by analysis by GC and GC/MS (figure 5.1), contained a number of compounds. These compounds were tentatively identified from their mass spectra and are believed to be;

peak 1: methyl salicylate (**8**);16%

peak 2: hexyl salicylate (**65**); 54%

peak 3: An unidentified compound; 18%

peak 4: dibenzo [b,f][1,5]dioxocin-6,12-dione (disalicylide[a]) (**67**); 15%

peak 5: tribenzo [b,f,j][1,5,9]trioxocine-6,12,18-trione (trisalicylide) (**68**); 9%

Literature evidence[91,92,93] suggests that higher polmers of salicylic acid, notably the hexasalicylide, will be formed, but because of its size and high melting point it is unlikely that it would be eluted from the gas chromatograph. The formation of these two salicylides involves (Scheme 5.1) the production, of firstly, the acid chloride, which then reacts with the hydoxyl group of the salicylic acid to give salicyloylsalicylic acid. If this then reacts to form the acid chloride 2-chlorocarbonylphenyl 2-hydroxybenzoate, the ring is likely to close

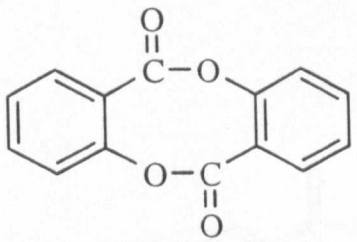
---

[a] The formation of di, tri and higer polymer salicylides is documented when dehydrating conditions were employed.

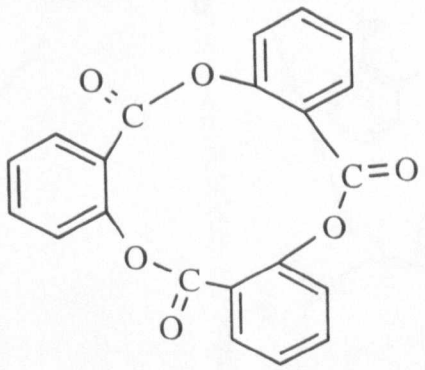
to form the disalicylide. Alternatively, the salicyloylsalicylate can react with another salicyloylchloride molecule with ring closure to give the trisalicylide. Other routes to similar compounds involve the use of phosphorous oxychloride[94]. The unknown, based on its mass spectra, is not one of the starting materials and has the following mass spectra;

unknown; 228(M^+, 15%); 121(5) 91(100) 65(16)

Structures 67 and 68

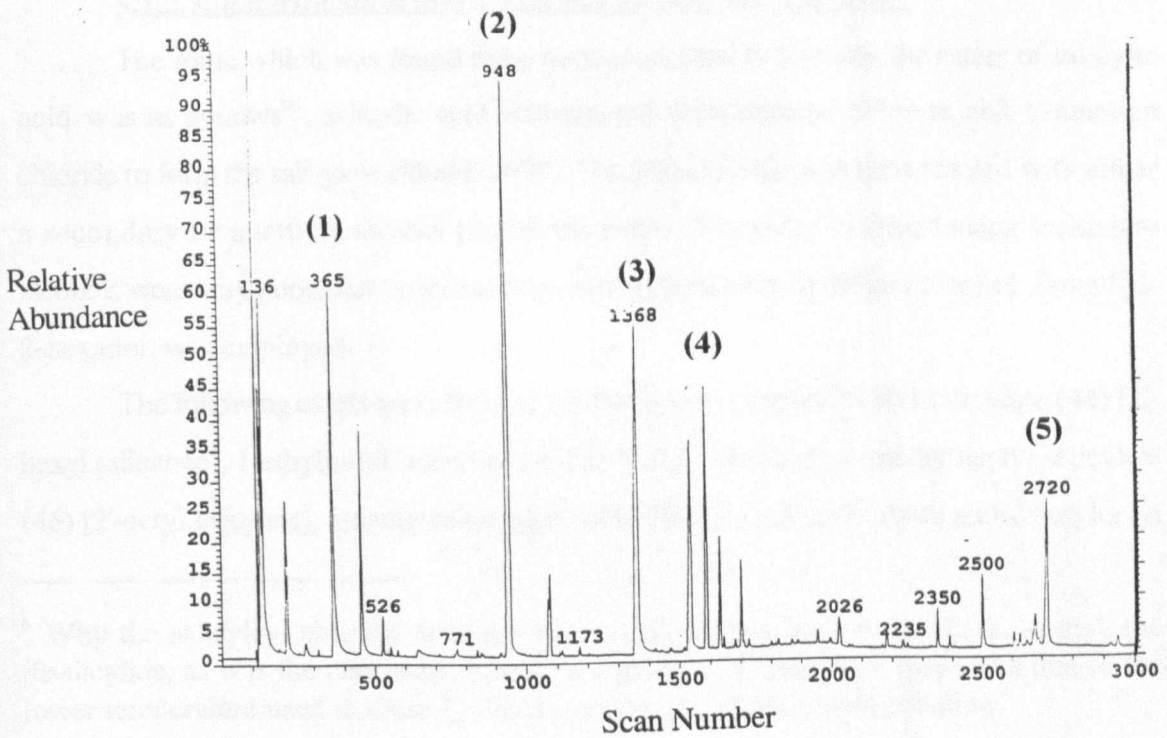


(67)

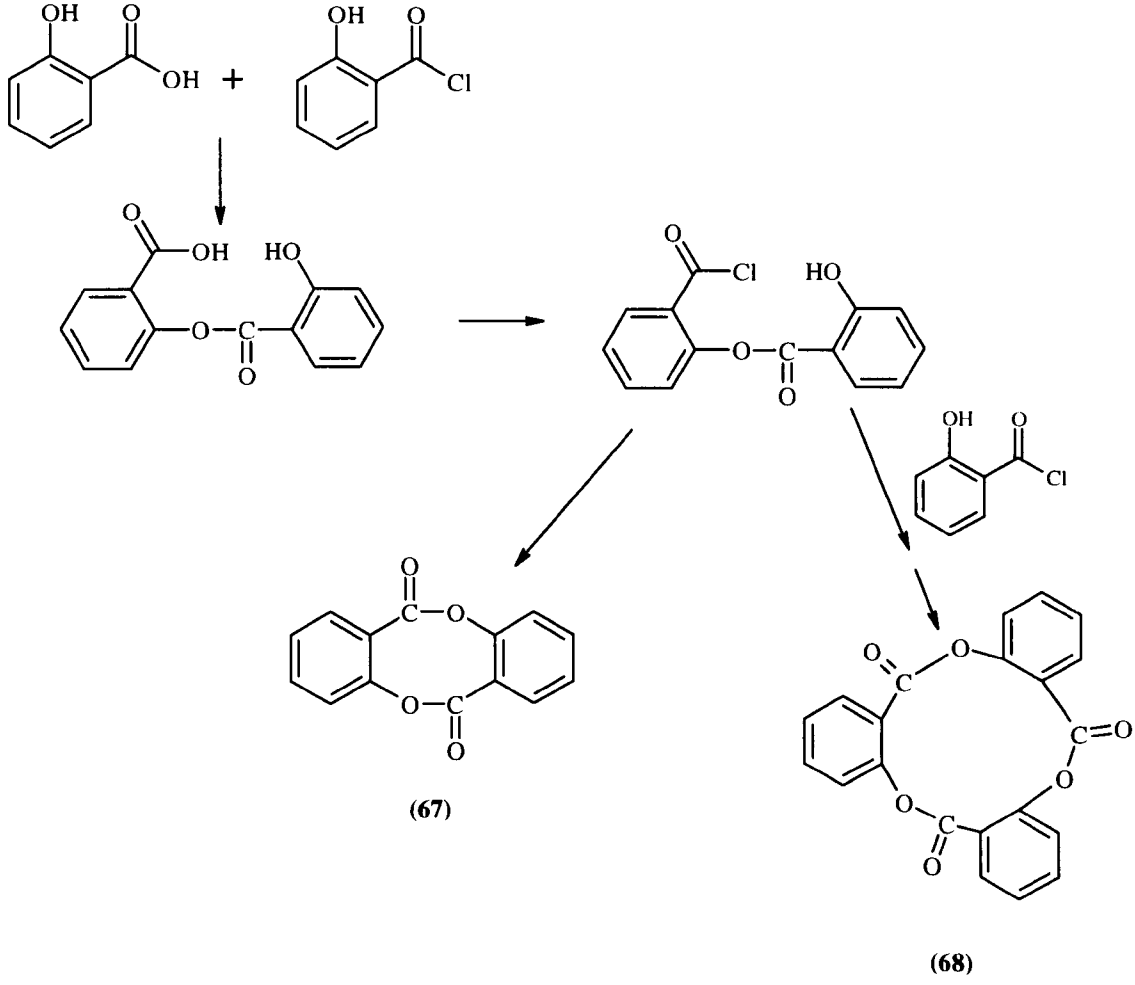


(68)

Figure 5.1. The GC trace (obtained from a GC/MS run) of the products from the esterification reaction using 2-hexanol (route 2).



Scheme 5.1.



(67)

(68)

5.1.2.3. Esterification in the Presence of Sulfonyl Chloride.

The route which was found to be most successful in forming the esters of salicylic acid was as follows[95]; salicylic acid was reacted with sulfonyl chloride and aluminium chloride to form the salicyloyl chloride (**69**)[b]. The acid chloride was then reacted with either a secondary or a tertiary alcohol to give the ester. The yields obtained using secondary alcohols were very good, but very little ester was formed when a tertiary alcohol, 2-methyl-2-hexanol, was employed.

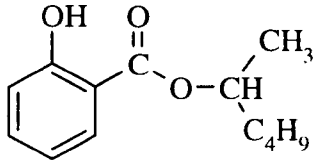
The following esters were formed via this route: 1-methylpentyl salicylate (**44**) [2'-hexyl salicylate], 1-ethylbutyl salicylate (**45**) [3'-hexyl salicylate], 1-methylheptyl salicylate (**46**) [2'-octyl salicylate], 1-methylnonyl salicylate (**50**)[(2'-decyl salicylate] and 1-butyloctyl

---

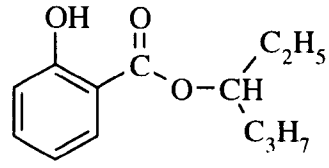
[b] Why the salicyloyl chloride does not react with salicylic acid, in this case, to give the disalicylide, as was the case with route 2, is unknown. However, it may to be due to the lower temperature used in route 3, which prevents the disalicylide formation.

salicylate (**70**) [4'- dodecyl salicylate].

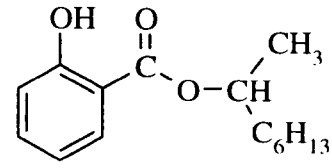
Structures 69 and 70



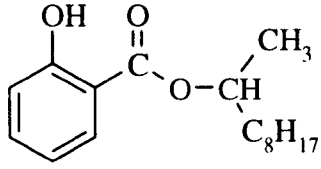
(44)



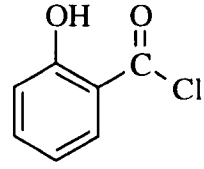
(45)



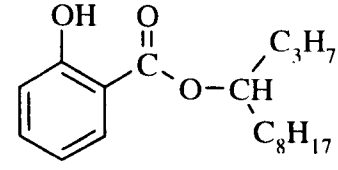
(46)



(50)



(69)



(70)

Prior to reacting these esters with sulfuric acid they were first purified by converting any unreacted salicylic acid (on work up any remaining salicyloyl chloride is converted back to the salicylic acid) to the methyl ester and then distilling off the methyl salicylate to leave the desired alkyl salicylates. This method did not remove completely all the methyl salicylate since some of the ester decomposed back to the carboxylic acid, but in general gave products of >95%purity which was deemed suitable for the next stage of the study.

As has already been discussed, the formation of the esters should be a reversible process which can be catalysed by either acids or bases. A small amount of hydrochloric acid will be formed in this ester synthesis which will catalyse the deesterification, resulting in a small amount of the salicylic acid after the distillation.

5.2. The Reactions of the Esters of Salicylic Acid.

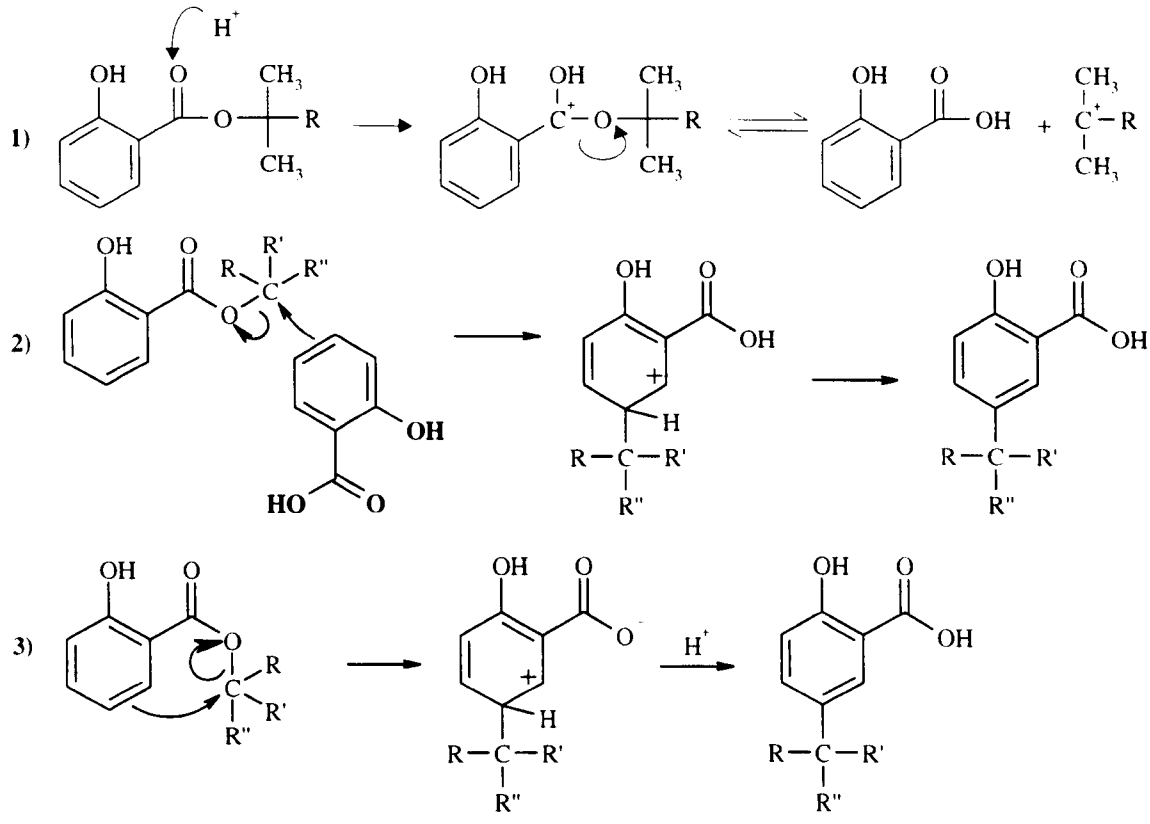
If the esters of salicylic acid are to rearrange when treated with sulfuric acid they will do so by one of three routes (Scheme 5.2):

1) Dissociation to give a carbocation and a carboxylate anion, the former, then attacking the aromatic ring.

2) Inter-molecular rearrangement resulting in the direct transfer of the alkyl group from the carboxylate function to the aromatic ring of a neighbouring molecule.

3) Intra-molecular rearrangement.

Scheme 5.2.



5.2.1. The Reactions of Tertiary Esters.

In an attempt to ascertain the route by which the esters rearrange to the alkylsalicylic acids, if they rearrange at all, t-butyl salicylate was heated at 60°C for 3 hours with 80% sulfuric acid (standard alkylating conditions), and, on work up, a pale cream solid resulted. GC/MS analysis, following methylation, confirmed the presence of the methyl 5-t-butyl salicylate. The actual product distribution as determined by GC/MS was:

methyl salicylate (**8**); 28%

methyl 5-t-butylsalicylate (**9**); 68%

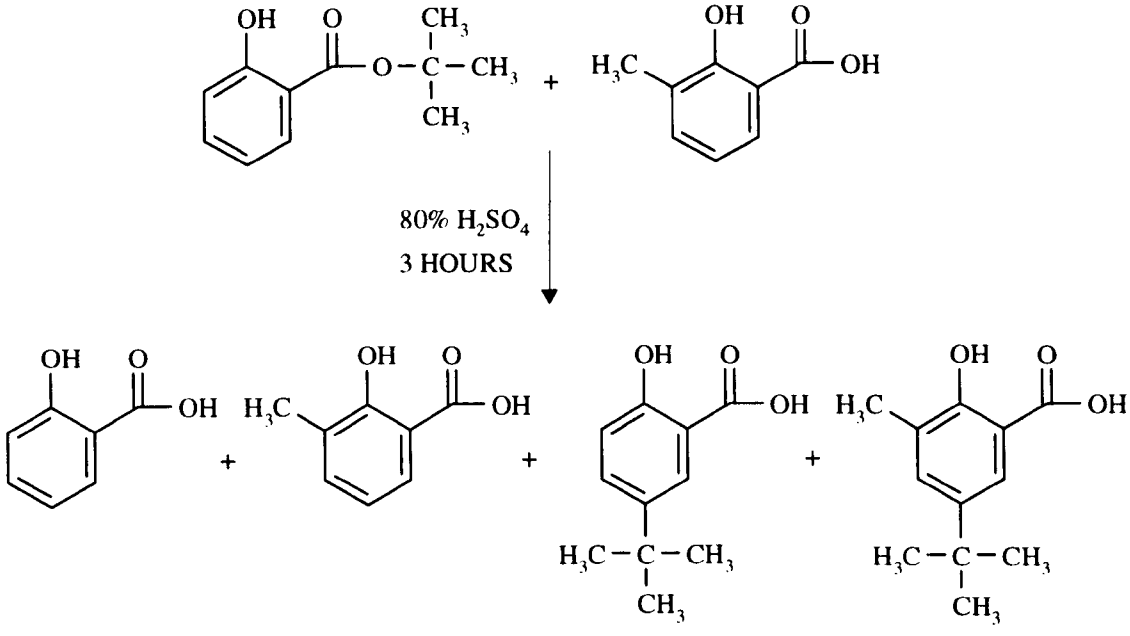
methyl 3,5-di-t-butylsalicylate (**10**); 3%

This reaction confirmed that the ester could be converted to the alkyl substituted acid and that the ester could therefore be an intermediate in the formation of the alkylsalicylic acid. However, it did not confirm by which of the three routes the acid was formed. To establish this point, the following reaction was undertaken. t-Butyl salicylate and 3-methylsalicylic acid (1:1 equivalents) were reacted together under standard alkylating conditions (the mixture was stirred in the presence of 80% sulfuric acid at 60°C for three

hours). Depending on the rearrangement route, two groups of products would be expected. If the ester were to dissociate to give a carbocation, or if an inter-molecular rearrangement were to take place, then a mixture of salicylic acid, 3-methylsalicylic acid, 5-t-butylsalicylic acid and 3-methyl-5-t-butylsalicylic acid would be expected, Scheme 5.3. However, if an intra-molecular rearrangement were to take place then only a mixture of 3-methylsalicylic acid and 5-t-butylsalicylic acid would result.

Analysis by GC and GC/MS following methylation showed the presence in the product of methyl salicylate, as well as methyl 3-methylsalicylate, methyl 5-t-butylsalicylate and methyl 3-methyl-5-t-butylsalicylate. This mixture of products demonstrates that the rearrangement does not proceed by an intra-molecular route, but either by dissociation to give the free carbocation or via an inter-molecular rearrangement. Further reactions were required to ascertain whether the rearrangement occurred via an inter-molecular rearrangement between neighbouring rings or via a free carbocation. Based on literature evidence that tertiary esters easily decompose to give a tertiary carbocation, it is likely that the rearrangement of the tertiary ester to the tertiary alkylsalicylic acid goes via a free carbocation.

Scheme 5.3.



5.2.2. The Reactions of Secondary Esters.

To see whether secondary esters behave in the same way as a tertiary one, the range

of secondary alkyl salicylates previously synthesised were reacted under standard alkylating conditions (stirred at 60°C for 3 hours in the presence of 80% sulfuric acid). Reacting the 2'-hexyl ester led to the formation of a number of products, which were identified by GC and GC/MS (Figure 5.2), after methylation, as:

peak 1: methyl salicylate (**8**); 2%

peak 2: 2'-hexyl salicylate (**45**); 4%

peak 3: methyl 5-t-pentylsalicylate (**22**);1%

peak 4: methyl 5-t-hexylsalicylate (**18**); 7%

peak 5: methyl 5-(1-ethylbutyl)salicylate [3'-hexyl](**23**); 15%

peak 6: methyl 3-(1-ethylbutyl)salicylate [3'-hexyl](**24**); 2%

peak 7: methyl 3-(1-methylpentyl)salicylate [2'-hexyl](**25**); 2%

peak 8: methyl 5-(1-methylpentyl)salicylate [2'-hexyl](**26**); 17%

peak 9: methyl 3,5-dihexylsalicylates (**27**); 12%

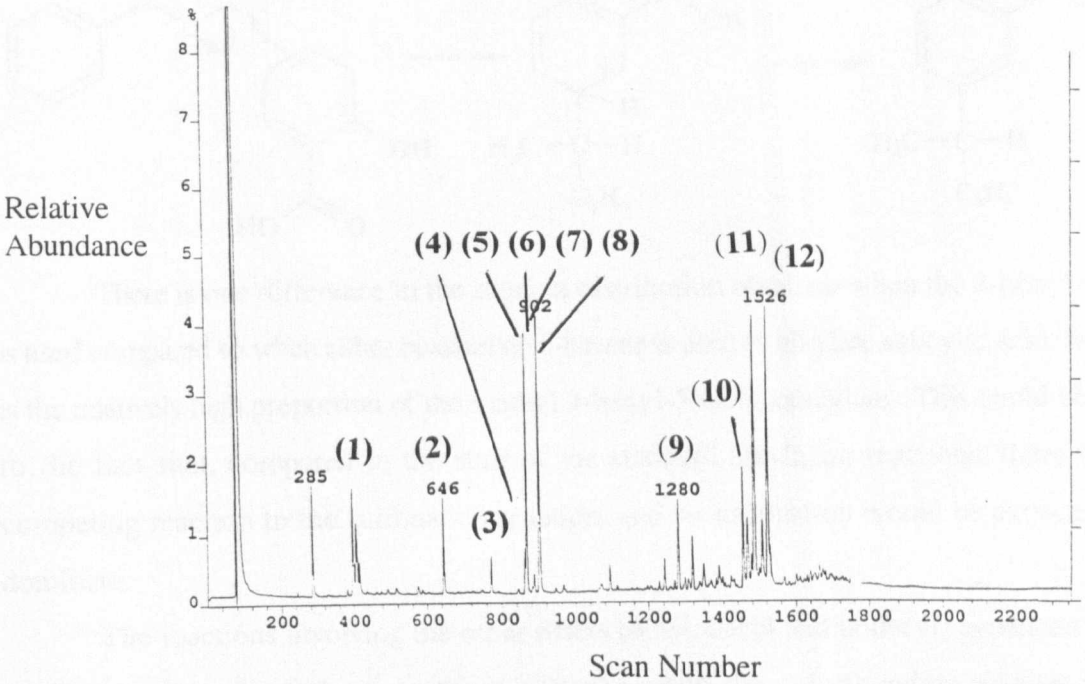
peak 10:5-hexyl-2-methoxy-3-methoxysulfonyl-benzoic acid methyl ester; 1%

peaks 11 and 12: unknowns; 34%; possibly two isomers of 5-hexyl-3-methoxysulfonyl-salicylate; m/z 330(M^+, 11) 273(M-C_4H_9, 100) 241(M-C_4H_9-CH_3OH, 96) and 330(M^+, 14) 301(M-C_2H_5, 26) 287(M-C_3H_7, 41)279(M-C_3H_7-CH_3OH, 40)255(M-C_3H_7-CH_3OH, 100).

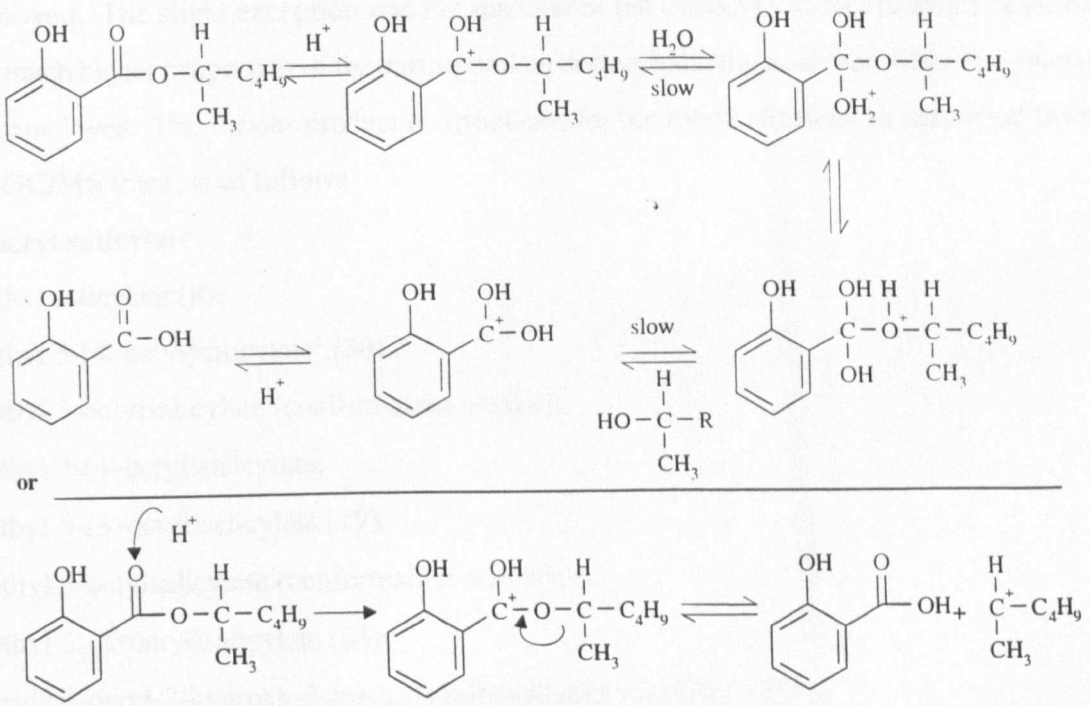
A very similar product distribution is obtained when the 3'-hexyl ester is ued in place of the 2'-hexyl ester.

The product distribution of the various hexylsalicylic acids was very similar to that obtained when 2-hexanol and salicylic acid were reacted together directly, suggesting a similar alkylation mechanism following deesterification. Deesterification can occur via one of two routes; the formation of the alcohol or the formation of a free carbocation, as shown in Scheme 5.4.

Figure 5.2. The GC trace (obtained from a GC/MS run) of the products from the alkylation of 2'-hexyl salicylate, under standard alkylating conditions.

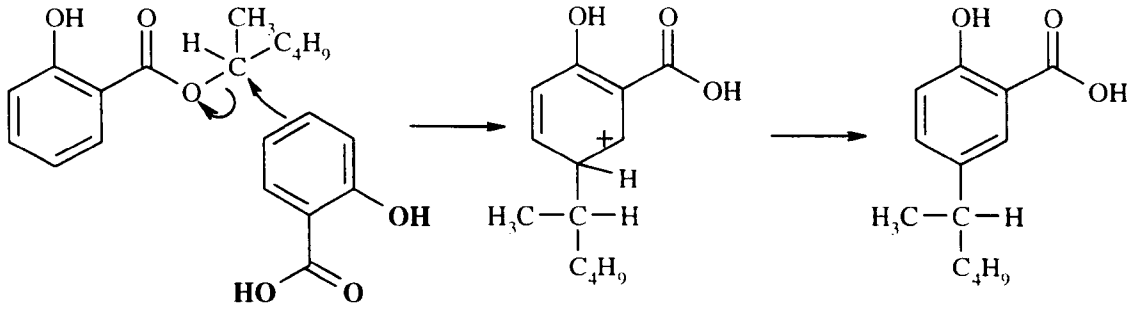


Scheme 5.4.



The distribution also suggests that the reaction does not go via an inter-molecular rearrangement, transferring the alkyl group from the carboxylate function to a neighbouring ring. Inter-molecular rearrangement would be likely to lead to only one product the 1-methylpentylsalicylic acid, as shown in Scheme 5.5.

Scheme 5.5.



There is one difference in the product distribution obtained when the 2-hexyl ester is used compared to when either hexanol or 1-hexene is used to alkylate salicylic acid, which is the relatively high proportion of the methyl 3-hexyl-5-sulfo salicylate. This could be due to the fact that, compared to the start of the standard alkylation reactions, there is no competing reaction to the sulfonation reaction, and so sulfonation would be expected to dominate.

The reactions involving the other esters (octyl, decyl and dodecyl) produced very similar product distributions to those obtained when the corresponding alkenes were employed. The slight exception was the reaction of the dodecyl salicylate, which resulted in a much higher proportion of the corresponding dodecylsalicylic acid than when the alkene was employed. The various product distributions for the range of esters, as identified from the GC/MS trace, is as follows:

2'-octyl salicylate

methyl salicylate (**8**);

methyl 5-(4'-octyl)salicylate[c] (**30**);

methyl 5-octylsalicylate (conformation unsure);

methyl 3-(4'-octyl)salicylate;

methyl 5-(3'-octyl)salicylate (**29**);

methyl 5-octylsalicylate (conformation unsure);

methyl 5-(2'-octyl)salicylate (**28**);

methyl 3-octyl-2-hydroxy-5-methoxysulfonyl-benzoate (**32**); <1%

methyl 5-octyl-2-methoxy-3-methoxysulfonyl-benzoate (**33**); <1%

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[c] The accuracy of the identification of the methyl alkylsalicylates depends a great deal on the orrientation of the alkyl group. Consequently some isomers are more easily and correctly identified.

2'-decyl salicylate

methyl salicylate (**8**); 38%

4'-decylsalicylate; (**50**); 5%

methyl 5-(5'-decyl)salicylate; 9%

methyl 5-(4'-decyl)salicylate; 10%

methyl 5-t-decylsalicylate (**13**); 12%

methyl 5-(3'-decyl)salicylate; 6%

methyl 5-(2'-decyl)salicylate; 7%

A number of other methyl decylsalicylates are also present, but in very low proportions.

4'-dodecyl salicylate

methyl salicylate (**8**); 10%

dodecene; 7%

At least twelve methyl dodecylsalicylates, including;

methyl 5-(1-methyl-1-propylheptyl)salicylate; 14%

methyl 5-(4'-dodecyl)salicylate;11%

methyl 5-(3'-dodecy)lsalicylate; 12%

methyl 5-t-dodecylsalicylate (**15**); 21%

methyl 3-(2'-dodecyl)salicylate; 9%

methyl 5-(2'-dodecyl)salicylate; 6%

5.3. Conclusions.

Based on the results from the reactions of the alkyl salicylates, it is fully feasible for the ester to be an intermediate in the alkylation reaction. It is likely that the ester is the kinetically controlled product in the alkylation reaction, with the alkylated acid being the thermodynamically controlled product. The ester is formed first because of the greater nucleophilic nature of the carbonyl group than the aromatic ring favouring electrophilic attack at the carbonyl group. Electrophilic attack on the aromatic ring requires the temporary loss of aromaticity, energetically disfavourable and consequently has a higher activation energy. However, once the electrophilic attack has taken place, the ester is thermally less stable and so can easily decompose back to starting materials. This is

comparable to the alkylation of phenol, for which it has been demonstrated that the ether is the kinetically controlled product and that the alkylphenol is the thermodynamically controlled product. Previous studies at York involving the alkylation of phenol[78] found the ether to be formed initially, but this rapidly disappeared as the reaction proceeded to be replaced by the alkylphenol.

The rearrangement of the ester is likely to involve the formation of a carbocation either directly or, more likely, especially with primary and secondary esters, indirectly via the alcohol rather than inter or intra-molecular rearrangement (Scheme 5.3).

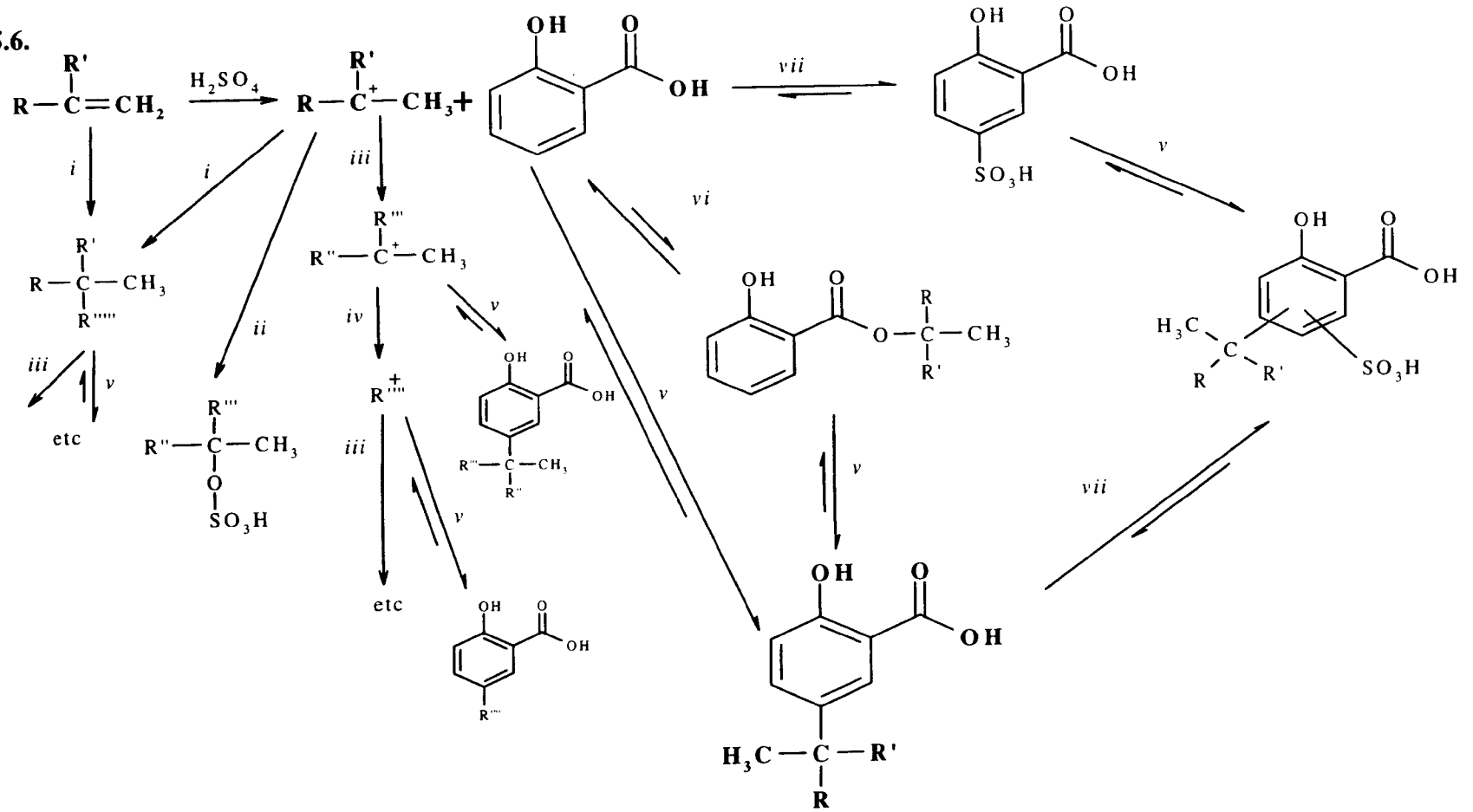
The ester formation equilibrium fits into the overall reaction scheme for all the reactions associated with the alkylation of salicylic acid (Scheme 5.6).

5.4. Future Work.

A number of areas concerning the alkylation of salicylic acid still remain to be investigated. These have not be followed up primarily because of time constraints. One area would involve the investigation of the possible rearrangement of primary alkylsalicylic acids under standard alkylating conditions. The primary alkylsalicylic acid can be synthesised by reacting salicylic acid with an alkyl acid chloride. Reduction of the resulting alkanoylsalicylic acid would give the corresponding primary alkylsalicylic acid[96].

Another area which could be investigated is the possibility of the ether of salicylic acid rather than the ester being a possible intermediate in the alkylation reaction. To achieve this would require the synthesis of the various ethers, and experience suggests that this is likely to prove difficult.

Scheme 5.6.



i) Formation of a larger alkene/carbocation
ii) Formation of the alkyl sulfate
iii) Isomerization
iv) Fragmentation
v) Alkylation and dealkylation
vi) Esterification and deesterification
vii) Sulfonation and desulfonation

Chapter 6

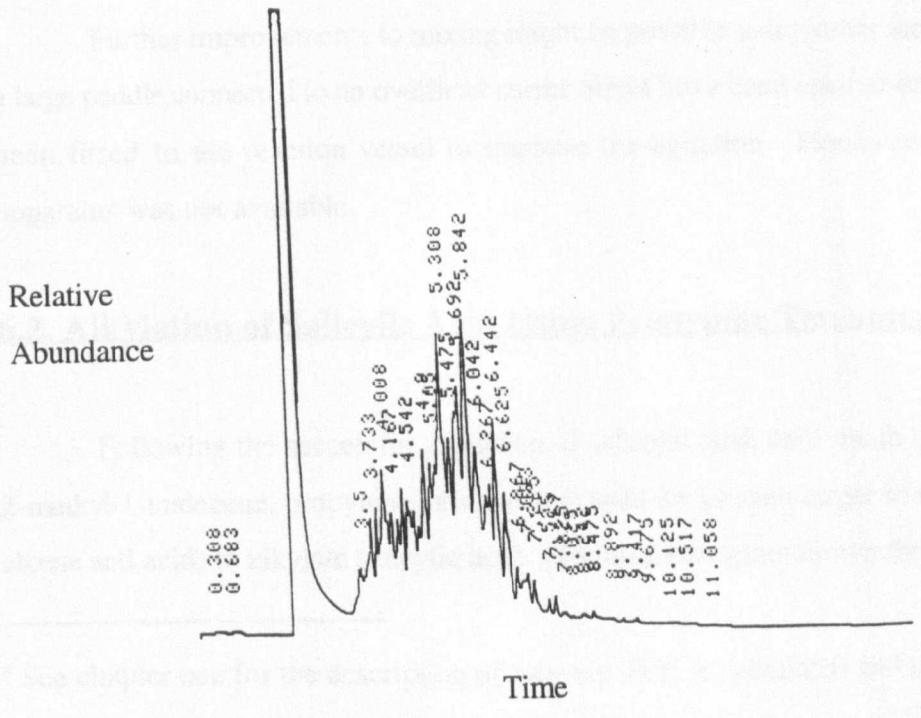
The Industrial Implications of the Alkylation of Salicylic Acid

6. Introduction.

The results obtained when 2-methyl-1-undecene was used to alkylate salicylic acid demonstrates that it is possible to synthesis a C_{12}-alkylsalicylic acid in high accountability and purity by using sulfuric acid as the catalyst. However, because of the high cost of the 2-methyl-1-undecene, it is not economical to use this alkene to produce the overbased detergents. A cheaper and far more easily available C_{12} alkene is propylene tetramer (made by the cationic polymerisation of propene). However, analysis by GC and GC/MS has shown that the propylene tetramer is not a single compound, but a mixture of C_{10}, C_{11} and C_{12} alkenes, as well as diene and triene analogues, with a wide variation in the degree of branching of the alkene. Figure 6.1 the GC trace of propylene tetramer, shows the complexity of the material. Using such a complex mixture in the alkylation reaction makes the identification of the individual products impossible, simply because of the increase in the number of products that can be formed following alkylation, even before any of the side reactions take place.

The scale employed in the work described previously is also far too small for a process to be used industrially. So the effect of scaling up the reaction and optimizing the reaction conditions has also been investigated.

Figure 6.1. The GC trace of propylene tetramer.



6.1. Scale up of the Alkylation of Salicylic Acid.

As was introduced in Chapter 1, in order for the alkylsalicylic acids to be used as detergents they are either neutralised or overbased by the addition of varying amounts of an alkali metal carbonate (typically calcium carbonate). All the overbasing work was carried out at the BP Hull research centre because of their expertise in the area and their ability to test the end product.

In order to produce enough C_{12}-alkylsalicylic acid to continue the next stage of the detergent manufacture, the overbasing, it was necessary to scale up the synthesis of the C_{12}-alkylsalicylic acid. The first reaction to be carried out on a larger scale (0.06 moles 2-methyl-1-undecene and 0.06 moles salicylic acid [previous studies in this thesis employed a typical scale of 0.01 moles of both alkene and salicylic acid]) using standard conditions (60°C, 80% sulfuric acid with the mixture being stirred by a magnetic flea over a three hour period) was not too successful, accountability (69%) and purity (20%) of the 5-t-dodecylsalicylic acid (**15**) being achieved. The mixing of the organic and aqueous phases of the reaction mixture appeared to be very poor. To improve the mixing, nitrogen was bubbled vigorously through the reaction flask, by means of a bubbler fitted with a frit. This resulted in a higher accountability (75%) and much higher purity (75%) of the 5-t-dodecylsalicylic acid (**15**). This sample was subsequently employed at the BP research centre at Hull in overbasing experiments. Under unoptimized conditions the alkylsalicylic acid overbased detergent had a high (and promising) Total Base Number (310 TBN)[a].

Further improvements to mixing might be possible using other techniques such as; a large paddle connected to an overhead stirrer might have been used or baffles might have been fitted to the reaction vessel to improve the agitation. However, the appropriate apparatus was not available.

6.2. Alkylation of Salicylic Acid Using Propylene Tetramer.

Following the successful alkylation of salicylic acid, on a much larger scale, using 2-methyl-1-undecene, propylene tetramer was used on an even larger scale (0.75 moles of alkene and acid) to alkylate salicylic acid. Nitrogen was again blown through the reaction

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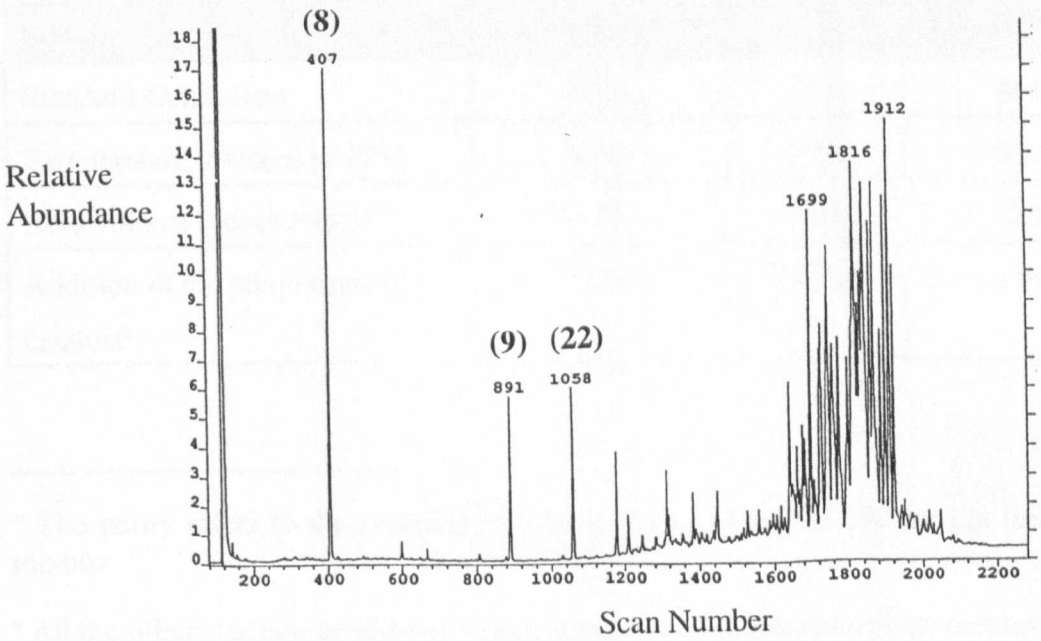
[a] See chapter one for the description of how the TBN is calculated and its relative values.

mixture to improve the mixing of the reactants. The accountability was 80%, with approximately 83% of the product mixture being the C_{10}, C_{11} and C_{12} alkylsalicylic acids, as estimated by GC and GC/MS. Again the product mixture was methylated by adding diazomethane prior to GC analysis. The GC/MS trace of the resultant product mixture is shown in Figure 6.2.

It was seen that the scaled up reaction proceeded through two distinct stages. The first stage consisted of the mixing of the two phases (the organic and the aqueous layer). The second stage started after about 30 minutes, two phases were no longer observable and a single phase resulted. This single phase reaction mixture started as a pale yellow solution and went progressively darker in colour as the reaction proceeded, through orange, to red and finally to a red/purple coloured solution. An excess of water was added to stop the reaction, resulting in an oily film. This oily film was extracted by a number of solvents, including diethyl ether, petroleum ether and toluene, being tried. The use of toluene as the extractant proved to be the most difficult due to separation problems of the aqueous and organic layers, but would be the preferred solvent industrially (the others have too low flashpoints).

Figure 6.2. The GC/MS trace of the product mixture from the alkylation reaction using propylene tetramer. Also present is methyl salicylate (**8**), methyl 5-t-butylsalicylate (**9**) and methyl 5-t-pentylsalicylate (**22**).



6.2.1. The Effect of Altering the Reaction Conditions.

The optimum conditions for the earlier model systems might not be ideal in a scaled up reaction and so a number of experiments were carried out, varying the acid volume, temperature and the introduction of a phase transfer catalyst. Initial experiments into reducing the volume of acid used (from $250cm^3$ to $200cm^3$ H_2SO_4) and reducing the temperature (from 60°C to 20°C) served to reduce the tendency of the reaction to produce the red/purple colour. The accountability was not affected but the amount of unreacted salicylic acid was much higher, with the lower acid volumes and reaction temperatures. The lower reaction temperatures would be expected to reduce the extent of any of the side reactions, rationalised in the preceding chapters. Most notable amongst these is the fragmentation of the alkyl groups. However, lower temperature would inevitably slow down the overall reaction.

The results obtained from the alkylation of salicylic acid using propylene tetramer, with lower acid volumes, lower temperature (room temperature) and the addition of the phase transfer catalyst (1 mmol tetrabutyl ammonium sulphate) were compared to the results obtained under the optimum conditions (60°C, 80%H_2SO_4, 3 hours and nitrogen bubbled through) and are set out in table 6.1.

Table 6.1. The effect of altering the reaction conditions on the accountability and purity of products when salicylic acid is alkylated using propylene tetramer.

Conditions	Accountability %	Purity %[b]	Overall Yield %
Standard Conditions	80%	83%	66%
Temperature lowered to 20°C	81%	65%	53%
Acid volume reduced by 25%	77%	75%	58%
Addition of the phase transfer catalyst[c]	78%	80%	62%

[b] The purity refers to the percentage of propylene tetramersalicylic acid in the product mixture.

[c] All the other reaction conditions (temperature, acid volume) were kept constant, except the phase transfer catalyst was added.

As can be seen, lowering the temperature or the acid volume or adding the phase transfer catalyst has little significant effect on the course of the reaction. However, there is no feasible way of comparing accurately the alkylsalicylic acid produced at the high or low temperatures as they are both very complex mixtures of alkylsalicylic acids, but comparing the performances of the two samples as overbased detergents is still a feasible proposition.

Early indications from the laboratories in Hull are that the high temperature reaction has the better potential to produce the overbased product. Further studies are currently in progress to confirm this.

6.3. Alkylation of Salicylic Acid Using Polyisobutene (PIB).

The alkylation of salicylic acid has also been attempted using 1000 molecular weight PIB (Glissopal). A compound with such a long alkyl chain could also act as a viscosity index improver as well as an overbased detergent. The salicylic acid was alkylated on a large scale (0.1 moles of both the salicylic acid and the Glissopal), using the PIB under the standard conditions, 60°C, 80% H_2SO_4, stirring for 3 hours and nitrogen blown through. A limited reaction took place with an orange sludge being produced, which on standing for a few days, went a red/purple colour (similar to the salicylic acid being treated with propylene tetramer). This colour change could simply be the autooxidation of the phenolic group in the salicylic acid. The sheer size of the alkyl chain and consequently high boiling point prohibited its analysis by GC or GC/MS. Therefore, analysis by ^{1}H nmr spectroscopy was attempted in order to ascertain if the aromatic splitting pattern had changed from that of salicylic acid to that of a substituted salicylic acid. The product from the reaction is only partly soluble in THF and forms 2 phases (the product would not dissolve completely in all the other nmr solvents that were tried) and each one of these two phases was analysed by ^{1}H nmr. The two phases can be classed as a water soluble phase (probably containing the more polar components) and a hydropbobic phase. The ^{1}H nmr of the latter phase, shown in Figure 6.3, is consistent with a 5-PIBsalicylic acid (**71**) with the integration values being about the right order of magnitude for an alkylsalicylic acid with a 1000 molecular weight chain. The aqueous phase ^{1}H nmr, shown in Figure 6.4, shows evidence of three components the 5-PIBsalicylic acid (**71**), the 5-sulfosalicylic acid (**72**) and the suspected 3-PIB-5-sulfosalicylic acid (**73**).

Figure 6.3. Part of the ^{1}H nmr spectrum in THF of the organic phase. The expanded aromatic region with the typical splitting pattern of a 5-alkylsalicylic acid is shown another, unidentified, species is also present.

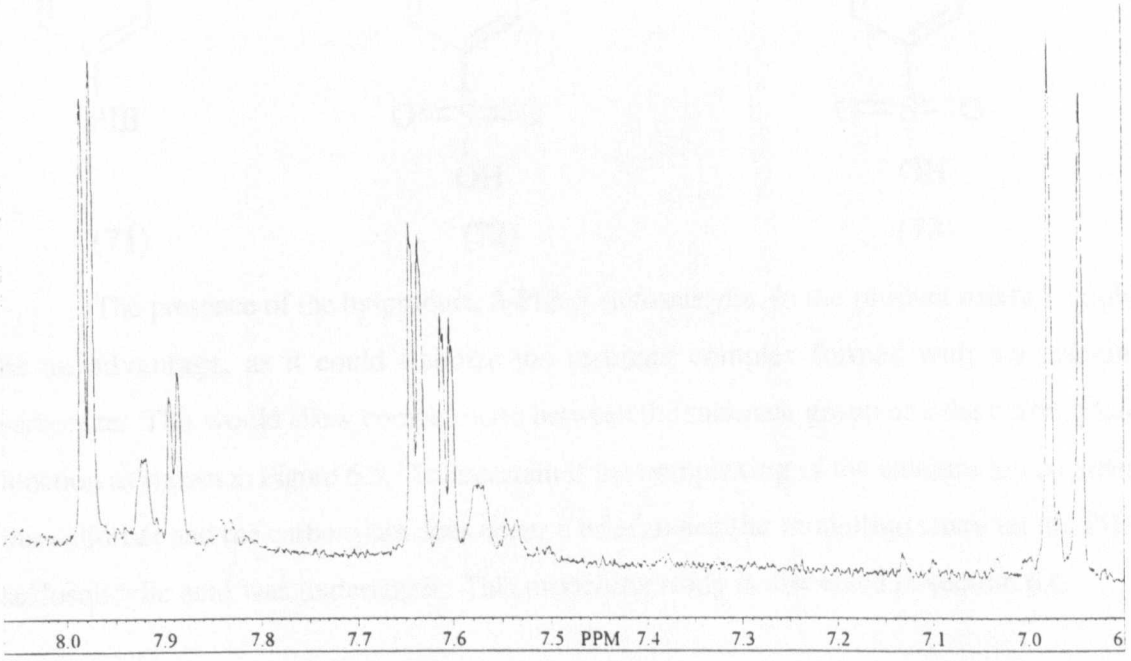
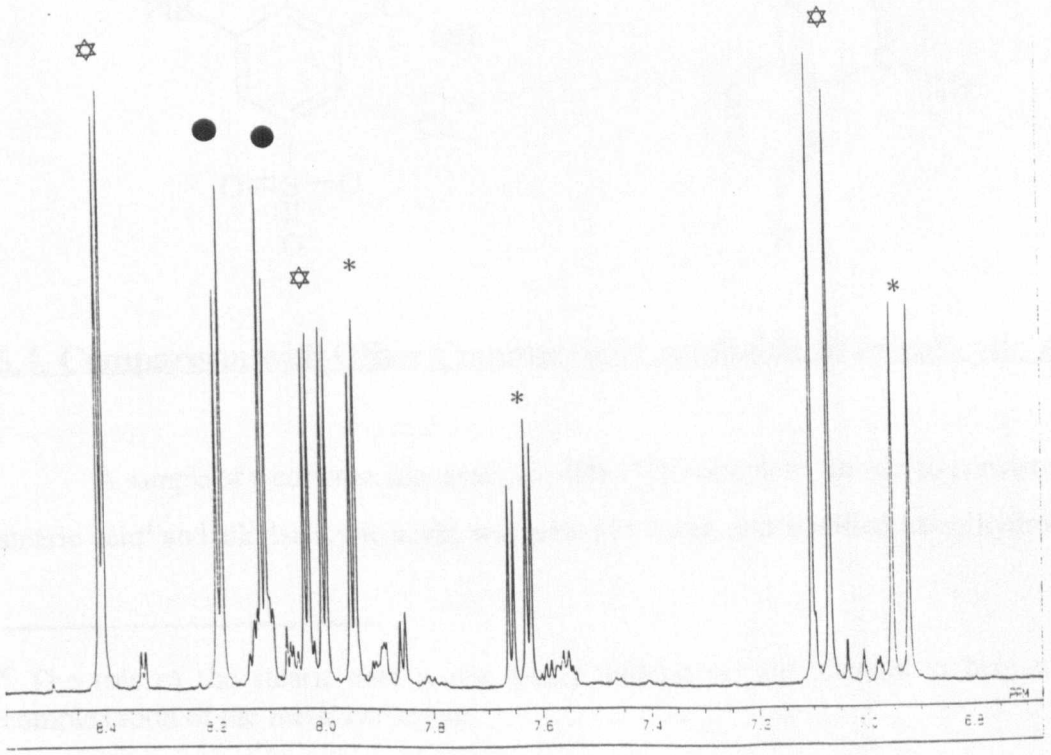
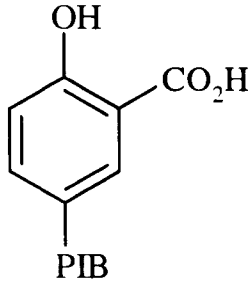


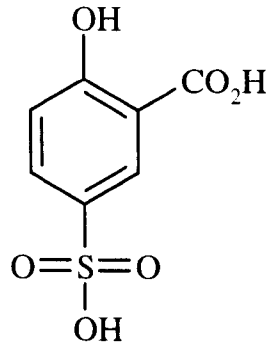
Figure 6.4. Part of the ^{1}H nmr spectrum in THF of the aqueous phase showing only the aromatic region. The peaks indicated with a * correspond to the 5-PIBsalicylic acid (**71**), peaks with a ✡ correspond to the 5-sulfosalicylic acid (**72**) and peaks with a ● correspond to the suspected 3-PIB-5-sulfosalicylic acid (**73**).



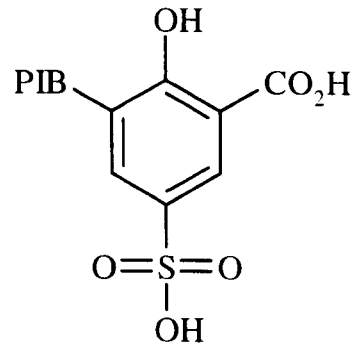
Structures 71-73



(71)



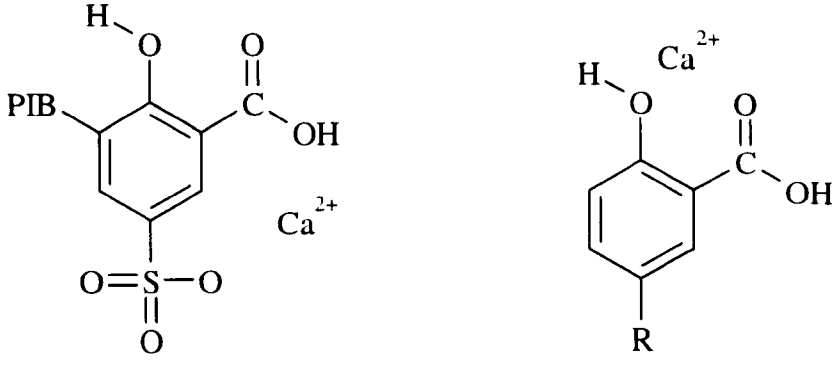
(72)



(73)

The presence of the by-product, 3-PIB-5-sulfosalicylic, in the product mixture could be an advantage, as it could stabilize the resultant complex formed with the calcium carbonate. This would allow complexation between the sulfonate group and the carboxylate function as shown in Figure 6.5. To ascertain if the complexing of the calcium ion between this sulfonate and the carboxylate does occur a brief molecular modelling study on the PIB-sulfosalicylic acid was undertaken. This modelling study is discussed in section 6.6.

Figure 6.5. A representation of the position that the calcium ion could take up if complexed to the PIB-sulfosalicylic acid or the standard alkylsalicylic acid.



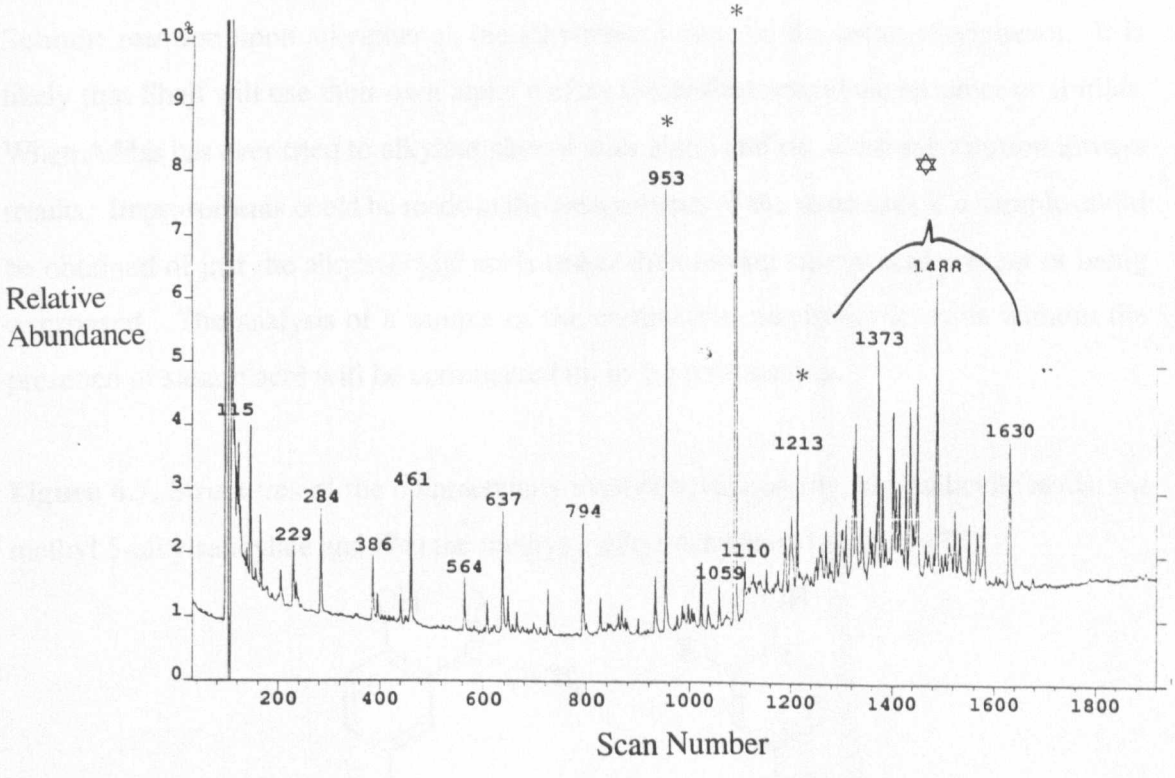
6.4. Comparison with Other Commercially Available Alkylsalicylic Acids.

A sample of a commercially available 400 TBN salicylate, known to consist of both stearic acid[d] and alkylsalicylic acids, was added to water, and acidified using hydrochloric

[d] The role of the stearic acid is not totally understood but appears to help with the complexation of the metal carbonate.

acid, to remove the calcium carbonate. The organic components were extracted with ether, the organic layer was separated, and then the ether was removed on the rotary evaporator. The alkylsalicylic acid and the stearic acid were then methylated by diazomethane, so that GC and GC/MS analysis could be performed. The GC/MS trace, shown in Figure 6.6, shows that, in the mixture, the commercially available salicylate consists predominately of homologues of stearic acid. These acids range from $CH_3(CH_2)_{14}CO_2H$ to $CH_3(CH_2)_{20}CO_2H$. The other group of peaks corresponds to the alkylsalicylic acids, with the alkyl chain ranging from C_{14} - C_{19}.

Figure 6.6. The GC trace (obtained from a GC/MS run) of the methylated commercially available alkylsalicylic acid. The peaks marked with a * correspond to the stearic acid and the group marked with a ✡ correspond to the alkylsalicylic acids.

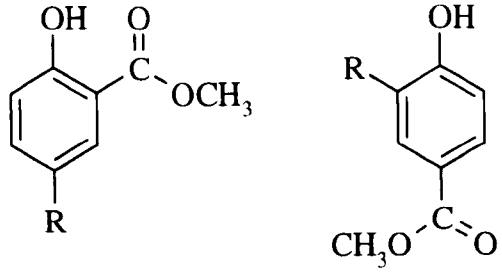


The identification of the alkylsalicylic acids was accomplished by the analysis of their mass spectrometric fragmentation patterns. As has been discussed in earlier chapters, typical fragments are lost, these being an alkyl group, followed by the loss of methanol or the direct loss of methoxy. The mass spectra of the methyl alkylsalicylates indicates that the alkyl group attached to the aromatic ring has both secondary and tertiary head groups, not just predominately the tertiary head groups that are observed from the alkylation using tertiary methyl ethers, tertiary alcohols or the trisubstituted alkenes. Analysis also revealed

that there was evidence from the mass spectra that the ethyl groups are attached to the alkyl end group, since in the mass spectra there is loss of 29 mass units, equivalent to CH_3-CH_2·.

There is, however, a major discrepancy between the Shell sample and the samples produced using sulfuric acid as the catalyst, in that, in some cases with the Shell sample there is no evidence for the loss of 32 mass units, equivalent to CH_3-OH, following the loss of the alkyl cation. This loss of methanol appears to be characteristic of methyl esters ortho to a hydroxyl group[97]. It is always observed with the methylated alkylsalicylic acids produced from salicylic acid using sulfuric acid as the catalyst, followed by methylation. There is also no evidence for the loss of 18 mass units, (water) followed by 28 mass units, equivalent to CO, which would be observed if the species in question was the alkylsalicylic acid (incomplete methylation for some reason) instead of the methyl alkylsalicylate. The type of products from the commercial sample that have tentatively been assigned by their mass spectra are shown in Figure 6.7. Given that the alkylsalicylic acids are made by the Kolbe-Schmitt reaction upon alkylphenol, the alkylphenol must be the ortho alkylphenol. It is likely that Shell will use their own alpha olefins rather than propylene tetramer or similar. When Adibis has ever tried to alkylate phenol with alpha olefins, ortho substitution always results. Improvements could be made in the assignments of the structures if a sample could be obtained of just the alkylsalicylic acids rather than having stearic acid present or being overbased. The analysis of a sample of the commercial alkylsalicylic acids without the presence of stearic acid will be commented on in the next section.

Figure 6.7. Structures of the commercially available, supposedly, alkylsalicylic acids. the methyl 5-alkylsalicylate and (**74**) the methyl 3-alkyl-4-hydroxybenzoate (**75**).



$$R = C_{14}H_{29} - C_{19}H_{39}$$

The presence of methyl 3-alkyl-4-hydroxybenzoate is inferred from the fact that there is no loss of methanol, which would be consistent with a methyl salicylate and that it is known that, on alkylating phenols[96], ortho and para isomers result. The ortho-para ratio depends on the catalysts and conditions employed. Thus on using a mixture of alkylphenols containing both the ortho and para-alkylphenols in the Kolbe-Schmitt route to alkylsalicylic acids, the 3-alkyl-4-hydroxybenzoic acid would result from the ortho-alkylphenol and the 5-alkylsalicylic acid from the para isomer.

6.4.1. Comparison with Other Commercially Available Alkylsalicylic Acids Which Lack Stearic Acid.

To enable the analysis of the alkylsalicylic acid content of the commercial additive without the interference from stearic acid required the separation of the acid from the base oil. This is normally achieved in other additive systems, such as the calixarates[98,99] or phenates, by dissolving the oil/additive mixture, 20% weight for weight, in a non-polar solvent such as hexane or toluene. Then by the addition of ten times the volume of acetone the overbased alkylsalicylic acid should precipitate out of solution. This method was used successfully used to separate the salicylic/stearic acid mixture from the base oil in the previous section[e].

However, this method did not work in this case. A very small amount of the alkylsalicylic acid was separated from the oil by carrying out acid/base washes with ether extractions. The alkylsalicylic acids were methylated using diazomethane so that GC and GC/MS analysis could be performed. This analysis showed that the alkyl chain attached to the salicylic acid ranged from C_{14} to C_{20}. Nmr analysis of the salicylic acids is inconclusive as the residual oil dominates the spectrum.

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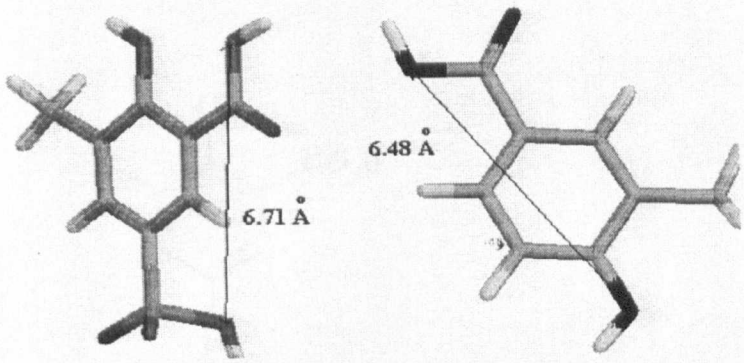
[e] The sample of the commercial 400 TBN salicylate containing the salicylic/stearic acid mixture was separated at Surrey University.

6.5. Molecular Modeling of the Alkylsalicylic Acids.

The molecular modelling was carried out using the MOPAC computer program which employed 3-methyl-5-sulfosalicylic acid as the model, with the help and assistance of Dr. A. C. Whitwood. The molecular modelling indicates that the distance between the hydroxy oxygen and the carboxylic oxygen is about 2.3Å. The distance between the sulfonate oxygen and the carboxylic oxygen is found to be about 6.71Å, which compares favourably with the distance between the hydroxy oxygen and the carboxylic oxygen (6.48Å) in the 3-alkyl-4-hydroxybenzoic acid which is found in the commercial salicylate (Figure 6.8). This suggests that the complexation of the calcium could possibly occur between the sulfonate oxygen and the carboxylic oxygen.

Figure 6.8. MOPAC calculated conformation and inter atomic distances between two oxygen atoms for 3-methyl-5-sulfosalicylic acid and 3-methyl-4-hydroxybenzoic acid.



6.6. Industrial Results.

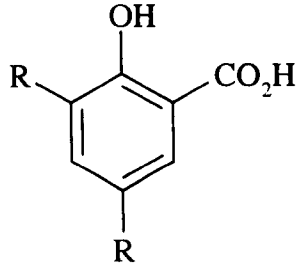
As well as acting as detergents, the alkylsalicylic acids are used to prevent the deposition of fine particles (a "black-paint") on to the inside of an engine. Comparing the performance of the propylene tetramersalicylic acid in "Black Paint" tests against current black paint additives has been disappointing, but some encouraging results have been observed. The black paint test involves heating a sample of the additive in the presence of the oil and fuel on a metal plate, at 100°C for 24 hours. The degree of deposition of particles, the black paint, determines how effective the additive is. The aim was to try to be at least as effective, if not more effective, than the current black paint additive which

consists of an overbased alkylsalicylic acid/stearic acid mixture.

Unfortunately our propylene tetramer salicylic acid was not as good as the better commercial products at preventing the black paint deposition. However, the test was carried out using the salicylic acid without any neutralisation or overbasing which would be expected to aid performance[f]. A comparison between the unneutralised propylene tetramersalicylic acid, one of the best black-paint additives, and a poor additive can be seen in Figure 6.9. The darker the plate the poorer the additive.

Further studies need to be undertaken to analyse the performance of both the neutralised propylene tetramer salicylic acid and the overbased version as black paint additives. A possible improvement could be made by using an additive with two alkyl chains attached to a polar head group. This twin tailed additive could possible provide an improved barrier, preventing the black paint deposition. The 3,5-di(propylene tetramer)salicylic acid (**76**) has been synthesised and black paint additive testing should take place in the near future.

Structure 76

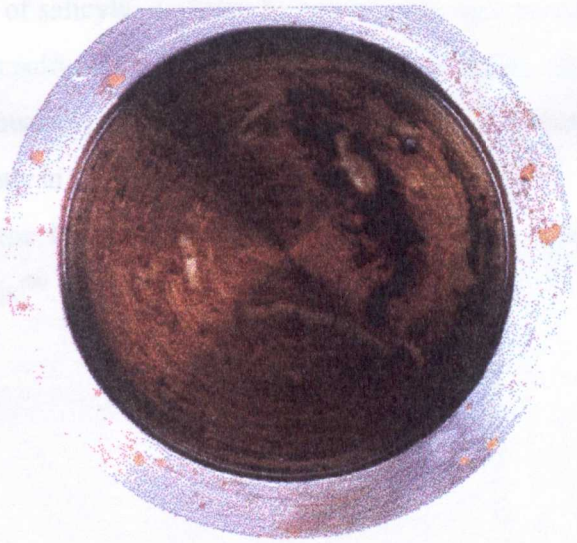


(76) R = Propylene Tetramer

[f] The black paint testing was carried out by Paul Robinson at the BP, Hull research centre.

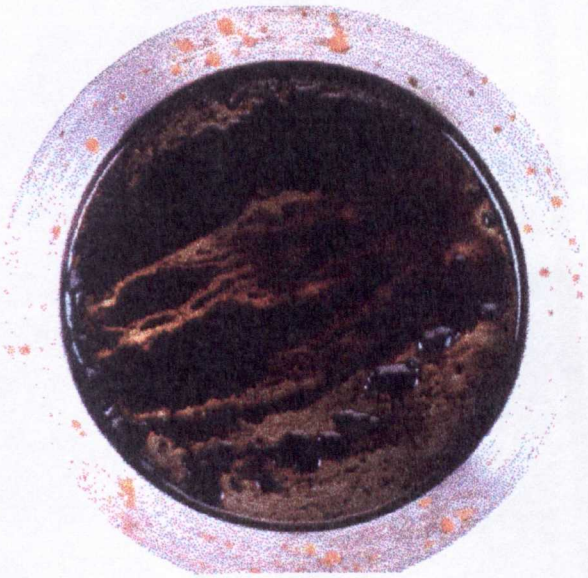
Figure 6.9. The black paint results for the mixture containing (a) overbased salicylic acid and stearic acid, (b) propylene tetramersalicylic acid (without overbasing) and a very poor black paint additive. The darker the plate the poorer the additive. (Original in colour).

(a)



(b)

(c)



6.7. Conclusions.

The alkylation of salicylic acid can be achieved in high accountabilities and purities on a large scale when sulfuric acid and an industrially available alkene, such as propylene tetramer, are used. However, the overbasing stage of the reaction has yet to be optimized. Further work is currently in progress to manufacture the alkylsalicylic acids on a much larger scale. This follows the filing of a patent covering the alkylation of salicylic acid work contained in this thesis[100].

Chapter 7

The Sulfurisation of Alkylphenols

7. Introduction.

The sulfurisation of alkylphenols is an important step in the manufacture of a number of overbased detergents, whose primary purpose is to transport a base to the interior of an engine, there to neutralise any acids formed. This is especially important in the case of marine engines which use a low grade, high sulfur content fuel, and in which there is the consequent possibility of a high concentration of acid in the engine, if no base is present. The presence of the acid is primarily due to the sulfur compounds in the fuel oxidising to form sulfuric acid, which left unneutralised would corrode the engine and reduce its lifespan.

An overbased detergent consists of two parts, a polar head group, which is used to complex the base (normally an alkali metal carbonate), and a non-polar tail to facilitate oil solubility. This non-polar tail is an alkyl chain. The sulfurisation process is used to link together two or more alkylphenols to form the sulfur-bridged di(alkylphenol), which is then reacted further to form the overbased detergent. The alkylphenols used are typically para-compounds with the alkyl chain consisting of at least eight carbon atoms. The number of carbon atoms can be in the hundreds when polyisobutene [PIB] is used to alkylate phenol, but the typical range is 10-25 carbon atoms. The size of the alkyl chain is very important. If the chain is too small, the resulting overbased detergent will not be oil soluble and hence will be ineffective at neutralising the acids formed in the engine. If the additive is not oil soluble or only partly soluble in the oil, it could "crash out" of the oil forming a large amount of precipitate which could clog the engine, doing more harm than good.

The industrial synthesis of the over based detergent is a 3-stage process. This work investigates the first stage, the sulfurisation of the alkylphenol to the monosulfide or to the polysulfide depending on the authors point of view[1,2,101]. The second stage is the neutralisation of the sulfurised alkylphenol, which is achieved by the addition of an equimolar amount of calcium carbonate to the sulfide. The final stage involves the addition of an excess of carbon dioxide to produce a more basic compound; this is termed overbasing. A typical value for the basicity of the sulfurised alkylphenol overbased detergent is a Total Base Number (TBN) of 400 but will ultimately depend on the end use of the detergent. A lower TBN can be used in an automotive oil because automotive engines use a higher grade fuel which contains less sulfur than is the case with marine engines. The standard method used to calculate TBN is described in chapter 1.

The work presented in this chapter is concerned with the sulfurisation of

alkylphenols, as the exact nature and composition of the sulfurised alkylphenols (SAP) are not at all well understood. The work builds on an earlier study by Maxine Darby[78] who investigated, briefly, the sulfurisation of alkylphenols. A major uncertainty is the presence or otherwise of multiple sulfur linkages joining the alkylphenols, as the presence of polysulfides is well documented in similar systems[102]. However, there is currently no evidence, as to whether polysulfur bonds can be formed between alkylphenols. This chapter will discuss the possible presence of these polysulfur bridges and also the identification of the range of products that can be formed.

7.1. Industrial Synthesis of Sulfurised Alkylphenols.

Industrially, the alkylphenol is manufactured from phenol and, usually, propylene tetramer. Another compound that can, and is used, instead of the propylene tetramer is polyisobutene. An industrial sample of the propylene tetramer consists, as can be clearly seen in the Gas Chromatographic (GC) trace, shown previously in Chapter 6, of a complex mixture of C_{10}, C_{11} and C_{12} alkenes. The use of such a complex starting material in the investigation into the sulfurisation of alkylphenols is clearly unsatisfactory, as the resultant products would be too numerous to be identified easily by GC. Also, the use of a C_{12} alkyl chain may well make the resultant sulfurised alkylphenol products too involatile to be eluted from a GC. The use of High Performance Liquid Chromatography (HPLC) instead of GC to separate and identify the products would not be a satisfactory solution for two reasons. Firstly, the resolution and separating efficiency of the HPLC is much lower than that of a GC and high resolution is obviously necessary. Secondly, mass spectra are required of the components in the product mixture to facilitate analysis and Liquid Chromatography /Mass Spectrometry (LC/MS) is a much less well developed technique than is Gas Chromatography /Mass Spectrometry GC/MS.

The general industrial synthesis of the sulfurised alkylphenol is as follows. A reaction vessel is charged with the alkylphenol, calcium carbonate, lubricating oil, sulfur, ethylene glycol, stearic acid and paraformaldehyde. This mixture is heated, with stirring, to 145°C under a slight vacuum. Calcium acetate, calcium carbonate and 2-ethylhexanol are then added and the temperature is increased to 165°C and kept for an hour. Solid carbon dioxide is then added, the temperature increased to 245°C for about 30 minutes, after which

time the pressure is decreased to about 10 mmHg.

To facilitate GC analysis simpler alkylphenols were chosen as models, starting initially with the simplest alkylphenol, p-cresol. However, the behaviour of these smaller molecules and the long chain alkylphenols may be different as it is possible that sulfurisation could involve the long alkylchains. It is known that alkanes will react with elemental sulfur at elevated temperatures to produce dehydrogenated products, though the smaller the alkane the higher the temperature required for dehydrogenated products[96]. One important observation about the propylene tetramer alkylphenol is that it can, and does, contain multiple double bonds (see chapter 6). This is likely to be important, because, in general, alkenes are more reactive than are alkanes to sulfur. So, these double bonds present in the alkyl chain of the alkylphenol could react with the sulfur to produce a whole host of products. At low temperatures, up to 140°C, the mixture of products resulting from the reaction between sulfur and mono olefins include 1,5-dienes, alkyl- and alkenyl-substituted thiacycloalkanes. Using a small alkyl group should have the advantage in that it will reduce the chance of attack of the sulfur on the alkyl chain, thus enhancing the products formed from attack on the benzene ring.

7.1.1. Simplified Industrial Synthesis.

Some of the components used in the full industrial synthesis are not relevant in studying the sulfurisation of alkylphenols, so a simplified process, omitting the paraformaldehyde, calcium carbonate, solvent neutral (SN) oil and stearic acid was used. The roles of these omitted compounds are to act as a crosslinking agent (paraformaldehyde), providing the initially basicity of the detergent (calcium carbonate). The role of the stearic acid in this reaction is not fully known, but is critical when overbasing the detergent. The simplified industrial synthesis consisted of heating, under vacuum, p-cresol, sulfur and ethylene glycol with a sodium hypochlorite trap to remove any hydrogen sulfide that was formed. On application of full vacuum the p-cresol was distilled into the sodium hypochlorite trap and no product was recovered. Under the reaction conditions the p-cresol would be in the vapour phase in the reaction vessel and would be unlikely to react with the sulfur to yield the sulfides.

7.1.2. 4-Isopropylphenol and Sulfur.

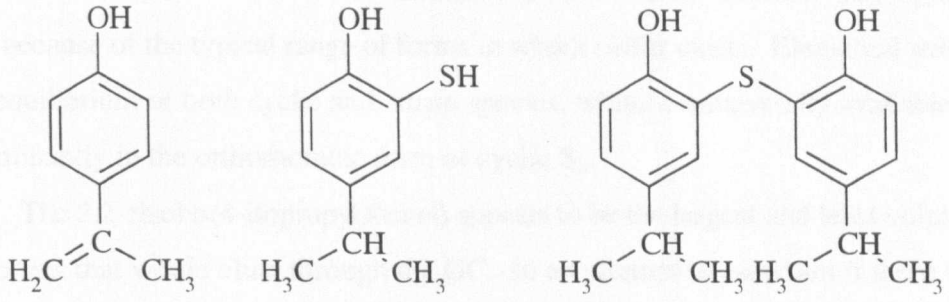
In an attempt to keep the alkylphenol in the liquid phase, and thus avoid it being distilled out of the reaction, a higher boiling alkylphenol, 4-isopropylphenol, was then used. This was chosen because it is higher boiling than p-cresol (212°C and 202°C respectively) and it has a symmetrical alkyl chain, which would facilitate easier analysis of any products formed from reacting with the alkyl chain. However, the 10°C difference in boiling points of the two alkylphenols cannot account for the difference in reactivity since the reaction is carried out well above their respective boiling points. They would therefore be expected to either be distilled over and no product collected, as was the case with p-cresol or to react and give some products, as was the case with p-isopropylphenol. An explanation for the difference in product distribution of the two alkylphenols cannot be given at this time. Reaction of this alkylphenol gave a product in which 3 major components were observed by GC, as illustrated in Figure 7.1. Besides the unreacted starting material, three major components were identified as dehydrogenated starting material 4-isopropenylphenol (**77**), 4-isopropyl-2-thiophenol (**78**) and 2,2'-thiobis(4-isopropylphenol) (**79**) [monosulfide] on the basis of mass spectral evidence. ^{1}H nmr of the isolated material confirmed the proposed structure of the 2,2'-thiobis(4-isopropylphenol). The presence of unreacted starting material was confirmed by comparing its retention times and its mass spectrum with those of an authentic sample.

peak 1: 4-isopropenylphenol (**77**): m/z 134(M^+, 100%); 133 (M-1, 16) 119(M-CH_3, 73) 91(24)

peak 2: 4-isopropyl-2-thiophenol (**78**): m/z 168(M^+, 45%); 153(M-CH_3, 100) 120(M-CH_4S, 27)119(21) 91(44)

peak 3: 2,2'-thiobis(4-isopropylphenol) (**79**): m/z 302(M^+, 100%); 303(M+1^+, 21) 287(M-CH_3, 37) 245(25) 136(79) 121(81) 91(43)

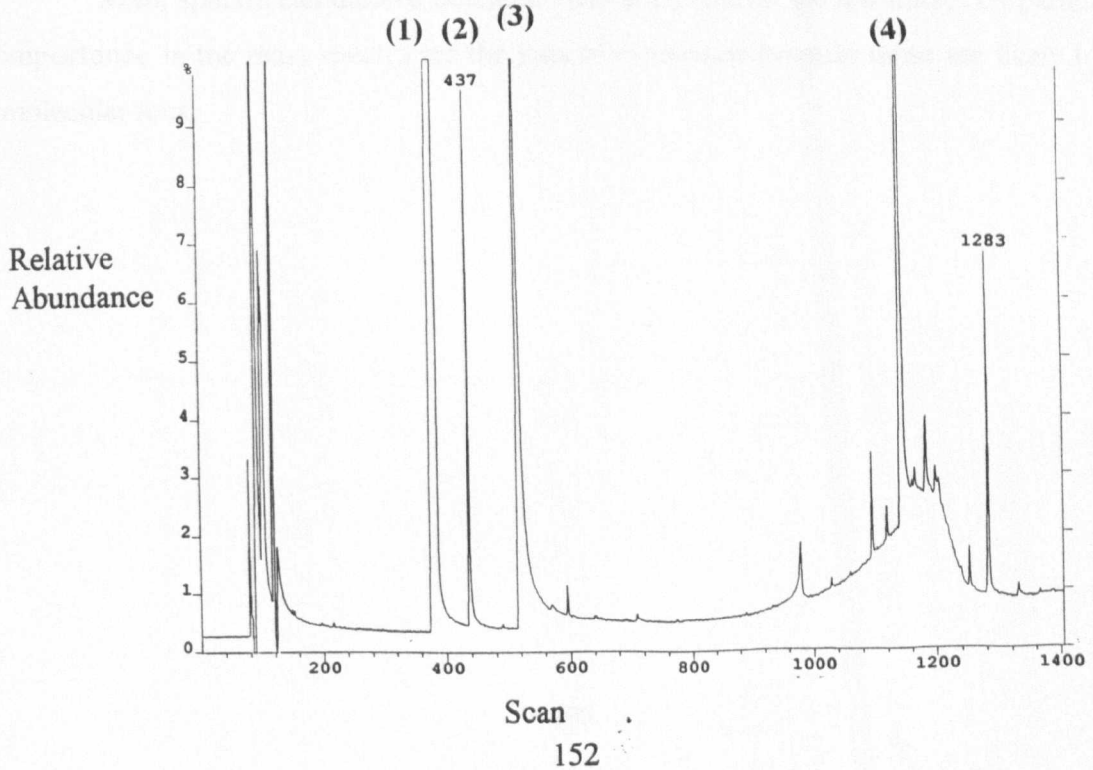
Structures 77-79



(77) **(78)** **(79)**

The configuration of the structures agrees with the assumption that if the sulfur were to attack via an electrophilic or a radical route, then it would be expected to attack in the 2 or 6-position. This is because of the intermediate formed when attack occurs in the 2 or 6-position has the greater degree of stablisation from the mesomeric effect of the hydroxyl group compared to attack at the 3 or 5-position. The 4-isopropenylphenol probably stems from a sulfur catalysed dehydrogenating process which is well documented[103]. A minor product is also observed which corresponds to the dehydrogenated 2,2'-thiobis(4-isopropylphenol).

Figure 7.1. The GC trace (obtained from a GC/MS run) of the product mixture from the reaction between 4-isopropylphenol and sulfur. The major products are; (1) 4-isopropylphenol, (2) 4-isopropenylphenol, (3) 4-isopropyl-2-thiophenol and (4) 2,2'-thiobis(4-isopropylphenol).

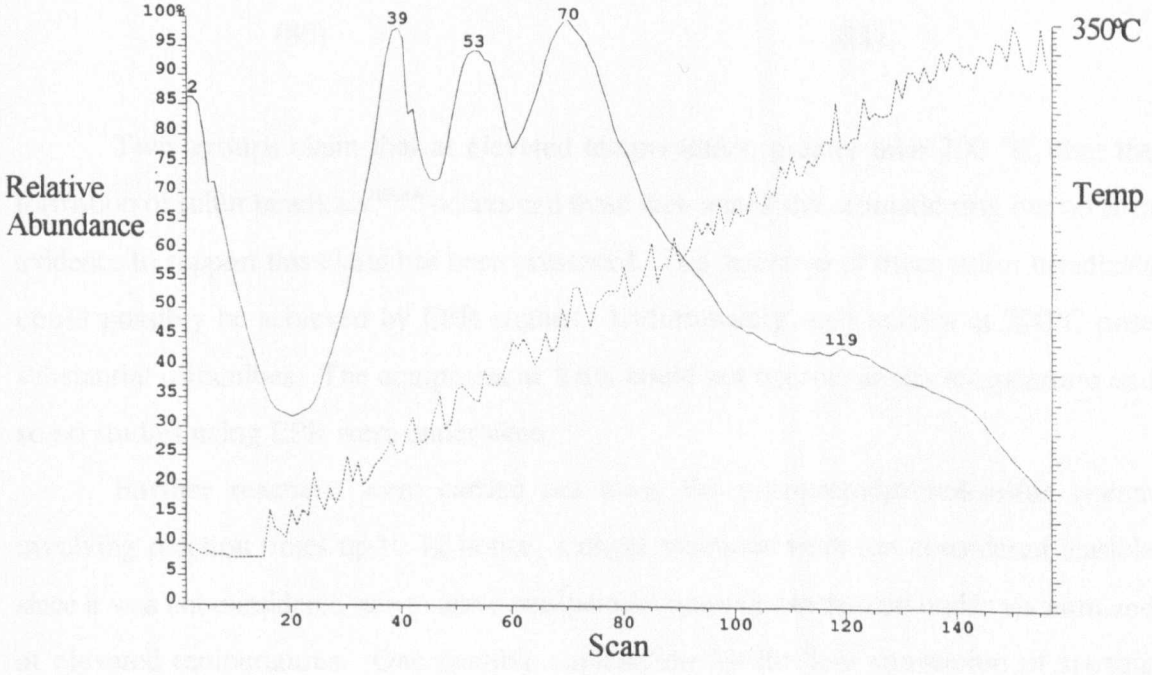


The broad leading edge of the GC trace from scan 900 upwards is due to the interconversion of the various forms of elemental sulfur on the column. The signal is very broad because of the typical range of forms in which sulfur exists. Elemental sulfur exists in an equilibrium of both cyclic and chain species, whilst commercially available sulfur is predominantly in the orthorhombic form of cyclic S_8.

The 2,2'-thiobis(4-isopropylphenol) appears to be the largest and least volatile major component that would elute through the GC. In an attempt to ascertain if there were any larger, more involatile components present in the product mixture from the reaction between 4-isopropylphenol and sulfur, the product mixture was submitted for probe mass spectrometry (probe MS)[104]. If there was a disulfide present in the mixture injected into the GC, it is unlikely that the disulfide would be eluted because of the difference in boiling point between the disulfide and the corresponding monosulfide. In general, a corresponding disulfide has a boiling point approximately 50°C higher than that of the monosulfide[96]. In this case the probe MS technique used involved the progressive heating of the sample on the probe leading to the various components volatilizing in a steady stream. The steady stream of volatilized sample is then ionised by either Chemical Ionisation (CI) or by Electron Impact (EI) methods to give a range of mass spectra. For future reference, this use of probe MS will be identified as variable temperature probe MS (VTPMS). The steady stream of volatilised sample gives rise to an ion trace, showing if anything was volatilised at a given time and temperature. The ion trace from the VTPMS of the crude product from the reaction between 4-isopropylphenol and sulfur can be seen in Figure 7.2.

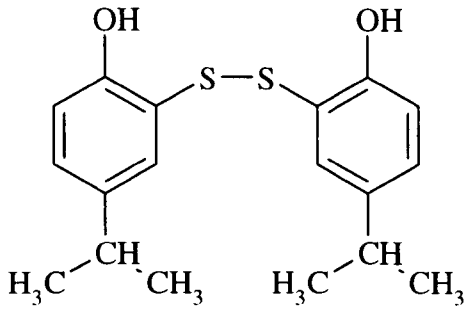
Mass spectra can then be obtained from any point on the ion trace. Of particular importance in the mass spectra are the ions of even mass because these are likely to be molecular ions.

Figure 7.2 The ion trace from the VTPMS of the crude product from the reaction between 4-isopropylphenol and sulfur. The dotted line (-----), rising left to right, is the temperature of the probe, reaching a maximumof 350°C. The solid line (——) is the ion trace, showing that three major components are being volatilised and then ionised as the temperature of the probe increases. All three components have very similar mass spectra.

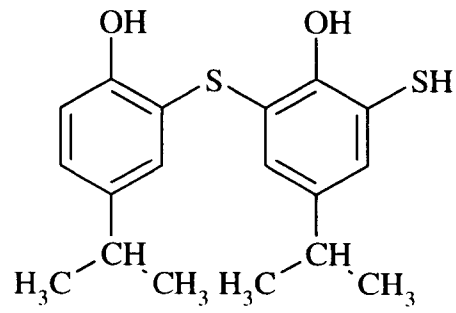


Analysis in this way of the product from the reaction between 4-isopropylphenol and sulfur showed at least one other component was present. This had a mass to charge ratio (m/z) of 334 and is probably a molecular ion. Accurate mass measurements gave a molecular formula of $C_{18}H_{20}O_2S_2$ and is consistent with the product containing two isopropylphenol groups and two sulfur atoms. Whilst several structures are possible, two are particularly likely, the disulfide (**80**) and the monosulfide with a thiol group (**81**){2,2'-thiobis(4-isopropyl-[6-thiophenol])}. If the component with m/z of 334 is the disulfide, then it was initially thought that it should have a very weak molecular ion, under EI conditions, because it would readily fall apart. However, results from recording a mass spectrum of an authentic disulfide, p-tolyldisulfide, confimed that, against initial expectations, disulfides do indeed have very stable molecular ions.

Structures 80 and 81



(80)



(81)

Two groups claim that at elevated temperatures, greater than 200 °C, that the formation of sulfur biradicals[105,106] occurs and these then attack the aromatic ring but no firm evidence to support this claim has been presented. The detection of these sulfur biradicals could possibly be achieved by EPR studies. Unfortunately such studies at 200°C pose substantial difficulties. The equipment at York could not operate at this temperature and so no studies using EPR were undertaken.

Further reactions were carried out using the p-isopropylphenol/sulfur system involving reaction times up to 12 hours. Longer reactions were not considered feasible since it was not considered safe to leave equipement running unattended under vacuum and at elevated temperatures. One possible explanation for the low conversion of starting materials to products could be the ready conversion of sulfur to hydrogen sulfide which would be lost in the system. This would leave a limited amount of sulfur able to react with the alkylphenol, and so reduce the conversion of starting materials to products. Based on uncalibrated GC areas, 75% of the product mixture consisted of unreacted starting material. The low conversion to products prompted the use of an alternative synthesis involving sulfur monochloride.

Throughout this work a number of techniques, which will be discussed later, have been used in an attempt to identify and separate all the components that are present. In most instances this has not proved possible which is unfortunate, since if this separation could have been achieved, the uncertainty as to whether a monosulfidethiol or a disulfide could have been formed could have been resolved by using ^{1}H NMR or IR spectroscopy.

7.2. Reactions Using Sulfur Monochloride.

As an alternative to heating with sulfur reactions using sulfur monochloride were investigated since this compound has been used in the past in this country[107] and is still used in Russia to produce sulfurised alkylphenols. Sulfur monochloride is not currently employed industrially in the UK and many others because of its high toxicity and the difficulty of handling it on a large scale.

7.2.1. Sulfur Monochloride and p-Isopropylphenol.

In an attempt to improve the conversion of starting material to products in the sulfurisation of p-isopropylphenol, sulfur monochloride was added to p-isopropylphenol at atmospheric pressure and at lower temperatures than those utilising sulfur. The reactions between sulfur monochloride and p-isopropylphenol were more successful, in that a greater proportion of the starting materials were converted to products, as can be seen from the GC trace in Figure 7.3. Based on uncalibrated GC areas, only 10% of the product mixture was unreacted starting material, compared to 75% when elemental sulfur was used. The major products, seen by GC, were, as with the sulfur reactions, dehydrogenated starting material (4-isopropenylphenol) [**77**], 4-isopropyl(-2-thiophenol) [**78**] and 2,2'-thiobis(4-isopropylphenol) [**79**]. Again, the presence of dehydrogenated starting material is to be expected as sulfur monochloride, like sulfur, has been well documented as a dehydrogenating agent. Again probe mass spectra of the crude product were obtained, to determine if any heavier and/or less volatile compounds were formed in the reaction, that would not pass through the GC. A plethora of ions can be seen from the probe mass spectrum, shown in Figure 7.4. Accurate mass measurements were taken of all the major components and from these molecular formula have been assigned, as illustrated in Table 7.1.

Figure 7.3. The GC trace of the products from the reaction between 4-isopropylphenol and sulfur monochloride. The major products are: **(1)** unreacted starting material, **(2)** 4-isopropyl-2-thiophenol and **(3)** 2,2'-thiobis(4-isopropylphenol).

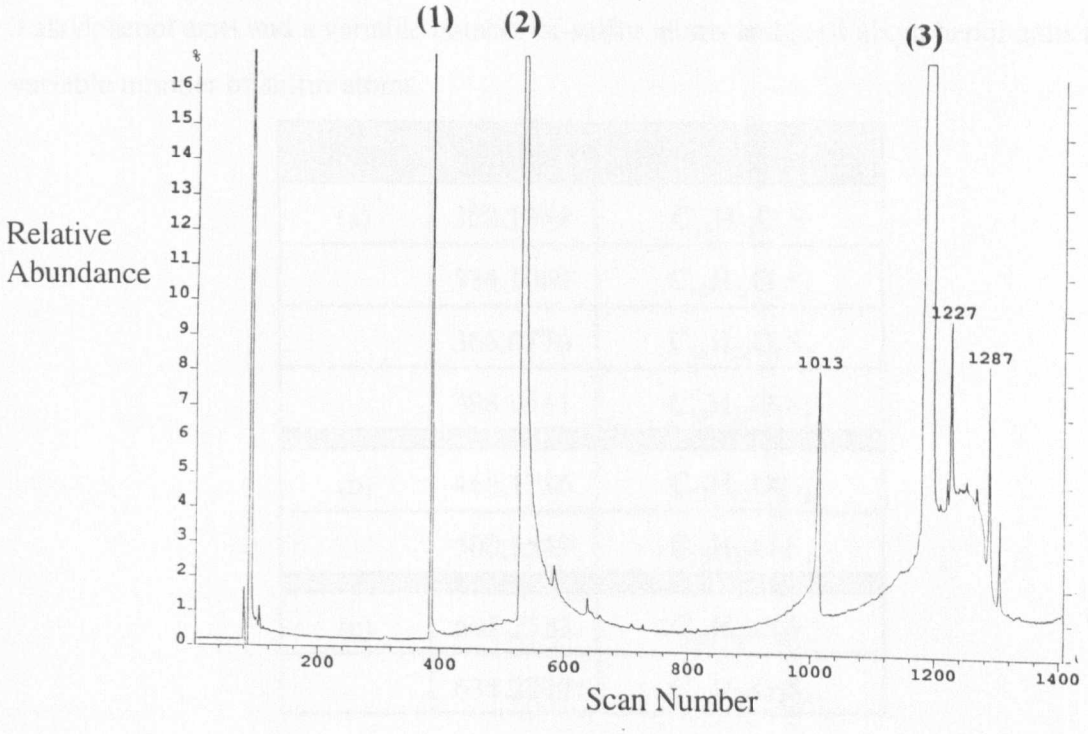


Figure 7.4. A sample mass spectrum from running a VTPMS of the crude product mixture from the reaction of sulfur monochloride and p-isopropylphenol. Note that the relative abundances of the ions with an m/z greater than 302 have been expanded to ten times or fifty times their real magnitudes.

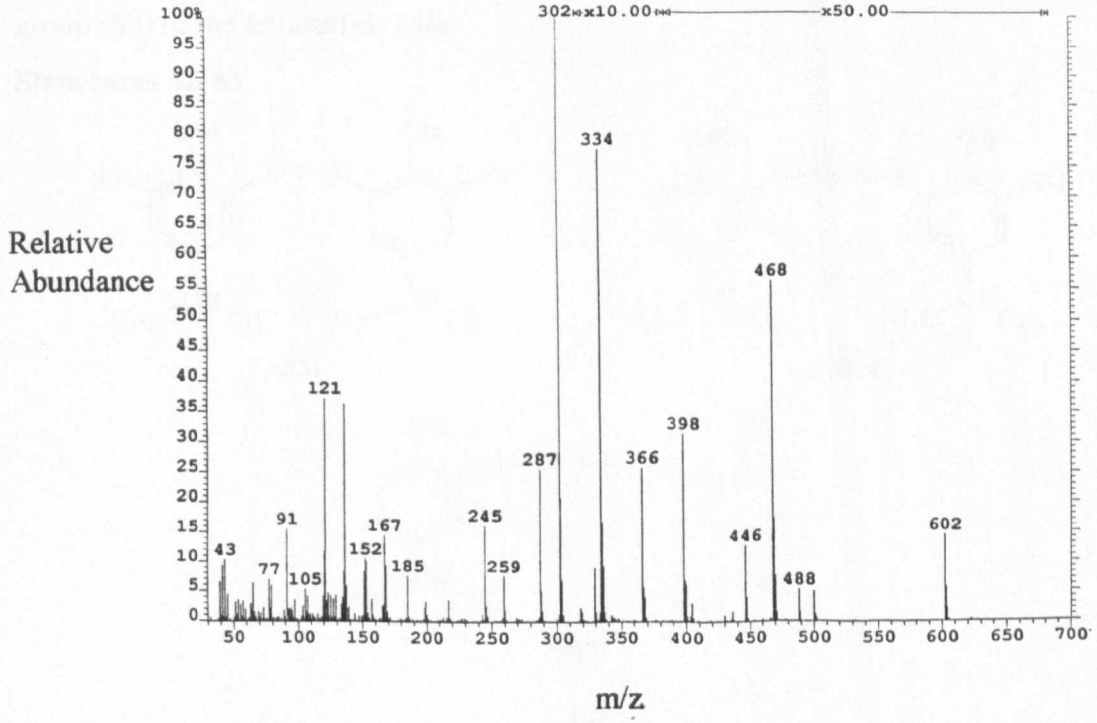
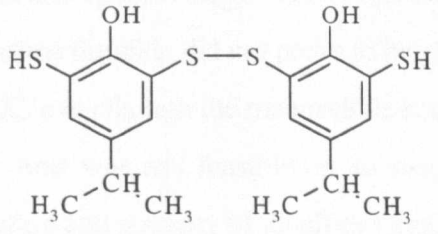


Table 7.1. The mass charge ratio (m/z) and molecular formula, obtained by accurate mass measurements from the VTPMS of the product mixture from the reaction between sulfur monochloride and p-isopropylphenol. The table is split up into three sections with components containing (a) 2 alkylphenol units and a variable number of sulfur atoms, (b) 3 alkylphenol units and a variable number of sulfur atoms and (c) 4 alkylphenol units and a variable number of sulfur atoms.

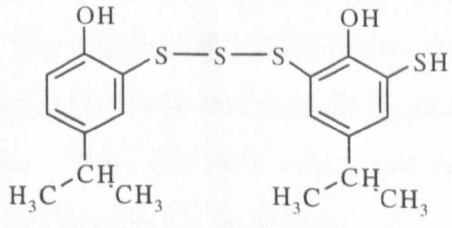
Group	m/z	Molecular Formula
(a)	302.1344	$C_{18}H_{22}O_2S$
	334.1069	$C_{18}H_{22}O_2S_2$
	366.0776	$C_{18}H_{22}O_2S_3$
	398.0511	$C_{18}H_{22}O_2S_4$
(b)	468.1786	$C_{27}H_{32}O_3S_2$
	500.1519	$C_{27}H_{32}O_3S_3$
(c)	602.2533	$C_{36}H_{42}O_4S_3$
	634.2227	$C_{36}H_{42}O_4S_4$

To take one of these ions from the probe mass spectrum appearing to have a mass charge ratio of 398, which corresponds to an elemental formula of $C_{18}H_{22}O_2S_4$, as an example: This compound could have a number of possible structures, but the three most likely structures are; the disulfide with two thiol groups (**82**), the trisulfide with one thiol group (**83**) or the tetrasulfide (**84**).

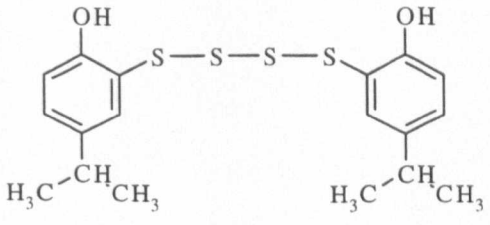
Structures 82-83



(82)



(83)



(84)

Whilst any of these structures is possible it is just as likely that the spectra represents the presence of all three species. However, it should be noted that disulfides are generally much more stable than polysulfides which are not very stable and can decompose to give mono and disulfides[108]. Riding and Hodgson have shown that it is possible to form polysulfides from the addition of a haloalkane to sodium polysulfide[109,110]. The synthesis of authentic samples even if the reaction works with haloarenes, still suffers from the problem, even for disulfides, in that sodium disulfide is an equilibrium mixture of polysulfides. The sodium disulfide contains a distribution of Na_2S, Na_2S_2 , Na_2S_4 and possibly Na_2S_5 and Na_2S_6, which can give rise to mono, di, tetra and possibly penta and hexasulfides. Tri and tetrasulfides can also be formed from reacting sulfur chlorides with mercaptans[111], but this approach again suffers from the problem that a mixture of polysulfides results. Separation of these mixtures has been shown to be very difficult and so this approach has not been pursued.

From the results from the reactions using sulfur monochloride, and the literature evidence, the possibility cannot be discounted that the component with a m/z ratio of 398 is a mixture of the di, tri and tetrasulfides. The same evidence and explanation can be applied to the ion with a mass charge ratio of 366. This species could be the monosulfide with two thiol groups, a disulfide with one thiol group or the trisulfide and again the possibility that all three are present, cannot be discounted.

A great deal of effort was devoted to the attempted isolation, purification and the characterisation of the various components with only limited success. Amongst the techniques used were; distillation, column chromatography and HPLC. Using column chromatography, 2,2'-thiobis(4-isopropylphenol) [**79**] was isolated and charcterised by ^1H and ^{13}C nmr spectroscopy. However, the isolation and characterisation of other products, such as the disulfide did not prove to be possible. The disulfide (**80**) could not be observed by TLC, even though the monosulfide could be seen very clearly and analysis by probe MS or by nmr was not feasible on so many samples. Work has been carried out into the formation and stability of disulfides and will be discussed in a later section.

7.2.2. Reactions of 2,2'-thiobis(4-isopropylphenol) with Sulfur Monochloride.

A pure sample of 2,2'-thiobis(4-isopropylphenol) [**79**] was obtained by column chromatography of the product from a reaction between 4-isopropylphenol and sulfur monochloride. This was reacted with sulfur monochloride, under the same conditions as the reactions between 4-isopropylphenol and sulfur monochloride. This reaction was attempted to try and produce one of two products, either sulfur-bridged polyalkylphenols or polysulfides, as both these compounds could possibly exist in the industrial synthesis. A variable temperature probe mass spectrum was run of the crude product mixture and this can be seen in Figure 7.5. Table 7.2 shows the mass to charge ratio and the corresponding molecular formula, of some of the new key ions, not observed before when a VTPMS was run of the crude product mixture from the reaction between 4-isopropylphenol and sulfur monochloride.

Figure 7.5. One mass spectrum from running a VTPMS of the crude product mixture from the reaction of sulfur monochloride and a pure sample of 2,2'-thiobis(4-isopropylphenol) [**79**]. Notice that there are a large number of components being volatilised as the probe temperature rises

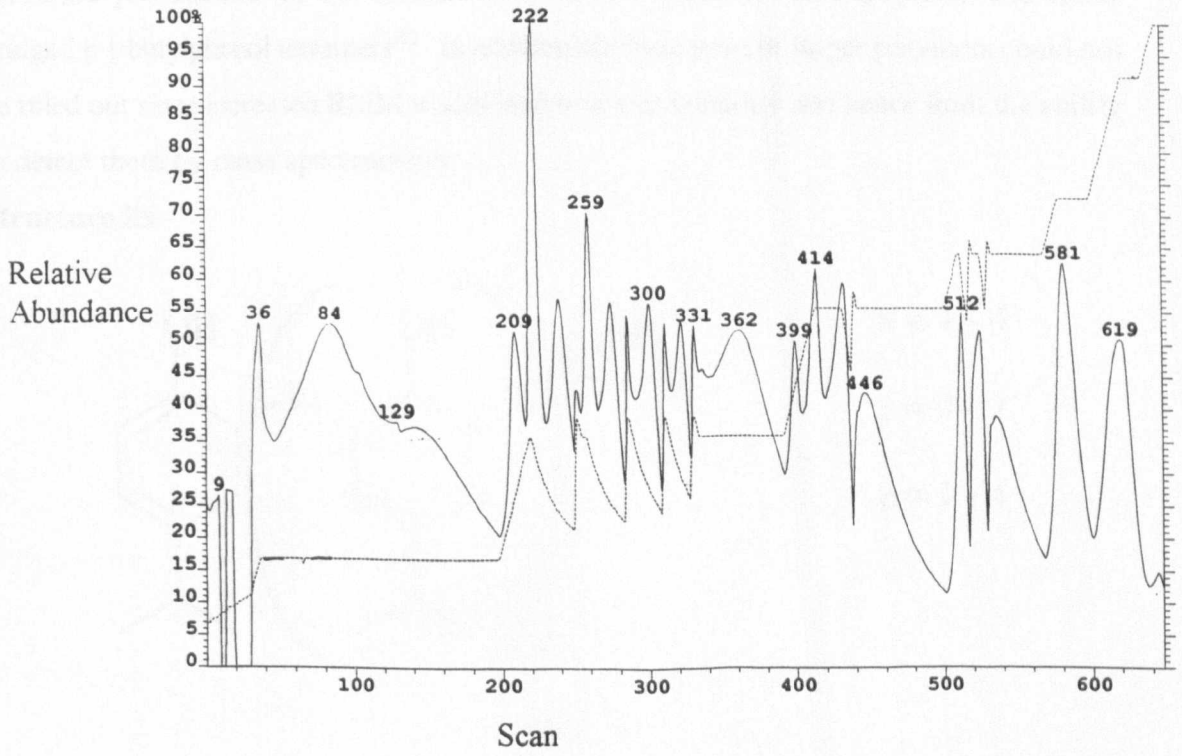
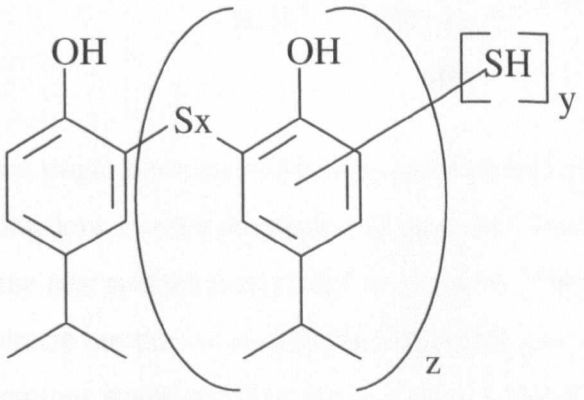


Table 7.2. The mass charge ratio (m/z) and molecular formula, obtained by accurate mass measurements from the VTPMS of the product mixture from the reaction between sulfur monochloride and 2,2'-thiobis(4-isopropylphenol) [**79**]. The table is split up into three sections with (a) 3 alkylphenol units and a variable number of sulfur atoms, dehydrogenated, (b) 4 alkylphenol units and a variable number of sulfur atoms, dehydrogenated and (c) 5 alkylphenol units and 4 sulfur atoms.

Group	m/z	Molecular Formula	Number of a) alkylphenol groups and b) sulfur atoms
(a)	530.1104	$C_{27}H_{32}O_3S_4$	a) 3 b) 4
	562.0845	$C_{27}H_{32}O_3S_5$	a) 3 b) 5
(b)	664.1811	$C_{36}H_{40}O_4S_4$	a) 4 b) 4
	696.1517	$C_{36}H_{40}O_4S_5$	a) 4 b) 5
	728.1246	$C_{36}H_{40}O_4S_6$	a) 4 b) 6
(c)	800.2670	$C_{45}H_{52}O_5S_4$	a) 5 b) 4

Variable temperature probe mass spectrometry of the crude products provided evidence for the formation of poly(isopropylphenols) with one or more sulfur atoms linking the phenol units. Such products would have the general structure of (**85**). There is literature precedence for the formation of sulfur-bridged p-cresol tetramers and sulfur bridged p-t-butylphenol tetramers[112]. In addition the formation of larger polymers could not be ruled out since increased RMM would lead to lower volatility and hence limit the ability to detect them by mass spectrometry.

Structure 85



x = 1 - 4

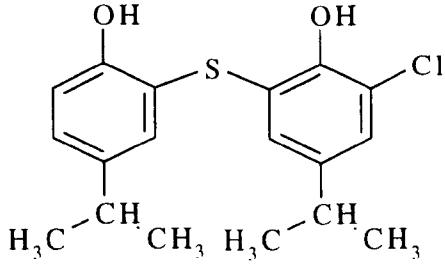
y = 0 - 2

z = 1 - 4

(**85**)

The product from the reaction between 2,2'-thiobis(4-isopropylphenol) and sulfur monochloride was separated into its components by HPLC, a method chosen because of its superior separating ability over TLCs and column chromatography, and because it can also be used to collect the compounds as they elute. As can be seen from the resulting HPLC trace in Figure 7.6, nine fractions were collected, with the last fraction likely to be a mixture of components because of the rapid change in solvent polarity at this point in order to ensure that all the components were eluted from the column. The HPLC was used preparatively, with all the fractions collected after each injection. Repeat injections enabled enough of each fraction to be obtained so that nmr analysis and probe mass spectrometric analysis could be carried out on each fraction. In general, these nmr spectra were very disappointing with only one spectrum (that from fraction 3) providing enough information to characterise the material. The nmr and the mass spectra suggested, surprisingly that the compound had the structure 2,2'-thiobis(4-isopropyl-[6-chlorophenol]) [**86**] in which chlorine has been introduced into the ring. The mass spectrum gave the typical 2:1 splitting pattern associated with chlorine. The presence of a chlorinated product is perhaps not totally unexpected as sulfur monochloride has been shown to replace either hydrogen or a thiol group by chlorine[111]. However, from the point of view of comparison with the industrial process the presence of 2,2'-thiobis(4-isopropyl-[6-chlorophenol]) [**86**] is not very helpful as it cannot be formed in the industrial synthesis in which sulfur is used rather than sulfur monochloride.

Structure 86

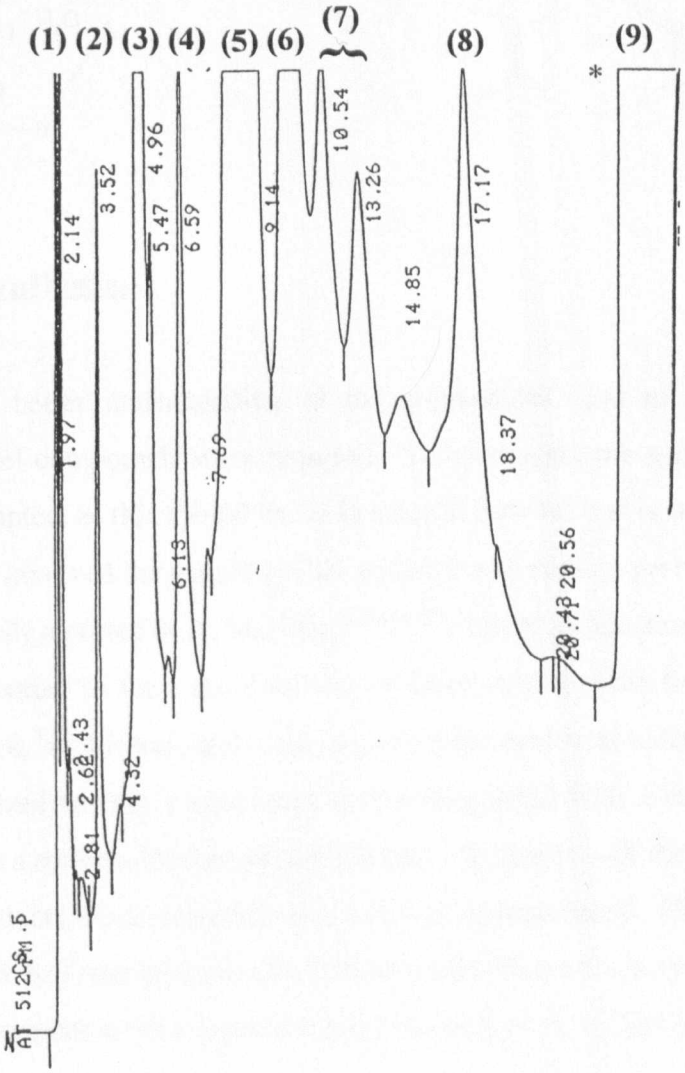


(86)

One might have expected to obtain structural information from some, if not all, of the other fractions, as enough sample was collected. Unfortunately they all showed a broad signal in the nmr spectra centred at δ = 1.5 ppm. There was evidence for some aromatic protons present but they were only just noticeable above the baseline. Such a low level of aromatic protons would still give rise to a large absorption in the UV/VIS region, resulting in their detection by the HPLC. It was possible that the signal at δ = 1.5 ppm was caused

by heavily shielded water protons, on shaking with D_2O the broad signal at $\delta = 1.5$ ppm at disappeared, confirming the presence of water. The cause of the shielding is consistent with one of two possible structures both comprising of micelles trapping water in the centre. The unknown compound giving the signal in the nmr could either be a micelle consisting of sulfur-bridged poly-p-isopropylphenol units trapping water inside, as shown in Figure 7.7, or a micelle of silica trapping water. To check this point pure solvent was passed through the HPLC column. Analysis of the eluent by ^1H nmr showed a broad signal at $\delta = 1.5$ ppm, supporting the view that the unknown compound was a micelle of silica.

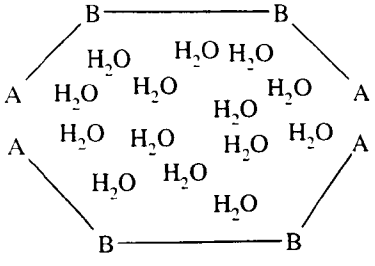
Figure 7.6. The HPLC trace of the products from the reaction between 4-isopropylphenol and sulfur monochloride, showing that 9 distinct fractions were collected. Note at the point marked by a * the solvent was changed manually to give a much more polar solvent, so that all the components were eluted from the column. Consequently fraction 9 may well be a mixture of compounds.



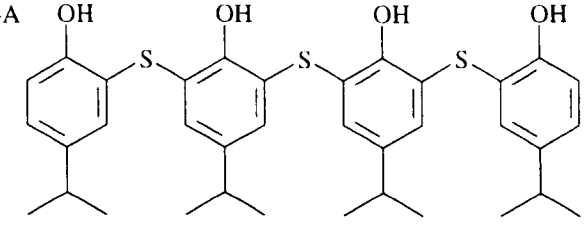
Probe mass spectra were run on each of the fractions and each one, apart from fraction 3, showed evidence for polysulfides and the sulfur-bridged p-isopropylphenol polymers. The silica micelles would not have been detected by the probe mass spectrometer because of their very low volatility. The probe mass spectral evidence is inconsistent with the ^{1}H nmr data and no explanation can be offered for this inconsistency. A full description and identification of all the fractions can be found in Chapter 8, section 7.

Following the lack of success with the HPLC separation, and problems of access to the HPLC instrument no further separation work was carried out on the sulfurised alkylphenols.

Figure 7.7. Possible structure of the ^{1}H nmr multiplet at δ = 1.5 ppm, showing a micelle consisting of sulfur-bridged poly-p-isopropylphenol units trapping water inside



Where A-B-B-A is

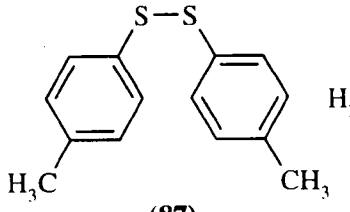


7.3. Disulfide Synthesis.

To gain a better understanding of the polysulfides, and to help with their identification, model compounds were required. To start with, the synthesis of simple disulfides was attempted, as this should be fairly straight forward and is well documented. The synthesis used involved the reaction of an arylthiol with sodium perborate to give the disulfide, as previously reported by A. McKillop[113,114,115]. Initially, thiocresol was chosen as the thiophenol substrate to form the disulfide. p-Thiocresol was the first isomer of the thiocresols to be used, but the meta and ortho isomers were used later to form the disulfide. The reaction involved stirring 1 equivalent of the thiophenol with 2 equivalents of the sodium perborate in a methanol/water solvent mixture. On analysis of the product mixture by GC, three products were detected, in a ratio of approximately 15:1:9. The three products by GC/MS had near identical mass spectra which showed a very stable molecular ion of *m/z* 246 (corresponding to a molecular formula of $C_{14}H_{14}S_2$). Such similarity is often

characteristic of aromatic isomers. A possible assumption on observing more than one product would be that there was an impurity present in the starting material. The fact that three identical mass spectra result, means it is likely that the impurity is m-thiocresol. If this was the case, the products would be, 4,4'-tolyldisulfide (**87**),4,3'-tolyldisulfide (**88**) and the 3,3'-tolyldisulfide (**89**). Unfortunately for this argument, the ratio of the products obtained would require that about 20% of the starting thiol would be expected to be the meta isomer, assuming, that is, that the m-thiocresol and the p-thiocresol show similar reactivity to dimerisation. The analysis of the p-thiocresol by GC shows that 97% of the p-thiocresol is in fact p-thiocresol, with the remaining 3% being the m-thiocresol. This 3% of m-thiocresol would be expected to give a product distribution of approximately 1000:1:60. Definitive identification of the products formed from the reaction of the thiophenol with perborate is required before any conclusions can be drawn. A number of methods were used to help with this identification. Firstly, the presence of m-thiocresol in the p-thiocresol was confirmed by comparing the retention time, on the GC, of an authentic sample of m-thiocresol and the retention time of the crude product mixture. The identification of the 4,4'-tolyldisulfide (**87**) in the oxidation product was achieved by comparing the retention times on the GC of an authentic sample and by ^{1}H nmr of a purified sample. The identification of the 3,3'-tolyldisulfide (**89**) was achieved by ^{1}H nmr of a purified sample.

Structures 87-89



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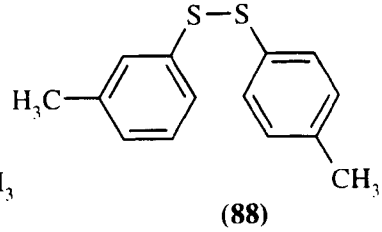

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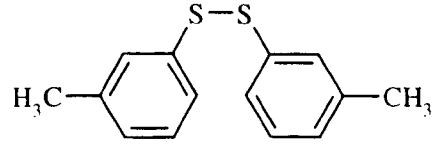


(89)

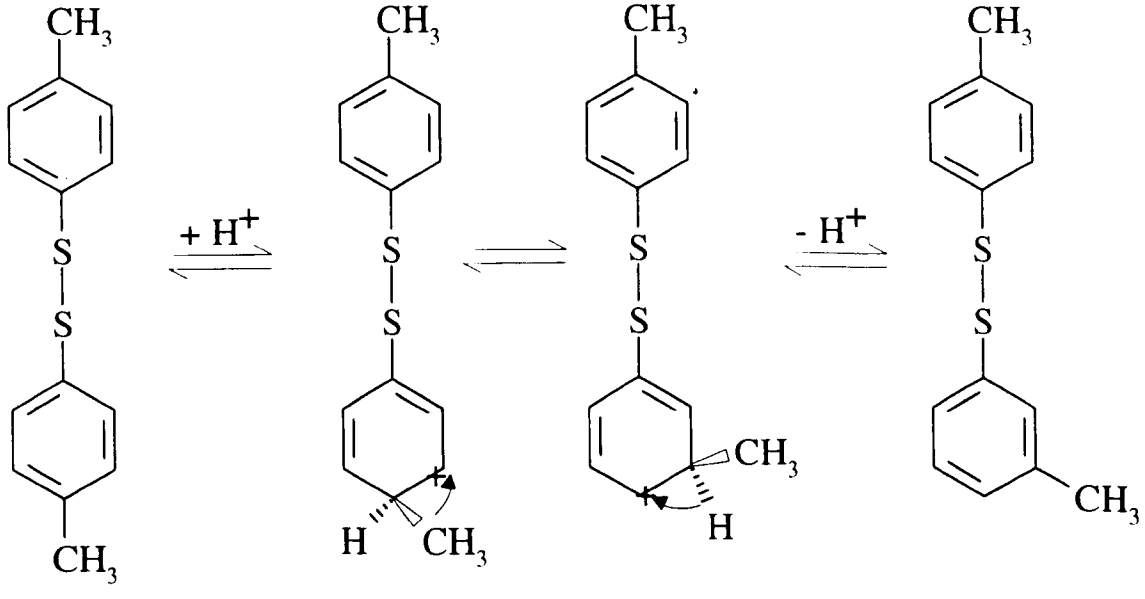
Repeating the reaction in dichloromethane rather than a methanol/water mixture gave a single product (4,4'-tolydisulfide), identified by GC/MS and ^{1}H nmr spectroscopy. The presence of 4,3'-tolyldisulfide is inferred from the assumption that there is both para and meta-thiocresol present in the starting material, and if these two combine they would give the mixed disulfide. There is no spectroscopic evidence for the presence of the 4,3'-tolyldisulfide (**88**) apart from an identical mass spectrum to that of both the 4,4'-tolyldisulfide (**87**) and the 3,3'-tolyldisulfide (**89**).

An inverse product distribution is observed when m-thiocresol is used as the starting

material compared to the p-thiocresol. The major component is the m-tolyldisulfide, followed by the p,m-tolyldisulfide and finally a small proportion of the p-tolyldisulfide.

As well as the presence, in this reaction using p-thiocresol, of more than the expected amount of the 4,3'-tolyldisulfide (**88**) and 3,3'-tolyldisulfide (**89**) a complication was that when reaction times were extended and the resultant products analysed by GC, extra products appeared. For instance, a 48 hour reaction yielded 5 disulfide peaks each with almost identical mass spectra. A possible explanation for these extra peaks and the unexpected product distribution is that a Friedel-Crafts type reaction is taking place, with the migration of the methyl groups around the benzene ring. The formation of extra products after longer reaction time implies that the product distribution is now approaching themodynamic rather than kinetic control. One possible route to form these extra products would require the ring to be protonated, followed by migration of the methyl group, as shown in the Scheme 7.1. To protonate the ring would require the perborate to be converted to boric acid and the boric acid then to catalyse the Friedel-Crafts reaction. There are, however, problems associated with this hypothesis. Firstly, it is unlikely that the boric acid would be a strong enough acid for the reaction to take place.

Scheme 7.1



Rearrangement of p-xylene to m-xylene requires, forcing conditions using aluminium trichloride and hydrochloric acid[116]. However, the stablilizing effect of the intermediate by the mesomeric effect of the sulfur atom could allow less forcing conditions. Secondly, when an authentic sample of 4,4'-tolyldisulphide is subjected to the same reaction conditions as the thiols, no change in the starting material is seen. The lack of reaction of the 4,4'-

tolyldisulphide implies that the rearrangement to the other isomers must occur before the disulfide is formed. Unfortunately, an authentic sample of 3,3'-tolyldisulphide was not available to confirm that all disulfides are stable to the reaction conditions. Reacting 4,4'-tolyldisulphide with boric acid for six hours resulted in unreacted 4,4'-tolyldisulphide being detected by GC. There was no evidence for methyl migration to produce the other tolyldisulphide isomers

Plotting the percentage of the various isomers in the product mixture against reaction duration gives some very interesting results. A graph of the percentage of 4,3'-tolyldisulfide and 3,3'-tolyldisulfide against reaction duration, Figure 7.8, showed that the product distribution changed after reaction times of greater than 4 hours. The suggested explanation for this has to be migration of the methyl group around the ring but against this is the apparent stability of the 4,4'-tolyldislufide, which shows no methyl migration. Methyl migration must occur either with the starting material before any reaction or whilst the reaction, intermediate is formed. The percentage 4,4-tolyldisulfide in the product mixture is shown in Figure 7.9.

Figure 7.8. A graph showing the percentage of 4,3-tolyldisulfide and 3,3-tolyldisulfide in the product mixture against reaction duration.

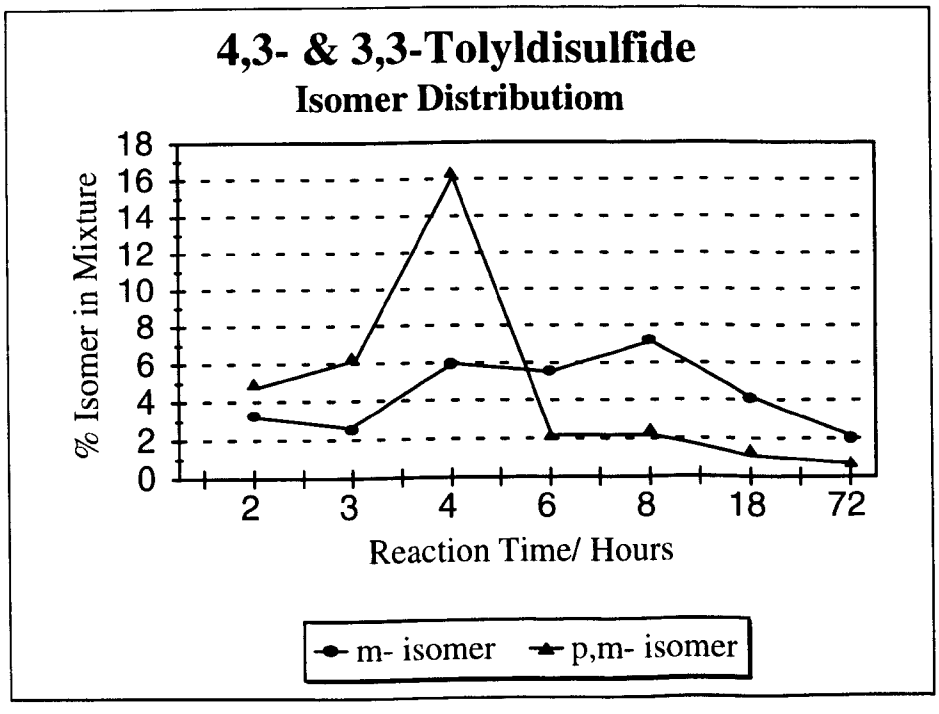
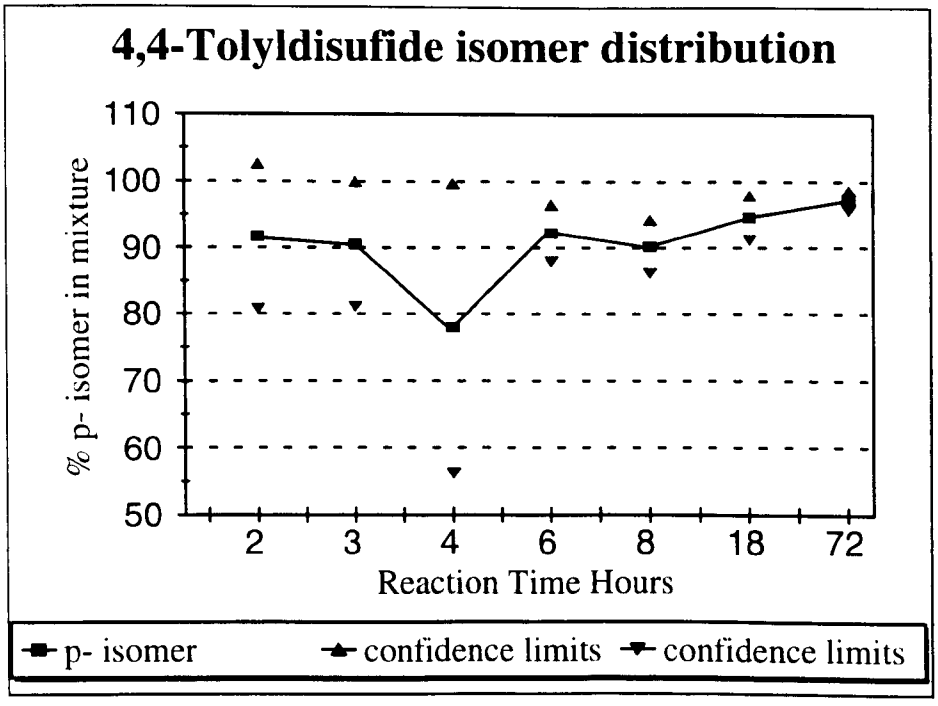


Figure 7.9. A graph showing the percentage of 4,4-tolyldisulfide in the product mixture against reaction duration, with 68% confidence limits.

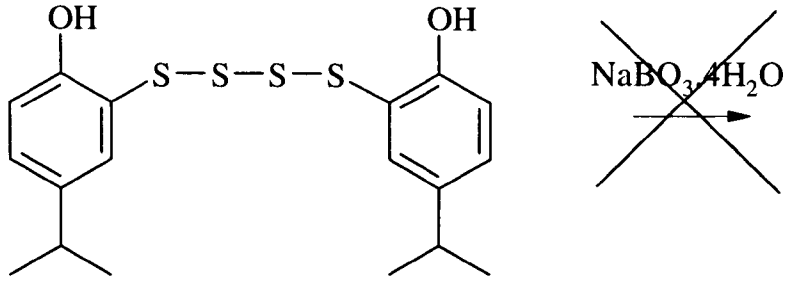


7.3.1 Further Reactions Involving Sodium Perborate.

In an attempt to confirm the presence of the polysulfides in the sulfur and sulfur monochloride reactions, a reaction between the crude sulphide mixture (produced by reacting sulfur monochloride with p-isopropylphenol) and the sodium perborate was to be undertaken. The crude sulfide mixture contains, it is believed, a mixture of thiols, sulfides and polysulfides (**85**). However, it was thought to be desirable to check whether a reaction between a species containing both a thiol and a hydroxyl group was required before the reaction between the crude sulfide could take place, because the perborate could possibly oxidise the hydroxyl group to the peroxide. p-Hydroxythiophenol was chosen as the model compound that contained both a thiol and a hydroxyl group.

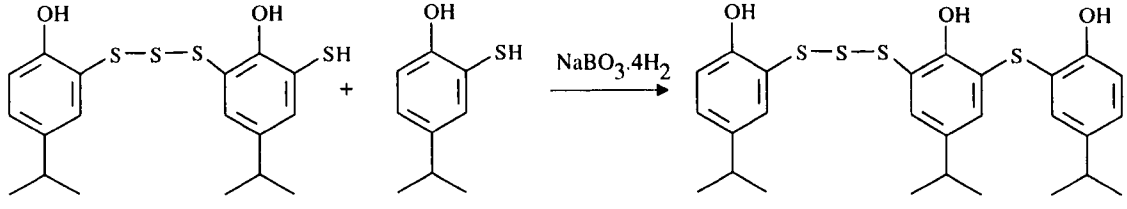
The theory behind the reaction between the crude sulfide mixture and the sodium perborate is that any thiols present in the reaction mixture will be oxidised to the corresponding disulfide. Take, for example, the species with a mass of 398, which contains four sulfur atoms and two isopropylphenol units. If it is the tetra sulfide, no reaction would be expected with the sodium perborate and the tetra sulfide should remain unreacted, as shown in Scheme 7.2a.

Scheme 7.2a



However, if the same species contains a thiol group, the thiol would be expected to be oxidised to a disulfide. Since a number of thiols are expected to be in the reaction mixture, a number of disulfides would be expected to be formed. Since the major thiol component in the crude sulfide mixture is the 4-isopropyl-2-thiophenol, any disulfides formed by the sodium perborate would be expected to contain the 2,2'-thiobis(4-isopropylphenol) group, as illustrated in Scheme 7.2b.

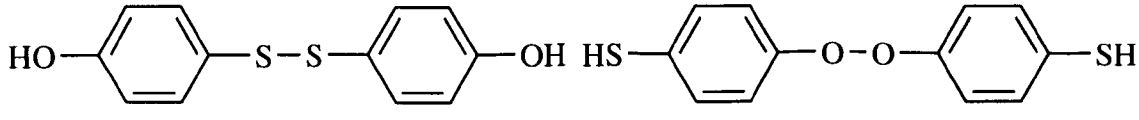
Scheme 7.2b.



7.3.1.1. Reactions Between Sodium Perborate and p-Hydroxythiophenol.

A reaction between p-hydroxythiophenol and sodium perborate was carried out. GC analysis was performed, but no components eluted from the GC. Probe MS analysis was therefore undertaken. This resulted in a single species with a mass charge ratio of 250, consistent with either bis(-p-hydroxyphenyl)disulfide (**90**) or bis(-p-thiophenol)peroxide (**91**).

Structures 90 and 91



(90) **(91)**

Taking into account bond enthalpies of an S-H bond (338 KJ mol^{-1}) and an O-H bond (463 KJ mol^{-1})[117], it is likely that the sodium perborate, being only a mild oxidant, would only break the S-H bond. This was confirmed by the analysis of the starting material and product by Infrared (IR) spectroscopy. The starting material, the thiol, had two major absorptions, a band at 2565 cm^{-1}, indicative of S-H bond stretching, and a broad band at 3417 cm^{-1} indicative of O-H bond stretching. When the product was analysed, it was found that the band at 3417 cm^{-1} remained but the band at 2565 cm^{-1} had disappeared, confirming that the hydroxythiophenol had been converted to the disulfide and not to the peroxide. It is also very likely that the peroxide would decompose very rapidly inside the GC. The symetrical S-S bond is more likely to be Raman active, so Raman spectroscopy could be used to detect the disulfides.

7.3.1.2. Reactions Between Sodium Perborate and the Crude Sulfide Mixture.

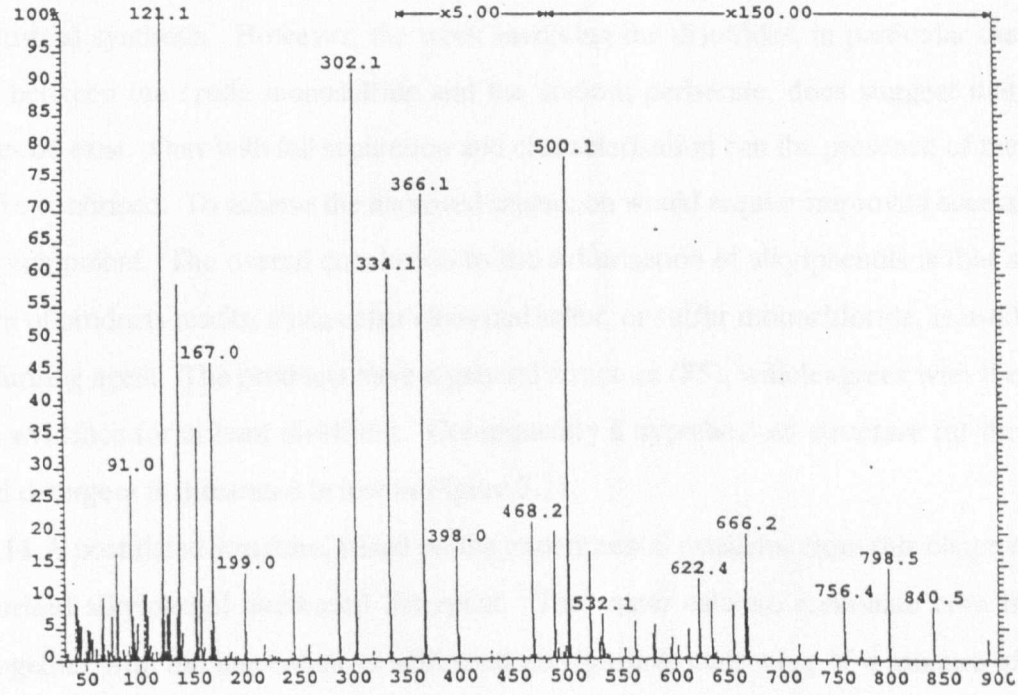
On analysing and comparing the probe mass spectra of the crude sulfide mixture (before) and the product mixture from the reaction between the crude sulfide mixture and the sodium perborate (after), it was showed that a limited reaction had taken place. The relative intensity of the peaks in the two samples, before and after, were slightly different to each other. However, probe mass spectrometry suffers from the problem that the intensity of the peaks varies from run to run, and from day to day. Therefore a slight change in intensities does not necessarily imply that anything has changed. If, as postulated, the tri and tetrasulfides do exist the two mass spectra of the crude sulfide mixture before and after reaction with perborate, as shown in Figure 7.10, should be very similar.

However, if the tri and tetra sulfides do not exist and thiols are present, the mass spectra would be expected to be quite different. The mass spectrum of the product mixture after the reaction with sodium perborate should have a higher intensity of higher mass species and a lower intensity of lower mass species, since the lower mass thiols would be oxidised to the higher mass disulfides.

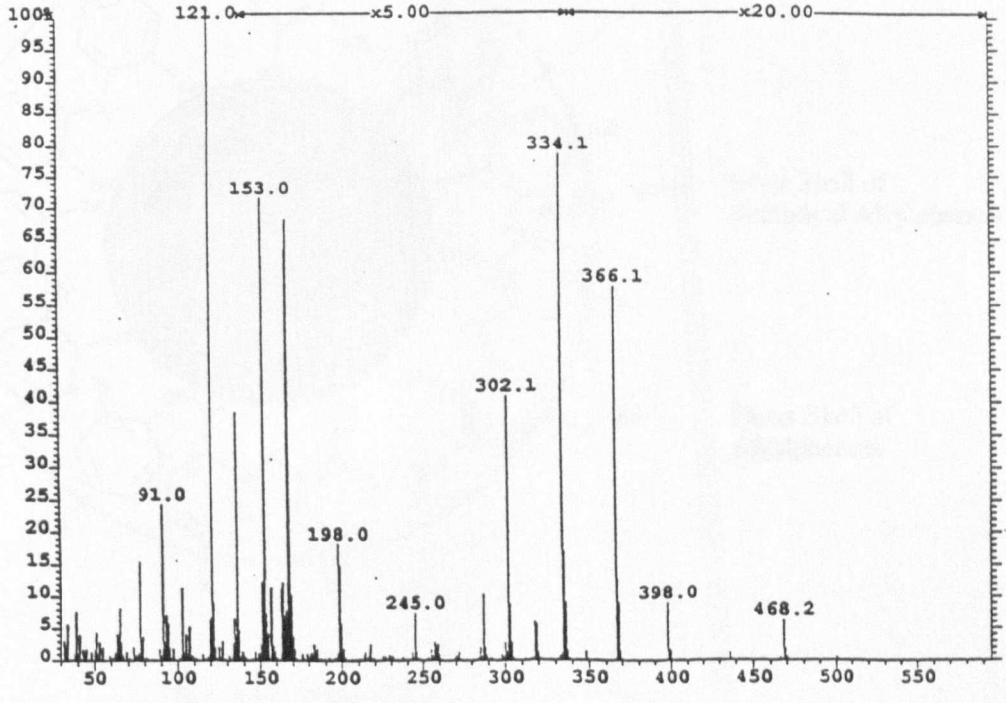
The mass spectra of of the crude sulfide mixture before and after reaction with sodium perborate do not show any significant differences, suggesting that the tri and tetra sulfides are formed in the system. The result only suggests that the tri and tetrasulfides do occur, because it could be that with both the hydroxyl and alkyl group present together on the ring, the thiol might not be oxidised to the disulfide, either for steric or electronic reasons.

Figure 7.10. Probe mass spectra of (a) a crude sample of monosulfide (produced by reacting p-isopropylphenol with sulfur monochloride) and (b) the same sample but after reacting with sodium perborate.

(a)



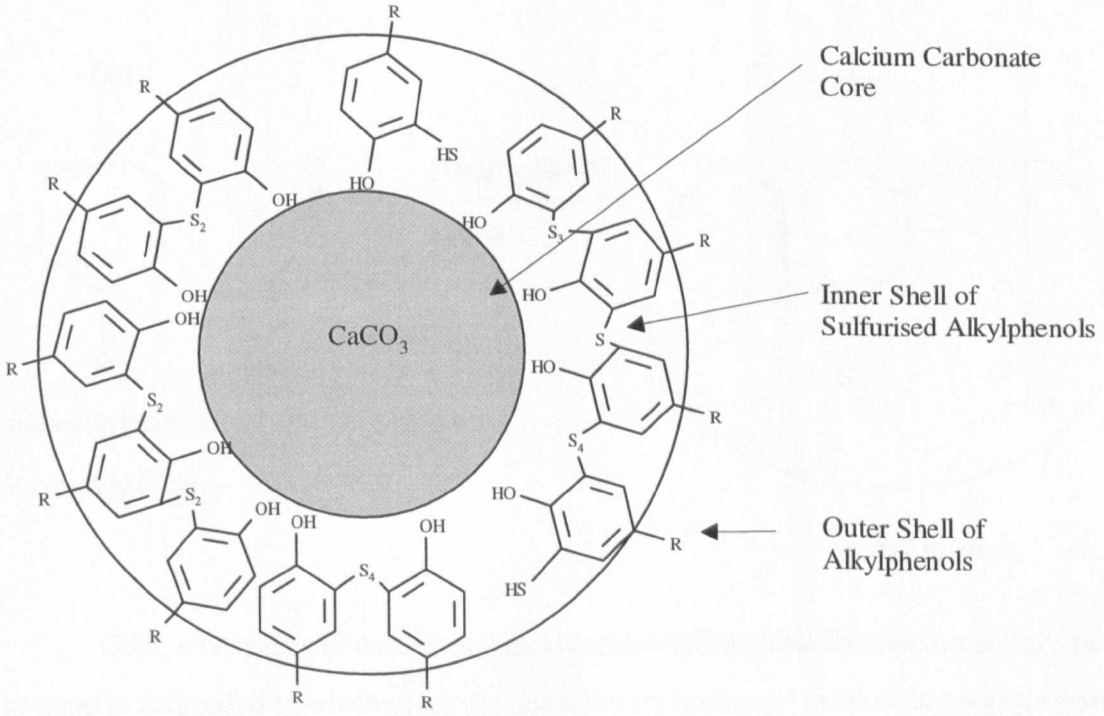
(b)



7.4. Conclusions and Future Work.

As can be seen from the results in this chapter it is impossible to say categorically that high polysulfur linkages (the number of sulfur atoms being 3 or greater) are produced in the industrial synthesis. However, the work involving the disulfides, in particular the reactions between the crude monosulfide and the sodium perborate, does suggest that polysulfides do exist. Only with full separation and characterisation can the presence of the disulfides be confirmed. To achieve the improved separation would require improved access to HPLC equipment. The overall conclusion to the sulfurisation of alkylphenols is that a distribution of products results, when either elemental sulfur, or sulfur monochloride, is used as the sulfurising agent. The products have a general structure (**85**), which agrees with the literature evidence for at least disulfides. Consequently a hypothesised structure for the overbased detergent is illustrated below in Figure 7.11.

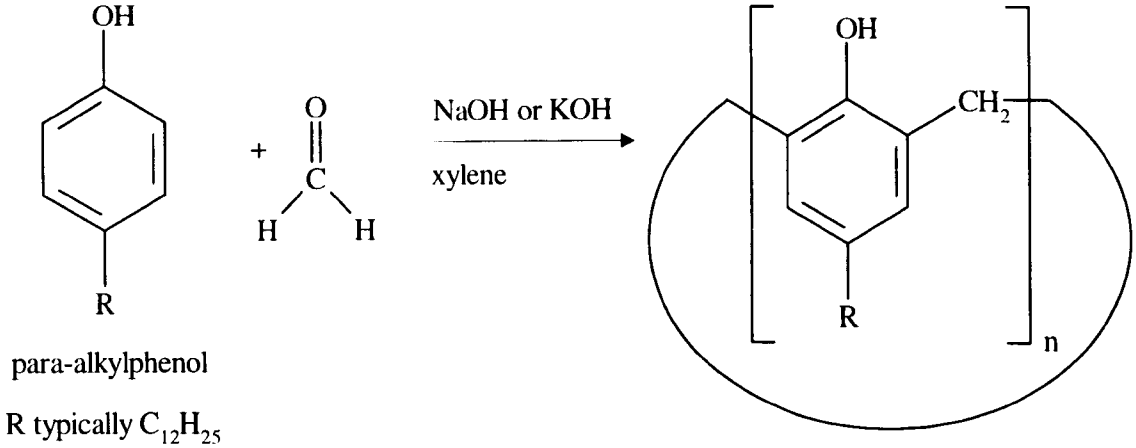
Figure 7.11 A postulated structure, based on the experimental evidence from this chapter of a sulfurised alkylphenol overbased detergent. The inner calcium carbonate core is shown, together with the inner shell of sulfurised alkylphenols consisting of a mixture of polysulfides and a mixture of the number of alkylphenols that are linked together.



To reiterate, to ascertain fully if polysulfides are present in the industrial synthesis will require the development of better separation and detection techniques. If a longer period of time had been available using the HPLC equipment, it should have been possible to develop improved separation techniques.

The main reason why this investigation into the sulfurised alkylphenols has not been pursued further is the development and implementation of a superior overbased detergent to the sulfurised alkylphenols. This superior class of surfactants are calixarenes[118] and they have a number of advantages over the sulfurised alkylphenols. Firstly, they do not contain extra sulfur into the engine oil, which could then form sulfuric acid. Since the major task of the sulfurised alkylphenols to neutralise any acids formed, the formation of extra acid would not be desirable. The calixarenes are also easier to manufacture than the SAPs, requiring less forcing conditions and a much higher purity is obtainable. A general synthesis is shown in Figure 7.12. The ring size of the calixarene can vary from 4 alkylphenol groups linked together, up to 12 linked together, with the typical sizes being 6 or 8. Whether a calix-6-arene or a calix-8-arene is produced, is governed by the nature of the catalyst employed and the concentration of catalyst.

Figure 7.12. A general synthesis for calixarenes



para-alkylphenol

R typically $C_{12}H_{25}$

calix-[n]-arene

Other advantages of the calixarenes over the SAPs are that the calixarenes are twice as good in antioxidancy, which gives the customer an improved product at no extra cost to the producer. They are 4 times more efficient at complexing calcium, this means that a quarter of the level of calixarene compared to the SAP is required to achieve the same TBN.

A very important advantage for BP is that they hold a very strong patent position concerning the manufacture of the calixarenes compared to the SAPs and as a result are developing the calixarenes in place of the SAPs. The one disadvantage of the calixarenes compared to the SAPs, is that the calixarenes are much more expensive to manufacture than the SAPs.

Future work by ADIBIS, will therefore, concentrate on the calixarenes as a greater understanding of these would be of more benefit to them, than some effort expended improving the sulfurised alkylphenols. Studies into the colouration of the sulfurised alkylphenols are planned to take place in the near furture.

Chapter 8

Experimental

In this chapter are detailed the experimental procedures leading to the results discussed in chapters 2-7. Section 8.1 outlines instrumentation and general information whilst sections 8.2 to 8.7 describe experimental procedures relevant to chapters 2 to 7 respectively.

8.1. General.

8.1.1. Gas Chromatography.

Gas Chromatographic (GC) analysis was performed on two different instruments (a Philips Pye Unicam PU4500 and a Hewlett Packard 5710A) connected to an integrator. Both chromatographs were fitted with a flame ionisation detectors (FID) and a split injection system, with a split ratio of approximately 80:1. In all cases the carrier gas used was helium, with a column head pressure ranging from 7 to12 psi depending on the machine and column used. The optimum conditions employed were found from the use of calibration samples and quality control chromatograms.[a] Injector and detector temperatures were as follows; for the PU4500, injector 250°C and detector 310°C and for the 5710A, injector 250°C and detector 300°C. Three capillary columns were used, each with a different phase polarity, in an attempt to improve separation of the various reaction products. These columns were all supplied by Alltech and were ofl the Econocap type, they were;

SE30 [30m x 0.25mm internal diameter, film thickness 0.25µm][b]

SE54 [30m x 0.25mm internal diameter, film thickness 0.25µm]

Carbowax [30m x 0.25mm internal diameter, film thickness 0.25µm][c]

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[a] Calibration standards and quality control chromatograms were obtained on purchase of the column.

[b] Most non-polar column.

[c] Most polar column.

8.1.2. Mass Spectrometry.

All mass spectra were obtained using a VG Autospec mass spectrometer operating in, unless otherwise stated, electron impact (EI) mode at 70 eV. For the combined technique of gas chromatography/mass spectrometry (GC/MS) the spectrometer was coupled to a Hewlett Packard 5890 Series II gas chromatograph. Again helium was used as the carrier gas. Where appropriate the mass spectra were compared to those in the NIST computerised library available on the instrument and the eight peak index[119].

8.1.3. NMR Spectroscopy.

All NMR spectra were recored on a Jeol EX270 spectrometer (^{1}H [270 MHz] and ^{13}C [68 MHz]). Tetramethylsilane (TMS) was used as the internal standard, and the chemical shifts were measured in parts per million (ppm) on the δ scale, downfield from the internal standard.

8.1.4. High Performance Liquid Chromatography (HPLC).

Two HPLC instruments were used. For the alkylsalicylic acid work a Varian 5000 Liquid Chromatograph fitted with a Hewlett Packard 1040A UV HPLC detection system was the instrument of choice and for the sulfurised alkylphenols a Spectraphysic 1000 HPLC fitted with a UV detector was used. In both cases a Phase Sep, reverse phase ODS2 3μm column was employed.

8.1.5. Chemical Reagents.

The propylene tetramer, polyisobutene (PIB) and Fulcat were supplied by BP Chemicals, Hull. All other chemicals were purchased from Aldrich or were used as available in the laboratory. Unless otherwise stated the chemicals were used as obtained but in some cases distillation or drying prior to use was carried out.

The salicylic acid used was purchased from Aldrich and was 99+%, salicylic acid - white powder mp. 159-161°C (lit[120]; 159-161°C).δ_H ($CDCl_3$) 6.95(dt, J=7Hz and 1.2 Hz, 1H, ArH meta to acid group) 7.00(dd, J=7.3Hz and 1.2Hz, 1H, ArH meta to acid group)

7.50(dt, 1H, J=1.7 and 6Hz, 1H, ArH para to acid group) 7.90(d, J=2Hz, 1H, ArH ortho to acid group) 10.2(br, 1H, OH).

8.2. Experimental Work Relating to Chapter 2.

8.2.1. General Synthesis of Alkylsalicylic Acids.

The standard reaction was carried out as follows:

To salicylic acid (0.025 moles) and 80% sulfuric acid[d] (18 cm^3), in a 100cm^3 round bottom flask fitted with a reflux condenser, the appropriate alkylating agent (ether, alcohol or alkene)(0.025 moles) was added. The reaction mixture was continually stirred, using a magnetic flea, for a total time of between 1.5 and 18 hours at the appropriate temperature and after the reaction mixture cooled, water was slowly added (approximately 40 cm^3). The resultant mixture was again allowed to cool. The resulting precipitate was filtered off and washed with water. If a precipitate was not formed (usually with the longer chain alkylsalicylic acids) ether extractions carried out. It was found necessary to carry out ether extractions for all alkylsalicylic acids with an alkyl chain greater than four carbon atoms. The diethyl ether and any residual water was removed on the rotary evaporator and the yield was determined. The alkylsalicylic acids in the product mixture were methylated by the addition of a few drops of diazomethane prior to analysis by GC and GC/MS. Analysis was performed by ^{1}H NMR, GC and by GC/MS using either an Econocap SE-30 column or an SE-54 column (temperature program; 120°C for 2 minutes then temperature ramping at 8°Cmin^{-1} to 300°C which temperature was maintained for 10 minutes).

8.2.1.1. Reaction of t-Butyl methyl ether.

Typical reaction conditions employed were as follows:

t-Butyl methyl ether was used as the alkylating agent in the presecence of 80% sulfuric acid (by volume) [18 cm^3] and the reaction mixture was heated at 60°C for three hours. Following cooling and the addition of water a cream precipitate resulted, which was treated as outlined above, yield 3.65g (theoretical yield of 5-t-butylsalicylic acid was 5.20g),

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[d] The 80% sulfuric acid was made by diluting concentrated sulfuric acid (98%) by volume with deionized water.

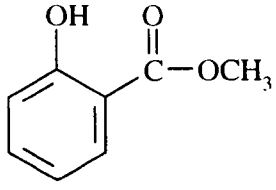
accountability = (3.65/5.20) x 100 = 70%. Analysis of the products by GC and GC/MS revealed the purity of the 5-t-butylsalicylic acid produced to be 95%. The major products in the reaction mixture were identified as:

Methyl salicylate (8); $C_8H_8O_3$ *m/z* 152($M^{+\cdot}$, 36%), 121(M-$CH_3O\cdot$, 35) ,120(M-$CH_3O\cdot H$, 100) and 92(M-$CH_3O\cdot H$- CO, 70).

5-t-Butylsalicylic acid. Cream powder mp. 148-150°C (Lit[121];148-150°C); δ_H ($CDCl_3$) 10.2(br, 1H, OH), 7.92(d, J=2.5Hz, 1H, ArH ortho to acid group), 7.58(1H, dd, J=2.5 and 8.7Hz, 1H, ArH para to acid group), 6.94(d, J=8.7Hz, 1H, ArH meta to acid group), 1.32(9H, s, ArC[$\mathbf{CH_3}$]$_3$).

Methyl 5-t-butylsalicylate (9); $C_{12}H_{16}O_3$ *m/z* 208($M^{+\cdot}$, 20%), 193(M-CH_3, 55), 161(M-CH_3 -CH_3OH, 100) and 77(10).

Methyl 3,5-di-t-butylsalicylate (10); $C_{16}H_{24}O_3$ *m/z* 264($M^{+\cdot}$, 22%), 249(M-CH_3, 50), 218(18) and 217(M-CH_3-CH_3OH, 100).



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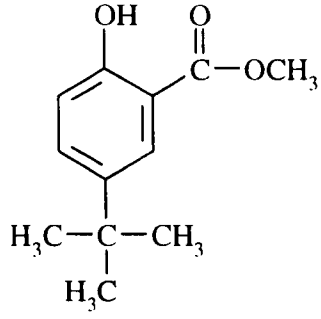

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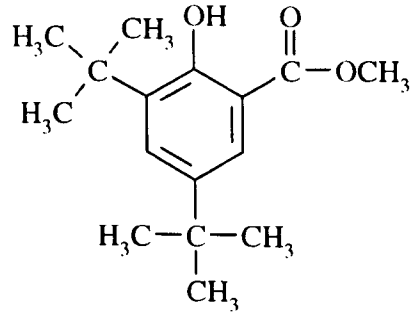

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8.2.1.2. Reaction of t-Butanol.

Standard alkylating conditions produced a similar product distribution to that obtained when t-butyl methyl ether was used as the alkylating agent. On work up a cream precipitate resulted. The accountability was 65%, and the purity of the 5-t-butylsalicylic acid 90%. 3,5-di-t-butylsalicylic acid was a product in 8% yield.

8.2.1.3. Reaction of n-Butanol.

Standard alkylating conditions were employed but only salicylic acid was recovered in a yield of 2.64g (51%).

8.2.2. Synthesis of the Sulfosalicylic Acid.

To salicylic acid (0.025 moles) was added 80% sulphuric acid (18 cm^3) and the mixture heated at 60°C for 3 hours. The solution was cooled, neutralised with sodium hydrogen carbonate solution and an excess of sodium chloride added. The resultant solution was heated to about 50°C, to help dissolve the sodium chloride, and was then filtered, the filtrate being cooled in an ice bath. The resultant precipitate, on cooling, was filtered again and washed with a saturated sodium chloride solution. The white precipitate was dried in an oven at 100°C to give 5-sulfosalicylic acid **(11)** (5.4 g, 51%).

5-Sulfosalicylic acid (11); δ_H ($CDCl_3$) 11.1(br, 1H, OH). 8.13(d, J=2.4Hz, 1H, ArH ortho to acid group), 7.75(1H, dd, J=2.4 and 8.3Hz, 1H, ArH para to acid group), 6.96(d, J=8.5Hz, 1H, ArH meta to acid group)

8.2.3. Synthesis of Diazomethane.

Diazomethane was synthesised using a special diazomethane kit[122], which does not have ground glass joints. To ethanol (9 cm^3) and high purity water (1 cm^3) in a round bottom flask was added 0.4g potassium hydroxide pellets. This was then heated to 40°C in a water bath. Diazald (2.14 g) was added to diethyl ether (30 cm^3) and this solution placed in a dropping funnel. The diazald mixture was then added dropwise over a period of about 30 minutes to the potassium hydroxide solution. The diazomethane was condensed in a round bottom flask which was cooled in an ice bath. A concentrated hydrochloric acid trap was used to destroy any diazomethane vapour.

8.3. Experimental Work Relating to Chapter 3.

The same experimental conditions employed for the work in chapter 2 were employed here, except in some cases a smaller scale was employed. Analysis was again performed by ^1H NMR, GC and by GC/MS using an Econocap SE-30 column (temperature program; 120°C for 2 minutes then ramping at 8°$Cmin^{-1}$ to 300°C which temperature was held for 10 minutes).

8.3.1. Alkylation of Salicylic Acid Using Ethers.

8.3.1.1. Synthesis and Reaction of 2-Methoxy-2-methylundecane.

The synthesis of 2-methoxy-2-methylundecane was carried out as follows[e];

A 1 litre 5 necked flange flask was set up on a water bath, with an overhead stirrer, condenser, thermometer and a pressure equalising dropping funnel. The vessel was charged with mercury (II) acetate (18.92g, 0.06moles) in methanol (100 cm^3). This mixture was stirred at 30°C for 15 minutes before the addition of THF (100 cm^3). A yellow colour appeared briefly before disappearing and the solution cleared slightly. The mixture was stirred for a further 15 minutes before the addition of 2-methyl-1-undecene (10g, 0.06 moles) in THF (10 cm^3). The solution was stirred vigorously for 1 hour and then $NaOH_{(aq)}$ 3 mol dm^{-3} (100 cm^3) was then added dropwise over a period of about 15 minutes and cooling applied to keep the temperature at 25°C. Then sodium borohydride (1.89g, 0.05 moles) dissolved in $NaOH_{(aq)}$ 3 mol dm^{-3} (100 cm^3) was added over 20 minutes and cooling was again applied to keep the temperature at 25°C. The solution turned orange/yellow with a large quantity of precipitate on addition of the $NaOH_{(aq)}$. The precipitate disappeared on the addition of the $NaBH_4$ in $NaOH_{(aq)}$, with the solution becoming clear and now a grey precipitate being formed. The grey suspension was then stirred at room temperature for three hours and transferred to a separating funnel.

The solution was allowed to separate for 48 hours. The lower mercury layer was removed and the aqueous layer was washed twice with diethyl ether (100 cm^3) and the organic layers were combined and dried ($MgSO_4$). The ether solution was then filtered and the ether was removed on a rotary evaporator leaving a clear liquid, yield 8.4g 70% (based on complete conversion to 2-methoxy-2-methylundecane).

The compostion of the product mixture by GC was:

2-Methyl-1-undecene; 5%; $C_{12}H_{24}$ *m/z* 168($M^{+\cdot}$, 6%); 153(M-CH_3, 1) 140(M-C_2H_4) 69(M-C_7H_{15}, 34) 56(M-C_8H_{17}, 100)

2-Methoxy-2-methylundecane; 84%; $C_{13}H_{28}O$ *m/z* 200; 185(M-CH_3, 100) 89(M-C_8H_{15}, 56)

1-Methoxy-2-methylundecane; 11%; $C_{13}H_{28}O$ *m/z* 200; 185(M-CH_3, 12) 73(M-C_9H_{19}, 6)

NMR of mixture, (significant peaks only). δ_H ($CDCl_3$)

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[e] Synthesis carried by Dr D. J. Moreton at the BP Hull research centre.

4.67(b, 2H, $\underline{\mathbf{CH_2}}C(CH_3)C_9H_{19}$), 3.45(m, 2H, $C_9H_{19}CH(CH_3)\underline{\mathbf{CH_2}}OCH_3$), 3.20(s, 3H, $C_9H_{19}CH(CH_3)CH_2O\underline{\mathbf{CH_3}}$), 3.17(s, 3H, $C_9H_{19}C(CH_3)_2O\underline{\mathbf{CH_3}}$), 1.32-1.41(m, 16H, $CH_3(\underline{\mathbf{CH_2}})_8C(CH_3)_2OCH_3$),1.42-1.47(m, 16H, $CH_3(\underline{\mathbf{CH_2}})_8CH(CH_3)CH_2OCH_3$), 1.10(s, 6H, $C_9H_{19}C(\underline{\mathbf{CH_3}})_2OCH_3$), 0.95(t, J=2 Hz, 3H, $\underline{\mathbf{CH_3}}(CH_2)_8C(CH_3)_2OCH_3$)

Standard alkylating conditions (on a smaller scale than was used in the work contained in Chapter 2, employing 0.01 moles of both the salicylic acid and the alkylating agent) produced a black oil which contained a number of products, accountability 40%. The black oil was extracted from the aqueous mixture by several extractions using diethyl ether (approximately $20cm^3$). Analysis by GC and GC/MS, following the standard analytical procedures outlined in Chapter 2, allowed the following species to be identified;

Methyl salicylate (8); 15%[f] (13% by mass)[g]; $C_8H_8O_3$ *m/z* 152($M^{+\cdot}$, 36%), 120(M-$CH_3O{\cdot}H$, 100), 92(M-$CH_3O{\cdot}H$- CO, 70).

Methyl 5-t-butylsalicylate (9); <1% (0.5% by mass); $C_{12}H_{16}O_3$ *m/z* 208($M^{+\cdot}$, 20%), 193(M-CH_3, 55), 161(M-CH_3 -CH_3OH, 100).

Unidentified product, postulated to be a dodecylsulfate ester (16); 11%; $C_{12}H_{26}O_4S$ m/z $M^{+\cdot}$ absent 193(1), 166(16), 141(8), 95(46), 69(55), 56(100).

Methyl 5-(1,1-dimethylnonyl)salicylate (12); 3%; $C_{19}H_{30}O_3$ *m/z* 306($M^{+\cdot}$, 3%), 291(M-CH_3, 1), 275(M-$CH_3O{\cdot}$, 2), 193(M-C_8H_{17}, 100), 161(M-CH_3 -CH_3OH, 58).

Methyl 5-(1-methyl-1-ethylnonyl)salicylate (13); 3%; $C_{20}H_{32}O_3$ *m/z* 320($M^{+\cdot}$, 2%), 291(M-C_2H_5, 38), 259(M-C_2H_5- CH_3OH, 3), 207(M-C_7H_{15}, 100), 175(M-C_7H_{15} -CH_3OH, 48).

Methyl 3-(1,1-dimethyldecyl)salicylate (t-dodecyl) (14); 5%; $C_{20}H_{32}O_3$ *m/z* 320($M^{+\cdot}$, 5%), 289(M-$CH_3O{\cdot}$, 2), 193(M-C_9H_{19}, 100), 161(M-C_9H_{19} -CH_3OH, 61).

methyl 5-(1,1-dimethyldecyl)salicylate (t-dodecyl) (15); 55%; $C_{20}H_{32}O_3$ *m/z* 320($M^{+\cdot}$, 5%) 305(M-CH_3, 1), 289(M-$CH_3O{\cdot}$, 2) ,193(M-C_9H_{19}, 100),161(M-C_9H_{19} -CH_3OH, 61).

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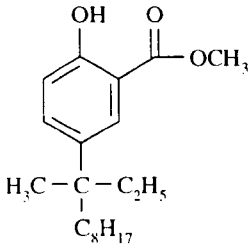
[f] The value corresponds to the percentage of the compound in the product mixture, based on uncalibrated GC areas.

[g] The value in brackets takes into account for the response factor of the GC towards different compounds. A full explantation on the use of correction factors in GC calibration is given in section 3.5.



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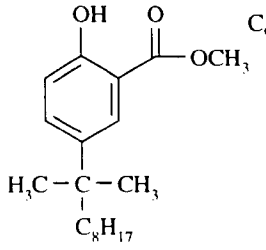

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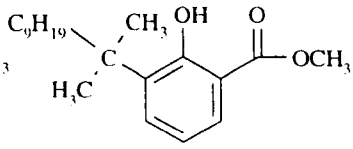

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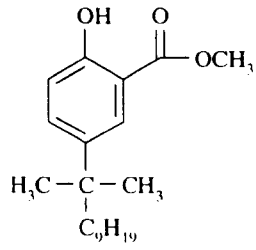

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8.3.2. Alkylation of Salicylic Acid Using Tertiary Alcohols.

8.3.2.1. Reaction of 2-Methyl-2-hexanol.

Standard alkylating conditions using 2-methyl-2-hexanol as substrate gave, accountability 68% (purple powder mp.113-116°C), purity of 5-(1,1-dimethylpentyl)salicylic acid (**17**) 81%.

5-(1,1-dimethylpentyl)salicylic acid; δ_H ($CDCl_3$) 0.82 (t, 3H J=7.3Hz, $ArC[CH_3]_2[CH_2]_3\mathbf{CH_3}$), 1.25(m, 6H, $ArC[CH_3]_2[\mathbf{CH_2}]_3CH_3$), 1.28(s, 6H, $ArC[\mathbf{CH_3}]_2[CH_2]_3CH_3$), 6.96(d, 1H, J=8.7Hz, ArH ortho to acid group), 7.52(dd, 1H, J=2.5 and 8.7Hz, ArH para to acid group), 7.86 (d, 1H, J=12.7Hz, ArH meta to acid group) 9.8(br, 1H, OH).

Seven significant products were identified by GC/MS:

Methyl salicylate (8); 1% (0.5% by mass); $CDCl_3C_8H_8O_3$ *m/z* 152($M^{+}\cdot$, 36%), 120(M-$CH_3O\cdot$H, 100), 92(M-$CH_3O\cdot$H- CO, 70).

Methyl 5-t-butylsalicylate (9); 1% (0.5% by mass); $C_{12}H_{16}O_3$ *m/z* 208($M^{+}\cdot$, 20%), 193($M^{+}\cdot$-CH_3, 55), 161(193-CH_3OH, 100).

Methyl 5-(1,1-dimethylbutyl)salicylate (t-hexyl) (18); 3% (2%); $C_{14}H_{22}O_3$ *m/z* 236($M^{+}\cdot$, 9%), 221(M-CH_3, 2) 205(M-$CH_3O\cdot$, 5) 193(M-C_3H_7, 90), 161(M-C_3H_7,-CH_3OH, 100).

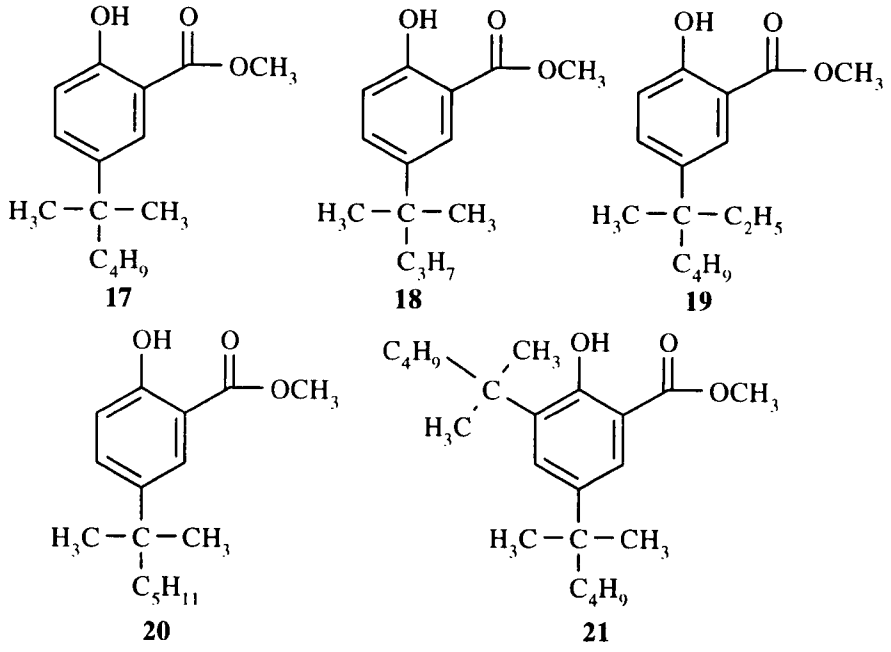
Methyl 5-(1,1-dimethylpentyl)salicylate (t-heptyl) (17); 80%; $C_{15}H_{24}O_3$ *m/z* 250($M^{+}\cdot$, 9%) 235(M-CH_3, 2), 219(M-$CH_3O\cdot$, 2), 193(M-C_4H_9, 100), 161(M-C_4H_9-CH_3OH, 92).

Methyl 5-(1-ethyl-1-methylpentyl)salicylate (19); 2%; $C_{16}H_{26}O_3$ *m/z* 264 ($M^{+}\cdot$, 7%) 235(M-C_2H_5, 55) 207(M-C_4H_9, 100) 175(M-C_4H_9-CH_3OH, 72) 147(26) 133(25).

Methyl 5-(1,1-dimethylhexyl)salicylate (t-octyl) (20); 3%; $C_{16}H_{26}O_3$ *m/z* 264($M^{+}\cdot$, 4%), 249(M-CH_3, 2), 233(M-$CH_3O\cdot$, 2), 193(M-C_5H_{11}, 100), 161(M-C_5H_{11}-CH_3OH, 78).

Methyl 3,5-di-t-heptylsalicylate (21); 2%; $C_{22}H_{38}O_3$ *m/z* 348($M^{+}\cdot$, 11%), 291(M-C_4H_9,

92), 259(M-C_4H_9-CH_3OH,100).



8.3.2.2. Synthesis and Reaction of 2-Methyl-2-undecanol.

The synthesis of 2-methyl-2-undecanol was very similar to that of the 2-methoxy-2-methylundecane and was as follows;

A 1 litre 5 necked flange flask was set up on a water bath, with an overhead stirrer, condenser, thermometer and a pressure equalising dropping funnel. The vessel was charged with mercury (II) acetate (18.92g, 0.06moles) in water (100 cm^3). This mixture was stirred at 30°C for 15 minutes before the addition of THF (100 cm^3). A yellow colour appeared briefly before disappearing and the solution cleared slightly. The mixture was stirred for a further 15 minutes before the addition of 2-methyl-1-undecene (10g, 0.06 moles) in 10 cm^3 THF. The solution was stirred vigorously for 1 hour and then $NaOH_{(aq)}$ 3 mol dm^{-3} (100 cm^3) was then added dropwise over a period of about 15 minutes and cooling applied to keep the temperature at 25°C. Then sodium borohydride (1.89g, 0.05 moles) dissolved in $NaOH_{(aq)}$ 3 mol dm^{-3} (100 cm^3) was added over 20 minutes and cooling was again applied to keep the temperature at 25°C. The solution turned orange/yellow with a large quantity of precipitate on addition of the $NaOH_{(aq)}$. The precipitate disappeared on the addition of the $NaBH_4$ in $NaOH_{(aq)}$, with the solution becoming clear and now a grey precipitate being formed. The grey suspension was then stirred at room temperature for three hours and transferred to a separating funnel.

The solution was allowed to separate for 48 hours. The lower mercury layer was

removed and the aqueous layer was washed twice with diethyl ether (100 cm^3) and the organic layers were combined and dried ($MgSO_4$). The ether solution was filtered and the ether was removed on a rotary evaporator leaving a clear liquid, yield 9.5g 85% (based on complete conversion to 2-methyl-2-hexanol. The product composition by GC was:

2-Methyl-1-undecene; 3%; $C_{12}H_{24}$ *m/z* 168($M^{+\cdot}$, 6%), 153(M-CH_3, 1), 140(M-C_2H_4), 69(M-C_7H_{15}, 28), 56(M-C_8H_{17}, 100)

2-Methyl-2-undecanol; 3%; $C_{12}H_{26}O$ *m/z*186 187(M +1, 4),171(M-CH_3 ,98), 97(31), 83(29), 75(100).

2-Methyl-1-undecanol; 93%; $C_{12}H_{26}O$ *m/z*186 171(M-CH_3, 8), 69(M-$C_7H_{17}O$, 6), 59(M-C_9H_{19}, 100).

NMR of mixture, (significant peaks only). δ_H ($CDCl_3$) 0.95(t, J=2 Hz, 3H, $\underline{CH_3}(CH_2)_8C(CH_3)_2OH$), 1.11-1.17(br, 16H, $CH_3(\underline{CH_2})_8C(CH_3)_2OH$), 1.10(s,6H, $C_9H_{19}C(\underline{CH_3})_2OH$). Standard alkylating conditions using 2-methyl-2-undecanol, produced a black oil, accountability 78% (extracted with diethyl ether). Following standard analytical procedures, GC and GC/MS allowed the following species to be identified:

Methyl salicylate (8); 5%; $CDCl_3C_8H_8O_3$ *m/z* 152($M^{+\cdot}$, 36%), 120(M-$CH_3O{\cdot}H$, 100), 92(M-$CH_3O{\cdot}H$- CO, 70).

Unidentified compound, postulated to be a dodecylsulfate ester (16); (17%); $C_{12}H_{26}O_4S$ *m/z* $M^{+\cdot}$ peak absent 249(M-OH,<1), 193(M-OH-C_4H_9, 1), 166(18) 141(8) 95(46), 69(55), 56(100).

Alkene dimers; (29% in total); $C_{24}H_{48}$ *m/z* 336($M^{+\cdot}$, 1%), 168($M^{+\cdot}$-$C_{12}H_{24}$, 55,) 153(7) 99(24), 85(50), 71(68), 57(100).

Methyl 3-(1,1-dimethyldecyl)salicylate (t-dodecyl) (14); 3%; $C_{20}H_{32}O_3$ *m/z* 320 ($M^{+\cdot}$, 6%) 289(M-$CH_3O{\cdot}$, 3) 193(M-C_9H_{19}, 100)161(M-CH_3 -CH_3OH, 58).

Methyl 5-(1,1-dimethyldecyl)salicylate (t-dodecyl) (15); 26%; $C_{20}H_{32}O_3$ *m/z* 320($M^{+\cdot}$, 5%), 289(M-$CH_3O{\cdot}$, 2), 194(16), 193(M-C_9H_{19}, 100), 161(193-CH_3OH, 61).

8.3.3. Alkylation of Salicylic Acid Using Primary and Secondary Alcohols.

8.3.3.1. Reactions of 1-, 2- and 3-Hexanol.

Standard alkylating conditions using, as the substrate; 1-hexanol, accountability 60%, 2-hexanol accountability 63% and 3-hexanol accountability 53% (all cream/brown powders). The 2- and 3-hexanol gave similar product distributions but the 1-hexanols

product distribution did not contain the methyl 3-(2'-hexylsalicylate).Following standard work up and analytical procedures, GC and GC/MS allowed the following species to be identified, for the 3-hexanol:

Methyl salicylate (8); 4%; $CDCl_3C_8H_8O_3$ *m/z* 152($M^{+\cdot}$, 36%), 120(M-CH_3O·H, 100), 92(M-CH_3O·H- CO, 70).

Methyl 5-t-butylsalicylate (9); 1%; $C_{12}H_{16}O_3$ *m/z* 208($M^{+\cdot}$, 20%), 193(M-CH_3, 55), 161(M-CH_3-CH_3OH, 100).

Methyl 5-(1,1-dimethylpropyl)salicylate [t-pentyl] (22); 1%;$C_{13}H_{18}O_3$ *m/z* 222($M^{+\cdot}$, 21%), 193(M-C_2H_5, 78), 161(M-C_2H_5-CH_3OH, 100).

Methyl 5-(1-ethylbutyl)salicylate [3'-hexyl] (23); 16%; $C_{14}H_{22}O_3$ *m/z* 236($M^{+\cdot}$, 23%), 207(M-C_2H_5, 25), 193(M-C_3H_7, 26), 175(M-C_2H_5-CH_3OH, 64), 161(M-C_3H_7-CH_3OH, 100)

Methyl 5-(1,1-dimethylbutyl)salicylate [t-hexyl] (18); 13%; $C_{14}H_{22}O_3$ *m/z* 236($M^{+\cdot}$, 7%) 221(M-CH_3, 2), 205(M-CH_3O·, 1), 193(M-C_3H_7, 91), 161(M-C_3H_7-CH_3OH, 100).

Methyl 3-(1-ethylbutyl)salicylate [3'-hexyl] (24); 2%$C_{14}H_{22}O_3$ *m/z* 236($M^{+\cdot}$, 28%), 207(M-C_2H_5, 56), 193(M-C_3H_7, 94), 175(M-C_2H_5-CH_3OH, 29), 161(M-C_3H_7-CH_3OH, 100).

Methyl 5-(1-methylpentyl)salicylate [2'-hexyl] (26); 8%; $C_{14}H_{22}O_3$ *m/z* 236($M^{+\cdot}$, 17%), 179(M-C_4H_9, 75), 147(M-C_4H_9-CH_3OH, 100).

Methyl 3-(1-methylpentyl)salicylate [2'-hexyl] (25); 19%; $C_{14}H_{22}O_3$ *m/z* 236($M^{+\cdot}$, 17%), 179(M-C_4H_9, 75), 147(M-C_4H_9-CH_3OH, 100).

Methyl 3,5-dihexylsalicylate (27), containing at least one t-hexyl group; $C_{20}H_{32}O_3$ *m/z* 320($M^{+\cdot}$, 9%), 277(M-C_3H_7, 100), 245(M-C_3H_7-CH_3OH, 74).

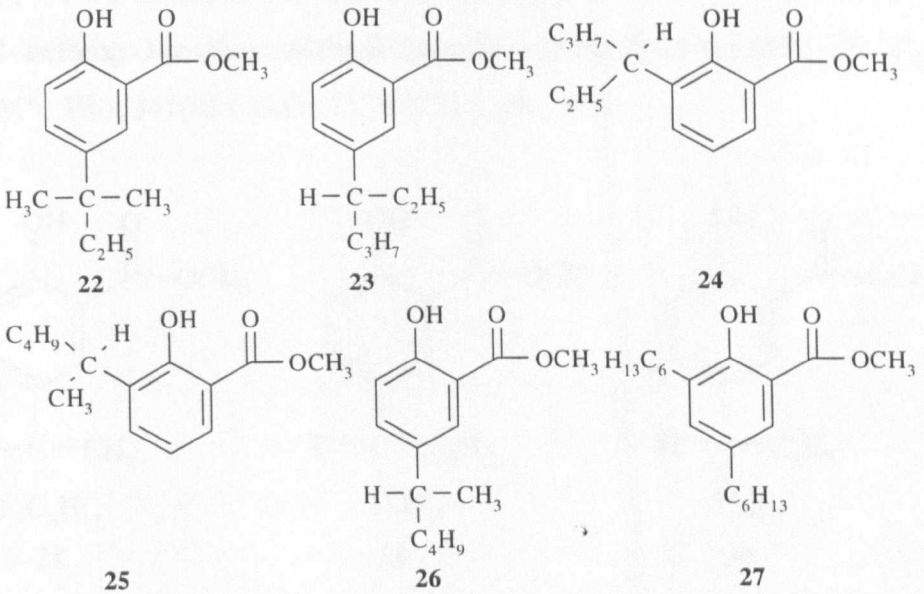
Methyl 3,5-dihexylsalicylate, containing at least one t-hexyl group; $C_{20}H_{32}O_3$ *m/z* 320 ($M^{+\cdot}$, 10%), 277(M-C_3H_7, 100), 245(M-C_3H_7-CH_3OH, 69).

Methyl 3,5-dihexylsalicylate, containing at least one 1-ethylbutyl group; $C_{20}H_{32}O_3$ *m/z* 320($M^{+\cdot}$, 6%), 291(M-C_2H_5, 100), 259(M-C_2H_5-CH_3OH, 56).

Methyl 3,5-dihexylsalicylate, containing at least one 1-methylpentyl group; $C_{20}H_{32}O_3$ *m/z* 320($M^{+\cdot}$, 17%), 263(M-C_4H_9, 100), 231(M-C_4H_9-CH_3OH, 91).

Table 8.1. The distribution of the various hexylsalicylic acids when 1-, 2- and 3-hexanol are used as alkylating agents.

	1-hexanol	2-hexanol	3-hexanol
methyl 5-(3'-hexyl)salicylate (**23**)	8%	17%	16%
methyl 5-(2'-hexyl)salicylate (**26**)	16%	19%	19%
methyl 5-t-hexylsalicylate (**18**)	14%	13%	13%
methyl 3-(3'-hexyl)salicylate (**24**)	6%	4%	2%
methyl 3-(2'-hexyl)salicylate (**25**)	0%	6%	8%



8.3.3.2. Reaction of 2-Octanol.

Standard alkylating conditions using 2-octanol, accountability 40%.Following standard work up and analytical procedures, GC and GC/MS allowed the following species to be identified:

Methyl salicylate (8); 55%; $CDCl_3C_8H_8O_3$ *m/z* 152($M^{+}\cdot$, 36%), 120(M-$CH_3O\cdot$H, 100), 92(M-$CH_3O\cdot$H- CO, 70).

Methyl 5-t-butylsalicylate (9); 3%; $C_{12}H_{16}O_3$ *m/z* 208($M^{+}\cdot$, 21%), 193(M-CH_3 63), 161(M-CH_3-CH_3OH, 100).

Methyl 5-(1-methylheptyl)salicylate [2'-octyl](28); 5%; $C_{16}H_{24}0_3$ *m/z* 264 ($M^{+}\cdot$, 19%), 233(M- CH_3O, 7), 179(M- C_7H_{15}, 100), 147(M-C_7H_{15}-CH_3OH, 89).

Methyl 5-(1-ethylhexyl)salicylate [3'-octyl](29); 5%; $C_{16}H_{24}O_3$ *m/z* 264($M^{+}\cdot$, 18%), 235(M- C_2H_5, 6), 203(M- C_2H_5-CH_3OH, 12), 193(M-C_6H_{13}, 100), 161(M-C_6H_{13}-CH_3OH,

75), 133(M-C_6H_{13}-CH_3OH-CO, 44).

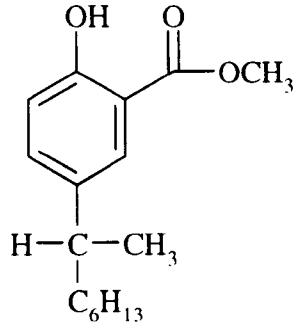
Methyl 5-(-1-propylpentyl)salicylate [4'-octyl](30); 5%; $C_{16}H_{24}O_3$ *m/z* 264($M^{+\cdot}$, 25%), 233(M- CH_3O, 6), 221(M-C_3H_7, 35), 207(M-C_4H_9, 33), 189(M-C_3H_7-CH_3OH, 74), 175(M-C_4H_9-CH_3OH, 75), 165(M-C_7H_{15}, 76), 133(M-C_7H_{15}-CH_3OH, 100).

Methyl 5-t-octylsalicylate (20); 6%; $C_{16}H_{24}O_3$ *m/z* 264($M^{+\cdot}$, 4%), 249(M-CH_3, 2), 233(M-$CH_3O\cdot$, 2), 193(M-C_5H_{11}, 100), 161(M-C_5H_{11}-CH_3OH, 78).

Methyl 3,5-dioctylsalicylate (31); 10%; $C_{24}H_{40}O_3$ *m/z* 376($M^{+\cdot}$, 5%), 361(M-CH_3, 2), 345(M-$CH_3O\cdot$, 1), 305(M-C_5H_{11}, 100), 273(M-C_5H_{11}-CH_3OH, 24).

3-Octyl-2-hydroxy-5-methoxysulfonyl-benzoic acid methyl ester (32); 2%; $C_{17}H_{26}O_6S$ *m/z* 358($M^{+\cdot}$, 2%), 341(M-$CH_3O\cdot$, 2), 301(M-C_5H_{11}, 100).

5-Octyl-2-methoxy-3-methoxysulfonyl-benzoic acid methyl ester (33); 1%; $C_{18}H_{28}O_6S$ *m/z* 372($M^{+\cdot}$, 3%), 341(M-$CH_3O\cdot$, 2), 301(M-C_5H_{11}, 100).



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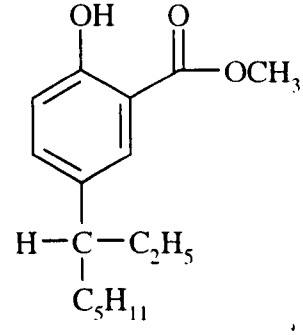

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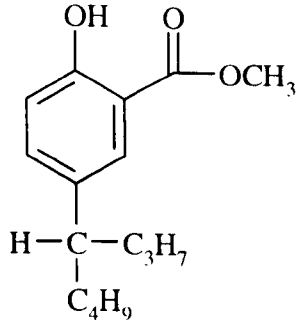

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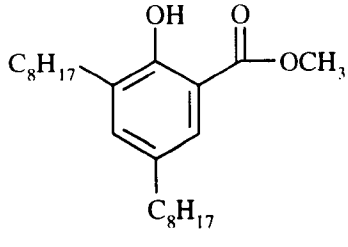

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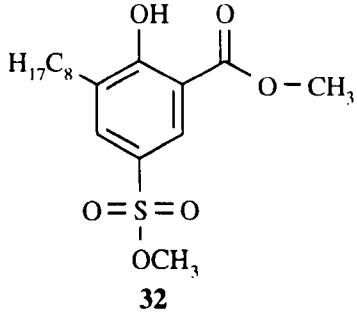

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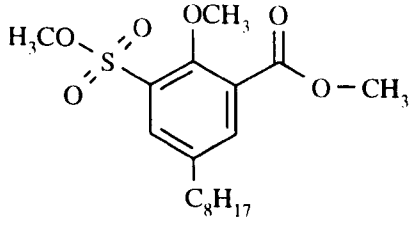

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8.3.4. Alkylation of Salicylic Acid Using Tertiary Alkenes.

8.3.4.1. Reaction of 2-Methyl-1-pentene.

Standard alkylating conditions using 2-methyl-1-pentene as the substrate, gave a

purple powder, accountability 27%. Following standard work up and analytical procedures, GC and GC/MS allowed the following species to be identified:

Methyl-5-t-butylsalicylate (9); 84%; $C_{12}H_{16}O_3$ *m/z* 208($M^{+\cdot}$, 20%), 193(M-CH_3, 55), 161(M-CH_3-CH_3OH, 100).

Methyl 5-t-pentylsalicylate (22); 9%; $C_{13}H_{18}O_3$ *m/z* 222($M^{+\cdot}$, 11%), 193(M-C_2H_5, 55), 162(14), 161(193-CH_3OH, 100).

Methyl 5-t-hexylsalicylate (18); 2%; $C_{14}H_{22}O_3$ *m/z* 236($M^{+\cdot}$, 9%), 221(M-CH_3, 2), 205($M^{+\cdot}$-CH_3O, 5), 193($M^{+\cdot}$-C_3H_7, 93), 161(193-CH_3OH, 100).

Methyl 5-octylsalicylate (20); <1%; $C_{16}H_{24}O_3$ *m/z* 264($M^{+\cdot}$, 5%), 249(M-CH_3, 3), 233(M-$CH_3O\cdot$, 2), 193(M-C_5H_{11}, 100), 161(M-C_5H_{11}-CH_3OH, 76).

Methyl 3,5-di-t-butylsalicylate (10); <1%; $C_{16}H_{24}O_3$ *m/z* 264($M^{+\cdot}$, 18%), 249(M-CH_3, 46), 218(17), 217(249-CH_3OH, 100), 175(13).

Methyl 5-t-nonylsalicylate (12); <1%; $C_{17}H_{26}O_3$ *m/z* 278($M^{+\cdot}$, 8%), 193(M-C_6H_{13}, 100), 161(M-C_6H_{13}-CH_3OH, 61).

8.3.4.2. Reaction of 2-Methyl-1-undecene.

Standard alkylating conditions using 2-methyl-1-undecene as the substrate gave a black oil, accountability 76%. Following standard work up and analytical procedures, GC and GC/MS allowed the following species to be identified:

2-Methyl-1-undecene; 1%; $C_{12}H_{24}$ *m/z* 168($M^{+\cdot}$, 8%), 153(M-CH_3, 2), 140(M-C_2H_4), 69(M-C_7H_{15}, 35), 56(M-C_8H_{17}, 100).

Methyl salicylate (8); 5%; $CDCl_3C_8H_8O_3$ *m/z* 152($M^{+\cdot}$, 36%), 120(M-$CH_3O\cdot H$, 100), 92(M-$CH_3O\cdot H$- CO, 70).

Methyl 5-t-butylsalicylate (9); <1%; $C_{12}H_{16}O_3$ *m/z* 208($M^{+\cdot}$, 18%), 193(M-CH_3, 54), 161(M-CH_3-CH_3OH, 100).

Methyl 5-t-pentylsalicylate (22); <1%; $C_{13}H_{18}O_3$ *m/z* 222($M^{+\cdot}$, 11%), 193(M-C_2H_5, 55) 162(14), 161(M-C_2H_5-CH_3OH, 100).

Methyl 3-t-dodecylsalicylate (14); 3%; $C_{20}H_{32}O_3$ *m/z* 320($M^{+\cdot}$, 5%), 289(M-$CH_3O\cdot$, 2), 194(16), 193(M-C_9H_{19}, 100), 161(M-C_9H_{19}-CH_3OH, 58).

Methyl 5-t-dodecylsalicylate (15); 87%; $C_{20}H_{32}O_3$ *m/z* 320($M^{+\cdot}$, 5%), 305(M-CH_3, 1), 289(M-$CH_3O\cdot$, 2), 193(M-C_9H_{19}, 100), 161(M-C_9H_{19}-CH_3OH, 60).

An unidentified product (16); 2%; $C_{12}H_{26}O_4S$ no $M^{+\cdot}$ peak 249(M-OH,<1), 193(M-OH-C_4H_9, 1), 166(16), 141(9), 95(51), 69(57), 56(100).

Alkene dimer; 1%; $C_{24}H_{48}$ *m/z* 336 ($M^{+\cdot}$, 1%), 168($M^{+\cdot}$-$C_{12}H_{24}$, 53), 153(8), 99(23), 85(55), 71(69), 57(100).

8.3.4.3. Reaction of 3,3-Dimethyl-1-butene.

Standard alkylating conditions using 3,3-dimethyl-1-butene as the substrate gave a black powder, accountability 83%. Following standard work up and analytical procedures, GC and GC/MS allowed the following species to be identified:

Methyl salicylate (8); 24%; $CDCl_3C_8H_8O_3$ *m/z* 152($M^{+\cdot}$, 38%), 120(M-CH_3O·H, 100), 92(M-CH_3O·H- CO, 74).

Methyl 5-t-butylsalicylate (9); 19%; $C_{12}H_{16}O_3$ *m/z* 208($M^{+\cdot}$, 22%), 193(M-CH_3, 63), 161(193-CH_3OH, 100).

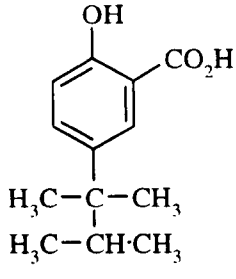
Methyl 5-t-pentylsalicylate (22); 7%; $C_{13}H_{18}O_3$ *m/z* 222($M^{+\cdot}$, 11%), 193(M-C_2H_5, 55), 161(193-CH_3OH, 100).

Methyl 5-(1,1,2-trimethypropyl)salicylate (36); 29%; $C_{14}H_{20}O_3$ *m/z* 236($M^{+\cdot}$, 4%), 205(M-CH_3O·, 4), 193(M-C_3H_7, 95), 161(M-C_3H_7-CH_3OH, 100).

Methyl 3-(1,1,2-trimethypropyl)salicylate (37); 4%; $C_{14}H_{20}O_3$ *m/z* 236($M^{+\cdot}$, 3%), 205(M-CH_3O·, 4), 193(M-C_3H_7, 88), 161(M-C_3H_7-CH_3OH, 100).

Methyl 5-hexenylsalicylate (38); 4%; $C_{14}H_{18}O_3$ *m/z* 234($M^{+\cdot}$, 36%), 203(M-CH_3O·, 16), 191(M-C_3H_7, 16), 165(M-C_5H_9, 56), 133(M-C_5H_9-CH_3OH, 100).

Methyl 3-t-butyl-5-hexenylsalicylate (39); 3%; $C_{18}H_{26}O_3$ *m/z* 290($M^{+\cdot}$, 46%), 275(M-CH_3, 66), 243(M-CH_3-CH_3OH, 46), 221(M-C_5H_9, 61), 189(M-C_5H_9-CH_3OH, 100).



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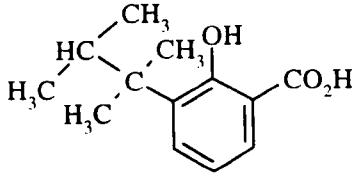

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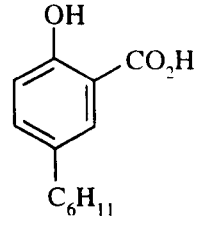

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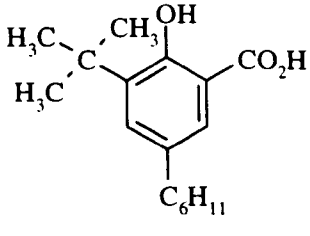

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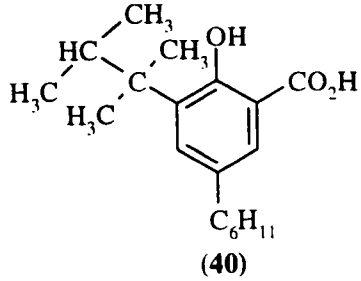

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Methyl 3-(1,1,2-trimethylpropyl)-5-hexenylsalicylate (40); 9%; $C_{20}H_{30}O_3$ *m/z* 318($M^{+\cdot}$, 4%), 275(M-C_3H_7, 100), 243(M-C_3H_7-CH_3OH, 35).

8.3.4.4. Reactions of 2,4,4-Trimethyl-1-pentene and 2,4,4-Trimethyl-2-pentene.

Standard alkylating conditions using as the substrate, 2,4,4-trimethyl-1-pentene gave a purple powder, accountability 78%, and 2,4,4-rimethyl-1-pentene also gave a purple poder, accountability 78%. Following standard work up and analytical procedures, GC and GC/MS allowed the following species to be identified, for the two pentenes:

Methyl 5-t-butylsalicylate (9); 84%; $C_{12}H_{16}O_3$ *m/z* 208($M^{+\cdot}$, 20%), 193(M-CH_3, 55), 162(14), 161(M-CH_3-CH_3OH, 100).

Methyl 5-t-pentylsalicylate (22); 9%; $C_{13}H_{18}O_3$ *m/z* 222($M^{+\cdot}$, 11%), 193(M-C_2H_5, 55), 162(14), 161(M-C_2H_5-CH_3OH, 100).

Methyl 5-t-hexylsalicylate (18); 2%; $C_{14}H_{22}O_3$ *m/z* 236 ($M^{+\cdot}$, 9%), 221(M-CH_3, 2), 205(M-$CH_3O\cdot$, 5), 193(M-C_3H_7, 93), 161(M-C_3H_7-CH_3OH, 100).

Methyl 3,5-di-t-butylsalicylate (10); <1%; **or methyl 5-(1,1,3,3-tetramethylbutyl) salicylate (41)**; <1%; $C_{16}H_{24}O_3$ *m/z* 264($M^{+\cdot}$, 22%), 249($M^{+\cdot}$-CH_3, 50), 218(18), 217(249-CH_3OH, 100), 175(15).

Methyl 5-(1,1-dimethylheptyl)salicylate (12); <1%; $C_{17}H_{26}O_3$ *m/z* 278($M^{+\cdot}$, 9%), 193(M-C_6H_{13}, 100), 161(M-C_6H_{13}-CH_3OH, 66).

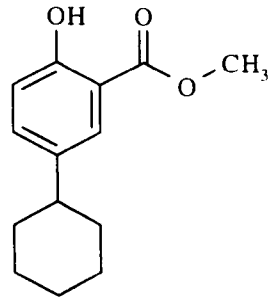
8.3.4.5. Reaction of Cyclohexene.

Standard alkylating conditions using cyclohexene as the substrate gave a black oil, accountability 75%. Following standard work up and analytical procedures, GC and GC/MS allowed the following species to be identified:

Methyl salicylate (8); 33%; $CDCl_3C_8H_8O_3$ *m/z* 152($M^{+\cdot}$, 36%), 120(M-CH_3OH, 100), 92(M-CH_3OH- CO, 70).

Methyl 5-cyclohexylsalicylate (42); 54%; $C_{14}H_{20}O_3$ *m/z* 234($M^{+\cdot}$, 66%), 202(M-CH_3OH, 100).

Tetracyclohexyl; $C_{24}H_{48}$ *m/z* 328($M^{+\cdot}$, 28%), 316(100), 284(52), 201(81).



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8.3.5. Alkylation of Salicylic Acid Using Monosubstituted Alkenes.

8.3.5.1. Reaction of 1-Hexene.

Standard alkylating conditions using 1-hexene as the substrate, accountability 45. Following standard work up and analytical procedures, GC and GC/MS allowed the following species to be identified:

Methyl salicylate (8); 2%; $C_8H_8O_3$ *m/z* 152($M^{+\cdot}$, 36%);120(M-CH_3OH, 100), 92(M-CH_3OH- CO, 70).

Methyl 5-(1-ethylbutyl)salicylate (23); 4%; $C_{14}H_{22}O_3$ *m/z* 236($M^{+\cdot}$, 23%), 207(M-C_2H_5, 25), 193(M-C_3H_7, 26), 175(M-C_2H_5-CH_3OH, 64), 161(M-C_3H_7-CH_3OH, 100).

Methyl 5-(1,1-dimethylbutyl)salicylate (t-hexyl) (18); 14%; $C_{14}H_{22}O_3$ *m/z* 236($M^{+\cdot}$, 7%) 221(M-CH_3, 2), 205(M-$CH_3O\cdot$, 1), 193(M-C_3H_7, 97), 161(M-C_3H_7-CH_3OH, 100).

Methyl 3-(1-ethylbutyl)salicylate (24); <1%; $C_{14}H_{22}O_3$ *m/z* 236($M^{+\cdot}$, 33%), 207(M-C_2H_5, 66), 193(M-C_3H_7, 94), 175(M-C_2H_5-CH_3OH, 29), 161(M-C_3H_7-CH_3OH, 100).

Methyl 5-(1-methylpentyl)salicylate (26); 8%; $C_{14}H_{22}O_3$ *m/z* 236($M^{+\cdot}$, 17%), 179(M-C_4H_9, 75%), 147(M-C_4H_9-CH_3OH, 100).

Methyl 3-(1-methylpentyl)salicylate (25); 8%; $C_{14}H_{22}O_3$ *m/z* 236($M^{+\cdot}$, 17%), 179(M-C_4H_9, 96%), 147(M-C_4H_9-CH_3OH, 100).

Methyl 3,5-dihexylsalicylate (27) 20% in total, containing at least one t-hexyl group; $C_{20}H_{32}O_3$ *m/z* 320($M^{+\cdot}$, 9%), 277(M-C_3H_7, 100), 245(M-C_3H_7-CH_3OH, 74).

Methyl 3,5-dihexylsalicylate, containing at least one t-hexyl group; $C_{20}H_{32}O_3$ *m/z* 320 ($M^{+\cdot}$, 10%), 277(M-C_3H_7, 100), 245(M-C_3H_7-CH_3OH, 69).

Methyl 3,5-dihexylsalicylate, containing at least one 1-ethylbutyl group; $C_{20}H_{32}O_3$ *m/z* 320($M^{+\cdot}$, 6%), 291(M-C_2H_5, 100), 259(M-C_2H_5-CH_3OH, 56).

Methyl 3,5-dihexylsalicylate, containing at least one 1-methylpentyl group; $C_{20}H_{32}O_3$

m/z 320($M^{+\cdot}$, 17%), 263(M-C_4H_9, 100), 231 (M-C_4H_9-CH_3OH, 91).

8.3.5.2. Reaction of 1-Octene.

Standard alkylating conditions using 1-octene as the substrate gave a black oil, accountability 92%. Following standard work up and analytical procedures, GC and GC/MS allowed the following species to be identified:

Methyl salicylate (8); 8%; $C_8H_8O_3$ *m/z* 152($M^{+\cdot}$, 33%), 120(M-CH_3OH, 100), 92(M-CH_3OH-CO, 68).

Methyl 5-t-butylsalicylate (9); 1%; $C_{12}H_{16}O_3$ *m/z* 208($M^{+\cdot}$, 20%), 193(M-CH_3, 55), 161(M-CH_3-CH_3OH, 100).

Methyl 5-(1-methylheptyl)salicylate [2'-octyl](28); 12%; $C_{16}H_{24}O_3$ *m/z* 264($M^{+\cdot}$, 16%), 233(M-$CH_3O\cdot$, 4), 179(M-C_7H_{15}, 100), 147(M-C_7H_{15}-CH_3OH, 84).

Methyl 5-(1-ethylhexyl)salicylate [3'-octyl](29); 14%; $C_{16}H_{24}O_3$ *m/z* 264($M^{+\cdot}$, 17%), 235(M-C_2H_5, 6), 203(M- C_2H_5-CH_3OH, 10), 193(M-C_6H_{13}, 100), 161(M-C_6H_{13}-CH_3OH, 79), 133(M-C_6H_{13}-CH_3OH-CO, 42).

Methyl 5-(1-propylpentyl)salicylate [4'-octyl](30); 13%; $C_{16}H_{24}O_3$ *m/z* 264($M^{+\cdot}$, 30%); 233(M-$CH_3O\cdot$, 7), 221(M-C_3H_7, 35), 207(M-C_4H_9, 40), 189(M-C_3H_7-CH_3OH, 74), 175(M-C_4H_9-CH_3OH, 77), 165(M-C_7H_{15}, 78), 133(M-C_7H_{15}-CH_3OH, 100).

Methyl 5-t-octylsalicylate (20); 27%; $C_{16}H_{24}O_3$ *m/z* 264($M^{+\cdot}$, 6%), 249(M-CH_3, 3), 233(M-$CH_3O\cdot$, 3), 193(M-C_5H_{11}, 100), 161(M-C_5H_{11}-CH_3OH, 83).

Methyl 3,5-dioctylsalicylate (31); 9%; $C_{24}H_{40}O_3$ *m/z* 376($M^{+\cdot}$, 5%), 361(M-CH_3, 2), 345(M-$CH_3O\cdot$, 1), 305(M-C_5H_{11}, 100), 273(M-C_5H_{11}-CH_3OH, 24).

8.3.5.3. Reaction of 1-Dodecene.

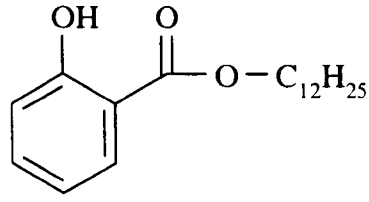
Standard alkylating conditions using 1-dodecene as the substrate gave a black oil, accountability 70%. Following standard work up and analytical procedures, GC and GC/MS allowed the following species to be identified:

Methyl salicylate (8); $C_8H_8O_3$ *m/z* 152($M^{+\cdot}$ 47%), 120(M-CH_3OH, 100), 92(M-CH_3OH-CO, 53).

1-Dodecene ; $C_{12}H_{24}$ *m/z* 168($M^{+\cdot}$, 26%), 111(M-C_4H_9, 11), 97(M-C_5H_{11}, 26), 83(M-C_6H_{13}, 44), 69(M-C_7H_{15}, 73), 55(M-C_8H_{17}, 100).

Dodecyl salicylates (43); 8%; $C_{19}H_{30}0_3$ *m/z* 306($M^{+\cdot}$, 2%), 168(M-$C_7H_6O_3$, 3), 138(M-

$C_{12}H_{24}$, 100), 120(M-$C_{12}H_{24}$-CH_3OH, 66), 92(M-$C_{12}H_{24}$-CH_3OH-CO, 3).



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8.3.6. GC Calibration.

A known mass of the internal standard, hexamethylbenzene, was added to a known mass of the pure methylated alkylsalicylic acids. These two compounds were then dissolved in dichloromethane and then injected into the GC. Using equation 3.1, the correction factor K was calculated.

$$K = \frac{A_{std} \times m_x}{A_x \times m_{std}} \qquad \textbf{3.1}$$

K= Correction Factor

A_{std} = area of the standard from the GC trace.

A_x = area of the compound of interest on the GC trace.

m_{std} = mass of standard.

m_x = mass of compound of interest.

Repeat runs were made with varying proportions of the internal standard to the methyl alkylsalicylates, with repeat injections for each sample and the average value of K was then quoted. This process was repeated for each of the pure samples of the alkylsalicylic acids. The values of K obtained for the various alkylsalicylic acids can be seen in table 8.1. By rearranging the equation 3.1, the percentage by mass of a particular alkylsalicylic acid, in a mixture can be calculated and this was undertaken for a number of the simpler reaction systems.

Table 8.1. The correction factors of various alkylsalicylic acids relative to hexamethylbenzene.

Alkylsalicylic acid	Correction factor
methyl salicylate	1.8
methyl 5-t-butylsalicylate	1.5
methyl 3,5-dit-butylsalicylate	≈3.0[h]
methyl 5-t-hexylsalicylate	2.4

8.3.6.1. Purification by Thin Layer Chromatography (TLC).

The solvent systems used in an attempt to purify the 5-t-dodecylsalicylic acid were as follows[i];

1) Various ratios of ethylacetate to 60/40 petroleum ether with one drop of glacial acetic acid.

2) Various ratios of dichloromethane to methanol.

3) Various ratios of diethyl ether to dichloromethane.

In all cases, no significant separation or extensive streaking took place.

8.3.6.2. Purification by (HPLC).

The optimized solvent system employed using the HPLC[j] in an attempt to purify the 5-t-dodecylsalicylic acid was as follows:

The wavelength used to detect the alkylsalicylic acids was 254 nm, the solvent system employed used a solvent program, shown in table 8.2, with a 1 ml min^{-1} flow rate. Three distinct peaks were observed, but on collection and analysis by GC all three peaks gave identical GC traces.

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[h] The value of K for the methyl 5-t-butylsalicylate was used to calculate this value.

[i] The petroleum ether was freshly distilled prior to use.

[j] The HPLC equipment used is described in section 8.1.4.

Table 8.2 the solvent program used in an attempt to purify the 5-t-dodecylsalicylic acid.

% (8%H_2O/MeOH)	% Acetonitrile	Time (mins)
1	99	0
2	98	10
5	95	15
50	50	20

8.3.6.3. Purification by Extraction.

The addition of acetonitrile to the crude sample of the 5-t-undecylsalicylic acid resulted in the formation of a black oil, which on separation from the acetonitrile and following standard alkylsalicylic acid analytical procedures, was found to contain alkylsalicylic acids with a chain containing at least ten carbon atoms.

Acid/ base washes were used in an attempt to separate the non-polar alkene dimer from the polar t-dodecylsalicylic acid. To the mixture of alkene dimer and the t-dodecylsalicylic acid was added approximately 40 cm^3 water and to this was added sodium hydrogen carbonate until the pH was approximately 9 (tested by full range pH indicator paper). Then an ether extraction was carried out and the remaining aqueous layer was reacidified to approximately pH 3 by the addition of, hydrochloric acid. Finally, another ether extraction was carried out. This method was quite inefficient with about 10% of the starting material remaining in the final ether extraction and even then total removal of the alkene dimer did not take place.

8.3.7.4. Purification by Distillation.

The distillation was a two stage process. The product mixture was first methylated by the addition of diazomethane. The methyl salicylate and 2-methyl-1-undecene were removed by heating to 100°C, with a vacuum of approximately 1mm Hg. The next fraction containing the two methyl dodecylsalicylates and the alkene dimer was collected at 200°C and approximately 1mm Hg.

The purest sample of methyl 5-t-dodecylsalicylate, obtained from using a combination of the above techniques contained 4% of the alkene dimer (based on GC and ^1H NMR analysis)

and 1% of the methyl 3-t-dodecylsalicylate, the remaining 95% was the methyl 5-t-dodecylsalicylate.

Methyl 5-t-dodecylsalicylate (15); δ_H ($CDCl_3$) 10.5(br, 1H, OH), 7.92(d, J=2.5Hz, 1H, ArH ortho to acid group), 7.58(1H, dd, J=2.5 and 8.7Hz, 1H, ArH para to acid group), 6.94(d, J=7.7Hz, 1H, ArH meta to acid group), 4.04(s, 3H, $ArCO_2\mathbf{CH_3}$) 1.32-1.39(m, 25H, $ArC[\mathbf{CH_3}]_2[\mathbf{CH_2}]_8CH_3$) [should be 22H if pure], 0.82 (t, 3H J=7.3Hz, $ArC[CH_3]_2[CH_2]_8\mathbf{CH_3}$).

8.4. Experimental Work Relating to Chapter 4.

8.4.1. Aqueous Solutions of Acids.

8.4.1.1. Reactions Using Sulfuric Acid.

Standard alkylating conditions were employed except the sulfuric acid concentration (by volume) was altered. Two alkylating agent were employed, 2-methyl-2-hexanol and 2-methyl-1-undecene, the results are presented in Table 8.3.

8.4.1.2. Reactions Using Orthophosphoric Acid.

Standard alkylating conditions (stirred at 60°C for three hours) were employed using t-butyl methyl ether as the alkylating agent except now the sulfuric acid was replaced by 80% orthophosphoric[k]. Standard work up procedures followed giving, accountability 96% and purity of the methyl 5-t-butylsalicylate 10%.

Repeating the above reaction except 88% orthophosphoric acid was used along with the larger alkylating agent 2-methyl-2-hexanol. Standard work up procedures gave accountability 65% and purity 17%.

The most forcing conditions 88% orthophosphoric acid, stirred at 110°C for six hours gave, accountability 70% and purity 22%.

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[k] The 80% orthophosphoric acid was obtained by dilluting concentrated orthophosphoric acid (88%) by the addition, by volume, of deionized water.

Table 8.3. The effect of sulfuric acid concentration on accountability and purity of the alkylsalicylic acids.

Alkylating Agent	Sulfuric Acid Concentration	Accountability %	Purity %	Overall Yield
2-methyl-2-hexanol	50% H_2SO_4	98%	0%[1]	0%
2-methyl-2-hexanol	65% H_2SO_4	57%	12%	7%
2-methyl-2-hexanol	70% H_2SO_4	66%	56%	37%
2-methyl-2-hexanol	75% H_2SO_4	62%	85%	53%
2-methyl-2-hexanol	80% H_2SO_4	70%	55%	39%
2-methyl-2-hexanol	85% H_2SO_4	54%	35%	19%
2-methyl-2-hexanol	90% H_2SO_4	15%	12%	2%
2-methyl-1-undecene	65% H_2SO_4	98%	11%	11%
2-methyl-1-undecene	70% H_2SO_4	95%	27%	26%
2-methyl-1-undecene	75% H_2SO_4	80%	62%	50%
2-methyl-1-undecene	80% H_2SO_4	87%	76%	66%
2-methyl-1-undecene	85% H_2SO_4	66%	32%	21%

8.4.1.3. Reactions Using Polyphosphoric Acid.

Standard alkylating conditions (stirred at 60°C for three hours) were employed using 2-methyl-2-hexanol as the alkylating agent except now the sulfuric acid was replaced by polyphosphoric acid. Initially a magnetic flea was used in an attempt to mix the reagents but with not success. Attempts to mix the reagents with an overhead stirrer was also unsuccessful.

8.4.1.4. Reaction Using p-Toluenesulfonic Acid.

Standard alkylating conditions were employed using 2-methyl-1-undecene as the alkylating agent, except the sulfuric acid was replaced with p-toluenesulfonic acid. An approximately 20 mol dm^{-3} aqueous solution of p-toluenesulfonic acid was used as the catalyst. After the standard work up procedures only unreacted starting materials were

[1] Only unreacted starting material was recovered.

found.

8.4.2. Solid Acid Catalysts.

8.4.2.1. Reactions Using Fulcat and Amberlyst 15.

Initial conditions involved heating t-butyl methyl ether (12 cm^3) with salicylic acid (3.45g, 0.025 moles) in the prescence of 2.5 g of the solid acid catalyst in toluene (20 cm^3) at 65°C for three hours (standard alkylating apparatus was employed). The reaction mixture was then allowed to cool, the acid filtered off and the solvent removed on a rotary evaporator. Standard analytical procedures identified that only unreacted salicylic acid was present. By altering the reaction conditions to; temperature increased to 90°C, solvent changed to methanol and the temperature at 65°C, reaction duration was increased to 15 hours with methanol as the solvent and the temperature at 65°C. These changes gave the same result after the standard work up, unreacted salicylic acid was the only species detected.

The revised standard Fulcat or Amberlyst 15 reaction is as follows: To a 50cm^3 round bottom flask fitted with a reflux condenser was added salicylic acid (1.38g, 0.01 moles), solid acid (0.25g) and of the alkylating agent (0.01 moles). The mixture was then stirred at 140-160°C (an oil bath on a hot plate provided the heat) using a magnetic flea for 1 hour, after which point the heating was stopped and the mixture was allowed to cool. The mixture was then washed twice with diethyl ether (approximately 20cm^3), the solid acid filtered off. The diethyl ether was removed and the mass of product recovered was recorded (accountability). Standard analysis procedures were then followed.

1-Hexene and Fulcat.

Standard Fulcat reaction conditions were employed using 1-hexene as the alkylating agent, accountability 75%. Following standard work up and analytical procedures, GC and GC/MS allowed the following species to be identified:

Methylsalicylate (8); 96%; $CDCl_3C_8H_8O_3$ *m/z* 152($M^{+\cdot}$ 44%), 120(M-CH_3OH, 100), 92(M-CH_3O·H- CO, 50).

Hexyl salicylate (2 isomers); 1% and 3%; $C_{13}H_{18}O_3$ *m/z* 222($M^{+\cdot}$, 6%), 138(M-C_6H_{12}, 52), 120(M-C_6H_{12}-H_2O, 100), 92(M-C_6H_{12}-H_2O-CO, 15).

Methyl 5-(1-methylpentyl)salicylate (26); $C_{14}H_{22}O_3$ *m/z* 236($M^{+\cdot}$, 17%), 179(M-C_4H_9,

78), 147(M-C_4H_9-CH_3OH, 100).

2-Methyl-1-pentene and Fulcat

Standard Fulcat reaction conditions were employed using 2-methyl-1-pentene as the alkylating agent gave a purple powder, accountability 75%. Following standard work up and analytical procedures, GC and GC/MS allowed the following species to be identified:

Methyl 5-t-pentylsalicylate (22); 4%; $C_{13}H_{18}O_3$ *m/z* 222($M^{+\cdot}$, 11%), 193(M-C_2H_5, 55), 161(193-CH_3OH, 100).

Methyl 3-t-hexylsalicylate; 2%; $C_{14}H_{22}O_3$ *m/z* 236($M^{+\cdot}$, 8%), 221(M-CH_3, 2), 205(M-$CH_3O\cdot$, 5), 193(M-C_3H_7, 88), 161(M-C_3H_7-CH_3OH, 100).

Methyl 5-t-hexylsalicylate (18); 86%; $C_{14}H_{22}O_3$ *m/z* 236($M^{+\cdot}$, 10%), 221(M-CH_3, 2), 205(M-$CH_3O\cdot$, 5), 193(M-C_3H_7, 76), 161(M-C_3H_7-CH_3OH, 100).

Methyl 5-t-heptylsalicylate (17); 5%; $C_{15}H_{24}O_3$ *m/z* 250($M^{+\cdot}$, 8%), 235(M-CH_3, 2), 219(M-CH_3O, 2), 193(M-C_4H_9, 100), 161(M-C_4H_9-CH_3OH, 89).

Methyl 3,5-di-t-hexylsalicylate (27); 3%; $C_{20}H_{32}O_3$ *m/z* 320($M^{+\cdot}$, 11%), 277(M-C_3H_7, 100), 245(M-C_3H_7-CH_3OH, 63).

1-Octene and Fulcat

Standard Fulcat reaction conditions were employed using 1-octene as the alkylating agent gave a black powder, accountability 62%. Following standard work up and analytical procedures, GC and GC/MS allowed the following species to be identified:

Methyl salicylate (8); $C_8H_8O_3$ *m/z* 152($M^{+\cdot}$ 49%), 120(M-CH_3OH, 100), 92(M-CH_3OH-CO, 64).

Octyl salicylate (3-isomers [postulated as, **1-methyl-heptyl (47) [2'-octyl salicylate], the 1-ethyl-hexyl (48) [3'-octyl salicylate]** and the **1-propyl-pentyl salicylate (49) [4'-octyl salicylate]** near identical mass spectra); $C_{15}H_{22}O_3$ *m/z* 250($M^{+\cdot}$, 7%), 138(M-C_8H_{16} 93), 120(M-C_8H_{16}-H_2O, 100).

Methyl 5-octylsalicylate (20); $C_{16}H_{24}O_3$ *m/z* 264($M^{+\cdot}$, 30%), 233(M-$CH_3O\cdot$, 7), 221(M-C_3H_7, 35), 207(M-C_4H_9, 40), 189(M-C_3H_7-CH_3OH, 74), 175(M-C_4H_9-CH_3OH, 77), 165(M-C_7H_{15}, 78), 133(M-C_7H_{15}-CH_3OH, 100).

Methyl 5-(3'-octyl)salicylate (29); $C_{16}H_{24}O_3$ *m/z* 264($M^{+\cdot}$, 20%), 235(M- C_2H_5, 7), 203(M-C_2H_5-CH_3OH, 14), 193(M-C_6H_{13}, 100), 161(M-C_6H_{13}-CH_3OH, 76), 133(M-C_6H_{13}-CH_3OH-CO, 46).

Methyl 3-(2'-octyl)salicylate (28); $C_{16}H_{24}O_3$ *m/z* 264($M^{+\cdot}$, 15%), 233(M-CH_3O, 5), 179(M-C_7H_{15}, 100), 147(M-C_7H_{15}-CH_3OH, 81).

Methyl 5-(2'-octyl)salicylate; $C_{16}H_{24}O_3$ *m/z* 264($M^{+\cdot}$, 17%), 233(M- CH_3O, 5), 179(M-C_7H_{15}, 100), 147(M-C_7H_{15}-CH_3OH, 86).

Octyl 5-octylsalicylate (two isomers, near identical mass spectra); $C_{23}H_{38}O_3$ *m/z* 362($M^{+\cdot}$, 5%), 250(M-C_8H_{16}, 31), 165(M-C_8H_{16}-C_6H_{13}, 100), 147(M-C_8H_{16}-C_6H_{13}-H_2O, 43).

Also present a number of unidentified products accounting for a very small percentage of the product mixture

1-Decene and Fulcat

Standard Fulcat reaction conditions were employed using 1-decene as the alkylating agent gave a black oil, accountability 80%. Following standard work up and analytical procedures, GC and GC/MS allowed the following species to be identified:

1-Decene; 27%

Methyl salicylate (8); 29%; $C_8H_8O_3$ *m/z* 152($M^{+\cdot}$, 49%), 120(M-CH_3OH, 100), 92(M-CH_3OH-CO, 64).

Decyl salicylate; 44% in total (four isomers with near identical mass spectra [postulated as **1-methylnonyl salicylate(53) [2'-decyl salicylate]** 29%, **1-ethyloctyl salicylate (52) [3'-decyl salicylate]** 9%, **1-propylheptyl salicylate (51) [4'-decyl salicylate]** 3% and **1-butylhexyl salicylate (50) [5'-decyl salicylate]** $C_{17}H_{26}O_3$ *m/z* 278($M^{+\cdot}$, 4%), 138(M-$C_{10}H_{20}$, 100), 120(M-$C_{10}H_{20}$-H_2O, 81).

Methyl 5-(1-methylnonyl)salicylate (2'-decyl); 1%; $C_{18}H_{28}O_3$ *m/z* 292($M^{+\cdot}$, 15%), 261(M-CH_3O, 3), 179(M-C_8H_{17}, 100), 147(M-C_8H_{17}-CH_3OH, 66).

Methyl 3-(1-methylnonyl)salicylate (2'-decyl); <1%; $C_{18}H_{28}O_3$ *m/z* 292($M^{+\cdot}$, 10%), 261(M- CH_3O, 3), 179(M-C_8H_{17}, 100), 147(M-C_8H_{17}-CH_3OH, 61).

1-Dodecene and Fulcat

Standard Fulcat reaction conditions were employed using 1-dodecene as the alkylating agent gave a black oil, accountability 95%. Following standard work up and analytical procedures, GC and GC/MS allowed the following species to be identified:

1-Dodecene; 30%; $C_{12}H_{24}$ *m/z* 168($M^{+\cdot}$,3%), 111(M-C_4H_9, 11), 97(M-C_5H_{11}, 33), 83(M-C_6H_{13}, 50).

69(M-C_7H_{15}, 64) 55(M-C_8H_{17}, 93) 41(M-C_9H_{19}, 100)

Methyl salicylate (8); 60%; $C_8H_8O_3$ *m/z* 152($M^{+\cdot}$, 41%), 120(M-CH_3OH, 100) ,92(M-CH_3OH-CO, 77).

Dodecyl salicylate (43); 10% in total (five isomers varying proportions, near identical mass spectra);$C_{19}H_{30}O_3$ *m/z* 306($M^{+\cdot}$, 1%), 168(M-$C_7H_5O_3$, 2), 138(M-$C_{12}H_{24}$, 100), 120(M-$C_{12}H_{24}$-H_2O, 80).

Methyl 5-(1-methylundecyl)salicylate; <1%; $C_{20}H_{32}O_3$ *m/z* 320($M^{+\cdot}$, 8%), 289(M-$CH_3O\cdot$, 2), 179(M-$C_{10}H_{21}$, 100), 147(M-$C_{10}H_{21}$-CH_3OH, 72).

Other methyl dodecylsalicylates <1%

2-Methyl-1-undecene and Fulcat

Standard Fulcat reaction conditions were employed using 2-methyl-1-undecene as the alkylating agent gave a black oil, accountability 95%. Following standard work up and analytical procedures, GC and GC/MS allowed the following species to be identified:

2-Methyl-1-undecene; 28%; $C_{12}H_{24}$ *m/z* 168($M^{+\cdot}$, 8%), 153(M-CH_3, 2), 140(M-C_2H_4), 69(M-C_7H_{15}, 35), 56(M-C_8H_{17}, 100).

Methyl salicylate (8); 61%; $C_8H_8O_3$ *m/z* 152($M^{+\cdot}$, 41%), 120(M-CH_3OH, 100), 92(M-CH_3OH-CO, 77).

Alkene dimer; 3%; $C_{24}H_{48}$ *m/z* 336 ($M^{+\cdot}$, 1%), 168(M-$C_{12}H_{24}$, 53), 153(8), 99(23), 85(55), 71(69), 57(100).

Methyl 5-(1,1-dimethyldecyl) salicylate (15); 8%; $C_{20}H_{32}O_3$ *m/z* 320($M^{+\cdot}$, 5%), 305(M-CH_3, 1), 289(M-$CH_3O\cdot$, 2), 193(M-C_9H_{19}, 100), 161(M-C_9H_{19}-CH_3OH, 65).

Standard Fulcat reaction conditions were employed using 2-methyl-1-undecene as the alkylating agent, except the temperature was lowered to 60°C gave a cream powder, accountability 95%. Following standard work up and analytical procedures, GC and GC/MS allowed the following species to be identified:

2-Methyl-1-undecene; 28%; $C_{12}H_{24}$ *m/z* 168($M^{+\cdot}$, 8%), 153(M-CH_3, 2), 140(M-C_2H_4), 69(M-C_7H_{15}, 35), 56(M-C_8H_{17}, 100).

Methyl salicylate (8); 59% ; $C_8H_8O_3$ *m/z* 152($M^{+\cdot}$, 41%), 120(M-CH_3OH, 100) ,92(M-CH_3OH-CO, 77).

Alkene dimer; 2%; $C_{24}H_{48}$ *m/z* 336 ($M^{+\cdot}$, 1%), 168(M-$C_{12}H_{24}$, 53), 153(8), 99(23), 85(55), 71(69), 57(100).

Methyl 5-(1,1-dimethyldecyl) salicylate (15); 5%; $C_{20}H_{32}O_3$ *m/z* 320($M^{+\cdot}$, 4%), 305(M-CH_3, 1), 289(M-$CH_3O\cdot$, 2), 193(M-C_9H_{19}, 100), 161(M-C_9H_{19}-CH_3OH, 57).

1,1-dimethyldecyl salicylate (54); 5%; $C_{19}H_{30}0_3$ *m/z* 306($M^{+\cdot}$, 1%), 168(M-$C_7H_50_3$, 2), 138(M-$C_{12}H_{24}$, 100), 120(M-$C_{12}H_{24}$-H_2O, 84).

8.4.2.2. Reactions Using Nafion-10.

Initial conditions involved heating t-butyl methyl ether (10 cm^3) with salicylic acid (1.79 g) in the prescence of Nafion 10 catalyst (1 g), heated at 90°C for three hours (standard alkylating apparatus was employed). On cooling and following standard solid acid catalysed work up and analytical procedures, only methyl salicylate was detected. On increasing the reaction temperature to 120°C, only methyl salicylate was again observed.

8.4.3. The Effect of Temperature on the Alkylation Reaction.

Standard alkylating conditions were employed, except now the temperature was altered using a variety of alkylating substrates. The results are presented in table 8.4. for monsubstituted alkenes and in table 8.5 for the tertiary alkenes.

Table 8.4. The effect of varying the reaction temperature on the accountability and purity of alkylation products when monosubstituted alkenes are used.

Alkylating Agent	Temperature °C	Accountability %	Purity %	Overall yield
1-hexene	20	100%	41%	41%
1-hexene	30	96%	61%	59%
1-hexene	40	95%	50%	48%
1-hexene	55	79%	57%	45%
1-hexene	60	45%	43%	19%
1-dodecene	20	91%	trace	trace
1-dodecene	55	79%	trace	trace
1-dodecene	60	70%	8%[m]	6%

[m] The products are the dodecyl esters of salicylic acid and not the methyl dodecyl salicylates.

Table 8.5. The effect of temperature on the accountability and purity of products when tertiary alkenes are used.

Alkylating Agent	Temperature °C	Accountability %	Purity %	Overall yield
2-methyl-1-pentene	20	99%	55%	54%
2-methyl-1-pentene	30	88%	43%	38%
2-methyl-1-pentene	40	86%	39%	34%
2-methyl-1-pentene	60	27%	3%	1%
2-methyl-1-pentene	70	28%	4% t-butyl	-
2-methyl-1-undecene	20	98%	11%	11%
2-methyl-1-undecene	40	95%	47%	45%
2-methyl-1-undecene	50	98%	53%	52%
2-methyl-1-undecene	60	87%	76%	66%
2-methyl-1-undecene	65	89%	60%	53%
2-methyl-1-undecene	75	71%	71%	50%
2-methyl-1-undecene	90	68%	75%	51%

8.4.3.1. Reaction of 2-Methyl-1-pentene.

Standard alkylating conditions apart from reaction temperature (30°C) using 2-methyl-1-pentene gave a purple powder, accountability 88%. Following standard work up and analytical procedures, GC and GC/MS allowed the following species to be identified:

Methyl 5-t-butyl salicylate (9); $C_{12}H_{16}O_3$ *m/z* 208($M^{+\cdot}$, 20%), 193(M-CH_3, 55), 161(M-CH_3-CH_3OH, 100).

Methyl 5-t-pentylsalicylate (22); $C_{13}H_{18}0_3$ *m/z* 222($M^{+\cdot}$, 11%), 193(M-C_2H_5, 55), 161(M-C_2H_5-CH_3OH, 100).

Methyl 5-(1,1-dimethylbutyl)salicylate (t-hexyl) (18); $C_{14}H_{22}O_3$ *m/z* 236($M^{+\cdot}$, 9%), 221(M-CH_3, 2), 205(M-$CH_3O\cdot$, 5), 193(M-C_3H_7, 93), 161(M-C_3H_7-CH_3OH, 100).

Methyl 5-(1-ethyl-1-methylpropyl)salicylate (19) ; $C_{14}H_{22}O_3$ *m/z* 236($M^{+\cdot}$, 9%), 207(M-C_2H_5, 100), 175(M-C_2H_5-CH_3OH, 95).

Methyl 5-(1,1-dimethylpentyl)salicylate (t-heptyl)(17); $C_{15}H_{24}O_3$ *m/z* 250($M^{+\cdot}$, 9%),

235(M-CH_3, 3), 219(M-CH_3O, 2), 193(M-C_4H_9, 100), 161(M-C_4H_9-CH_3OH, 87).

8.4.3.2. Reaction of 3,3-Dimethyl-1-butene.

Standard alkylating conditions employed, except the reaction is now done at 0°C, accountability 91%. Following standard work up and analytical procedures, GC and GC/MS allowed the following species to be identified:

Methyl salicylate (8); 48%; $C_8H_8O_3$ *m/z* 152($M^{+\cdot}$, 36%), 120(M-CH_3OH, 100), 92(M-CH_3OH- CO, 70).

Methyl 5-t-butylsalicylate (9); 9%; $C_{12}H_{16}O_3$ *m/z* 208($M^{+\cdot}$, 20%), 193(M-CH_3, 55), 161(M-CH_3-CH_3OH, 100).

Methyl 5-t-pentylsalicylate (22); 3%; $C_{13}H_{18}0_3$ *m/z* 222($M^{+\cdot}$, 11%), 193(M-C_2H_5, 55) 161(M-C_2H_5-CH_3OH, 100).

Methyl 5-t-hexylsalicylate (18); 37%; $C_{14}H_{22}O_3$ *m/z* 236($M^{+\cdot}$, 9%), 221(M-CH_3, 2), 205(M-CH_3O, 5), 193(M-C_3H_7, 93), 161(M-C_3H_7-CH_3OH, 100).

Methyl 5-t-octylsalicylate (20); <1%; $C_{16}H_{24}O_3$ *m/z* 264($M^{+\cdot}$, 4%), 249(M-CH_3, 1), 233(M-CH_3O, 3), 207(M-C_4H_9, 8), 193(M-C_5H_{11}, 100), 161(M-C_5H_{11}-CH_3OH, 78).

Methyl 5-t-nonylsalicylate (12); 1%; $C_{17}H_{26}0_3$ *m/z* 278($M^{+\cdot}$, 5%), 263(M-CH_3, 1), 247(M-CH_3O, 3), 207(M-C_5H_{11}, 2), 193(M-C_6H_{13}, 100), 161(M-C_6H_{13}-CH_3OH, 71).

8.4.3.3. Reaction of 2,4,4-Trimethyl-1-pentene.

The variable temperature alkylation of salicylic acid using 2,4,4-trimethyl-1-pentene as the substrate. Standard alkylating conditions employed, except the reaction is now done at 0°C, accountability 74%. Following standard work up and analytical procedures, GC and GC/MS allowed the following species to be identified:

Methyl 5-t-butylsalicylate (9); 13%; $C_{12}H_{16}O_3$ *m/z* 208($M^{+\cdot}$, 20%), 193(M-CH_3, 55), 162(14), 161(M-CH_3-CH_3OH, 100).

Methyl 5-t-pentylsalicylate (22); 10%; $C_{13}H_{18}0_3$ *m/z* 222($M^{+\cdot}$, 11%), 193(M-C_2H_5, 55), 161(M-C_2H_5-CH_3OH, 100).

Methyl 5-t-hexylsalicylate (18); 8%; $C_{14}H_{22}O_3$ *m/z* 236($M^{+\cdot}$, 9%), 221(M-CH_3, 2), 205(M-$CH_3O\cdot$, 5), 193(M-C_3H_7, 93), 161(M-C_3H_7-CH_3OH, 100).

Methyl 3,5-di-t-butylsalicylate (10) or methyl 5-(1,1,3,3-tetramethylbutyl)salicylate; 15%; $C_{16}H_{24}O_3$ *m/z* 264($M^{+\cdot}$, 22%), 249(M-CH_3, 50), 218(18), 217(M-CH_3-CH_3OH, 100), 175(15).

Methyl 5-(1,1-dimethylheptyl)salicylate (12); 22%; $C_{17}H_{26}O_3$ *m/z* 278($M^{+\cdot}$, 6%), 193(M-C_6H_{13}, 100), 161(M-C_6H_{13}-CH_3OH, 71).

Methyl 5-(decyl)salicylate (55); 13%; $C_{18}H_{28}O_3$ *m/z* 292($M^{+\cdot}$, 9%), 263(M-C_2H_5, 21), 207(M-C_6H_{13}, 51), 193(M-C_7H_{15}, 100), 175(M-C_6H_{13}-CH_3OH, 31), 161(M-C_7H_{15}-CH_3OH, 66).

Methyl 5-(t-undecyl)salicylate (13); 3%; $C_{19}H_{30}O_3$ *m/z* 306($M^{+\cdot}$, 1%), 193(M-C_8H_{17}, 100), 161(M-C_8H_{17}-CH_3OH, 57).

Methyl 5-(t-tetradecyl)salicylate (56); 8%; $C_{22}H_{36}O_3$ *m/z* 348($M^{+\cdot}$, 1%), 193(M-$C_{11}H_{23}$, 100), 161(M-$C_{11}H_{23}$-CH_3OH, 52).

8.4.4. The Dealkylation of Alkylsalicylic Acids.

8.4.4.1. Reaction of t-Hexylsalicylic Acid.

A sample containing predominately t-hexylsalicylic acid was reacted under standard alkylating conditions (stirred at 60 °C for three hours in 80% sulfuric acid). The initial composition, by GC/MS was:

Methyl 5-t-butylsalicylate (9); 1%; $C_{12}H_{16}O_3$ *m/z* 208($M^{+\cdot}$, 18%), 193(M-CH_3, 61), 161(M-CH_3-CH_3OH, 100).

Methyl 5-t-pentylsalicylate (22); 1%; $C_{13}H_{18}O_3$ *m/z* 222($M^{+\cdot}$, 13%), 193(M-C_2H_5, 89), 161(M-C_2H_5-CH_3OH, 100).

Methyl 5-t-hexylsalicylate (18); 2%; $C_{14}H_{20}O_3$ *m/z* 236($M^{+\cdot}$, 10%), 193(M-C_3H_7, 100), 161(M-C_3H_7-CH_3OH, 94).

Methyl 5-t-heptylsalicylate (17); 65%; $C_{15}H_{22}O_3$ *m/z* 250($M^{+\cdot}$, 9%), 193(M-C_4H_9, 100), 161(M-C_4H_9-CH_3OH, 84).

Methyl 5-t-octylsalicylate (20); 2%; $C_{16}H_{24}O_3$ *m/z* 264($M^{+\cdot}$, 9%), 193(M-C_5H_{11}, 100), 161(M-C_5H_{11}-CH_3OH, 81).

Methyl 5-(1-methyl-1-ethylpentyl)salicylate (57); 1%; $C_{16}H_{24}O_3$ *m/z* 264($M^{+\cdot}$, 9%), 235(M-C_2H_5, 63), 207(M-C_4H_9, 100), 203(M-C_2H_5-CH_3OH, 14), 175(M-C_4H_9-CH_3OH, 64).

Methyl 5-decylsalicylate (59); 15%; $C_{18}H_{28}O_3$ *m/z* 292($M^{+\cdot}$, 4%), 249(M-C_3H_7, 2), 235(M-C_4H_9, 100) ,207(M-C_6H_{13}, 7), 193(M-C_7H_{15}, 28) ,161(M-C_6H_{13}-CH_3OH, 21).

Methyl 3,5-diheptylsalicylate (21); 1%; $C_{22}H_{34}O_3$ *m/z* 348($M^{+\cdot}$, 9%), 291(M-C_4H_9, 100), 259(M-C_4H_9-CH_3OH, 64).

On reacting the above mixture under standard alkylating conditions gave, accountability 65%. Following standard work up and analytical procedures, GC and GC/MS allowed the following species to be identified:

Methyl 5-t-butylsalicylate (9); 2%; $C_{12}H_{16}O_3$ *m/z* 208($M^{+\cdot}$, 16%), 193(M-CH_3, 55), 161(M-CH_3-CH_3OH, 100).

Methyl 5-t-pentylsalicylate (22); 2%; $C_{13}H_{18}O_3$ *m/z* 222($M^{+\cdot}$, 12%), 193(M-C_2H_5, 76), 161(M-C_2H_5-CH_3OH, 100).

Methyl 5-t-hexylsalicylate (18); 2%; $C_{14}H_{20}O_3$ *m/z* 236($M^{+\cdot}$, 9%), 221(M-CH_3, 2), 205(M-$CH_3O\cdot$, 4), 193(M-C_3H_7, 91), 161(M-C_3H_7-CH_3OH, 100).

Methyl 5-t-heptylsalicylate (17); 45%; $C_{15}H_{22}O_3$ *m/z* 250($M^{+\cdot}$, 9%), 193(M-C_4H_9, 100), 161(M-C_4H_9-CH_3OH, 89).

Methyl 5-t-octylsalicylate (20); 1%; $C_{16}H_{24}O_3$ *m/z* 264($M^{+\cdot}$, 9%), 193(M-C_5H_{11}, 100), 161(M-C_5H_{11}-CH_3OH, 81).

Methyl 5-(1-methyl-1-ethylpentyl)salicylate (57); 1%; $C_{16}H_{24}O_3$ *m/z* 264($M^{+\cdot}$, 9%), 235(M-C_2H_5, 63), 207(M-C_4H_9, 100), 203(M-C_2H_5-CH_3OH, 14), 175(M-C_4H_9-CH_3OH, 64).

Methyl 5-t-heptyl-2-methoxy-3-methoxysulfonylbenzoate (58); 37%; $C_{17}H_{26}O_6S$ *m/z* 358 ($M^{+\cdot}$, 7%), 327(M-$CH_3O\cdot$, 3), 301(M-C_4H_9, 100).

8.4.4.2. Reaction of 3-Methylsalicylic acid with 5-t-butyl and 3,5-di-t-butylsalicylic acid.

Standard alkylating conditions using 0.01 moles of 5-t-butyl (90%) and 3,5-di-t-butylsalicylic acid (8%)(combined) with 0.01 moles 3-methylsalicylic acid, as the substrate gave, accountability 25%. Following standard work up and analytical procedures, GC and GC/MS allowed the following species to be identified:

Methyl salicylate (8); 17%; $C_8H_8O_3$ *m/z* 152($M^{+\cdot}$, 42%), 120(M-CH_3OH, 100) ,92(M-CH_3OH-CO, 85).

Methyl 3-methylsalicylate (60); 34%; $C_{13}H_{18}O_3$ *m/z* 166($M^{+\cdot}$, 49%),134(M-CH_3OH, 100), 106(M-CH_3OH-CO, 82).

Methyl 5-t-butylsalicylate (9); 21%; $C_{12}H_{16}O_3$ *m/z* 208($M^{+\cdot}$, 20%), 193(M-CH_3, 55), 162(14), 161(M-CH_3-CH_3OH, 100).

Methyl 3-methyl-5-t-butylsalicylate (61); 11%; $C_{13}H_{18}O_3$ *m/z* 222($M^{+\cdot}$, 11%), 193(M-C_2H_5, 55), 161(M-C_2H_5-CH_3OH, 100).

Methyl 3,5-di-t-butylsalicylate (10); 4%; $C_{16}H_{24}O_3$ *m/z* 264($M^{+\cdot}$, 22%), 249(M-CH_3, 50), 218(18), 217(249-CH_3OH, 100), 175(15).

8.5. Experimental Work Relating to Chapter 5.

8.5.1. Synthesis of t-butyl salicylate

To a refluxing mixture of salicylic acid (0.69g) in dry benzene (8 cm^3)[the benzene was freshly distilled and dried over molecular sieves prior to use] was added dropwise over a period of 10 minutes, N,N-dimethylformamide di-t-butyl acetal (4.1g). The mixture was refluxed for a further 30 minutes before cooling. The mixture was then washed twice with water (10 cm^3), saturated sodium hydrogen carbonate solution, (5 cm^3) and brine (5 cm^3). The organic layer was dried with sodium sulfate and then the solvent was removed. Analysis by GC and GC/MS after methylation with diazomethane showed that there were 2 major species;

t-Butyl salicylate (63); 96%; $C_{11}H_{14}O_3$ *m/z* 194($M^{+\cdot}$, 2%), 138(M-C_4H_8, 43), 120(M-C_4H_8,-CO, 100).

t-Butyl 2-t-butoxylbenzoate (64); 4%; $C_{15}H_{22}O_3$ *m/z* 250 (M^+ peak absent), 194(M- C_4H_8, 4) 138(M-C_4H_8-C_4H_8, 96), 120(M-C_4H_8-C_4H_8,-CO, 100).

8.5.2 Synthesis of secondary alkyl salicylates

8.5.2.1. Reactions of Haloalkanes with Salicylic Acid.

To NaOH (2.8g, 0.07 mol) in water (10 cm^3) in a 100 cm^3 round bottom flask fitted with a reflux condenser was added salicylic acid (4.55g, 0.033 mol) in ethanol (20 cm^3) and 1:1 water/ethanol mixture (20 cm^3). This mixture was heated to reflux and then 1-bromohexane (6.34g, 0.038 moles) was added and the mixture was refluxed for a further 3 hours. On cooling the products were extracted into diethyl ether (twice 20 cm^3). Analysis was performed by GC and GC/MS with the product mixture methylated first by the addition of diazomethane. Four major products were observed:

Unknown: 94 ($M^{+\cdot}$, 100%) 66(27) 65(24) 55(9) 39(21).

Hexyl salicylate (66); $C_{13}H_{18}O_3$ *m/z* 222($M^{+\cdot}$, 11%), 138(M-C_6H_{12}, 39), 120(M-C_6H_{12}-

CO,100).

Methyl 2-hexoxybenzoate (65); $C_{14}H_{22}O_3$ *m/z* 236($M^{+\cdot}$, 6%), 152(M-C_6H_{12},38), 120(M-C_6H_{12}-CH_3OH, 100).

Hexyl 2-hexyloxyl-benzate (67); $C_{19}H_{30}O_3$ *m/z* 306($M^{+\cdot}$, 6%), 222(M-C_6H_{12}, 10), 138(M-C_6H_{12}-C_6H_{12}, 80), 120(M-C_6H_{12}-C_6H_{12}-CO, 100).

8.5.2.2.Esterifcation in the Prescence of Methylsulfonyl Chloride.

To a 250 cm^3 round bottom flask fitted with a reflux condenser was added salicylic acid (2.76g), potassium carbonate (11.04g), methylsulfonyl chloride (1.54g), TEBAB (triethylbenzylammonium bromide) [0.54g] and 1:1 mixture of benzene/chloroform (100 cm^3). The mixture was stirred at 40°C for 45 minutes before the addition of 1-hexanol (2.04g) and the mixture was refluxed for a further 90 minutes. The product mixture was cooled and then filtered, the filtrate was collected and the solvent was removed on the rotary evaporator. Product distribution by GC/MS:

Methyl salicylate (8);16%; $C_8H_8O_3$ *m/z* 152($M^{+\cdot}$, 47%), 120(M-CH_3OH, 100) ,92(M-CH_3OH-CO, 88).

Hexyl salicylate (65); 54%; $C_{13}H_{18}O_3$; *m/z* 222($M^{+\cdot}$, 8%), 138(M-C_6H_{12}, 49), 120(M-C_6H_{12}-CO,100).

An unidentified compound; 18%: 228($M^{+\cdot}$, 15%), 121(5), 91(100), 65(16).

Dibenzo [b,f][1,5]dioxocin-6,12-dione (disalicylide) (67)[n]; 15%; $C_{14}H_8O_4$; *m/z* 240($M^{+\cdot}$, 47), 120(M-$C_7H_4O_2$,100), 92(M-$C_7H_4O_2$-CO, 71).

Tribenzo [b,f,j][1,5,9]trioxocine-6,12,18-trione (trisalicylide) (68); 9%;$C_{21}H_{12}O_6$; *m/z* 360($M^{+\cdot}$, 27), 240(M-$C_7H_4O_2$,69), 120(M-$C_7H_4O_2$-$C_7H_4O_2$,100), 92(M-$C_7H_4O_2$-CO, 71).

8.5.2.3.Esterification in the prescence of sulfonyl chloride.

To a 250 cm^3 round bottom flask fitted with a reflux condenser was added salicylic acid (40g, 0.29 moles) thionyl chloride (50cm^3) and anhydrous aluminium chloride (0.08g). This mixture was then heated at reflux (40-50°C) for one hour, resulting in a yellow/green solution. This solution was then concentrated to about half its volume by using a water pump, this was to remove any thionyl chloride (no yield was recorded). The produced salicoyl chloride was divided into four equal portions. To the salicoyl chloride was added

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[n] The mass spectra matches with the NIST eight peak index.

an excess of an alcohol (typically >11g) in small portions. The mixture was then cooled in an ice bath and with a drying tube fitted was left to stand for 24 hours. The solution was washed several times with ice water, then with a small quantity of dilute sodium carbonate, and again washed several times with ice water. The material was dried in ether over anhydrous sodium sulfate and after removal of the ether, was purified using repeat distillation under reduced pressure.

Alcohols employed, with GC/MS results following methylation of crude sample before distillation (100°C, ≈1mm Hg) and the ^{1}H NMR following purification;

2-methyl-2-hexanol;

Methyl salicylate (8); $C_8H_8O_3$ *m/z* 152($M^{+\cdot}$, 43%), 120(M-CH_3OH, 100), 92(M-CH_3OH-CO, 95).

2-Hexanol;

Methyl salicylate (8); $C_8H_8O_3$ *m/z* 152($M^{+\cdot}$, 41%), 120(M-CH_3OH, 100), 92(M-CH_3OH-CO, 88).

2'-Hexyl salicylate (44); $C_{13}H_{18}O_3$ *m/z* 222($M^{+\cdot}$, 7%), 138(M-C_6H_{12}, 47), 120(M-C_6H_{12}-H_2O, 100), 92(M-C_6H_{12}-H_2O-CO, 19).

δ_H ($CDCl_3$) 7.93(d, J=1.7Hz, 1H, ArH ortho to acid group), 7.55(dt, 1H, J=1.7 and 6.8Hz, 1H, ArH para to acid group), 7.06(dd, J=7.1Hz and 1.2Hz, 1H, ArH meta to acid group), 6.96(dt, J=7Hz and 1.2 Hz, 1H, ArH meta to acid group) 5.29(tq, J=6.3Hz, 1H, ArO**CH**[CH_3][CH_2]$_3CH_3$), 1.94-1.99(m, 6H, ArOCH[CH_3][**CH_2**]$_3CH_3$), 1.46(d, J=6.3Hz, 3H, ArOCH[**CH_3**][CH_2]$_3CH_3$), 1.00(t, J=5.8Hz, 3H, ArOCH[CH_3][CH_2]$_3$**CH_3**).

3-Hexanol;

Methyl salicylate (8); 45%; $C_8H_8O_3$ *m/z* 152($M^{+\cdot}$, 41%), 120(M-CH_3OH, 100), 92(M-CH_3OH- CO, 88).

3'-Hexyl salicylate (45); 55%; $C_{13}H_{18}O_3$ *m/z* 222($M^{+\cdot}$, 7%), 138(M-C_6H_{12}, 47), 120(M-C_6H_{12}-H_2O, 100), 92(M-C_6H_{12}-H_2O-CO, 19).

δ_H (270MHz ; $CDCl_3$) 7.93(d, J=1.7Hz, 1H, ArH ortho to acid group), 7.55(dt, 1H, J=1.7 and 6.8Hz, 1H, ArH para to acid group), 7.06(dd, J=7.3Hz and 1.2Hz, 1H, ArH meta to acid group), 6.96(dt, J=7Hz and 1.2 Hz, 1H, ArH meta to acid group), 5.29(tt, J=6.3Hz, 1H, ArO**CH**[CH_2CH_3][CH_2]$_2CH_3$), 1.45-2.01(m, 6H, ArOCH[**CH_2**CH_3][**CH_2**]$_2CH_3$), 0.99-1.03(m, 6H, ArOCH[CH_2**CH_3**][CH_2]$_2$**CH_3**).

2-Octanol;

1-Octene; 20%

Methyl salicylate (8); 10%; $C_8H_8O_3$ *m/z* 152($M^{+\cdot}$, 44%), 120(M-CH_3OH, 100), 92(M-CH_3OH- CO, 88).

2'-Octyl salicylate (46); 70%; $C_{15}H_{22}O_3$ *m/z* 250($M^{+\cdot}$, 3%), 138(M-C_8H_{16}, 61), 120(M-C_8H_{16}-H_2O, 100), 92(M-C_8H_{16}-H_2O-CO, 29).

δ_H ($CDCl_3$) 7.93(d, J=2Hz, 1H, ArH ortho to acid group), 7.55(dt, 1H, J=1.7 and 6.8Hz, 1H, ArH para to acid group), 7.06(dd, J=7.3Hz and 1.2Hz, 1H, ArH meta to acid group), 6.96(dt, J=7Hz and 1.2 Hz, 1H, ArH meta to acid group) 5.27(tq, J=6.3Hz, 1H, O**CH**[CH_3][CH_2]$_5CH_3$), 1.88-1.38(m,10H, ArOCH[CH_3][**CH_2**]$_5CH_3$), 1.28(d, J=6.3Hz, 3H, ArOCH[**CH_3**][CH_2]$_5CH_3$), 0.98(t, J=5.8Hz, 3H, ArOCH[CH_3][CH_2]$_5$**CH_3**).

4-Decanol;

4-Decanol; 16%

Decene; two isomers; 20% in total;

Methyl salicylate (8); 50% ; $C_8H_8O_3$ *m/z* 152($M^{+\cdot}$, 47%), 120(M-CH_3OH, 100), 92(M-CH_3OH-CO, 91).

4-Decyl salicylate (70); 13%; $C_{17}H_{26}O_3$ *m/z* 278($M^{+\cdot}$, 2%), 138(M-$C_{10}H_{20}$, 100), 120(M-$C_{10}H_{20}$-H_2O, 93).

δ_H ($CDCl_3$) 7.93(d, J=2Hz, 1H, ArH ortho to acid group), 7.55(dt, 1H, J=1.7 and 6.8Hz, 1H, ArH para to acid group), 7.06(dd, J=7.3Hz and 1.2Hz, 1H, ArH meta to acid group), 6.96(dt, J=7Hz and 1.2 Hz, 1H, ArH meta to acid group), 5.29(tt, J=6.3Hz, 1H, ArO**CH**[(CH_2)$_2CH_3$][CH_2]$_5CH_3$), 1.35-2.01(m, 14H,ArOCH[(**CH_2**)$_2CH_3$][**CH_2**]$_5CH_3$), 0.99-1.03(m, 6H,ArOCH[(CH_2)$_2$**CH_3**]{[CH_2]$_5$**CH_3**}).

2-dodecanol;

2-Dodecanol; 34%

Methyl salicylate (8); 50% ; $C_8H_8O_3$ *m/z* 152($M^{+\cdot}$, 47%), 120(M-CH_3OH, 100), 92(M-CH_3OH-CO, 91).

2-Dodecyl salicylate (70); 13%; $C_{19}H_{30}O_3$ *m/z* 306($M^{+\cdot}$, 2%), 138(M-$C_{12}H_{24}$, 100), 120(M-$C_{12}H_{24}$-H_2O, 93).

δ_H ($CDCl_3$) 7.93(d, J=2Hz, 1H, ArH ortho to acid group), 7.55(dt, 1H, J=1.7 and 6.8Hz, 1H, ArH para to acid group), 7.06(dd, J=7.3Hz and 1.2Hz, 1H, ArH meta to acid group),

6.96(dt, J=7Hz and 1.2 Hz, 1H, ArH meta to acid group) 5.29(tq, J=6.3Hz, 1H, OC**H**[CH_3][CH_2]$_9CH_3$), 1.88-1.38(m,18H, ArOCH[CH_3][**CH_2**]$_9CH_3$), 1.28(d, J=6.2Hz, 3H, ArOCH[**CH_3**][CH_2]$_9CH_3$), 0.99(t, J=5.9Hz, 3H, ArOCH[CH_3][CH_2]$_9$**CH_3**).

8.5.3. Rearrangements and Reactions of the Alkyl Salicylates

t-Butyl salicylate was reacted under standard alkylating conditions and gave accountability 65%. Following standard work up and analytical procedures, GC and GC/MS allowed the following species to be identified:

Methyl salicylate (8); 28%; $C_8H_8O_3$ *m/z* 152($M^{+\cdot}$, 51%), 120(M-CH OH, 100), 92(M-CH_3OH- CO, 95).

Methyl 5-t-butyl salicylate (8); 68%; $C_{12}H_{16}O_3$ *m/z* 208($M^{+\cdot}$, 16%), 193(M-CH_3, 65), 161(M-CH_3-CH_3OH, 100).

Methyl 3,5-di-t-butyl salicylate (10); 3%; $C_{16}H_{24}O_3$ *m/z* 264($M^{+\cdot}$, 14%), 249(M-CH_3, 31), 217(M-CH_3-CH_3OH, 70).

0.01 moles (1.94g) t-butyl salicylate and 0.01 moles (1.52g) 3-methylsalicylic acid were reacted together under standard alkylating conditions (8cm^3 80% sulfuric acid, 60°C for three hours. Major products by GC/MS:

Methyl salicylate (8); $C_8H_8O_3$ *m/z* 152($M^{+\cdot}$, 51%), 120(M-CH_3OH, 100), 92(M-CH_3OH-CO, 95).

Methyl 3-methylsalicylate (60); $C_9H_{10}O_3$ *m/z* 166($M^{+\cdot}$, 51%), 134(M-CH_3OH, 100), 106(M-CH_3OH-CO, 93).

t-Butyl salicylate (62); $C_{11}H_{14}O_3$ *m/z* 194($M^{+\cdot}$, 2%), 138(M-C_4H_8, 47), 120(M-C_4H_8,-CO, 100).

Methyl 5-t-butyl salicylate (8); $C_{12}H_{16}O_3$ *m/z* 208($M^{+\cdot}$, 17%), 193(M-CH_3, 57), 161(M-CH_3-CH_3OH, 100).

Methyl 3-methyl-5-t-butyl salicylate (61); $C_{13}H_{18}O_3$ *m/z* 222($M^{+\cdot}$, 19%), 207(M-CH_3, 45), 190(M-CH_3O·H, 25), 175(M-CH_3-CH_3OH, 100).

Methyl 3,5-di-t-butyl salicylate (10); $C_{16}H_{24}O_3$ *m/z* 264($M^{+\cdot}$, 15%), 249(M-CH_3, 31), 217(M-CH_3-CH_3OH, 70), 175(11).

Reacting the various alkyl esters under standard alkylating conditions and following standard

work up and analytical procedures the following product distributions were found by GC/MS:

2'-hexyl salicylate

Methyl salicylate (8); 2%; $C_8H_8O_3$ *m/z* 152($M^{+\cdot}$, 46%), 120(M-CH_3OH, 100) ,92(M-CH_3OH-CO, 78).

Hexyl salicylate (45); 4%; $C_{13}H_{183}$ *m/z* 222($M^{+\cdot}$, 10%), 138(M-C_6H_{12}, 47), 120(138-CO, 100).

Methyl 5-t-pentylsalicylate (22); <1%; $C_{13}H_{18}O_3$ *m/z* 222($M^{+\cdot}$, 11%), 193(M-C_2H_5, 55), 161(M-C_2H_5-CH_3OH, 100).

Methyl 5-t-hexylsalicylate (18); 7%; $C_{14}H_{22}O_3$ *m/z* 236($M^{+\cdot}$, 9%), 193(M-C_3H_7, 97), 161(M-C_3H_7-CH_3OH, 100).

Methyl 5-(1-ethylbutyl)salicylate [3'-hexyl](23); 15%; $C_{14}H_{22}O_3$ *m/z* 236($M^{+\cdot}$, 28%), 207(M-C_2H_5, 66), 193(M-C_3H_7, 92), 175(M-C_2H_5-CH_3OH, 95), 161(M-C_3H_7-CH_3OH, 100).

Methyl 3-(1-ethylbutyl)salicylate [3'-hexyl](24); 2% ; $C_{14}H_{22}O_3$ *m/z* 236($M^{+\cdot}$, 15%), 207(M-C_2H_5, 100), 175(M-C_2H_5-CH_3OH, 83).

Methyl 3-(1-methylpentyl)salicylate [2'-hexyl](25); 2%; $C_{14}H_{22}O_3$ *m/z* 236($M^{+\cdot}$, 20%), 205(M-$CH_3O\cdot$, 66), 179(M-C_4H_9, 87), 161(M-C_4H_9-CH_3OH, 100).

Methyl 5-(1-methylpentyl)salicylate [2'-hexyl](26); 17%; $C_{14}H_{22}O_3$ *m/z* 236($M^{+\cdot}$, 20%), 205(M-$CH_3O\cdot$, 66), 179(M-C_4H_9, 87), 161(M-C_4H_9-CH_3OH, 100).

Methyl 3,5-dihexylsalicylates (27) more than one isomer; 12% ;$C_{20}H_{32}O_3$ *m/z* 320($M^{+\cdot}$, 11%), 277(M-C_3H_7, 100), 245(M-C_3H_7-CH_3OH, 64).

5-Hexyl-2-methoxy-3-methoxysulfonyl-benzoic acid methyl ester; 1%; $C_{16}H_{24}O_6S$ *m/z* 344($M^{+\cdot}$, 3%), 313(M-$CH_3O\cdot$, 1), 301(M-C_3H_7, 100).

Two unknowns; 34%: *m/z* 330($M^{+\cdot}$, 11), 273(M-C_4H_9, 100), 241(M-C_4H_9-CH_3OH, 96) and 330($M^{+\cdot}$, 14), 301(M-C_2H_5, 26), 287(M-C_3H_7, 41), 279(M-C_3H_7-CH_3OH, 40), 255(M-C_3H_7-CH_3OH, 100), possibly two isomers of 5-hexyl-3-methoxysulfonylsalicylate.

2'-octyl salicylate

Methyl salicylate (8); $C_8H_8O_3$ *m/z* 152($M^{+\cdot}$ 44%), 120(M-CH_3OH, 100), 92(M-CH_3OH-CO, 74)

Methyl 5-(4'-octyl)salicylate (30); $C_{16}H_{24}O_3$ *m/z* 264($M^{+\cdot}$, 26%), 233(M- CH_3O, 7), 221(M-C_3H_7, 28), 207(M-C_4H_9, 38), 189(M-C_3H_7-CH_3OH, 69), 175(M-C_4H_9-CH_3OH, 73),

165(M-C_7H_{15}, 69), 133(M-C_7H_{15}-CH_3OH, 100).

Methyl 5-octylsalicylate; $C_{16}H_{24}O_3$ *m/z* 264($M^{+\cdot}$, 7%), 233(M- CH_3O, 3), 221(M-C_3H_7, 100), 189(M-C_3H_7-CH_3OH, 35), 179(M-C_6H_{13}, 73), 165(M-C_7H_{15}, 25), 147(M-C_6H_{13}-CH_3OH, 37), 133(M-C_7H_{15}-CH_3OH, 28).

Methyl 3-(4'-octyl)salicylate; $C_{16}H_{24}O_3$ *m/z* 264 $M^{+\cdot}$, 18%), 233(M- CH_3O, 7), 221(M-C_3H_7, 43), 207(M-C_4H_9, 61), 189(M-C_3H_7-CH_3OH, 15), 175(M-C_4H_9-CH_3OH, 17), 165(M-C_7H_{15}, 100), 133(M-C_7H_{15}-CH_3OH, 96).

Methyl 5-(3'-octyl)salicylate (29); $C_{16}H_{24}O_3$ *m/z* 264($M^{+\cdot}$, 10%), 235(M-C_2H_5, 17), 207(M-C_4H_9, 30), 193(M-C_6H_{13}, 100), 175(M-C_4H_9-CH_3OH, 24), 161(M-C_6H_{13}-CH_3OH, 80).

Methyl 5-octylsalicylate; $C_{16}H_{24}O_3$ *m/z* 264($M^{+\cdot}$, 19%), 235(M-C_2H_5, 43), 193(M-C_6H_{13}, 100), 161(M-C_6H_{13}-CH_3OH, 80).

Methyl 5-(2'-octyl)salicylate (28); $C_{16}H_{24}O_3$ *m/z* 264($M^{+\cdot}$, 12%), 233(M- CH_3O, 3), 179(M-C_6H_{13}, 73), 165(M-C_7H_{15}, 100), 147(M-C_6H_{13}-CH_3OH, 81).

3-Octyl-2-hydroxy-5-methoxysulfonyl-benzoic acid methyl ester (32); $C_{17}H_{26}O_6S$ *m/z* 358 ($M^{+\cdot}$, 2%), 341(M-$CH_3O\cdot$, 1), 301(M-C_5H_{11}, 100)

5-Octyl-2-methoxy-3-methoxysulfonyl-benzoic acid methyl ester (33); $C_{18}H_{28}O_6S$ *m/z* 372 ($M^{+\cdot}$, 2%), 341(M-$CH_3O\cdot$, 2), 301(M-C_5H_{11}, 100).

<u>4'-decyl salicylate</u>

Methyl salicylate (8); 38%; $C_8H_8O_3$ *m/z* 152($M^{+\cdot}$, 46%), 120(M-CH_3OH, 100), 92(M-CH_3OH-CO, 54).

4'-Decylsalicylate; (50); 5%; $C_{17}H_{26}O_3$ *m/z* 278($M^{+\cdot}$, 3%), 138(M-$C_{10}H_{20}$, 100), 120(M-$C_{10}H_{20}$-H_2O, 89).

Methyl 5-(5'-decyl)salicylate; 9%; $C_{18}H_{28}O_3$ *m/z* 292($M^{+\cdot}$, 14%), 235(M-C_4H_9, 41), 221(M-C_5H_{11}, 51), 203(M-C_4H_9-CH_3OH, 11), 189(M-C_5H_{11}-CH_3OH, 12), 165(M-C_9H_{19}, 100), 133(M-C_9H_{19}-CH_3OH, 64).

Methyl 5-(4'-decyl)salicylate; 10%; $C_{18}H_{28}O_3$ *m/z* 292($M^{+\cdot}$, 14%), 249(M-C_3H_7, 37), 217(M-C_3H_7-CH_3OH, 11), 207(M-C_6H_{13}, 66), 175(M-C_6H_{13}-CH_3OH, 17), 165(M-C_9H_{19}, 100), 133(M-C_9H_{19}-CH_3OH, 69).

Methyl 5-t-decylsalicylate; (13); 12%; $C_{18}H_{28}O_3$ *m/z* 292($M^{+\cdot}$, 4%), 261(M-$CH_3O\cdot$, 2), 193(M-C_7H_{15}, 100), 161(M-C_7H_{15}-CH_3OH, 50).

Methyl 5-(3'-decyl)salicylate; 6%; $C_{18}H_{28}O_3$ *m/z* 292($M^{+\cdot}$, 16%), 263(M-C_2H_5, 37),

231($M-C_2H_5-CH_3OH$, 14), 193($M-C_7H_{15}$, 100), 161($M-C_7H_{15}-CH_3OH$, 56).

Methyl 5-(2'-decyl)salicylate; 7%; $C_{18}H_{28}O_3$ *m/z* 292($M^{+\cdot}$, 8%), 261($M-CH_3O\cdot$, 1), 179($M-C_8H_{17}$, 100), 147($M-C_8H_{17}-CH_3OH$, 56).

A number of other methyl decylsalicylates are also present, but in very low proportions.

2'-dodecyl salicylate

Methyl salicylate (8); 10%; $C_8H_8O_3$ *m/z* 152($M^{+\cdot}$, 44%), 120($M-CH_3OH$, 100), 92($M-CH_3OH-CO$, 54).

Dodecene; 7%; $C_{12}H_{24}$ *m/z* 168($M^{+\cdot}$, 13%), 111($M-C_4H_9$, 21), 97($M-C_5H_{11}$, 43), 83($M-C_6H_{13}$, 53), 69($M-C_7H_{15}$, 73), 55($M-C_8H_{17}$, 84), 43($M-C_9H_{19}$, 100).

At least twelve methyl dodecylsalicylates, including;

Methyl 5-(1-methyl-1-propylheptyl)salicylate; 14%; $C_{20}H_{32}O_3$ *m/z* 320($M^{+\cdot}$, 14%), 289($M-CH_3O\cdot$, 2), 277($M-C_3H_7$, 33), 245($M-C_3H_7-CH_3OH$, 7), 221($M-C_7H_{15}$, 100), 189($M-C_7H_{15}-CH_3OH$, 21).

Methyl 5-(4'-dodecyl)salicylate; 11%;$C_{20}H_{32}O_3$ *m/z* 320($M^{+\cdot}$, 14%), 289($M-CH_3O\cdot$, 2), 277($M-C_3H_7$, 33), 245($M-C_3H_7-CH_3OH$, 7), 207($M-C_8H_{17}$, 100), 175($M-C_8H_{17}-CH_3OH$, 21).

Methyl 5-(3'-dodecy)lsalicylate; 12%; $C_{20}H_{32}O_3$ *m/z* 320($M^{+\cdot}$, 14%), 291($M-C_2H_5$, 12), 289($M-CH_3O\cdot$, 2), 259($M-C_2H_5-CH_3OH$, 34), 193($M-C_9H_{19}$, 100), 161($M-C_9H_{19}-CH_3OH$, 60).

Methyl 5-t-dodecylsalicylate (15); 21%; $C_{20}H_{32}O_3$ *m/z* 320($M^{+\cdot}$, 5%) ,305($M-CH_3$,1), 289($M-CH_3O\cdot$, 2), 193($M-C_9H_{19}$, 100), 161($M-C_9H_{19}-CH_3OH$, 60).

Methyl 3-(2'-dodecyl)salicylate; 9%; $C_{20}H_{32}O_3$ *m/z* 320($M^{+\cdot}$, 12%), 305($M-CH_3$, 1), 289($M-CH_3O\cdot$, 1), 179($M-C_{10}H_{21}$, 100), 147($M-C_{10}H_{21}-CH_3OH$, 55).

Methyl 5-(2'-dodecyl)salicylate; 6%; $C_{20}H_{32}O_3$ *m/z* 320($M^{+\cdot}$, 6%), 305($M-CH_3$, 1), 289($M-CH_3O\cdot$, 1), 179($M-C_{10}H_{21}$, 100), 147($M-C_{10}H_{21}-CH_3OH$, 60).

8.6. Experimental Work Relating to Chapter 6.

8.6.1. Scale up Reactions.

8.6.1.1. Reactions of 2-Methyl-1-undecene.

Standard alkylating conditions were employed with 2-methyl-1-undecene as the alkylating agent. Then the 2-methyl-1-undecene (10g, 0.06 moles) and salicylic acid (8.28g, 0.06 moles) with of 80% sulfuric acid ($40cm^3$) was reacted under standard reaction conditions. Standard work up and analysis procedures were followed giving accountability 69% and purity of the methyl 5-t-undecylsalicylate (**15**) 20%.

Revised conditions involved the same conditions as previously except nitrogen was vigorously bubbled through by means of a frit. This time the accountability was 75% and the purity of the methyl 5-t-undecylsalicylate (**15**) was 75%.

8.6.1.2. Reactions of Propylene tetramer.

Standard alkylating conditions were employed with propylene tetramer as the alkylating agent (126g, 0.75 moles, based on the propylene tetramer consisting of entirely C_{12} alkylgroups), salicylic acid (103.5g ,0.75 moles) and sulfuric acid ($250cm^3$). The mixture was heated to 60°C, for three hours, with nitrogen vigorously bubbled through and the mixture was also stirred by means of a magnetic flea. On such a large scale two distinct stages to the reaction are observed. Firstly there are two phases observed, with little mixing of the alkene with the acid when the bubbler is removed, momentarily. As the reaction proceeds a single phase is observed, after about 30 minutes. This single phase starts out yellow in colour, then goes orange and as the reaction proceeds to completion goes darker and darker untill it is dark red/purple in colour. Standard work up procedures were then followed, giving accountability 80% and purity 83%.

Optimization of the scaled up reactions are as follows;

1) The above conditions were employed except the temperature was lowered to 20°C. Accountability 81% and purity 65%.

2) The above conditions were employed except the acid volume was lowered to $200cm^3$. Accountability 77%and purity 75%.

3) The above conditions were employed except a phase transfer catalyst (1mmol) tetrabutyl ammonium sulfate was added. Accountability 78% and purity 80%.

8.6.1.3. Reaction of Polyisobutene (PIB).

A 1000 molecular weight, PIB (Glissopal[o]), was reacted with an equivalent of

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[o] Glissopal contains predominately vinylidene end groups (>90%).

salicylic acid (13.5g, 0.1 moles) under standard scaled up alkylation conditions with 80% sulfuric acid (75 cm^3). The mixture was heated to 60°C, for three hours with nitrogen vigorously bubbled through and the mixture was also stirred by means of a magnetic flea. On cooling and the addition of water, a very viscous orange sludge resulted, which on standing went a red/purple colour. No yield was recorded because of the inability to separate, effectively, the sulfuric acid from the alkylsalicylic acid.

Due to the size of the alkyl chain standard analytical procedures were not followed because the compound would not be eluted through the GC. Probe MS was attempted but provided no useful information. Analysis was performed by ^1H nmr, using deuterated THF. On addition of THF, two phases were produced, an organic and an aqueous phase.

^1H nmr organic phase; δ_H (THF) 7.98(d, J=2.4Hz, 1H, [5-alkylsalicylic acid] ArH ortho to acid group), 7.88(1H, d, J=2.4Hz, unknown) 7.62(1H, dd, J=2.4 and 6.3Hz, 1H, [5-alkylsalicylic acid] ArH para to acid group), 6.96(d, J=8.5Hz, 1H, [5-alkylsalicylic acid] ArH meta to acid group), 1.30-1.34(m, approximately 210H)

^1H nmr aqueous phase;

5-sulfosalicylic acid; δ_H (THF) 8.41(d, J=2.4Hz, 1H, ArH ortho to CO_2H), 8.05(1H, dd, J=2.4 and 6.3Hz, 1H, ArH para to CO_2H), 7.08(d, J=8.3Hz, 1H, ArH meta to CO_2H)

5-PIBsalicylic acid; δ_H (THF)7.93(d, J=2.5Hz, 1H, ArH ortho to acid group), 7.64(1H, dd, J=2.5 and 8.7Hz, 1H, ArH para to acid group), 6.94(d, J=7.7Hz, 1H, ArH meta to acid group), 1.30-1.34(m, approximately 207H).

3-PIB-5-sulfosalicylic acid; δ_H (THF) 8.19(d, J=2.4Hz, 1H, ArH ortho to CO_2H), 8.11(d, J=2.2Hz, 1H, ArH para to CO_2H), 1.31-1.35(m, approximately 207H).

8.6.2. Analysis of Commercial Alkylsalicylic Acids.

8.6.2.1. Containing stearic acid.

Analysis of the commercial alkylsalicylic acids. The commercial alkylsalicylic acid containing stearic acid was supplied as a powder. The powder was added to water and acidified by adding hydrochloric acid (approximately 5 molar). An ether extraction was carried out to remove the salicylic acid and the stearic acid from the calcium carbonate. The solvent was removed, the mixture was then methylated by the addition of diazomethane, followed by GC and GC/MS analysis. GC/MS analysis of a selection of the alkylsalicylic acids showing general characteristics;

Methyl tetradecylsalicylate; $C_{22}H_{34}O_3$ *m/z* 348($M^{+\cdot}$, 7%), 179(M-$C_{12}H_{25}$,100), 147(M-C_6H_{13}-CH_3OH, 61).

Methyl-3-(1-ethylhexadecyl)-4-methoxybenzoate; $C_{27}H_{46}O_3$ *m/z* 418($M^{+\cdot}$, 7%), 389(M-C_2H_5,18), 207(M-$C_{15}H_{31}$, 61), 179(M-$C_{15}H_{31}$-CO).

Methyl-3-(t-octadecyl)-4-methoxybenzoate; $C_{27}H_{46}O_3$ *m/z* 418($M^{+\cdot}$, 7%), 193(M-$C_{16}H_{33}$, 100).

8.6.2.2. Without the Presence of Stearic Acid.

Separation of the alkylsalicylic acid from the lubricating oil. Standard procedure for alkylsalicylic acids and other overbased detergents, as follows: a 20% weight for weight solution of the oil containing the overbased detergent, in hexane (or toluene) is produced. Then ten times the volume of the hexane/oil solution (more if the solvent is toluene) of acetone is added to the hexane/oil solution and a solid, the overbased detergent should precipitate out. When the above procedure was carried out on the alkylsalicylic acid overbased detergent, a very fine white precipitate was formed, but could not, under any circumstance (filtering, centifuge) be separated from the solution.

A very small amount of the alkylsalicylic acid was separated from the oil by; mixing the oil with concentrated hydrochloric acid (approximately 6M) and then removing the aqueous layer. The aqueous layer was neutralised with calcium hydroxide, diethyl ether added, the mixture shaken, and the aqueous layer was separated from the organic layer. The diethyl ether was removed on the rotary evaporator and the alkyl salicylic acids were methylated using diazomethane so that GC and GC/MS analysis could be performed.

GC/MS analysis showed that the alkyl chain attatched to the salicylic acid ranged from C_{14} to C_{20}, with a similar distribution of products found when stearic acid was present. NMR analysis of the salicylic acids is inconclusive as the residual oil dominates the spectrum.

8.6.3. Molecular Modeling.

The molecular modelling was carried out using the MOPAC6 program on the PC. Using the MNDO approximation. Molecular geometries were determined by first giving an initial geometry and then using the inbuilt optimization method. The values quoted were taken from these results.

8.7. Experimental Work Relating to Chapter 7.

8.7.1. Standard Industrial Synthesis.

This synthesis consists of the three stages in the formation of a sulfurised alkylphenol overbased detergent, the sulfurisation, neutralisation and the overbasing. A 1 litre 5-necked flask was charged with ADX405[p] (58 g), lubricating oil (SN 150)(171 g), ethylene glycol (42 g), paraformaldehyde (6 g), lime (10 g) and stearic acid (68 g). The mixture was heated at 145 °C and at a pressure of 530 mm Hg for 15 minutes. The mixture was cooled to 100 °C and 2-ethylhexanol (150g), lime (100g) and of calcium acetate (6g) was added. The mixture was then heated to 130 °C at 280 mm Hg for 10 minutes. Then CO_2 (cardice or cylinder) (70 g) was added at 130 °C/ 1 bar. The vacuum was increased to maximum (10 mm Hg) and the temperature was also increased to 210 °C and held at this temperature and pressure untill the distillation had ceased. Finally the product was filtered using celite and a sinter funnel.

The product has the composition 14.0% weight for weight (w/w) calcium, 0.7% w/w sulfur, alkalinity value 400 TBN (400 mg KOH/g) and a viscosity at 100 °C (50 to 120 cst)[q]

8.7.2. Simplified Industrial Synthesis.

Sulfur flowers (0.64 g, 0.02 mol) and p-cresol (2.16 g, 0.02 mol) were heated to 145°C, with stirring and then approximately 10 drops of ethylene glycol were added. The temperature was increased to 165°C and maintained there for 1hour with a slight vacuum applied (a water pump slightly on). After the hour the temperature was increased further to 210°C and a full vacuum (approximately 5 mm Hg) was applied using an oil pump for a further hour. The temperature was maintained by means of a silicone oil bath on a stirrer hotplate. Fitted between the reaction vessel and the pump was a sodium hypochlorite trap; this was used to destroy any hydrogen sulfide formed during the reaction. When p-cresol was used as the alkylphenol, nothing remained in the reaction flask.

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[p] ADX405 is an alkylphenol comprising predominantly of C_{12} branched propylene tetramer

[q] Analysis carried out by the analytical department at the BP Hull research centre.

8.7.2.1. Reactions of sulfur with p-isopropylphenol.

On replacing p-cresol with p-isopropylphenol (2.72 g, 0.02 mol) a product was produced. The product was then washed with methanol, then filtered and then the solvent removed on the rotary evaporator, leaving a black/brown solid. This solid was analysed first by GCand then GC/MS both using an SE-30 column with dichloromethane as the solvent. Four major peaks were observed, with one of these being unreacted starting material which was readily identified by comparison of retention times and mass spectra with those of authentic materials.

4-isopropenylphenol (77); $C_9H_{10}O$; *m/z* 134($M^{+\cdot}$, 100%), 133(M-1, 16), 119(M-CH_3, 73), 91(24).

4-isopropyl-2-thiophenol (78); $C_9H_{12}OS$; *m/z* 168($M^{+\cdot}$, 45%), 153(M-CH_3, 100), 120(M-CH_3-HS, 27),119(21), 91(44).

2,2'-thiobis(4-isopropylphenol) (79); $C_{18}H_{20}O_2S$; *m/z* 302($M^{+\cdot}$, 100%), 303(M+1, 21), 287(M-CH_3, 37), 245(25), 136(79), 121(81), 91(43).

Probe mass spectrometry was also carried out on this product giving the following mass spectrum.

602($C_{36}H_{42}O_4S_3$, <1%), 468($C_{27}H_{32}O_3S_2$, 1), 398($C_{18}H_{22}O_2S_4$, <1), 366($C_{18}H_{22}O_2S_3$, 2), 334($C_{18}H_{22}O_2S_2$, 8), 302($C_{18}H_{22}O_2S$, 100).

8.7.2.2. Reaction of sulfur monochloride with p-isopropylphenol.

The sulphur monochloride (1.34 g, 0.01 mol) was added slowly, over a period of about 20 minutes, to the p-isopropyl phenol (2.72 g, 0.02 mol) in 30 cm^3 dichloromethane at 0°C. A sodium hypochlorite trap was used to remove any hydrogen sulphide formed during the reaction. The mixture was then stirred for about 3 hours, after this time the reaction flask was heated to 140°C to remove any unreacted sulphur monochloride and dichloromethane and then the removal of any residual solvent was carried out on the rotary evaporator. Again the solid was analysed by GC and then GC/MS both using an SE-30 column with dichloromethane as the solvent. Four major peaks were observed, with one of these being unreacted starting material which was readily identified by comparison of retention times and mass spectra with those of authentic materials.

4-isopropenylphenol (77); $C_9H_{10}O$; *m/z* 134($M^{+\cdot}$, 100%), 133(M-1, 16), 119(M-CH_3, 73), 91(24).

4-isopropyl-2-thiophenol (78); $C_9H_{12}OS$; *m/z* 168($M^{+\cdot}$, 45%), 153(M-CH_3, 100), 120(M-CH_3-HS, 27),119(21), 91(44).

2,2'-thiobis(4-isopropylphenol) (79); $C_{18}H_{20}O_2S$; m/z 302($M^{+\cdot}$, 100%), 303(M+1, 21), 287(M-CH_3, 37), 245(25), 136(79), 121(81), 91(43).

8.7.2.3. Purification of 2,2-thiobis(4-isopropylphenol) by column chromatography.

A pure sample of 2,2-thiobis(4-isopropylphenol) was obtained by column chromatography, using as the solvent 9:1 ethylacetate:chloroform.

^{1}H NMR δ_H ($CDCl_3$) 6.95(d, J=2.5Hz, 1H, ArH ortho to S bridge), 6.80(1H, dd, J=2.5 and 8.7Hz, 1H, ArH para to S bridge), 6.53(d, J=8.7Hz, 1H, ArH meta to S bridge), 5.83(s, 1H, OH), 2.51(q, 1H, J=6.9Hz, ArCH[$\mathbf{CH_3}$]$_2$). 1.22(d, J=6.9Hz, 6H, ArCH[$\mathbf{CH_3}$]$_2$).

8.7.2.4. Purification of the product nixture from the reaction between 2,2-thiobis(4-isopropylphenol) and sulfur monochloride by HPLC.

A sample of the product mixture from the reaction between 2,2-thiobis(4-isopropylphenol) and sulfur monochloride was separated by HPLC. The product mixture was first passed through a silica column to remove any unreacted sulfur monochloride.

A column was attached to a Spectraphysic 1000 HPLC machine. The solvent system employed was a 95:5 hexane:ethylacetate mixture, with a direct change to a 1:1 mixture, to wash any other compounds from the column before the next run. The concentration of the sample injected was 45 mg cm^{-3}, with the UV/VIS detector set at 280 nm. Nine fractions were collected on numerous runs. The solvent was removed on the rotary evaporator and the nine fractions were analysed by ^{1}H nmr and by Probe MS.

Nmr analysis of fractions 1,2 and 4 to 9 were all very similar, with an example below;

δ_H ($CDCl_3$) 6.8-7.3(br, ArH), 1.45-1.55(br), 1.51(s)

Following a D_2O shake the following nmr was obtained.

δ_H ($CDCl_3$) 6.8-7.3(br, ArH), 1.45-1.55(br). (The loss of the singlet at δ=1.51)

Probe MS fraction 1: elemental sulfur S_8; *m/z* 256($M^{+\cdot}$, 19), 192(M-S_2, 20), 160(M-S_3,21), 128(M-S_4, 20), 96(M-S_5, 16), 64(M-S_6, 100).

Probe MS fraction 2: no use, plastizer detected; *m/z* 279(6), 149(56),

Probe MS fraction 3: *m/z* 336($M^{+\cdot}$, 100), 338(M+2, 36), 279(16), 153(22), 121(29), and 453(37), 285(100), 168(54), 57(76), 43(83).
δ_H ($CDCl_3$) 7.35(d, J=2.3Hz, 1H, ArH ortho to S bridge), 7.19(dd, J=2.3Hz and 8.1Hz,1H, ArH para to S bridge), 7.06(d, J=1.6Hz, 1H, ArH para to Cl group), 6.95(d, J=8.2Hz, 1H, ArH meta to S bridge), 6.79(d, J=2.1Hz, 1H, ArH ortho to Cl group), 6.51(s, 1H, OH ortho to Cl group), 6.04(s, 1H, OH), 2.83(q, J=6.9 Hz, 1H, Ar**CH**[CH_3]$_2$), 2.71(q, J=6.9Hz,1H, Ar**CH**[CH_3]$_2$), 1.56(s, 37H), 1.20(d, J=6.9Hz, 10H, ArCH[**CH_3**]$_2$), 1.11(d, J=6.9Hz, 10H, ArCH[**CH_3**]$_2$).

Probe MS fraction 4: 336(62), (M+2, 21), 321(16), 244(27), 213(34), 168(51), 153(100), and 602($C_{36}H_{42}O_4S_3$, 1), 502(3), 466($C_{27}H_{30}O_3S_2$, 5), 436(3), 394(3), 360(7), 336(11), 302($C_{18}H_{22}O_2S$, 8), 187(12), 168(51), 153(100), 121(52).

Probe MS fraction 5: no mass spectrum recorded

Probe MS fraction 6: 468($C_{27}H_{32}O_3S_2$, 35), 334($C_{18}H_{22}O_2S_2$, 24), 302($C_{18}H_{22}O_2S$, 26), 168(47), 153(100), 121(71).

Probe MS fraction 7: 634($C_{36}H_{42}O_4S_4$, 22), 602($C_{36}H_{42}O_4S_3$, 5), 530($C_{27}H_{30}O_3S_4$, 5), 502(8), 500($C_{27}H_{32}O_3S_3$, 7), 468($C_{27}H_{32}O_3S_2$, 36), 334($C_{18}H_{22}O_2S_2$, 100), 302($C_{18}H_{22}O_2S$, 15), 168(50), 153(96), 121(52), and 800($C_{45}H_{52}O_5S_4$, 3), 696($C_{36}H_{42}O_4S_6$, 6), 666($C_{36}H_{42}O_4S_5$,11), 634($C_{36}H_{42}O_4S_4$, 44), 530($C_{27}H_{30}O_3S_4$, 22), 500($C_{27}H_{32}O_3S_3$, 77), 468($C_{27}H_{32}O_3S_2$, 24), 366($C_{18}H_{22}O_2S_3$, 48), 334($C_{18}H_{22}O_2S_2$, 67), 302($C_{18}H_{22}O_2S$, 47), 168(69), 153(100),121(70).

Probe MS fraction 8: 634($C_{36}H_{42}O_4S_4$, 6), 562(2), 530($C_{27}H_{30}O_3S_4$, 4), 500($C_{27}H_{32}O_3S_3$, 3), 468($C_{27}H_{32}O_3S_2$, 33), 368(60), 334($C_{18}H_{22}O_2S_2$, 100), 153(42), 121(46) and 634($C_{36}H_{42}O_4S_4$, 18), 530($C_{27}H_{30}O_3S_4$, 14), 500($C_{27}H_{32}O_3S_3$, 59), 468($C_{27}H_{32}O_3S_2$, 18),

366($C_{18}H_{22}O_2S_3$, 17), 334($C_{18}H_{22}O_2S_2$, 65), 153(100), 121(79).

Probe MS fraction 9: 334($C_{18}H_{22}O_2S_2$, 100), 185(45), 168(31), 153(54), 121(33) and 530($C_{27}H_{30}O_3S_4$, 4), 500($C_{27}H_{32}O_3S_3$, 5), 468($C_{27}H_{32}O_3S_2$, 6), 366($C_{18}H_{22}O_2S_3$, 11), 334($C_{18}H_{22}O_2S_2$, 85), 168(50), 153(100), 121(50).

8.7.3. Reactions Using Sodium Perborate.

The standard reaction conditions were as follows: To a 50cm^3 round bottom flask was added 10 mmol ArSH (thiocresol, hypdroxythiophenol, p-tolyldisulphide and crude sulfide produced previously). To this was added sodium perborate tetrahydrate (20 mmol) in methanol (25 cm^3) and water (10 cm^3), and the whole mixture was stirred at room temperature using a magnetic flea. After varying reaction durations the product mixture was filtered, and the residue washed with methanol. The filtrate was then placed on a rotary evaporator and the solvents completely removed. The product was analysed by GC, with methanol as the solvent (Carbowax column, temperature program 120°C for 2 minutes then tmperature ramping at 8°Cmin^{-1} to 300°C and maintained there for 10 minutes).

8.7.3.1. Reactions Using Sodium Perborate with p-Thiocresol.

Using p-thiocresol three products were observed by GC in a ratio of 15:1:9, from the two hour reaction and they were identified as;

4,4'-tolyldisulfide (87); $C_{14}H_{14}S_2$ *m/z* 246 ($M^{+\cdot}$, 72%), 248(5), 125(7), 123(100).

4,3'-tolyldisulfide (88); $C_{14}H_{14}S_2$ *m/z* 246 ($M^{+\cdot}$, 69%), 248(4), 125(7), 123(100).

3,3'-tolyldisulfide (89); $C_{14}H_{14}S_2$ *m/z* 246 ($M^{+\cdot}$, 75%), 248(5), 125(8), 123(100).

^{1}H NMR of 4,4'-tolyldisulfide

δ_H ($CDCl_3$) 7.15(d, J=7.9Hz, 2H, ArH ortho to S bridge), 7.04(d, J=7.9Hz ,2H, ArH ortho to CH_3 group), 2.71(s, 3H, Ar**CH_3**).

8.7.3.2. Reactions Using Sodium Perborate with m-Thiocresol.

Similar results were observed when m-thiocresol was used instead of the p-thiocresol, except the overall distribution was different.

8.7.3.3. Reactions Using Sodium Perborate with 4-Hydroxythiophenol.

Using 4-hydoxythiophenol as the thiol, analysis by probe MS of the product mixture gave; $C_{12}H_{10}O_2S_2$; *m/z* 250 ($M^{+\cdot}$, 76%) 252(7) 127(11) 125(100).

IR of product mixture in hexachloro-1,3-butadiene, with calcium fluoride cells: broad band at 3417 cm^{-1}OH stretch, no band at 2565 cm^{-1} corresponding to SH stretch.

8.7.3.4. Reactions Using Sodium Perborate with the Crudfe Sulfide Mixture.

A probe MS of the crude sulfide mixture before reaction:

798($C_{45}H_{50}O_5S_4$, <1), 756($C_{45}H_{50}O_4S_3$, <1), 666($C_{36}H_{42}O_4S_5$, <1), 634($C_{36}H_{42}O_4S_4$, <1), 500($C_{27}H_{32}O_3S_3$, <1), 468($C_{27}H_{32}O_3S_2$, <1), 398($C_{18}H_{22}O_2S_4$, 4), 366($C_{18}H_{22}O_2S_3$, 15), 334($C_{18}H_{22}O_2S_2$, 63), 302($C_{18}H_{22}O_2S$, 91), 168(69), 153(45),121(100).

After reaction;

468($C_{27}H_{32}O_3S_2$, <1), 398($C_{18}H_{22}O_2S_4$, <1), 366($C_{18}H_{22}O_2S_3$, 3), 334($C_{18}H_{22}O_2S_2$, 17), 302($C_{18}H_{22}O_2S$, 7), 168(15), 153(16), 121(100).

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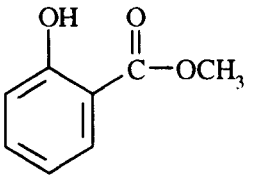
10. Appendix.

Stuctures

methyl salicylate (**8**)

methyl 5-t-butylsalicylate (**9**)

methyl 3,5-di-t-butylsalicylate (**10**)



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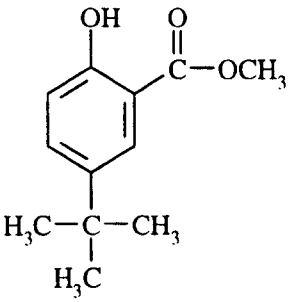

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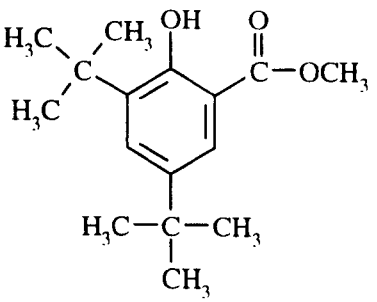


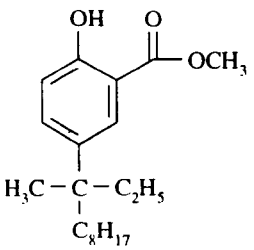
10

methyl 5-(1-methyl-1-ethylnonyl)salicylate (**12**)

methyl 5-(1,1-dimethylnonyl)salicylate (**13**) (t-undecyl)

methyl 3-(1,1-dimethyldecyl)salicylate (**14**) (t-dodecyl)

methyl 5-(1,1-dimethyldecyl)salicylate (**15**) (t-dodecyl)



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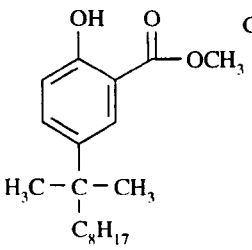

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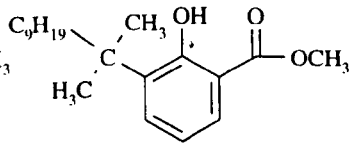

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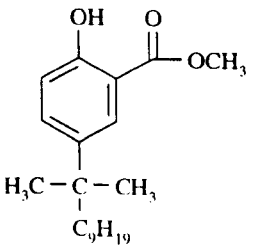

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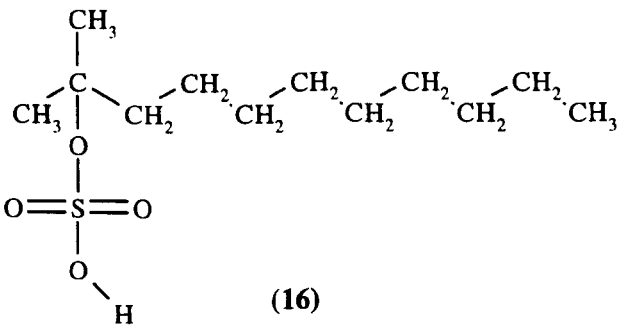
dodecyl sulfate (**16**)



(16)

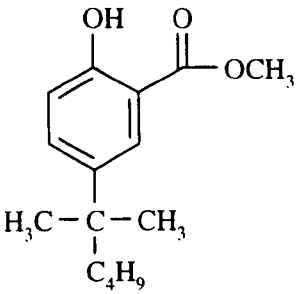
methyl 5-(1,1-dimethylpentyl)salicylate (t-heptyl) (**17**)

methyl 5-(1,1-dimethylbutyl)salicylate (**18**) (t-hexyl)

methyl 5-(1-methyl-1-ethylpropyl)salicylate (**19**)

methyl 5-(1,1-dimethylhexyl)salicylate (**20**) (t-octyl)

methyl 3,5-di-t-heptylsalicylate (**21**)



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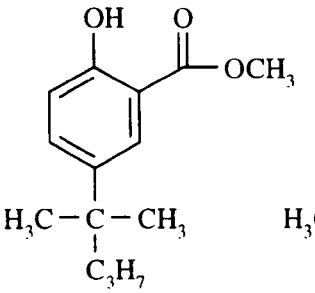

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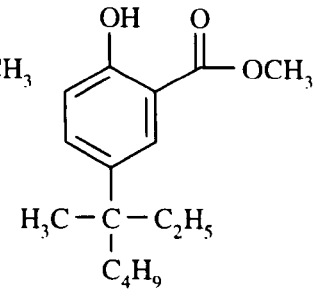

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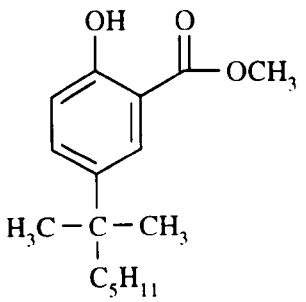

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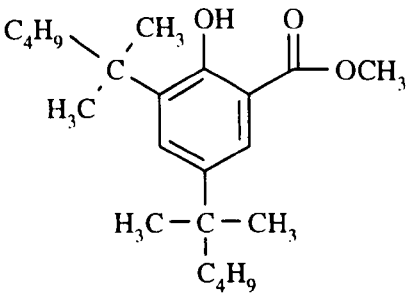

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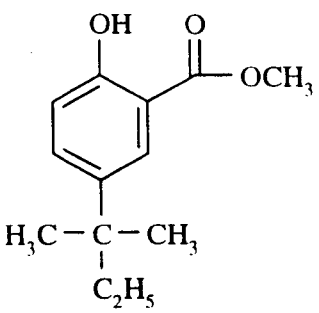
methyl 5-t-pentylsalicylate (**22**)



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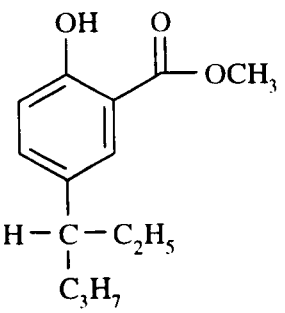

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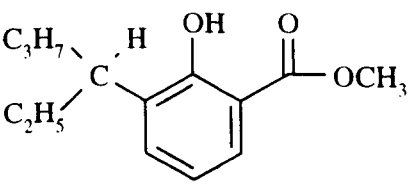

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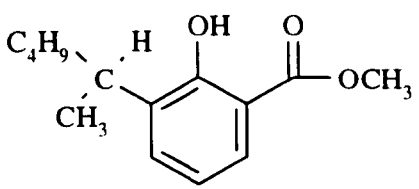

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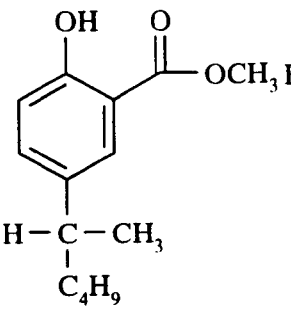

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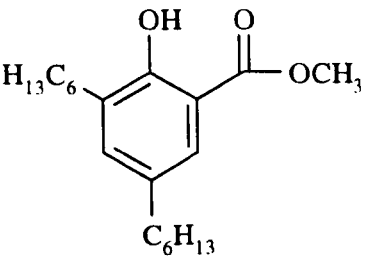


27

methyl 5-(1-ethylbutyl)salicylate [3'-hexyl](**23**)

peak 6: methyl 3-(1-ethylbutyl)salicylate [3'-hexyl](**24**)

peak 7: methyl 3-(1-methylpentyl)salicylate [2'-hexyl](**25**)

methyl 5-(1-methylpentyl)salicylate [2'-hexyl](**26**)

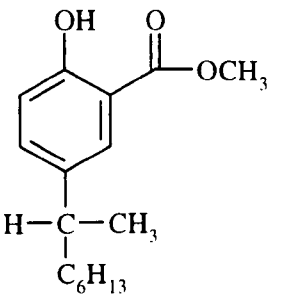
methyl 3,5-dihexylsalicylates (**27**)

methyl 5-(1-methylheptyl)salicylate [2'-octyl](**28**)

methyl 5-(1-ethylhexyl)salicylate [3'-octyl](**29**)

methyl 5-(-1-propylpentyl)salicylate [4'-octyl](**30**)

methyl 3,5-dioctylsalicylate (**31**)



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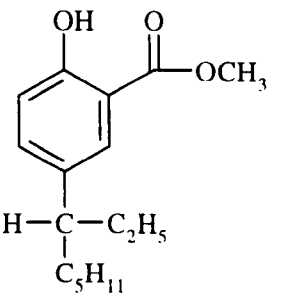

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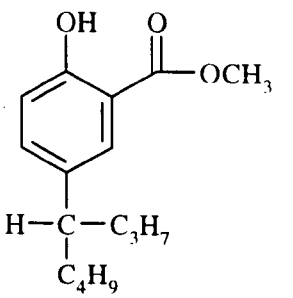

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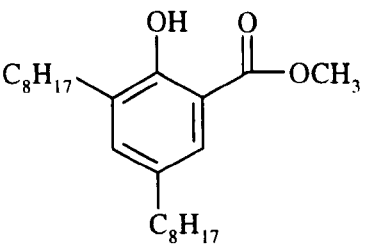
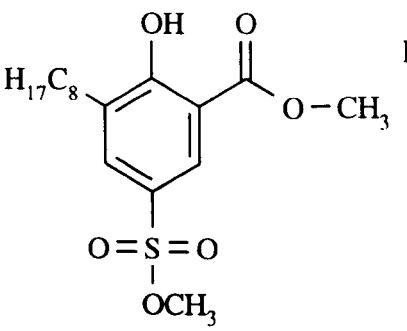


31

3-octyl-2-hydroxy-5-methoxysulfonyl-benzoic acid methyl ester (**32**)

5-octyl-2-methoxy-3-methoxysulfonyl-benzoic acid methyl ester (**33**)



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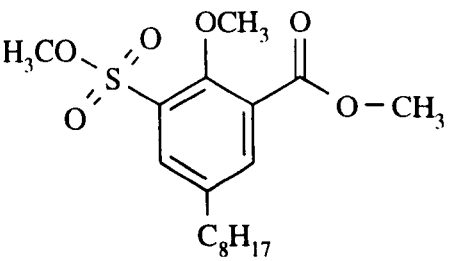


33

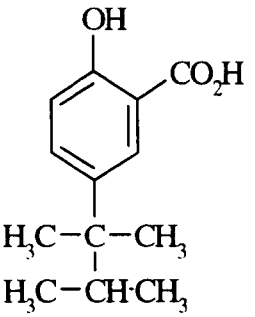
methyl 5-(1,1,2-trimethypropyl)salicylate (**36**)

methyl 3-(1,1,2-trimethypropyl)salicylate (**37**)

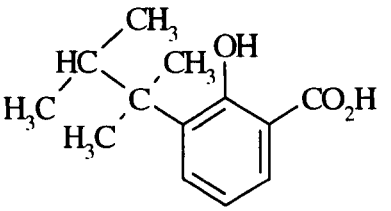
methyl 5-hexenylsalicylate (**38**)

methyl 3-t-butyl-5-hexenylsalicylate (**39**)

methyl 3-(1,1,2-trimethylpropyl)-5-hexenylsalicylate (**40**)



(36)



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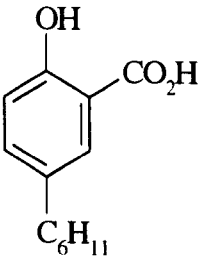

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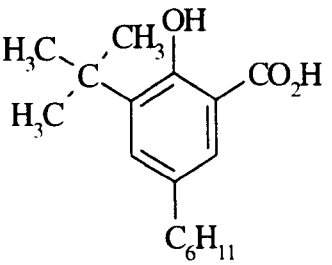

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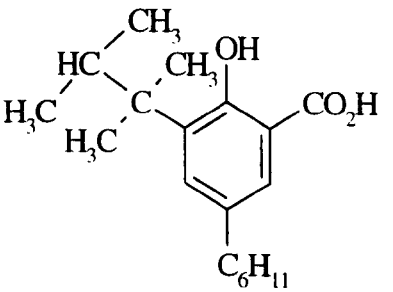
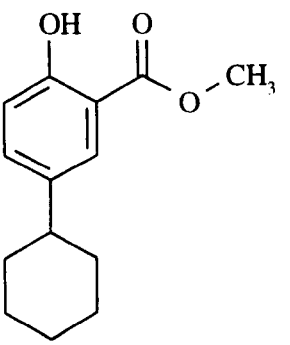


(40)

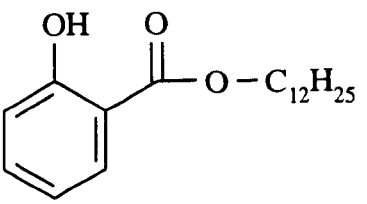
methyl 5-(1,1,3,3-tetramethylbutyl) salicylate (**41**)

methyl 5-cyclohexylsalicylate (**42**)



42

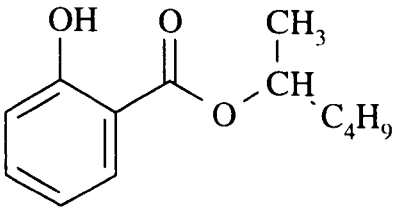
dodecyl salicylate (**43**)



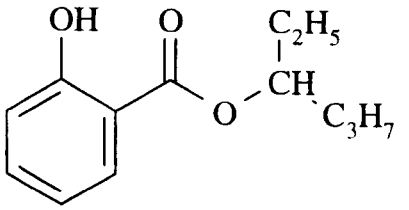
(43)

1-methylpentyl salicylate (**44**) [2'-hexyl salicylate]

1-ethylbutyl salicylate (**45**) [3'-hexyl salicylate]



(44)

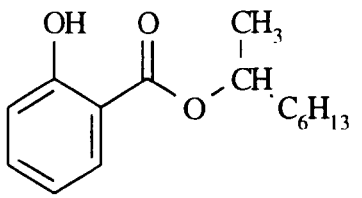


(45)

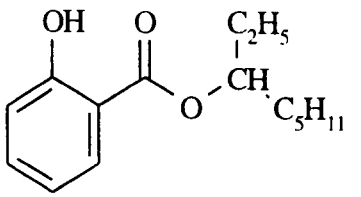
1-methyl-heptyl salicylate (**46**) [2'-octyl salicylate]

1-ethyl-hexyl salicylate (**47**) [3'-octyl salicylate]

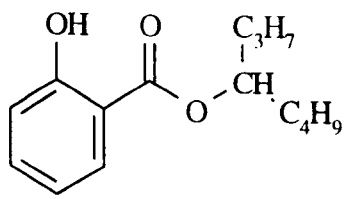
1-propyl-pentyl salicylate (**48**) [4'-octyl salicylate]



(46)

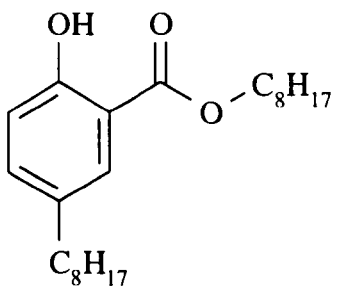


(47)



(48)

octyl 5-octylsalicylate (**49**).



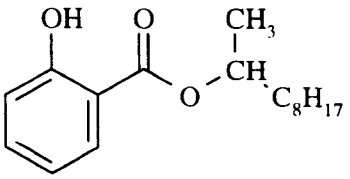
(49)

1-methyl-nonyl salicylate (**50**) [2'-decyl salicylate]

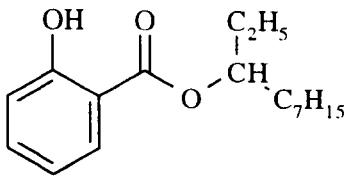
1-ethyl-octyl salicylate (**51**) [3'-decyl salicylate]

1-propyl-heptyl salicylate (**52**) [4'-decyl salicylate]

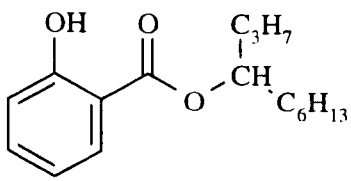
1-butyl-hexyl salicylate (**53**) [5'-decyl salicylate].



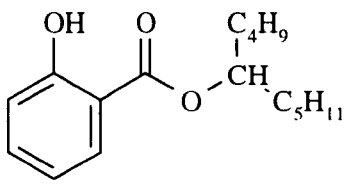
(50)



(51)



(52)

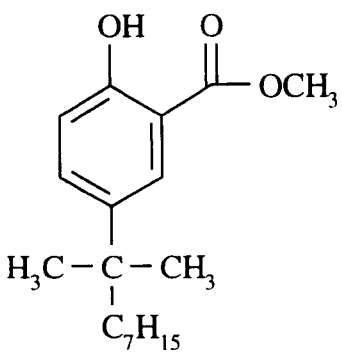


(53)

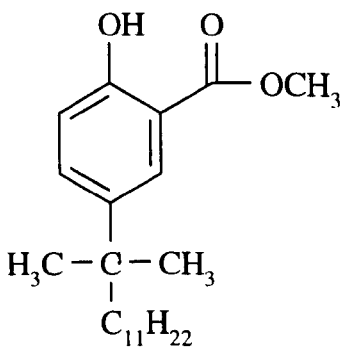
1,1-dimethyldecyl salicylate (**54**)

methyl 5-(decyl)salicylate (**55**)

methyl 5-(t-tetradecyl)salicylate (**56**)



(55)

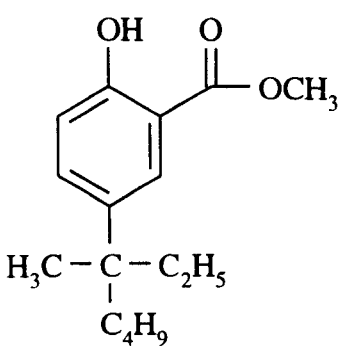


(56)

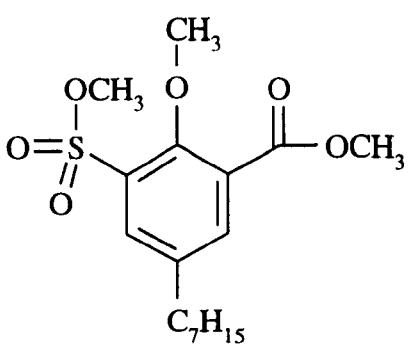
methyl 5-(1-methyl-1-ethylpentyl)salicylate (**57**)

methyl 5-heptyl-2-methoxy-3-methoxysulfonylbenzoate (**58**)

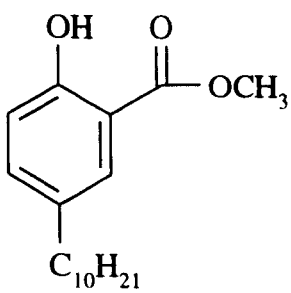
methyl 5-decylsalicylate (**59**)



(57)



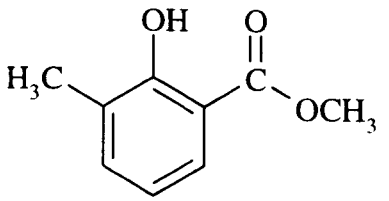
(58)



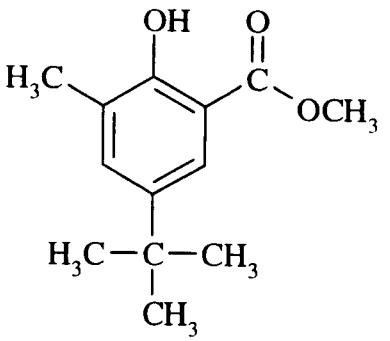
(59)

methyl 3-methylsalicylate (**60**)

methyl 3-methyl-5-t-butylsalicylate (**61**)



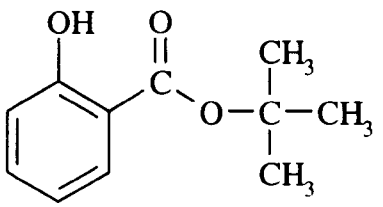
(**60**)



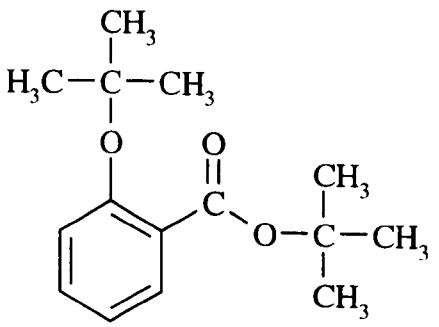
(**61**)

t-butyl salicylate (**62**)

t-butyl 2-t-butoxybenzoate (**63**)



(**62**)

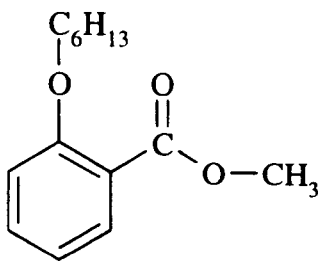


(**63**)

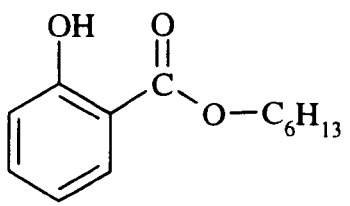
methyl 2-hexoxybenzoate (**64**)

hexyl salicylate (**65**)

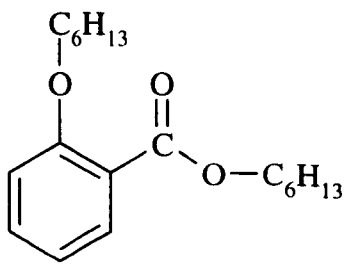
hexyl 2-hexoxybenzoate (**66**)



(**64**)



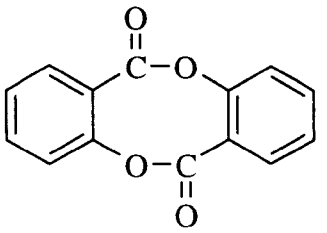
(**65**)



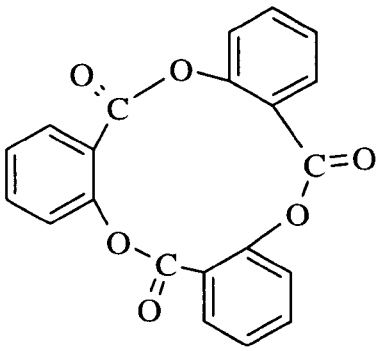
(**66**)

dibenzo [b,f][1,5]dioxocin-6,12-dione (disalicylide) (**67**)

tribenzo [b,f,j][1,5,9]trioxocine-6,12,18-trione (trisalicylide) (**68**)



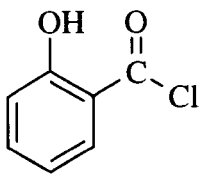
(**67**)



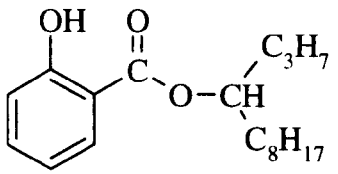
(**68**)

salicoyl chloride (**69**)

1-butyloctyl salicylate (**70**) [4'- dodecyl salicylate]



(**69**)

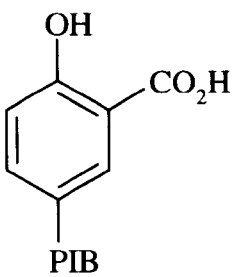


(**70**)

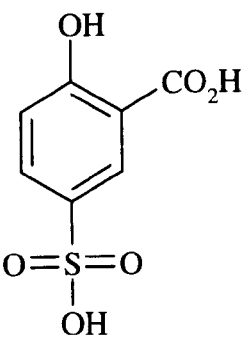
5-PIBsalicylic acid (**71**)

5-sulfosalicylic acid (**72**)

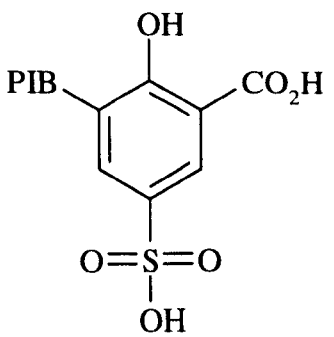
3-PIB-5-sulfosalicylic acid (**73**)



(**71**)



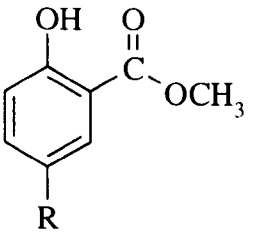
(**72**)



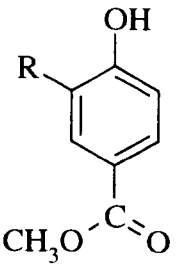
(**73**)

methyl 5-alkylsalicylate and (**74**)

methyl 3-alkyl-4-hydroxybenzoate (**75**).



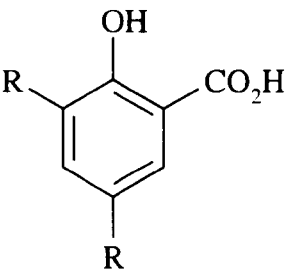
(**74**)



(**75**)

$R = C_{14}H_{29} - C_{19}H_{39}$

3,5-di(propylene tetramer)salicylic acid (**76**)

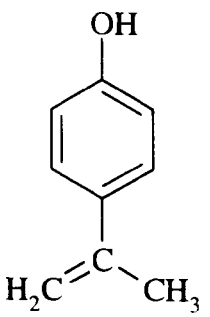


(**76**) R = Propylene Tetramer

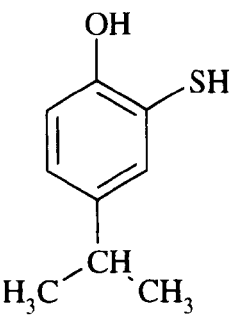
4-isopropenylphenol (**77**)

4-isopropyl-2-thiophenol (**78**)

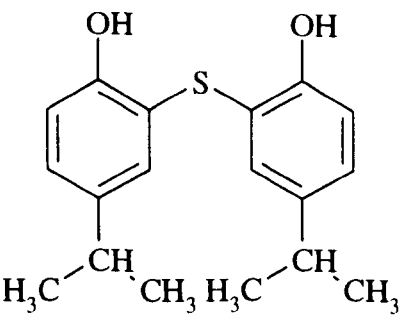
2,2'-thiobis(4-isopropylphenol) (**79**) [monosulfide]



(**77**)



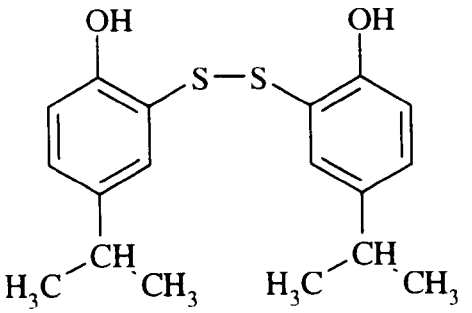
(**78**)



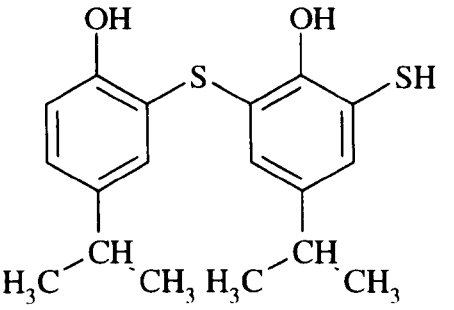
(**79**)

disulfide (**80**)

2,2'-thiobis(4-isopropyl-[6-thiophenol]) [monosulfide with a thiol group] (**81**)



(80)

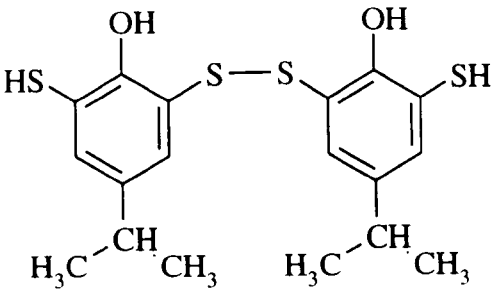


(81)

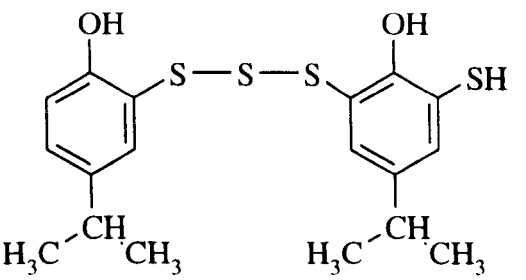
disulfide with two thiol groups (**82**)

trisulfide with one thiol group (**83**)

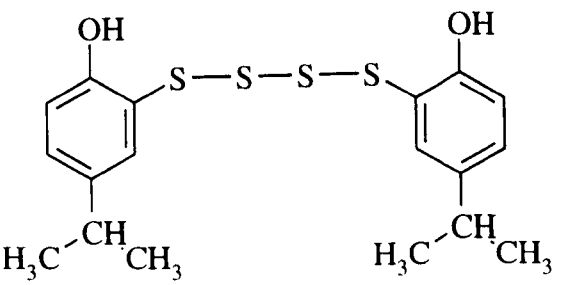
tetrasulfide (**84**)



(82)

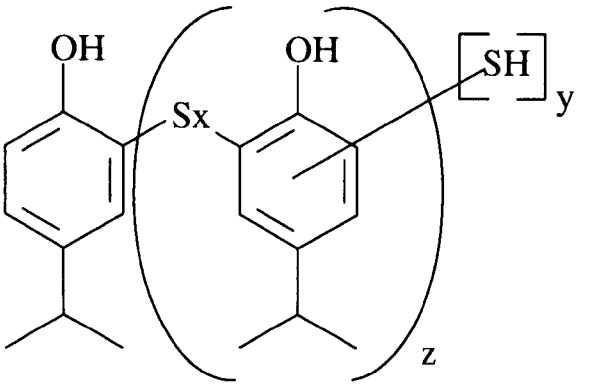


(83)



(84)

poly(isopropylphenols) [**85**]



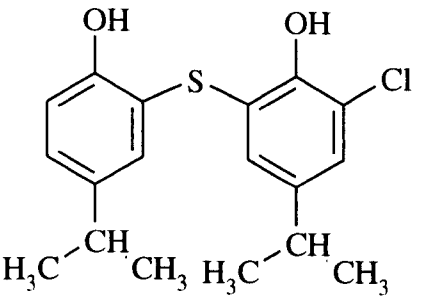
x = 1 - 4

y = 0 - 2

z = 1 - 4

(**85**)

2,2'-thiobis(4-isopropyl-[6-chlorophenol]) [**86**]

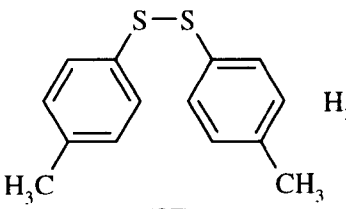


(**86**)

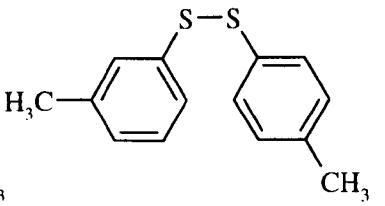
4,4'-tolyldisulfide (**87**)

4,3'-tolyldisulfide (**88**)

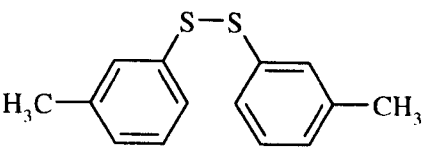
3,3'-tolyldisulfide (**89**)



(**87**)



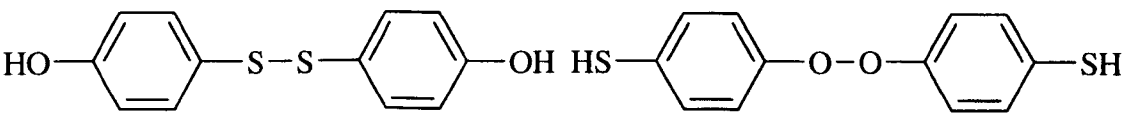
(**88**)



(**89**)

bis(-p-hydroxyphenyl)disulfide (**90**)

bis(-p-thiophenol)peroxide (**91**)



(**90**) (**91**)