INTRODUCTION
An examination of the molecular structures of terpenoids reveals that in great majority of cases, the carbon skeleton can be built up theoretically by the union of two or more isoprene or isopentane residues. These units are usually united in a head to tail fashion. This is so called isoprene rule, first proposed by Wallach in 1887. It has been of great help as a working hypothesis in the elucidation of terpenoid structure, both simple and complex.

The structure of isoprene indicates that the formation of acyclic mono-terpenoids should contain three double bonds and monocyclic mono-terpenoids should contain two double bonds. Sesquiterpenoids are formed by the union of three isoprene units and as a result acyclic sesquiterpenoids should contain four double bonds while monocyclic sesquiterpenoids should have three double bonds. In most of the terpenoids one of the double bonds was respectively designated as isopropenyl or isopropylidene, i.e.

\[
\begin{align*}
\text{CH}_2 & \equiv C - C - \\
\text{CH}_3 & \equiv C = C - \\
\text{(Isopropenyl)} & \quad \text{(Isopropylidene)}
\end{align*}
\]

A close study of presumably pure sample of terpenoids containing either isopropenyl or isopropylidene group, whether of natural or of synthetic origin has often shown them to be
mixture of the two isomers. The interrelationship between these two forms has been one of the perplexing problems encountered by terpene chemists.

The question of fixing this double bond in a natural terpenoid aroused considerable controversy (1) and till recently the position with regard to this moot point remained unsolved. The chemical method used for investigating this terminal double bond was the oxidative degradation whereby acetone being formed from an isopropylidene form and formaldehyde from an isopropenyl group (1,2).

\[
\begin{align*}
\text{CH}_3&\hspace{1cm} \text{C} = \text{C} \\
\text{CH}_3&\hspace{1cm} \rightarrow \hspace{1cm} \text{CH}_3\hspace{1cm} \text{C} = \text{O}
\end{align*}
\]

\[
\begin{align*}
\text{CH}_2&\hspace{1cm} \text{C} \hspace{1cm} \rightarrow \hspace{1cm} \text{CH}_3 \\
\text{CH}_3&\hspace{1cm} \hspace{1cm} \hspace{1cm} \hspace{1cm} \rightarrow \hspace{1cm} \text{HCHO}
\end{align*}
\]

This procedure is, however, reported to be associated with certain ambiguities since on ozonolysis many terpenoids yield both acetone and formaldehyde indicating thereby the presence of the mixtures of both isopropylidene and isopropenyl end groupings (1). But there are other evidences which suggest that the terpenoids are structurally homogeneous and that the anomalous results of oxidation are attributed to partial rearrangements (1-3). A classical instance is
provided by Kuhn and Roth (4) who observed that the ultraviolet curves of the two crystalline cis and trans isomeric dehydrogeranic acids (A) were incompatible with the presence of some 30 per cent of less highly conjugated isopropenyl form (B) which is required by ozonolytic experiments (4,5).

\[
\begin{align*}
\text{CH}_3 & \quad \text{CH}_3 \\ \text{CH}_3 & \quad \text{C} = \text{CH} - \text{CH} = \text{CH} - \text{C} = \text{CH}_2 \text{COOH}
\end{align*}
\]

(A)

\[
\begin{align*}
\text{CH}_3 & \quad \text{CH}_3 \\ \text{CH}_2 & \quad \text{C} = \text{CH}_2 - \text{CH} = \text{CH} - \text{C} = \text{CH}_2 \text{COOH}
\end{align*}
\]

(B)

Again, while oxidation of \( \alpha \)-santaly malonic acid (ob) by alkaline potassium permanganate solution gave the keto acid (D) (6), ozonolysis of the same yielded solely the aldehyde (E) (6). This was explained on the basis of a postulation that in a neutral solution the above acid exists as (Cₐ) while in the alkaline medium a facile tautomerism occurs converting (Cₐ) into (Cₖ) (1):

\[
\begin{align*}
\text{C}_{11} \text{H}_{17} - \text{CH}_2 - \text{C} - \text{CH}_2 - \text{CH} - (\text{COOH})_2 & \xrightarrow{\text{C}_{11} \text{H}_{17} - \text{CH} = \text{C} - \text{CH}_2 - \text{CH} (\text{COOH})_2} \\
\downarrow & \\
\text{C}_{11} \text{H}_{17} - \text{CH}_2 - \text{C} - \text{CH}_2 - \text{CH} - (\text{COOH})_2 & \xrightarrow{\text{C}_{11} \text{H}_{17} \cdot \text{CHO}} \\
\end{align*}
\]
The difficulty encountered in settling the nature of isopropenyl or isopropylidene terminal double bond in ease of the terpenoids is accentuated by the fact that the majority of the terpenoids are liquids of questionable purity. On the basis of chemical evidence, therefore, it is generally held that in terpenoids, particularly acyclic and monocyclic, one of the double bonds is present both in isopropenyl and isopropylidene forms and these natural substances are called 'tautomerie mixtures'. It may be pointed out, however, that the double bond in isopropylidene form should be more stable in view of its hyperconjugation with two methyl groups as compared to the isopropenyl form wherein the ethylenic bond is capable of hyperconjugation with one methyl group only.

On the whole, the oxidative degradation, therefore, as unequivocal method of structure diagnosis, is not free from suspect (7-10). In recent years, the physical methods of structural analysis, such as infrared absorption spectroscopy have made possible to settle, this long-disputed problem of the two types of olefinic groupings by showing characteristic infrared absorption bands for the isopropylidene and isopropenyl form (11-15). This technique permits detection of even minor structure variations and also a degree of analytical and structure control in the
synthetic work. The nature of the olefinic linkage can be detected with this method. The absence of particular bond structure in a molecule can be inferred without the shadow of any doubt from the absence of characteristic infrared absorption bands at required frequencies at suitable path-length. Sutherland and coworkers (12) have found on the basis of infrared absorption studies that most of the acyclic terpenoids exist in the form of isopropylidene groupings. However infrared spectroscopy as well as chemical evidences (16) confirmed the existence of some terpenoids having exocyclic double bond, methylenic linkage or isopropylidene terminal i.e. ocimene, carvone and \( \gamma \)-bisabolene.

Further the extensive use of ultraviolet spectroscopy in the field of terpenoids has greatly helped particularly in the detection of conjugation (17). Raman spectra have also been used for the determination of the
structure of organic compounds. But the value of Raman spectra in the field of terpenoids is limited by the fact that very little data is available for the individual constituents (isopropenyl and isopropylidene forms) in terpene mixtures (18, 19).

Molecular rotation correlation and X-ray spectra have also been of valuable help not only in uncovering the structure but also of the stereochemistry of the terpenoids (20-26). Optical rotatory dispersion studies have also greatly assisted in unfolding the structural detail of terpenoids (27) i.e. determining the stereochemistry and absolute configuration. Nuclear magnetic resonance technique and mass spectroscopy have greatly facilitated the determination of structural anatomy and also of absolute stereochemistry of the terpenoids (28).

The physical tools, therefore, have been of great utility in the elucidation of structures of terpenoids. The dilemma of the terminal unsaturation in terpenoids having been resolved, the final and rigorous confirmation of its constitution is sought through a synthesis. Synthetic investigations, therefore, along these lines, would be welcome. This work will serve two purpose. Firstly it would enable comparison possible with natural substances, secondly it should make individual components available in pure form for
examination through spectroscopic instruments. In the present dissertation some of the terpenoids having endo-cyclic double bond, isopropenyl chain or methylenic and iso-propylidene bonds have been synthesised.

To achieve this target for the synthesis of individual terpenoid constituent with the particular double bond, the literature reveals that there are several methods available namely dehydration of alcohols (29,30), submission of acetate (31-33), boric ester (34), xanthates (35,36) and tosylates (37,38) to pyrolysis for olefin synthesis. But all these techniques invariably involve isomerisation under the drastic conditions employed for execution of these procedures. The decarboxylation of olefinic acids is limited to the formation of styrenes and stilbenes (39,40). Further the method of Hofmann degradation for the introduction of double bond claimed to be free from any structural rearrangement or isomerisation also involve circuitous route and drastic experimental conditions (41). A recent procedure involving the conversion of mercaptans to the terminal olefins with one additional carbon atom has also been reported (42). This however is limited by the presence of at least one hydrogen atom:

\[
\begin{align*}
R^- & \xrightarrow{3 \text{ steps}} R^- C = CH_2 \\
R^- \overset{C}{\xrightarrow{SH}} H & \quad R^- \overset{C}{\xrightarrow{CH_2}}
\end{align*}
\]
A prime consideration in the successful synthesis of terpenoids having terminal unsaturation or isopropenyl or isopropylidene chain, is the conditions employed in such synthesis. To achieve the synthesis of the individual terpenoid in a particular pure form and without the shadow of any ambiguity in the present investigation, the routes employed is the well known Wittig reaction (43) and modified Wittig reaction (44).

It was shown by Wittig and Schollkopf (43) that alkylidene and arylidene triphenylphosphoranes prepared by the action of suitable base on an alkyl or aryltriphenylphosphonium halide, react rapidly with aldehydes and ketones to form olefins. The Wittig reaction is usually assumed to proceed via the four membered complex; Wittig and others (45-47) postulated the first intermediate to be betaine (A).

\[
\begin{align*}
(C_6H_5)_3P^+ & \quad C^- (R)_2 \\
\rightarrow & \\
\text{Scheme I}
\end{align*}
\]
It would seem that the formation of betaine (A) i.e.,
electrophilic attack of the ylid carbon by the carbonyl
carbon (Scheme I) is not the only route, an alternate
pathway, e.g., nucleophilic attack on the ylid phosphorus
by the carbonyl oxygen (Scheme II), which course the reaction
takes depends upon the steric and electronic factors, as
well as upon the environment. Conformational analysis shows
that if the reaction between the phosphoryl ylid and aldehyde
begins with nucleophilic attack on the phosphorus trans
olefins should result, whereas electrophilic attack upon
the ylid carbon lead to both cis and trans olefins (47).
The reaction of phosphonate carbanions (B) (44) with ketone and aldehyde to produce olefins proceeds smoothly under mild conditions to give fair to excellent yield of olefins and indeed, this synthesis is very useful supplement to well known Wittig reaction. The phosphonate carbanions (B) have many instances a number of advantages over the triarylphosphoranes or Wittig reagents. They are in most cases less expensive and react with a wider variety of ketones and aldehydes, usually under mild conditions and are not particularly sensitive to atmospheric oxygen:

\[
\begin{align*}
0 & \quad \uparrow + \quad \downarrow \quad \downarrow \\
(C_2H_5O)_2P-CH=CO.C_6H_5 + C_6H_5CH0 & \rightarrow \\
(B) & \quad 0 \\
C_6H_5CH = CH.C-C_6H_5 & \\
\end{align*}
\]

Phosphonate carbanion modification (48) of the Wittig reaction has been reported to invariably furnish a great preponderance of trans olefins. A variety of the substituted olefins prepared by this method with both aromatic and aliphatic aldehydes have in every case been a trans configuration.

The mechanism of trans olefins formation is similar to that proposed by Bergelson and Shemakin (47) for Wittig
reaction of carbethoxymethylenetriphenylphosphorane with aldehyde and ketone. Thus the reaction of carbethoxymethylenetriphenylphosphorane (C) with benzaldehyde yields only trans-cinnamic ester. The specifically trans directed reaction of the ylid (C) with benzaldehyde may be explained by the electron density distribution in the ylid.

\[
\text{C}_6\text{H}_5\text{-CHO} + (\text{C}_6\text{H}_5)_3\text{P} = \text{CH-COO}\text{C}_2\text{H}_5 \quad \rightarrow \\
(\text{C})
\]

\[
(\text{C}_6\text{H}_5)_3\text{P}=\text{O} + \text{C}_6\text{H}_5,\text{CH} \quad = \quad \text{CH-COO}\text{C}_2\text{H}_5
\]

\[
(\text{C}_6\text{H}_5)_3\text{P}^+ \quad \text{CH} \quad \text{C} \quad \text{OC}_2\text{H}_5
\]

The deficiency in electron density at the ylid C-atom hinders electrophilic attack by the carbonyl carbon so that nucleophilic attack on the ylid phosphorus by the carbonyl oxygen becomes more probable. Of the two possible conformations for the resultant dipolar ion—that preferred is (E)—leading to more stable four-membered ring (F) and thence to the trans isomer. The lower energy of the transition state (E) as compared to (D) is due to one hand to less steric interaction of the substituents and
on the other hand to the circumstances that only in the case of (E) can there be maximum overlap of the $\pi$ electrons of the carboxyl and phenyl groups and developing ethylenic bond (coplanarity factor) (48).
In marked contrast to aforementioned olefin syntheses, the Wittig and modified Wittig reactions result in the fixation of the double bond even when it occupies an energetically unfavourable position. Also the sequence of the reactions proceed under mild conditions and is singularly free from any complications (45,46).

The important application of modified Wittig reaction is provided by a recently reported synthesis of Protoemetine (50), which occupies a key position among the ipecacuanha alkaloid. The scheme of synthesis is as follow:

![Chemical structures]

1. **Top diagram:**
   - Initial structure with 
     - CH₃O
     - CH₃O
     - H
     - C₂H₅
   - Reaction yields a structure with
     - CH₃O
     - CH₃O
     - H
     - C₂H₅
     - H
     - C₂H₅

2. **Bottom diagram:**
   - Initial structure with
     - CH₃O
     - CH₃O
     - H
     - C₂H₅
     - CH₂
     - CO₂Et
   - Reaction yields a structure with
     - CH₃O
     - CH₃O
     - H
     - C₂H₅
     - CH₂
     - CO₂Et

Another equally potential synthetic approach for the fixation of terminal methylene bonds in terpenoids in the present studies is the Claisen rearrangement. This involves (51,52) the pyrolysis of appropriate vinyl ether prepared from suitable constituted allylic alcohol through mercuric acetate catalysed (53,54) vinyl-trans-etherification reaction with ethyl vinyl ether to provide the aldehyde with exomethylenic bond in the skeleton. For example this technique has been used as a key step in the synthesis of (+) carvone (55).
The plausible mechanism (56) of Claisen rearrangement is represented below, which is a thermal rearrangement:

In the present dissertation the modified Wittig reaction has been made use in the synthesis of monocyclic sesquiterpenoid (+)Nuciferal. Further employing the Claisen rearrangement of vinyl ether as well as the modified Wittig reaction on suitable carbonyl function, the synthesis of monocyclic sesquiterpenoid alcohol (+) Lanceol and acyclic
monoterpenoid leaf alcohol have been achieved. These are included in Chapters I, II and III respectively.

The syntheses of monocyclic sesquiterpenoid hydrocarbon (+) \( \alpha \)-curcumene isomers have been achieved by employing the Wittig reaction. The Wittig reaction along with Claisen rearrangement has been utilized for the syntheses of the monocyclic sesquiterpenoid hydrocarbon (+) \( \beta \)-bisabolene and monocyclic diterpenoid hydrocarbon (+) Artemisene. These are incorporated in Chapters VI, V and IV respectively.

Chapter VII includes the syntheses of \( \alpha \)-, \( \beta \)- and \( \gamma \)-isomers of cyclogeraniolene and these are monocyclic monoterpenoid hydrocarbons.

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