Work these problems on a blank copy of your Personal Workshop Form.

1. Farnesyl pyrophosphate is an important precursor in the biosynthesis of many sesquiterpenes. Provide a mechanism for the biosynthesis of \( \gamma \)-bisabolene, a sesquiterpene found in ginger, ginko and wormwood.

   ![Farnesyl pyrophosphate](image1)

   ![\( \gamma \)-bisabolene](image2)

2. In the previous problem, the central double bond of farnesyl pyrophosphate attacked the primary carbon. If the double bond farthest from the pyrophosphate groups attacks, a different series of sesquiterpenes can be synthesized.

   ![Farnesyl pyrophosphate](image3)

   ![Intermediate I](image4)

   Several compounds, such as \( \alpha \)-caryophyllene, \( \beta \)-caryophyllene and \( \gamma \)-humulene can be made from intermediate I.

   ![\( \alpha \)-caryophyllene](image5)

   ![\( \beta \)-caryophyllene](image6)

   ![\( \gamma \)-humulene](image7)

   a. Provide a mechanism from intermediate I to each of the three sesquiterpenes shown above. The mechanisms for the two caryophyllenes are easy. The one for \( \gamma \)-humulene involves a 1,3-hydride shift.

   b. Pentalenene can be made from \( \alpha \)-caryophyllene under acidic conditions. Provide a mechanism for this transformation. This one is a bit more challenging than the previous ones. It involves a 1,2-hydride shift.
3. Limonene is a cyclic monoterpane that is found in the rind of lemons, as well as other citrus fruits. It can be made from geraniol under acidic conditions. Exposing limonene to heat leads to compound $X$ ($C_6H_8$). Ozonolysis of limonene gives a branched carbonyl compound and formaldehyde.

$$\text{HCHO} + \text{acetone} \rightarrow \text{limonene} \xrightarrow{1. \text{O}_3} \xrightarrow{2. \text{Me}_2\text{S}} \xrightarrow{\text{heat}} X$$

\[\begin{align*}
\text{geraniol} & \\
\end{align*}\]

a. Determine and draw the structure of limonene.

b. Determine and draw the structure of compound $X$.

4. One of the major components of cardamom seeds is $\alpha$-terpinyl acetate. Propose a synthesis of $\alpha$-terpinyl acetate from compounds containing 2 carbons or less.

$$\text{\alpha-terpinyl acetate}$$