

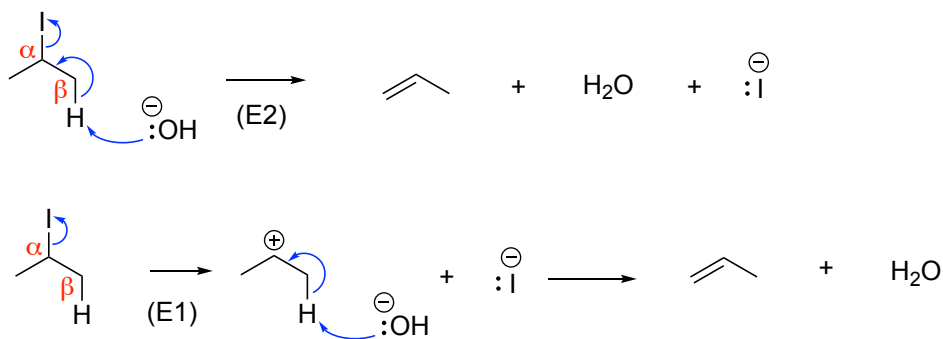
**The Dehydration of Methylcyclohexanols and the Evelyn Effect**  
(adapted from Lehman, J.W. *Multiscale Operational Organic Chemistry*,  
2<sup>nd</sup> edition, pp. 188)

**Overview:**

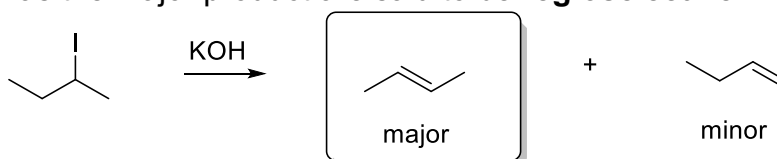
This two-week laboratory features a common synthetic method used for the preparation of alkenes, the acid-catalyzed dehydration of alcohols. 2-Methylcyclohexanol will be converted to 1- and/or 3-methylcyclohexene while 4-methylcyclohexanol will be converted to 1-, 3-, and/or 4-methylcyclohexene. Analytical techniques, such as gas chromatography (GC) and infrared spectroscopy (IR) will be used to analyze the composition of the alkene mixtures produced. GC will also be used to determine if the distribution of alkene products changes as the reaction proceeds (a phenomenon called the Evelyn effect). Additionally, you will also learn about a common laboratory technique used for the separation or purification of liquids, called simple distillation.

**Introduction:**

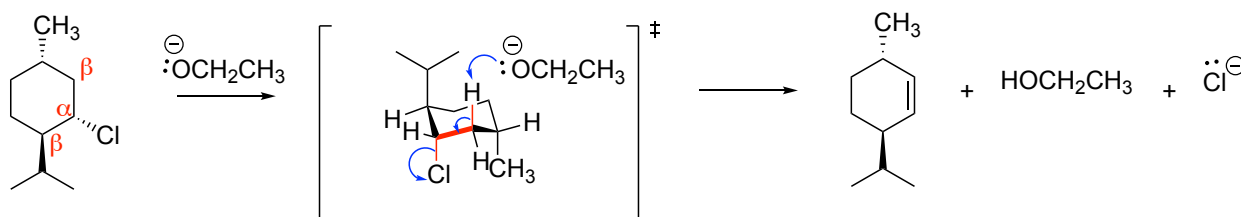
Synthesis of alkenes often involves performing an elimination reaction. For alkyl halides and alcohols, elimination reactions involve removal of a beta ( $\beta$ ) hydrogen and a leaving group to form an alkene. There are two major mechanisms underlying this transformation: E2 and E1. The **E2 mechanism is concerted**, where loss of the leaving group occurs simultaneously with removal of a  $\beta$ -hydrogen by a base. The **E1 mechanism is step-wise**, where loss of a leaving group occurs prior to removal of a  $\beta$ -hydrogen by a base.



It has been widely noted that when an alkyl halide (or in this case, an alcohol) undergoes E2 elimination, the  $\beta$ -hydrogen is preferentially removed from the carbon with fewer hydrogens to produce the most stable (or substituted) alkene. This phenomenon is known as **Zaitsev's rule**. For instance, when 2-iodobutane undergoes a dehydrohalogenation with alcoholic potassium hydroxide, the major product is 2-butene. Reactions that can produce more than one structural isomer, but only produce one structural isomer as the major product are said to be **regioselective**.



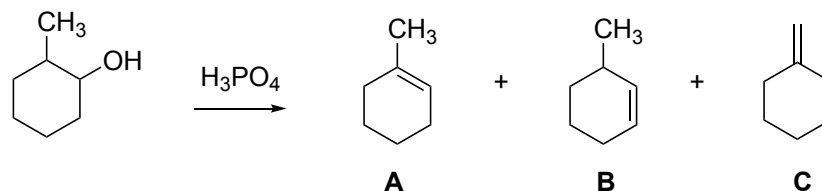
Another requirement for E2 reactions is that the  $\beta$ -hydrogen must be anti-periplanar to the leaving group for the reaction to proceed, even if it means adopting a less energetically favorable conformation. For instance, the reaction of menthyl chloride with ethoxide yields only one product because there is only one antiperiplanar  $\beta$ -hydrogen to the leaving group. This stereochemical requirement makes the E2 reaction **stereospecific**, where one stereoisomer is produced for a given stereoisomerically pure substrate. The E1 mechanism does not have any stereochemical requirements, but generally obeys Zaitsev's rule to form the most stable alkene.



It should be noted that E1 reactions can produce rearrangements of carbocation intermediates, via hydride or alkyl shifts, to generate multiple products. Generally, the high energy carbocations rearrange to form more stable intermediate carbocations. Eliminations that proceed via an E2 mechanism do not rearrange.

Alcohol eliminations often require addition of an acid to transform the alcohol into a better leaving group so the reaction can proceed. In the case of primary substrates, the reaction always proceeds via an E2 mechanism, while tertiary substrates undergo E1 elimination. For secondary alcohols, it is possible to produce multiple products from both E1 and E2 mechanisms; this is especially true when the substrate must proceed through an energetically unfavorable conformation to yield the E2 substrate via an antiperiplanar  $\beta$ -hydrogen. One indicator that competing reaction mechanisms are involved is when the product composition changes during the course of the reaction; this is generally known as an **Evelyn Effect**.

The Evelyn Effect was originally observed during the dehydration of 2-methylcyclohexanol (1:1, *cis*: *trans* isomers). Three products were observed, with the composition of major product **A** decreasing with time. Depending on the starting stereochemistry of the alcohol, both products **A** and **B** can form via E1 and E2 processes. The formation of minor product **C** was surprising because it can only be formed from an E1 type process involving the rearrangement of a carbocation.

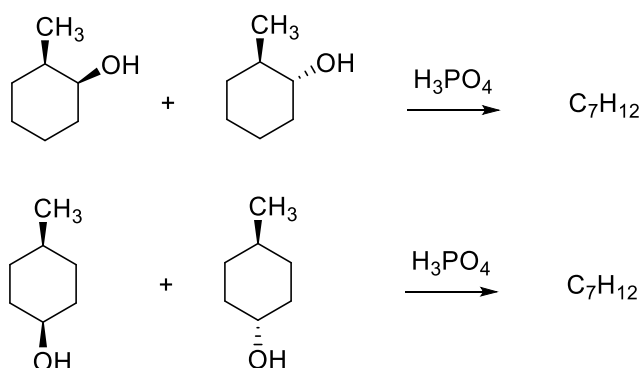


This observation of competing mechanisms was thought to be due to reactivity differences between the *cis*- and *trans*- isomeric substrates in the E2 mechanism. The

*cis*-isomer could react quickly via both E2 and E1 pathways because the reactive conformation for the E2 mechanism was also the energetically favorable conformation. However, the *trans*- isomer reacted slower in E2 because the active conformation was energetically disfavored; therefore, it reacted mainly via an E1 mechanism.

Because a mechanism is a scientific hypothesis about processes that are not directly observable, it is subject to controversy. In this experiment, you will carry out the dehydration of either 2- or 4-methylcyclohexanol (1:1, *cis*: *trans* isomers) by distilling the alcohol in the presence of phosphoric acid. You will analyze the percent composition of compounds in your distillate by gas chromatography to determine whether an Evelyn effect is observed for one or both substrates.

### Reactions:



**Table 1. Physical Properties**

	Molecular Weight (g/ mole)	Boiling Point (°C)	Density (g/ mL)
2-methylcyclohexanol	114.2	166	0.930
4-methylcyclohexanol	114.2	173	0.914
1-methylcyclohexene	96.2	110	0.813
3-methylcyclohexene	96.2	104	0.801
4-methylcyclohexene	96.2	102	0.799
Phosphoric acid (85% in water)	98.0	n/a	1.70

### Additional Reading:

Read the following sections in *The Organic Chem Lab Survival Manual: A Student's Guide to Techniques* by James W. Zubrick, John Wiley & Sons, Inc.: Simple Distillation; Microscale Distillation: Hickman Still; Gas Chromatography; and Infrared Spectroscopy

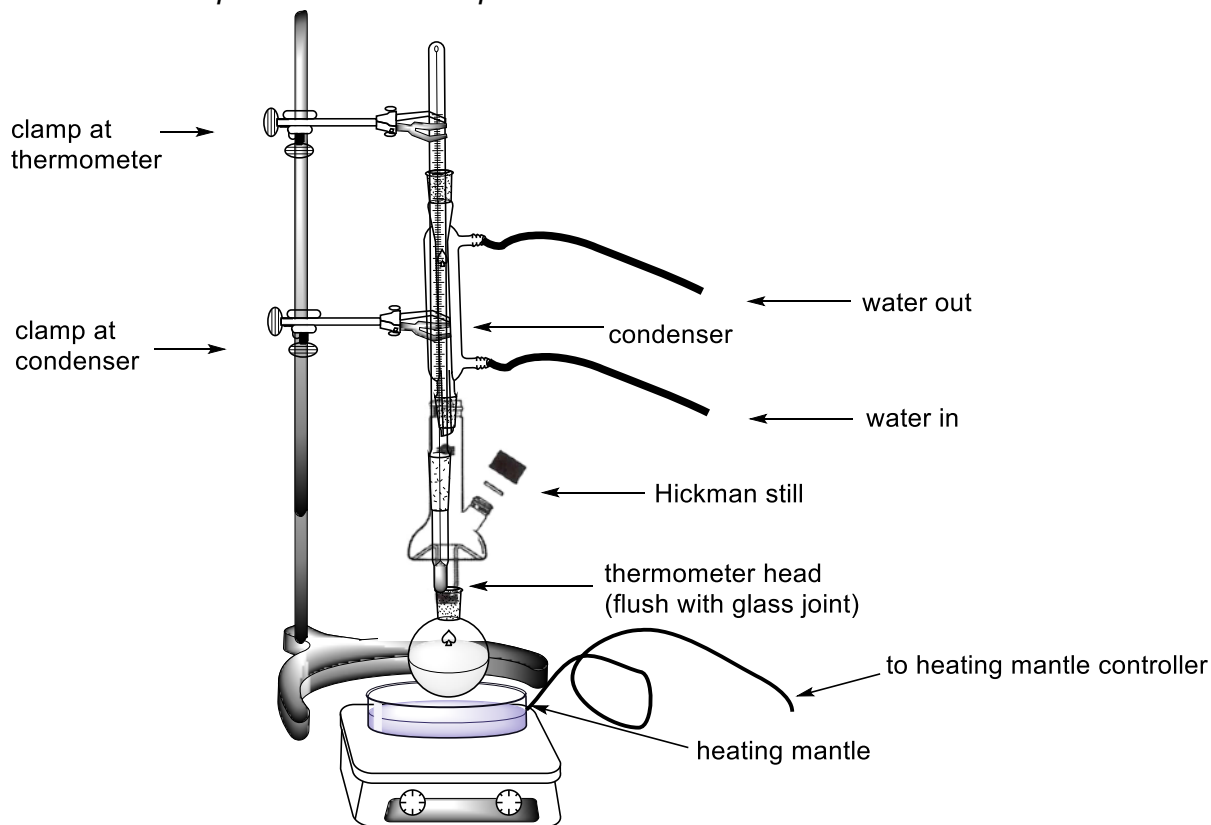
### Safety and Waste Disposal:

All methylcyclohexanols and alkenes are harmful and flammable. Do not inhale, ingest, or come in skin or eye contact with them. Avoid contact with vapors and keep away from flames and hot surfaces. Phosphoric acid causes serious burns, especially to eyes, so avoid skin or eye contact. Perform all reactions in a fume hood and use nitrile gloves.

Check out all glassware from your instructor and return clean at the end of the period. Dispose of all waste in the specified container. Do not put reactants down the drain. Rinse all glassware with a minimal amount of acetone (and dispose of this in the specified waste container) prior to washing it with soap and water in the sink.

### Apparatus:

#### *Microscale simple distillation setup*



### Procedure:

With a glass graduated pipet, measure either 2- or 4-methylcyclohexanol (2.45 mL, 20.0 mmol) into a 10 mL round-bottom flask. Next, with a clean graduated glass pipet, add 0.70 mL of 85% phosphoric acid. (Be careful not to cross contaminate pipets and reagent bottles). Add a Teflon stirbar to your round-bottom flask and clamp it to a ring stand. Assemble the apparatus for a microscale simple distillation as pictured above, using a Hickman still, thermometer, and water-cooled condenser. Pre-weigh and label two clean scintillation vials for your final distillate samples. Position a stir plate underneath a heating mantle so you can stir the reaction while you heat the round bottom. Make sure to plug the heating mantle into the variac and set the initial voltage to ~50. The alkene and water products will collect in the Hickman still, while the higher boiling alcohol and acid will stay in the reaction flask. As the still head fills, use a pipet to remove 1 mL of distillate to a labeled test tube (fraction 1). Repeat this step at a separate point over the course of the reaction (fraction 2). When the reaction is over, the residue in the source flask will emit white vapors or foam. Remove the flask from the heat source at this point to avoid the formation of toxic vapors. Wash each fraction with 1.5 mL of 5% aqueous  $\text{NaHCO}_3$ .

Separate, then dry each organic layer over anhydrous  $\text{CaCl}_2$ . Decant each organic layer into a pre-weighed scintillation vial and calculate the mass.

**Analysis:**

1. Analyze your sample via IR. Identify functional groups and assess purity.
2. Analyze both distillate samples via representative gas chromatograms. Measure the areas and retention times of each peak in the chromatograms, as well as identify any peaks by comparing them with the standard chromatograms provided. Calculate the percent composition of alkenes in each sample, and determine if one or both methylcyclohexanols exhibit an Evelyn Effect. **Note:** You will be provided representative chromatograms for each sample of distillate (collected at different times), as well as chromatograms for standard alkene compounds. The GC method cannot resolve a mixture of 3-methylcyclohexene and 4-methylcyclohexene, however, you can use your knowledge of mechanism to determine whether one or both alkenes could be present in your sample. When both are possibly present, calculate their combined percentage. The percentage of any methylenecyclohexene produced will be insignificant.