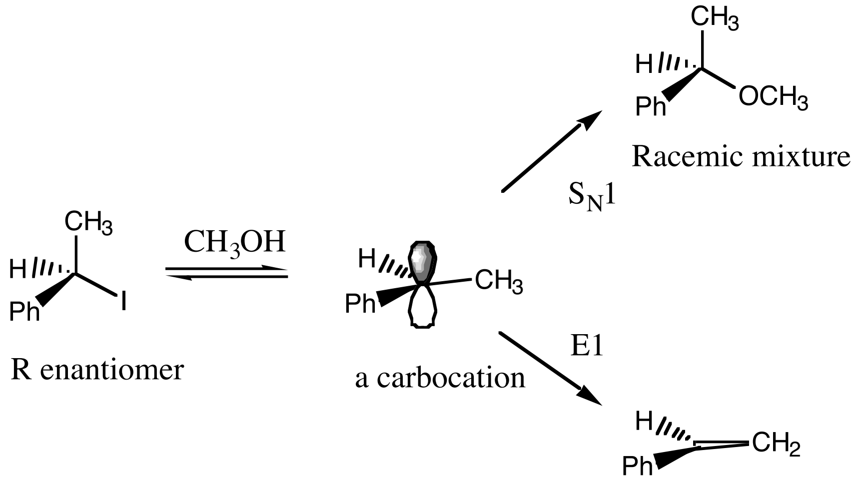
Elimination Reactions

Elimination reactions discussed here are reactions that produce alkenes, usually from the loss of two particles, x-y, from a substrate. The nucleophilic substitution reactions discussed in another section are often accompanied by elimination reactions as competing reactions. Conditions can be met that make the elimination reaction the main reaction.

Fluorine can be eliminated as fluoride but it is the least reactive of the halogens because of its strong C-F bond. Thus for halogens the rate of elimination is I>Br>Cl>F. Fluorine, because of its great electronegativity, can cause the beta hydrogen to become acidic. The mechanism of elimination form many fluorinated compounds involves a carbanion in the E1cb (Elimination first order carbanion) mechanism. Stereoselectiviy of elimination is not always observed.

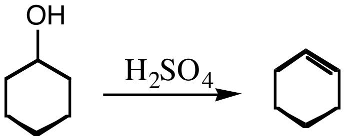
Elimination first order (E1)

Secondary substrates give products from both substitution and elimination, by first rate limiting ionization of the substrate to produce a carbocation. The carbocation then can react with a nucleophile (SN1) or lose a beta hydrogen (E1) to form an alkene. Of course, carbocations can do other things such as rearrange to a more stable carbocation followed by substitution and elimination. The E1 mechanism is unlikely for fluorinated compounds because of the requirement to break the strong carbon-fluorine bond in the rate determining step.

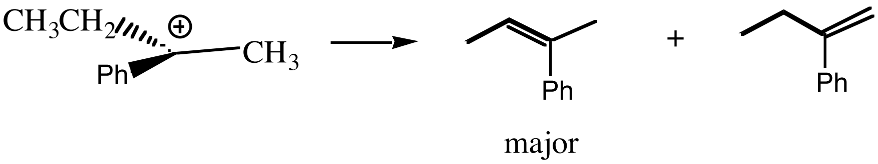


The elimination reactions requires removal of a beta hydrogen by a base. Thus increasing the base strength of the reaction medium increases the amount of elimination product. If the above reaction were performed in aqueous hydroxide medium the entire product would be the alkene.

The acid catalyzed dehydration of alcohols generally yields an alkene (or mixture after rearrangements) because the medium contains no effective nucleophile. The main problem is that the acid medium can cause further reactions of the alkene.

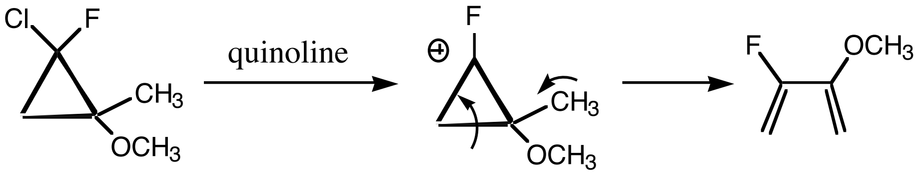


When more than one alkene can be formed from a single carbocation, the major alkene is the one with the most substituents. Substituents tend to increase alkene stability. The more substituted alkene is called the Saytzeff product.



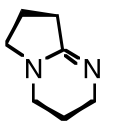
Thus, the E1 reaction is an extension of carbocation chemistry. It is first-order because the reate depends only on the substrate concentration. The carbocation has the same mechanism of formation with ion-pairs but the effect of ion-pairs on the elimination reactions seems little known.

Ionization of the chloro-fluoro cyclopropane compound below in hot quinoline shows the preferential loss of chloride, and after loss of a proton, provides the synthetically useful fluorinated diene.

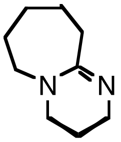


Elimination second-order (E2)

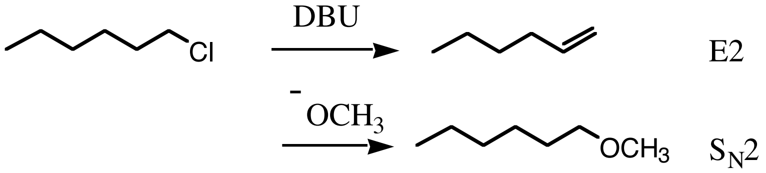
This elimination process is often considered as a competing process for the S_N2 reaction, especially when a strong base is present. It can occur with primary, secondary and tertiary substrates. Primary substrates in the presence of strong bases often give just substitution unless special non-nucleophilic amine bases are used.



Diazabicyclononene (DBN)

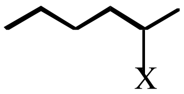


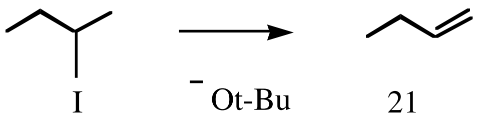
Diazabicycloundecene (DBU)



Elimination occurs readily with secondary and tertiary substrates with strong bases and amine bases. The elimination is second-order and depends on both the substrate and the base concentration. The base is required to attack a beta hydrogen in a one step process.

Most E2 reactions provide the most substituted alkene as the major isomer but conditions may be used change the regioselectivity. Formation of the more substituted alkene is called Saytzeff elemination.The regioselectivity of the reaction is greatly affected by the nature of the base. The large t-butoxide base is too large to attack the interal CH_2 group and thus attacks the CH_3 group to give mainly the 1-alkene. Methoxide is smaller and shows more attack on the CH2 group than does tert-butoxide, but the main product is still the 1-alkene

	$^{-}$Ot-Bu				$^{-}OCH_3$			
 X	I	Cl	F	OTs	I	Cl	F	OTs
	78	91	97	83	19	33	69	83
	12	9	3	17	81	67	21	17

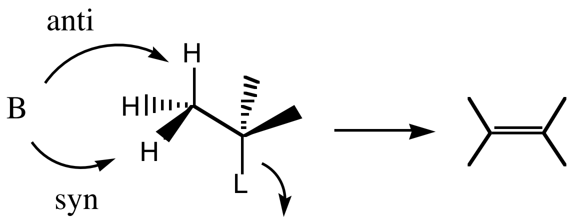


$^{-}$Ot-Bu	21
$^{-}$OCH$_3$	17
$^{-}$OAc	7
$^{-}$OPh	11

Nearly all elimination reactions give mixtures of alkenes instead of just one clean product. The reactions are governed by the stability of the product (and the transition state) and thus there is very little difference in the stability of alkenes. Alkenes with higher substitution are more stable than less substituted alkenes but the energy difference is small. Also when E and Z alkene isomers are possible, the major isomer is the E isomer but the Z isomer is usually present to some degree.

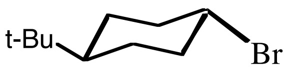
Stereochemistry

The stereochemistry of elimination generally follows anti-beta elimination. In this process the leaving group and a hydrogen atom lie in a plane with the groups anti to each other, and the elimination proceeds in a one-step concerted process. There are many recorded instances however where syn elimination is observed.

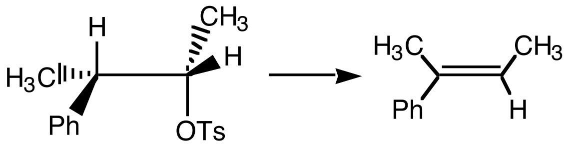


The two examples below show the importance of anti-beta elimination. The cis isomer of the bromo compound reacts faster than the trans because only the cis isomer has an anti beta hydrogen. The toslyate gives only one 2-butene because of the requirement for rotation to a conformation that has the H and OTs anti to each other.

$10^{-3}\ m^{-1}s^{-1}$



$10^{-6}\ m^{-1}s^{-1}$



The E1cb mechanism

Ellimination can also occur by a mechanism known as the E1cb mechansim. The elimination first-order carbanion mechansim is used to explain the results of some elimination reactions in which a highly polar leaving group is present and the least substituted alkene is the major product. But only few studies have actually proven the E1cb process. The kinetics of the E1cb process are shown below. The reaction is actually not first order but the slow step is the elimination from S$^-$, a first order step in the process.

$$\mathrm{SH} + {}^{-}\mathrm{B} \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} \mathrm{S}^{-} + \mathrm{BH}$$

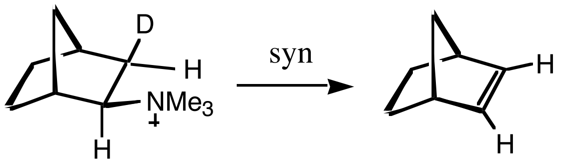
$$\mathrm{S}^{-} \xrightarrow{k_2} \text{Alkene}$$

$$\text{rate} = \frac{k_1k_2[\mathrm{SH}]\,[\mathrm{B}^{-}]}{k_{-1}[\mathrm{BH}] + k_2}$$

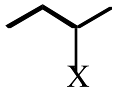
second step is slow $k_1 > k_2$

$$\text{rate} = \frac{k_1k_2[\mathrm{SH}]\,[\mathrm{B}^{-}]}{k_{-1}[\mathrm{BH}]}$$

Syn elimination often occurs and it is associated with poor leaving groups or the absence of an anti-beta hydrogen. The bicyclic compound shows syn elimination because no anti beta hydrogen is available because of the geometry of the system. In open chain compounds, leaving groups such as $^{+}NR_3$ and F show strong tendencies for syn elimination especially in long chain carbon systems.



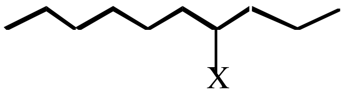
4 carbons



$^{-}$Ot-Bu

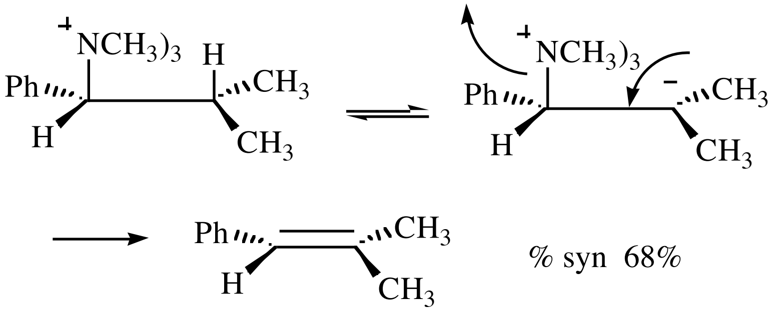
	% syn
Br	0
OTs	0
$\overset{+}{N}(CH_3)_3$	0

10 carbons

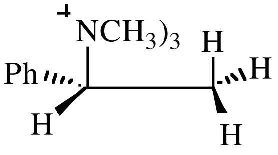


	% syn
Br	40
OTs	7
$\overset{+}{N}(CH_3)_3$	76
F	80

Reactions that produce stabilized carbanions adjacent to poor leaving groups provide the best evidence for the E1cb process. The elimination of quaternary ammoniums salts, also called Hoffmann elimination, is believed to follow a carbanion process with syn elimination and the formation of the least substituted alkene.

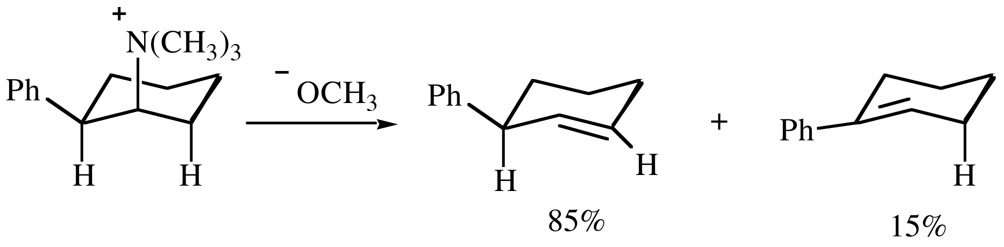


% syn 68%

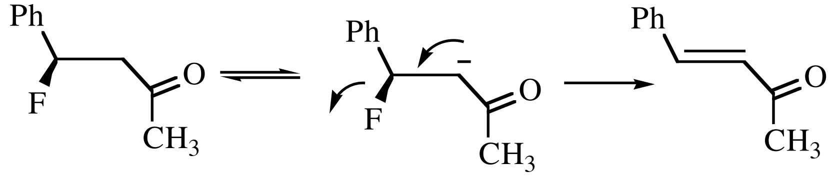


% syn 26%

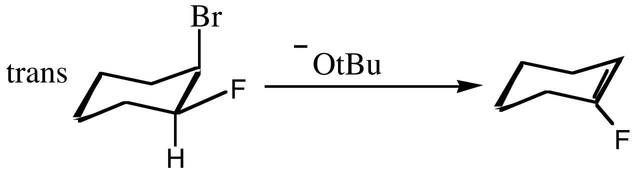
When reactions show E1cb character they generally produce the least substitued alkene as the major product. This occurs because carbanion stability is of the order: primary> secondary > tertiary. In the example below the major product comes from the carbanion formed at the secondary carbon atom.



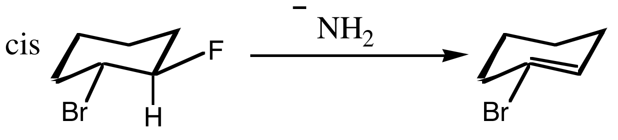
An E1cb mechanism is known for the elimination of the fluoro compound below.



The cis and trans 1-fluoro-2-bromocyclohexane isomers follow different elimination paths. The trans isomer has an anti-beta hydrogen available for elimination and the reaction proceeds with tert-butoxide. The cis isomer must use a syn hydrogen in the E1cb process that causes loss of HF, and requires amide as a stronger base.



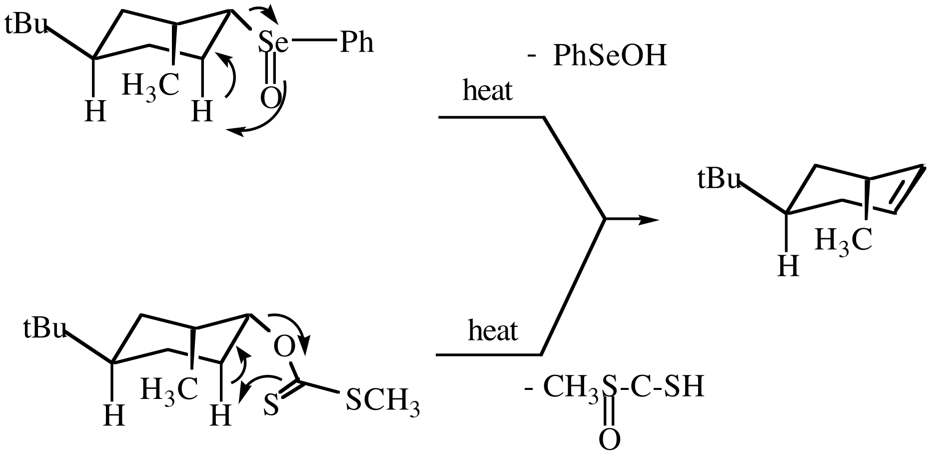
E2, anti-beta



syn, E1cb

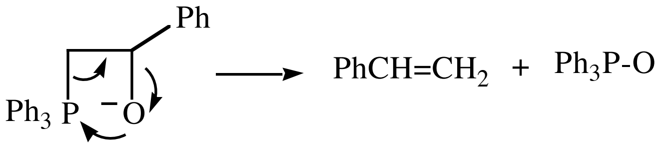
Cyclic eliminations

Alkenes are formed in several processes in which a cyclic transistion state or a cyclic intermediate is involved. Selenoxide pyrolysis and xanthate pryrolysis (Chugaev reactio) are two of the commonly know reactions. The eliminations have competition between syn and anti elimination depending on the conformation of the ring system. Syn eliminations are common in acyclic compounds.

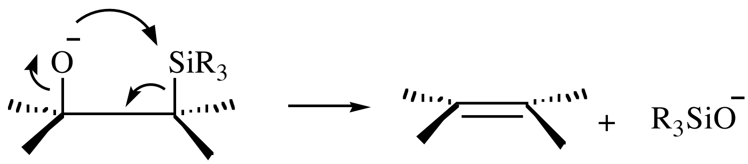


The well-known reactions below consist of several synthetic steps to produce an alkene. Each reaction has a step that involves a cyclic process to produce the alkene. The entire reaction sequence is not given here.

The Wittig Reaction



Petersen Olefination



Corey -Winter