

Date: 02.04.2020

Lecture notes on

Elimination Reaction

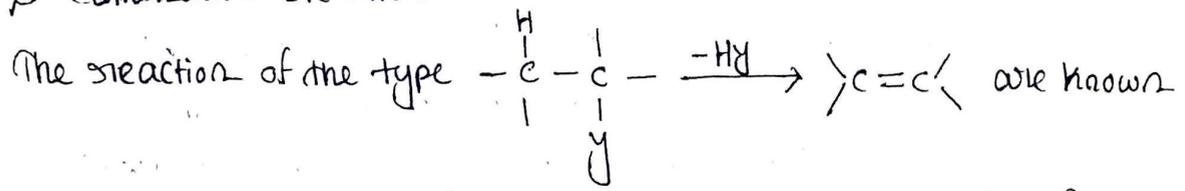
for 2nd Semester students

by

Dr Subhra Mishra

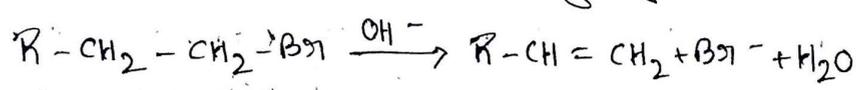
Elimination reaction:

β -elimination reaction -

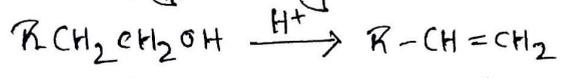


as 1,2 or β -elimination reaction, i.e. the groups are lost from the adjacent carbon atoms. Some examples are -

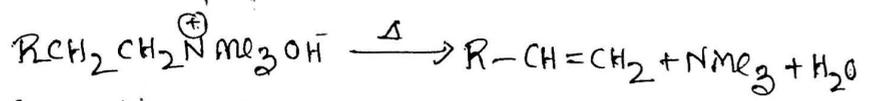
(i) Base induced elimination of hydrogen halide -



(ii) Acid catalysed dehydration of alcohols -



(iii) The Hoffman dehydration of quaternary ammonium hydroxides -



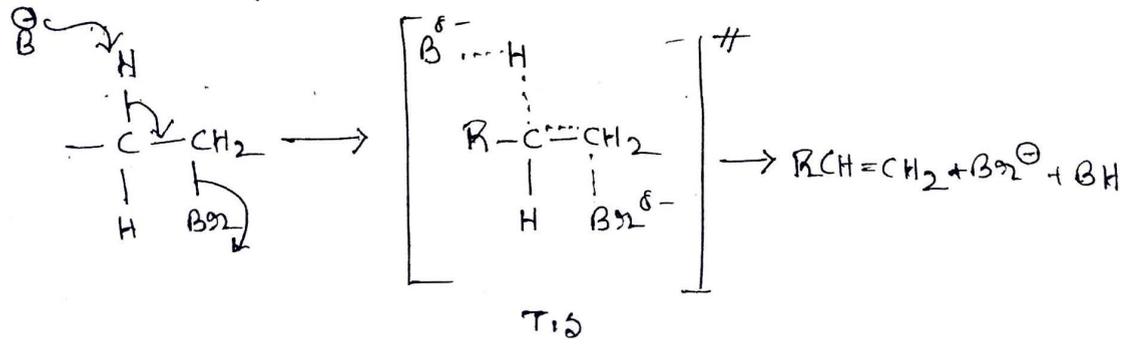
The different simplified mechanisms can be suggested for 1,2-elimination, these are described below -

Elimination Bimolecular (E2):

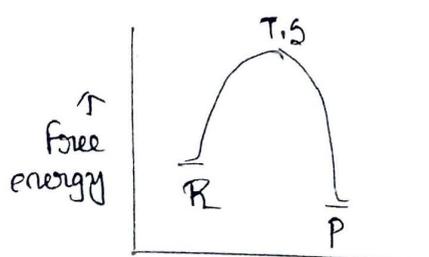
For the base induced elimination of HBr from the halide $\text{RCH}_2\text{CH}_2\text{Br}$, the rate law is -

$\text{Rate} = k [\text{RCH}_2\text{CH}_2\text{Br}] [\text{base}]$

This can be represented as -



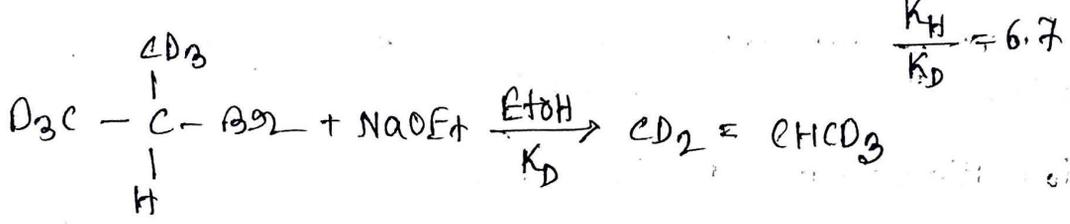
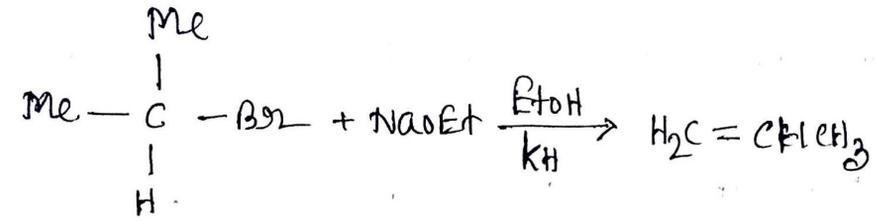
i.e. an one step process, passing through a single T.S. This is referred to as E2. An approximate energy profile diagram of the process is -



Evidence in support of E2:

An interesting technique which has been used to support the E2 mechanism is based upon the fact that breaking of C-D bond is slower than the breaking of a similar C-H bond. If the C-H bond breaks in the rate determining step of the reaction, then the same reaction of the deuterium substituted compound will be slower. The result is the so called kinetic isotope effect.

In a typical experiment the rate of elimination of HBr from 2-bromopropane was compared with that of deuterium analog. A kinetic isotope effect 6.7 was observed.



The principle features of the reactions are as follows -

- (i) The reaction rate increases with increasing the strength of the base e.g. $\text{AcO}^- < \text{HO}^- < \text{EtO}^- < \text{Me}_3\text{CO}^- < \text{NH}_2^-$.
- (ii) The rate increases with increase in leaving capacity of the departing group. Amongst substituents in which the same element is bonded to carbon, leaving group ability parallels the stability of the anion. For example alcohols and ethers do not undergo E2 elimination because HO^- and RO^- are unstable, whereas Sulphonates undergoes elimination easily because of the stability of the Sulphonate ion.



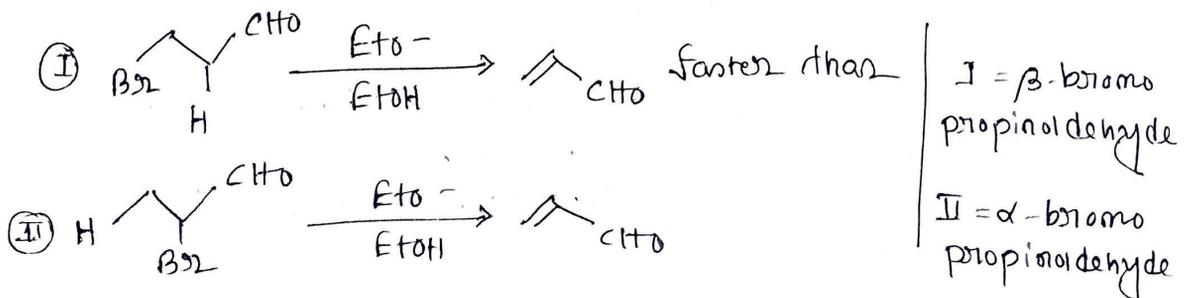
(iii) The ease of E2 reaction on alkyl halides are $I > Br > Cl > F$, since the bond strengths are in the order $C-I > C-Br > C-Cl > C-F$ and this factor here is dominant, so that iodide is the best leaving group of the series and fluorine is the poorest

	$PhCH_2CH_2F$	$PhCH_2CH_2Cl$	$PhCH_2CH_2Br$	$PhCH_2CH_2I$
rate in EtO/EtOH	1	70	4.2×10^3	2.7×10^4

amongst the alkyl group, the order of reactivity is tertiary > secondary > primary; e.g. $Me_3C \xrightarrow{iB} Me_2C=CH_2$ is faster than $Me_2CHBr \xrightarrow{iB} Me-CH=CH_2$, which is also faster than $MeCH_2Br \xrightarrow{iB} CH_2=CH_2$. The reason is that the thermodynamic stability of an alkene increases as $C=C$ is bonded to an increasing number of alkyl groups and this stabilizing influence is the preceding T.S in which the π bond is partially formed.

(iv) Elimination occurs more readily when the new double bond comes into conjugation with existing unsaturated bonds, because the stabilization energy due to the conjugation in the products is partly developed at the transition state. e.g. elimination of HBr occurs more readily from $CH_2=CH-CH_2CH_2Br$ to give $CH_2=CH-CH=CH$ than from $CH_3-CH(Br)-CH_2CH_3$.

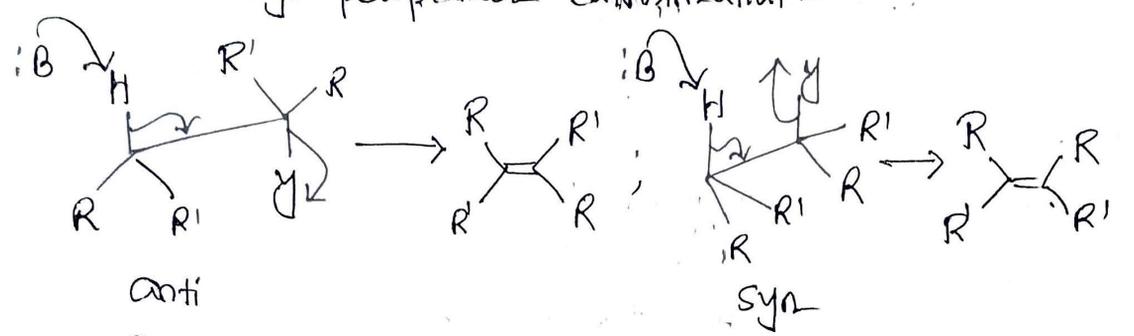
(v) -R group facilitates elimination more strongly when the proton to be eliminated is attached to the α -carbon atom than when it is attached to the β -carbon atom, e.g.



This is because the -R group stabilizes structure, such as which contributes to the transition state structure, thereby lowering the activation energy.

Similarly, CC(C)C(=O)Br reacts slower than CCC(=O)Br in EtO/EtOH to yield CC=C due to the same reason.

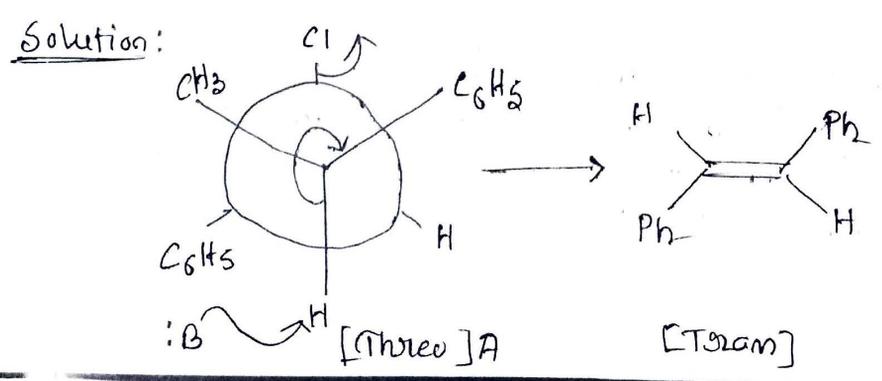
(vi) With cyclic molecules elimination could occur from anti and syn-periplanar conformation -

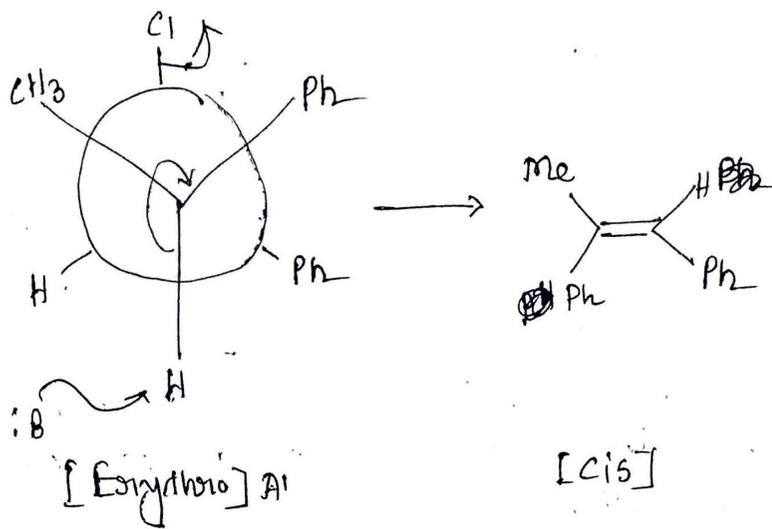


For acyclic molecules elimination occurs from anti-periplanar conformation because -

- (a) Elimination would then be taking place from the lower energy "staggered conformation" rather than from the higher energy "eclipsed conformation" and this energy difference is likely to be reflected on the corresponding transition state.
- (b) The attacking base B^- and the departing leaving group Y^- would be as far apart from each other as possible.
- (c) The electron pair developing from the initial C-H bond would be attacking the α -carbon atom from the side opposite to that from which the electron pair of the initial C-Y bond will be departing.

Problem: The three isomers of 1-chloro-1,2-diphenylpropane undergoes elimination at a faster rate than the erythro isomer does. Consider steric interaction to explain this rate difference.



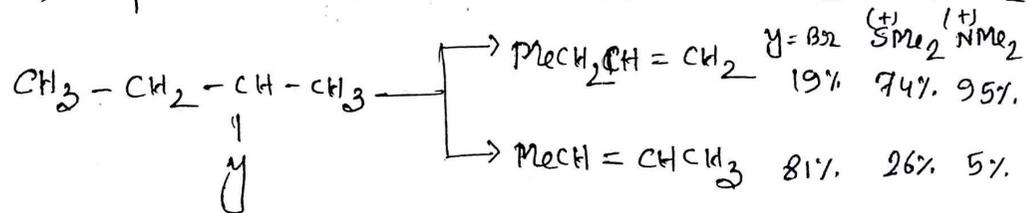


In the threo isomer the rotamer which can undergo anti elimination has also the most stable rotamer, thus provides the energetically most favourable pathway for reaction.

For the erythro isomer the rotamer which can undergo anti elimination is not the most stable rotamer is regard to anti elimination is therefore slower for the erythro isomer.

Orientation in E2:

In substrates which have alternative β -hydrogen atoms available, its possible to obtain more than one alkene on elimination

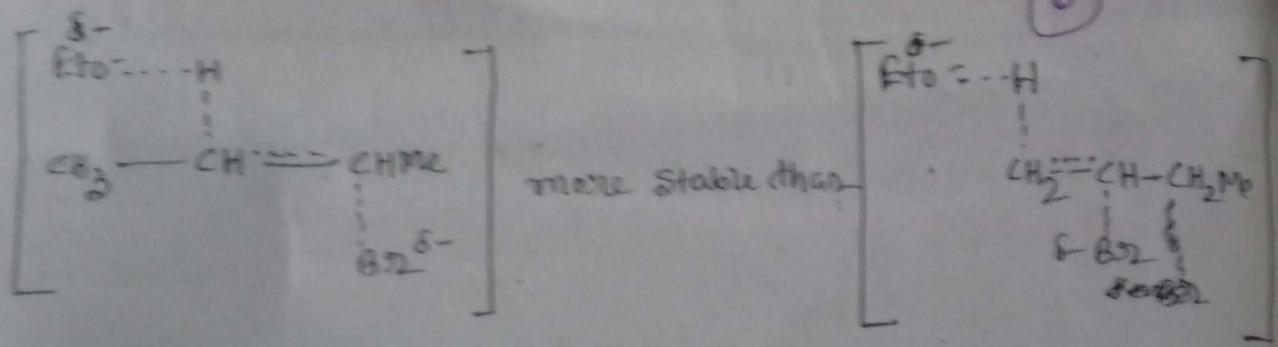


To know which alkene is formed in predominant amount two empirical rules have been proposed.

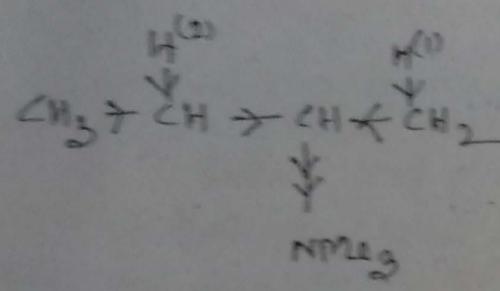
- (a) Hofmann (working on $\text{R-N}^+(\text{Me})_2$ compounds) stated that, "that alkene will be predominant which has the least alkyl substituents on the double bond carbon".
- (b) Saytzev (working on R-Br compounds) stated that, "that the alkene will be predominant which has the most alkyl substituents on the double bond carbon".

Explanation:

Saytzev domination actually proceeds through a transition state in which a considerable alkene character is developed. Therefore the alkyl substituents are able to stabilise the transition state, thus lowers the activation energy.

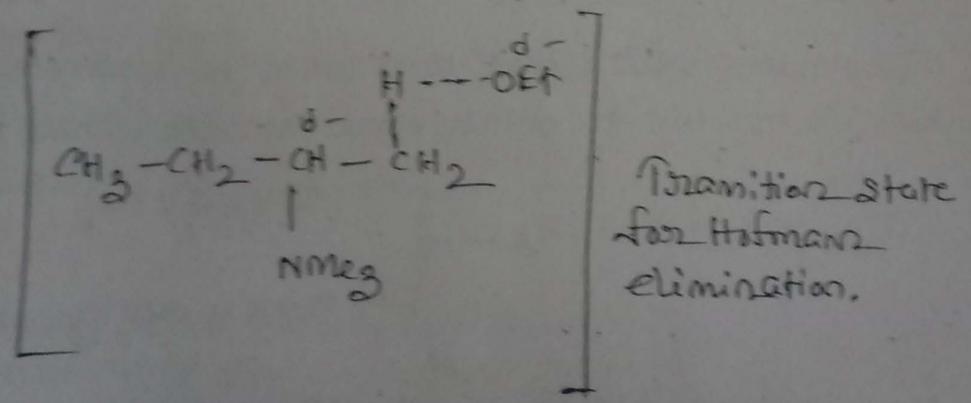


But in Hofmann elimination, the powerful electron withdrawing inductive effect of the NMe_3 groups makes the β hydrogens acidic.

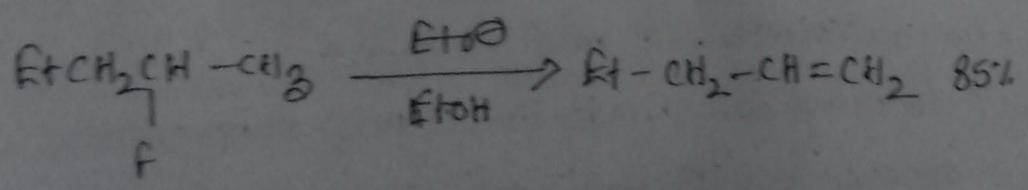


The reaction now proceeds through a transition state possessing some degree of carbanion character of the two β hydrogens, $\text{H}^{(1)}$ & $\text{H}^{(2)}$. $\text{H}^{(2)}$ is less acidic due to the positive inductive effect of $-\text{CH}_3$ group, hence proton $\text{H}^{(1)}$ is removed easily by base.

effect of $-\text{CH}_3$ group, hence proton $\text{H}^{(1)}$ is removed easily by base.



An interesting example in this respect is that $\text{EtCH}_2\text{CH}(\text{F})\text{CH}_3$ leads mainly Hofmann product although it is a neutral species. Then -

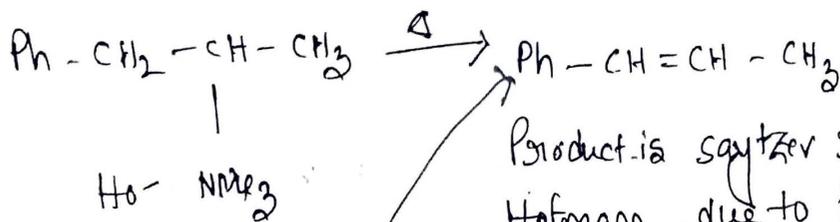


cause:

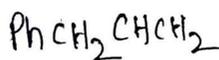
① Powerful electron withdrawing effect of the F, which forced the reaction to proceed through a transition state possessing carbanion character rather than alkene character.

(ii) F^- is an extremely poor leaving group.

Again we have the following example,



Conjugation of the double bond with the Ph group, helps to stabilize the molecule than the other isomer

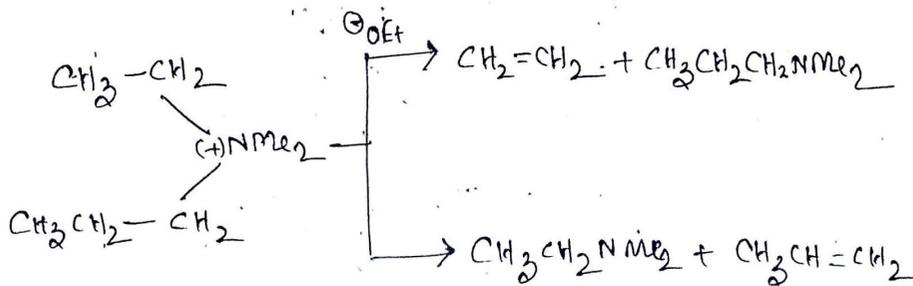


Product is Saytzev rather than Hofmann, due to product stability as well as the T.S also.

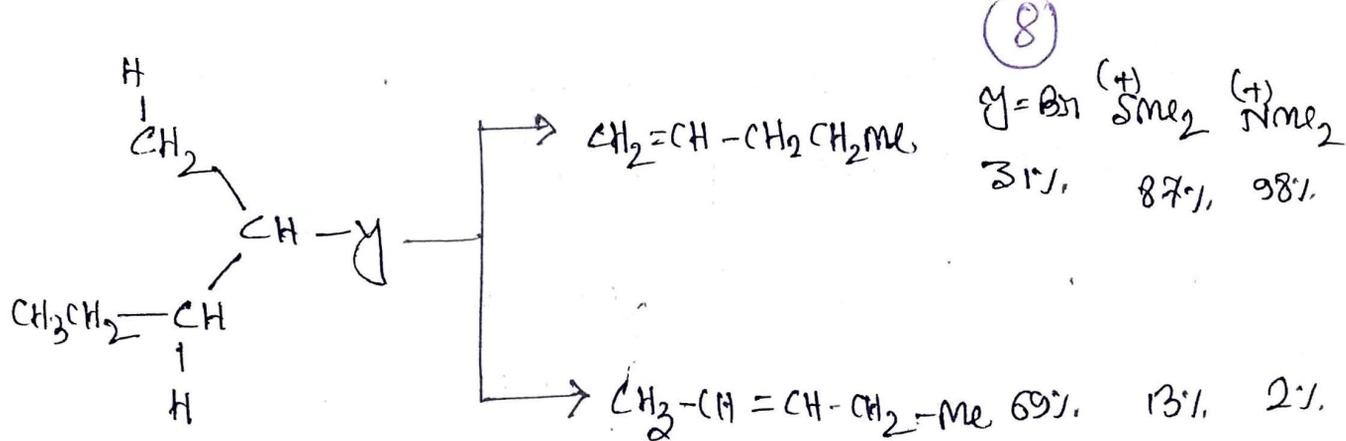
Evidence for the carbanion character of the T.S for Hofmann elimination:

(a) Increasing in strength of the base attacking R_γ , whether γ is positively charged or not also leads to increasing formation of the Hofmann Product.

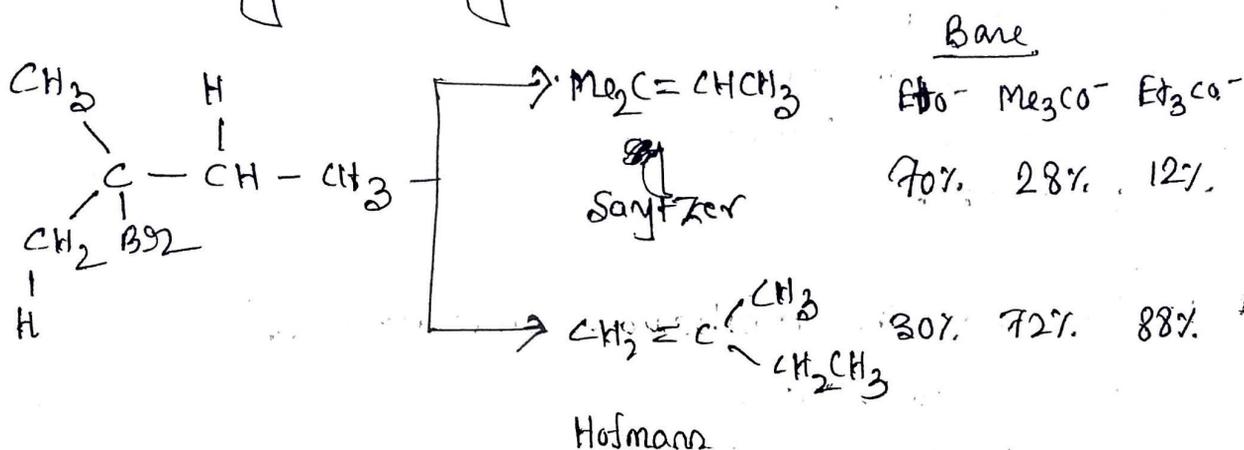
(b) β -substituents that would help to stabilise a developing negative charge promote formation of Hofmann Product but substituents such as Ph, $C=C$ etc, promote the formation of the product which ever has its double bond conjugated with them, Always least substituted alkene is formed preferentially.



It is found that increase in size of γ and more particularly branching in it, leads to an increasing proportion of Hofmann elimination with the same alkyl group.

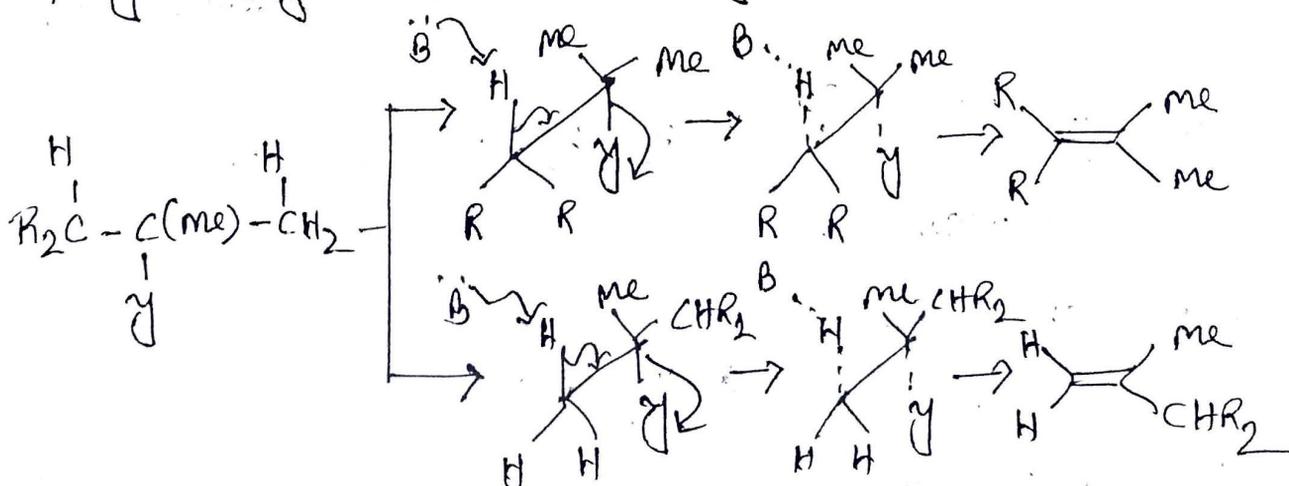


The Proportion of Hofmann elimination is also increase with increasing branching in base.

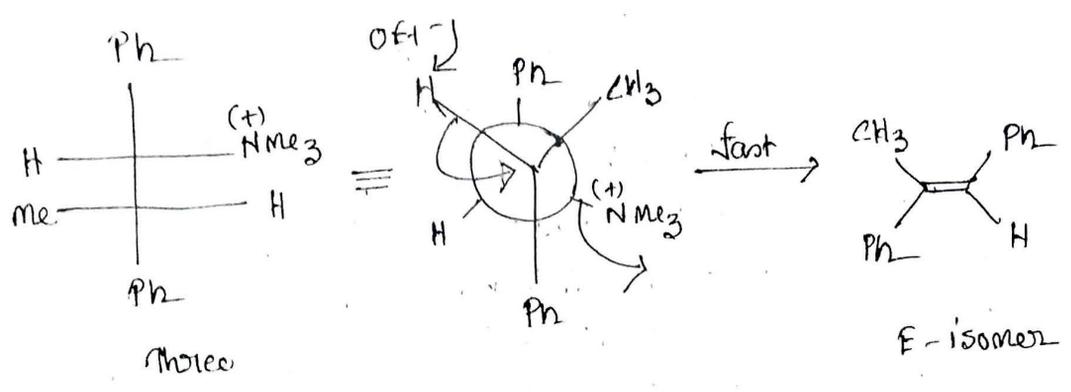
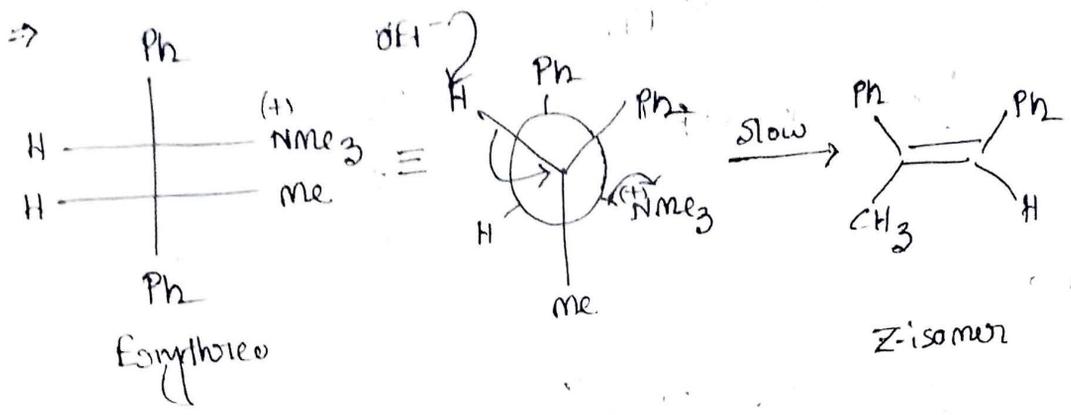


Cause:

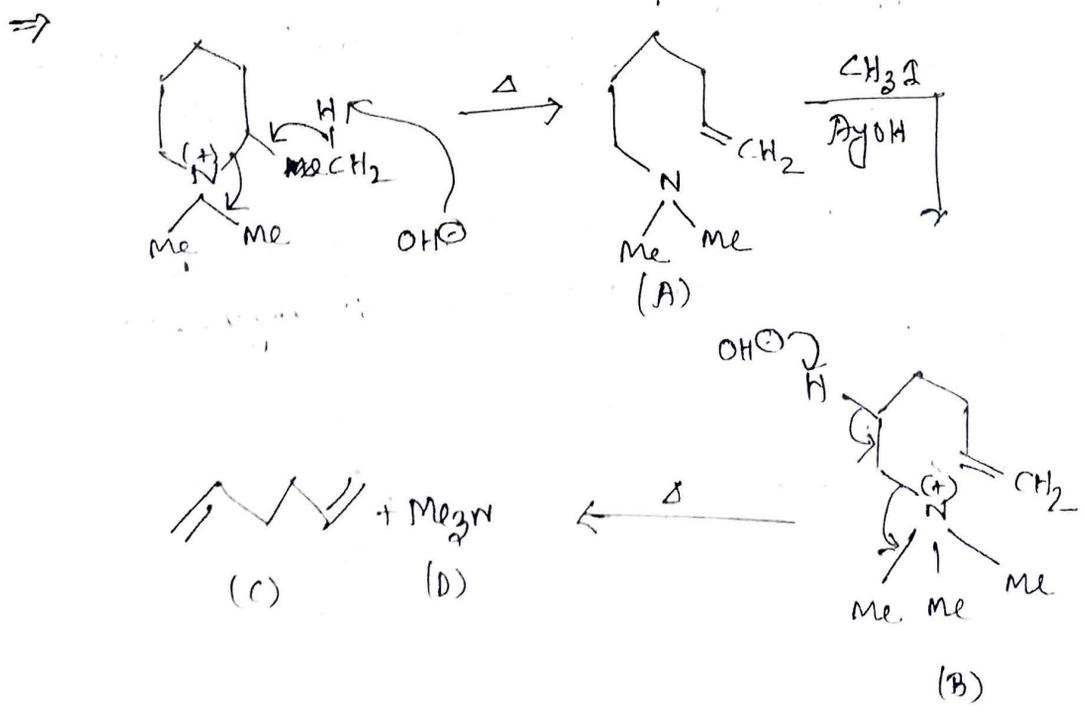
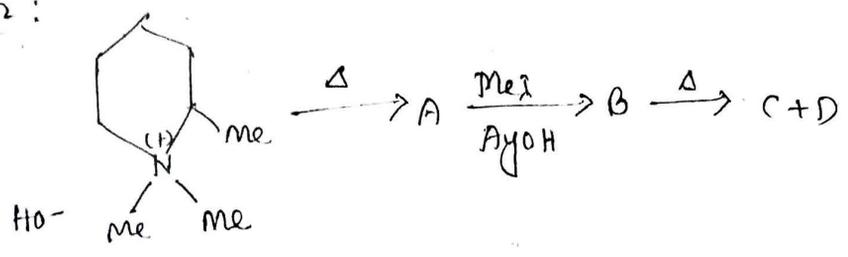
These several steric effects are exploited on the fact that any crowding irrespective of its origin will make the TS of saytzer elimination relatively more crowded than the TS of the Hofmann elimination. As the crowding increases (in β, γ, δ) the Hofmann elimination will thus be progressively favoured over saytzer.



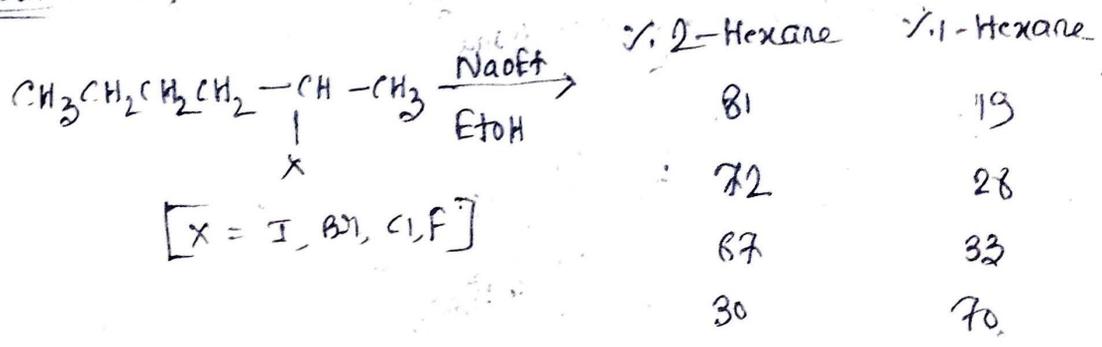
Problem: $\text{Ph}-\text{CH}(\text{Me})-\text{CHPh}-\text{N}^+(\text{Me})_3 \text{I}^- \xrightarrow[\Delta]{\text{NaOEt}} ?$
 (both diastereoisomers)



Problem:



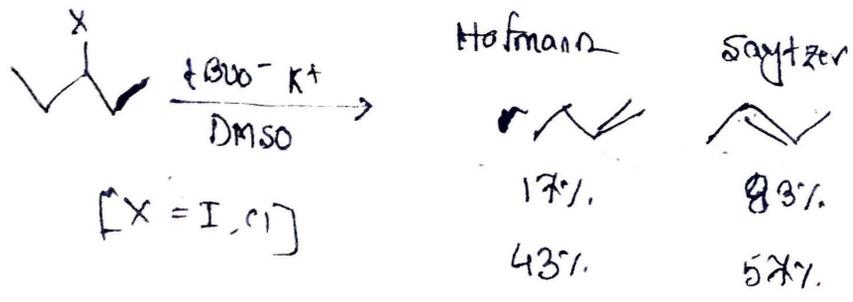
Problem:



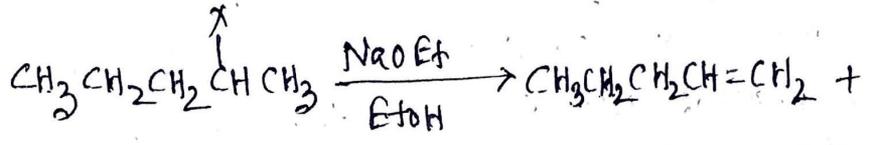
Explain -

⇒ Since the substrate contains two alternative β-protons, so it is possible to obtain two alkenes on elimination, one product is less substituted i.e. 1-hexene and another product is more substituted i.e. 2-hexene, the former is called Hofmann product and the latter is called Saytzev product. Generally Saytzev elimination occurs in neutral substrate and Hofmann elimination occurs in charged substrate. Here the substrate is neutral, so the product of Saytzev elimination should be formed in major amount in all cases. But on moving from I to F, the % of Saytzev product is gradually decreases. Naturally the % of Hofmann product is gradually increases. This is because of the fact that on moving from I to F, electronegativity gradually increases and leaving aptitude decreases. These two factors together clearly explain the above trends of reaction.

Problem: Explain why changing the leaving group (X) has an effect on the relative amount of Hofmann ~~vs~~ vs Saytzev product in the reaction below -



Problem: Account for the following change in ratio of the 1-pentene to 2-pentene products as the leaving group changes.



X = -Br -OTs -SM₂ -SO₂Me -N⁺Me₃

$\frac{1\text{-ene}}{2\text{-ene}} = 0.45 \quad 0.97 \quad 6.7 \quad 7.7 \quad \approx 50$

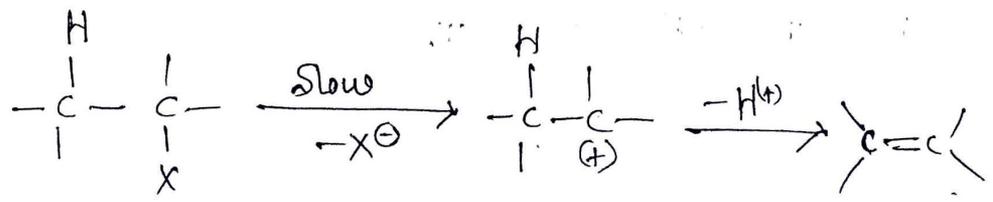
⇒

Problem: Draw newman projection formula's and energy profile diagrams for formation of the Hofmann and Saytzev products from the base promoted elimination of N,N,N-trimethyl-2-pentyl ammonium iodide. Use a single graph for energy profiles.

⇒

E1 elimination:

Elimination can also occur without the participation of base. The reaction occurs in two stages, the first step is the breaking of carbon-leaving group bond, as a result a carbonium ion is formed. The second step is the resultant carbonium ion subsequently loses a proton. Here the first step is the r.d.s.



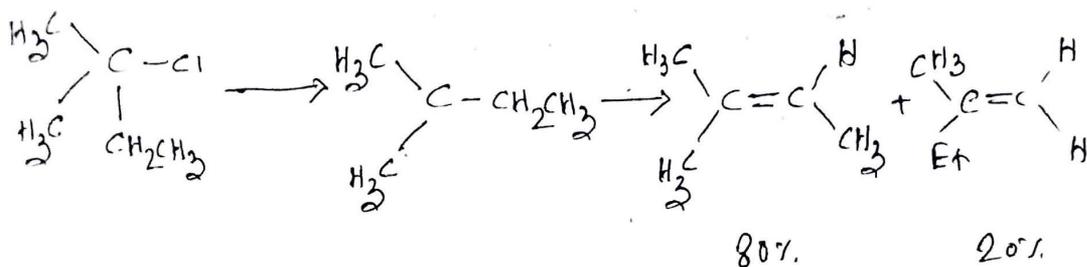
The main characteristic features of this process are as follows -

- (i) The order of reactivity of alkyl groups is tertiary > secondary > primary. This is because of the rate determining step is the formation of carbocation and

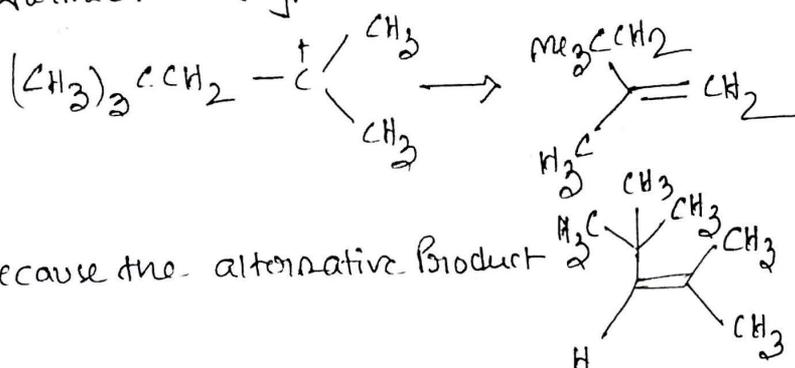
The stabilities of these ions increases in the order
 Primary < Secondary < tertiary. The rate of elimination
 from primary alkyl groups is usually negligible.

(ii) The effect on the rate of the nature of the leaving groups
 are the same as in the E2 Process.

(iii) The direction of elimination from the carbocation usually
 follows the Saytzev rule, e.g.



However when the product of saytzev elimination is the
 more sterically compressed, the less substituted alkene may
 be formed. e.g.

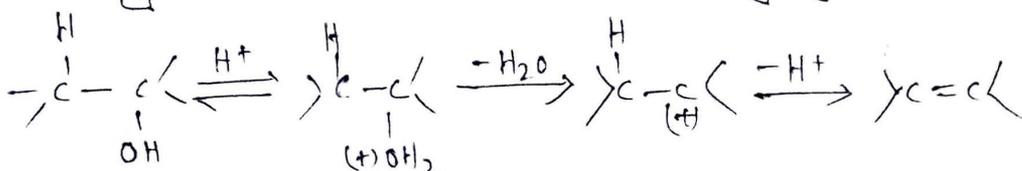


because the alternative product possesses

Significant repulsive forces between the hydrogen on
 the t-butyl groups and those on the methyl group cis to
 it.

(iv) The carbocation may not only eliminate but may also
 add a nucleophile species to give a substitution product
 (S_N2 reaction) the E1 and S_N1 reaction are therefore
 competitive.

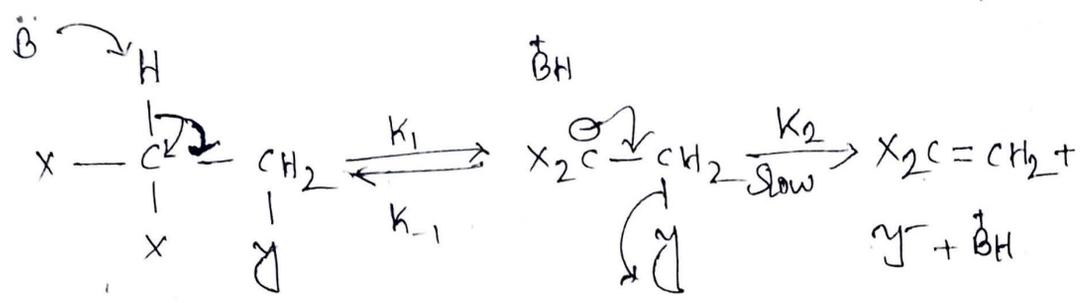
(a) Alcohols undergo E1 elimination under the influence
 of strong acid, water being the leaving group.



(b) Lewis acids such as Al³⁺ ion increase the reactivity of
 halides in E1 reaction. e.g. R-Cl + Al³⁺ → R⁺ + AlCl₃

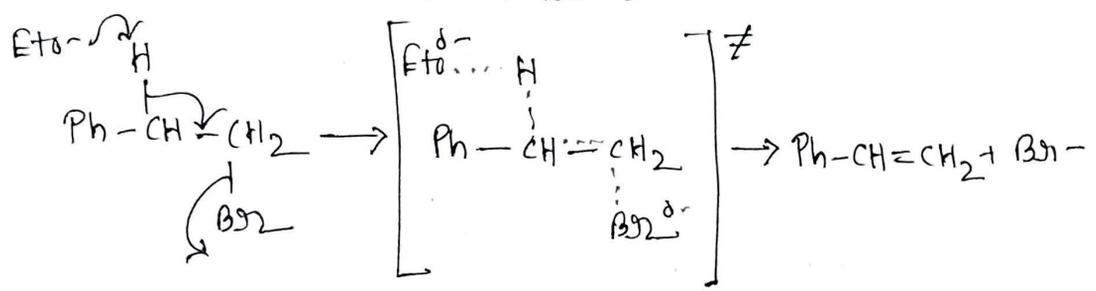
E₁CB mechanism:

The reaction of the following type, where C-H bond is broken first to form a carbanionic species is known as E₁CB (elimination from conjugate base) mechanism.

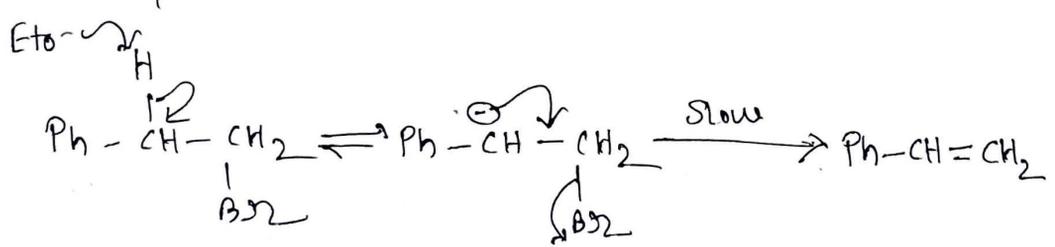


The reaction will follow the same state as in E₂ pathway. i.e. Rate = [RY][B]. These two type can be distinguished by the following way.

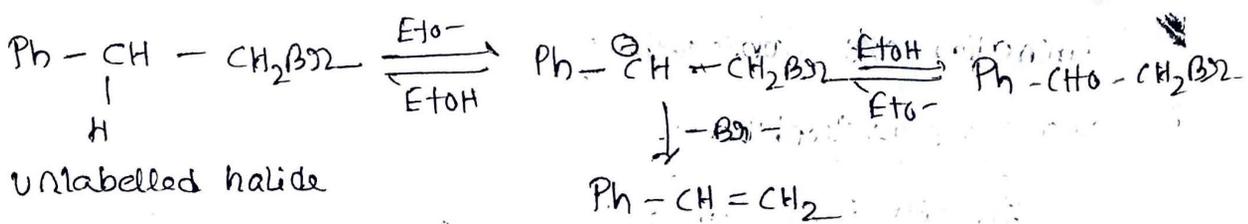
Let us consider the dehydrobromination of phenyl ethyl bromide with EtO/EtOH to form styrene. The concerted mechanism (E₂) will be as follows-



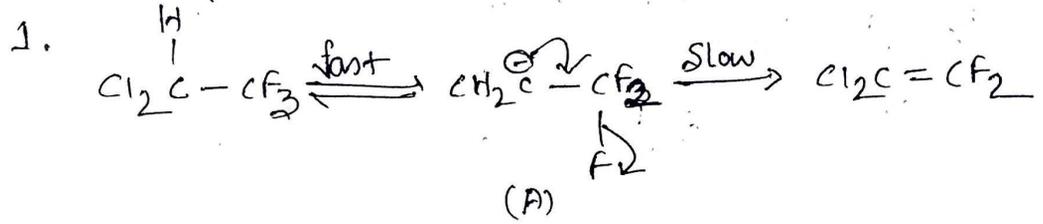
The stepwise mechanism is -



The reaction was carried out in EtO/EtOH. The reaction is allowed to run until about half the substrate been converted to alkene, reaction is then interrupted and unconverted 2-Phenyl ethyl bromide was recovered. Mass spectrometric analysis showed it contained no deuterium. If the reaction were stepwise then the regenerated starting material must contained deuterium. So the reaction follows concerted mechanism (E₂).

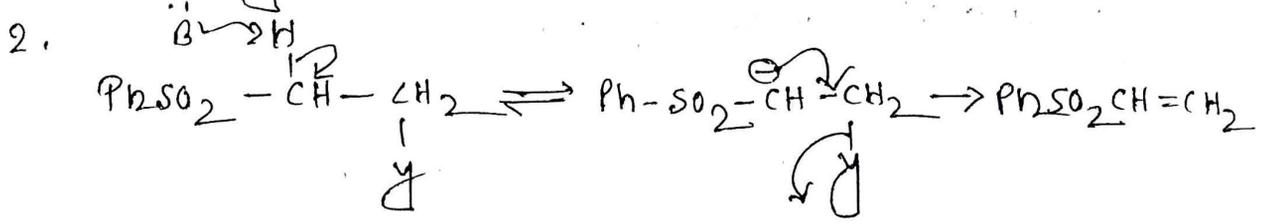


In fact reaction proceeding by this carbanion pathway are very rare. However this mechanism does operate under special circumstances.



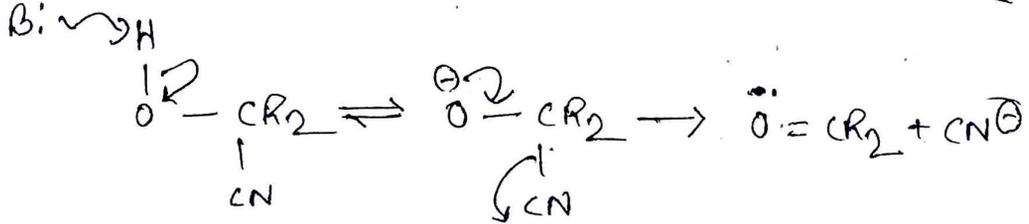
Cause:

- (a) Electronegative halogen atom on the β -carbon makes the β -hydrogen acidic.
- (b) Stabilization of carbanion (A) through electron-withdrawing effect by the halogen.
- (c) Poor leaving aptitude of F.



$\text{Y} = \text{PhSe} > \text{PhO} > \text{PhS} \approx \text{PhSO}_2 > \text{PhSO} > \text{Me} \gg \text{CN}$

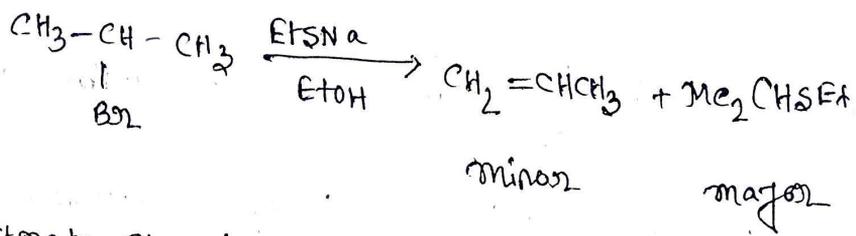
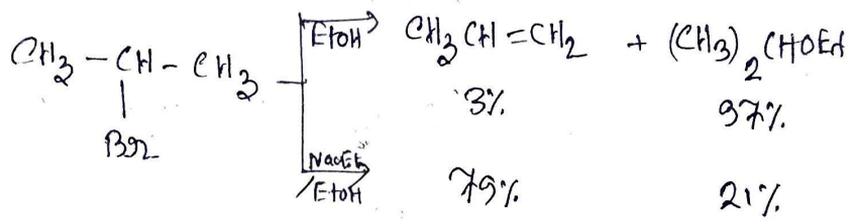
3. Base induced elimination of HCN from cyanohydrins.



Elimination v/s Substitution:

(A) Basicity v/s nucleophilicity:

Basicity is the important factor for elimination and nucleophilicity is prominent in substitution. It is therefore is the desired reaction.



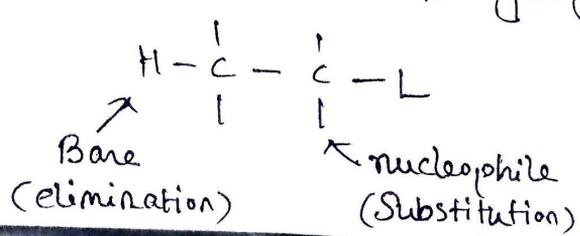
(B) Substrate structure:-

The proportion of elimination increases with increasing chain branching of the reactant. e.g.

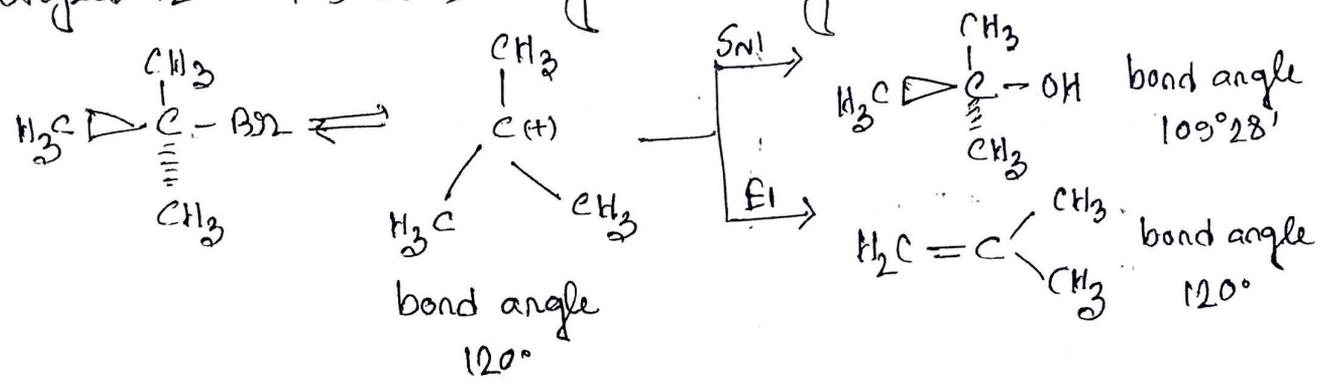
<u>Substrate</u>	<u>$k_2 \times 10^5$ (Relative rates at E2 reaction)</u>
$\text{CH}_3\text{CH}_2\text{Br}$	1.6
$\text{CH}_3\text{CH}_2\text{CH}_2\text{Br}$	5.3
$\text{CH}_3\text{CH}_2\text{CH}(\text{CH}_3)\text{Br}$	8.6
$\text{PhCH}_2\text{CH}_2\text{Br}$	561

Cause:

- (a) Greater stability of highly substituted alkenes formed from substrate.
- (b) The approach of the nucleophile to a carbon atom is usually exposed too much more steric hindrance than in abstraction of a β -hydrogen atom.

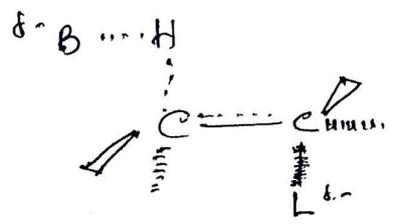


Steric reason is mainly applicable to unimolecular reactions, the carbonium ion are the common intermediate. As we take that carbonium ion are the Planar, with the bond angle of 120° and with their increase in branching they will show more resistance to the decrease in bond angles $120^\circ - 109^\circ 28'$ - brought about by substitution.

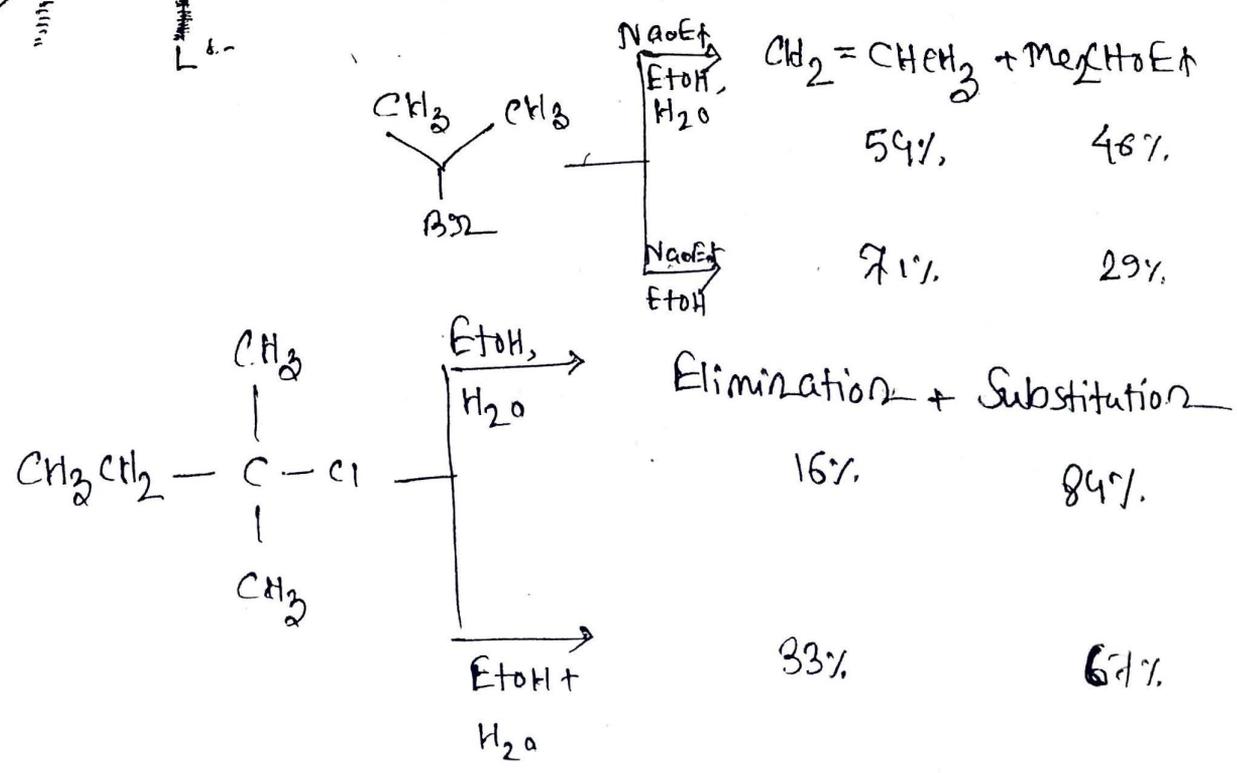


(C) Solvent :-

We have already seen that charge is dispersed in the transition state of the S_N2 reaction. The process is therefore followed by decreasing solvent polarity. Examination of the transition state for an $E2$ reaction shows that charge is even more dispersed than in the S_N2 complex because five atoms are involved.

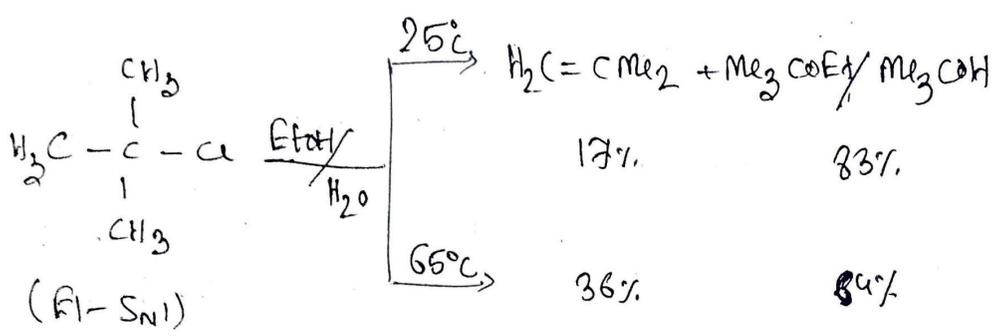
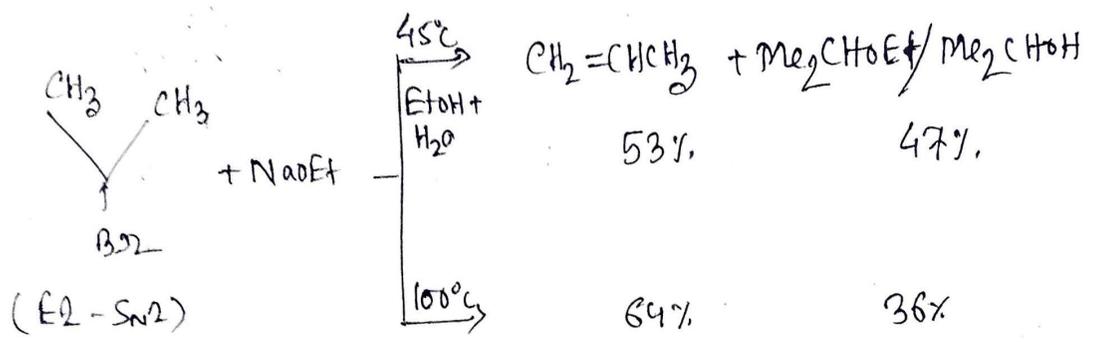


decreasing solvent polarity favours the elimination more than substitution.



(d) Temperature:-

Competing elimination usually becomes relatively faster than substitution as the temperature increases. This is true whether the reaction proceed by the E1-S_N1 or the E2-S_N2 Pathway.



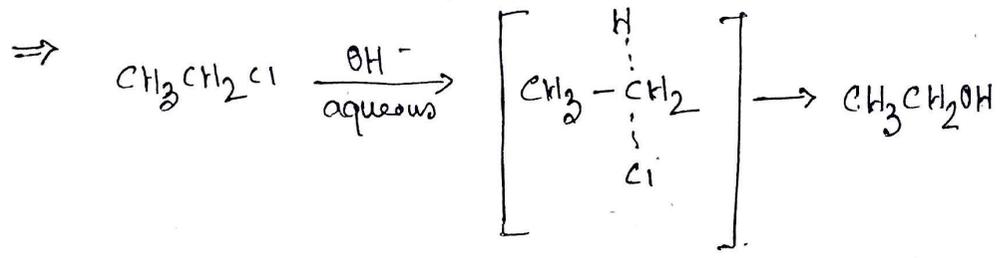
Cause: Considering the changes in bonding that take place in substitution vs those take place in elimination, we may tell that a large number of atoms and associated bond charges are involved in elimination relative to substitution. The greater thermal energy associated with increasing temperature, thus has a relatively greater influence as favouring the elimination reaction.

Problem: Potassium tertiary butoxide is often used to promote E2 reaction at the expense of S_N2 reaction - Explain.

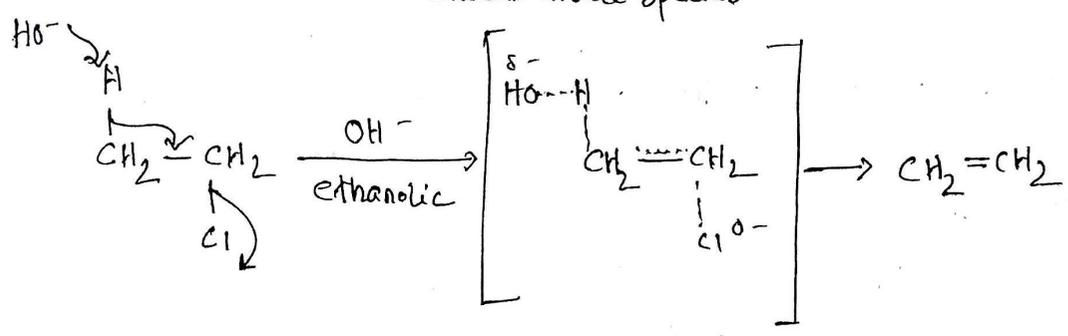
→ In S_N2 reaction tBuO^\ominus acts as a nucleophile where as in E2 reaction, it acts as a base. Thus strong base favours elimination and strong nucleophile favours substitution reaction, because of the large size of tBuO^\ominus it acts as a base rather than nucleophile, since the size of H^+ is smaller than

That of $-C^+$, so it can be abstracted by $tBuO^-$ easily, thus favours elimination process.

Problem: During formation of alcohols from alkyl halide, we often treat the substrate by aqueous alkali; but for the formation of alkene, we use ethanolic alkali. Explain -



dispersed of charge between three species



dispersed of charge between five species

In case of elimination reaction, the charge is more dispersed than substitution reaction, so the former favours in less polar solvent.

I⁻ induced debromination:

It has been proposed that the conversion of vicinal dihalides into alkene by action of iodide ion can proceed by either a one step mechanism (i) or a three step mechanism (ii).

(i) Anti elimination with I^- as base.

