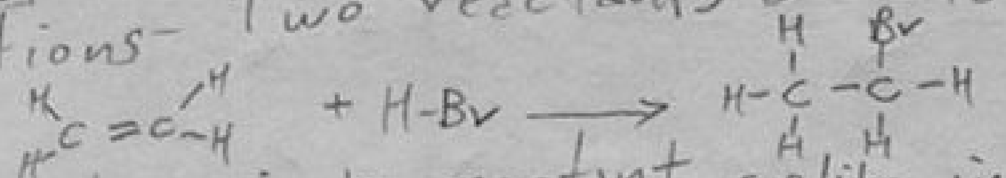
138 Chemistry study sheet CH 5

Organic Rxs

→ addition reactions – two reactants add to form a single product, with no atoms left over.



→ elimination Rx – when single reactant splits into two products.

→ substitution Rx – when two reactants exchange parts to give two new products

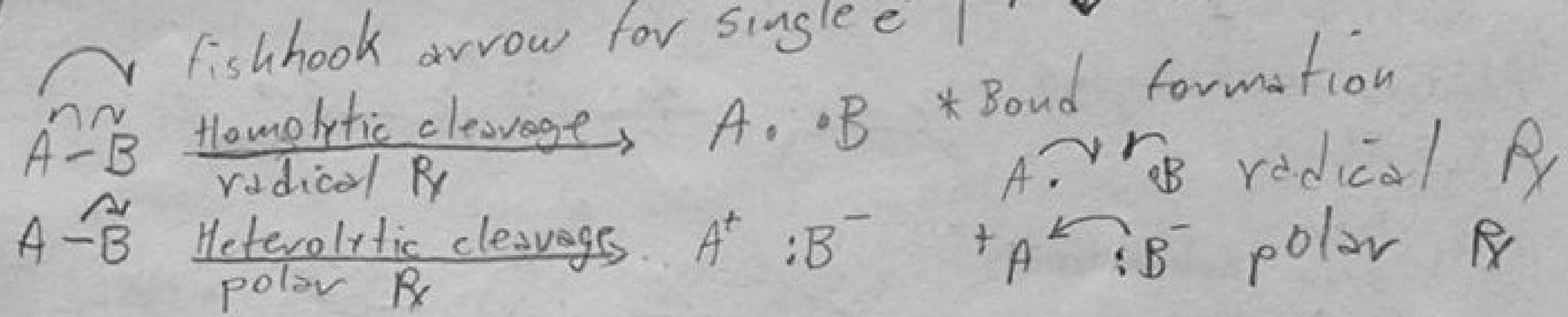
→ rearrangement Rx – when single reactant undergoes a reorganization of bonds and atoms to yield an isomeric product.

Rx Mechanisms

fishhook arrow for single e^- | full arrow for a pair of e^-

* e^- counting

* bond cleavage

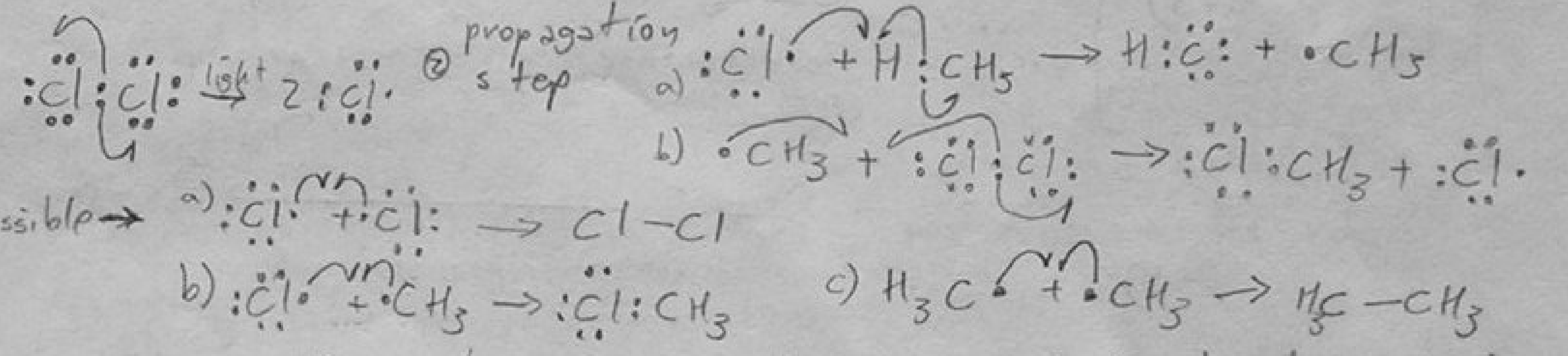


Radical Rx

① initial step (radical generation)

② propagation step

③ Termination steps



Polar Rx

occur because of the attraction between + & – charges on ≠ functional groups in molecules

- nucleophile (electron-rich) eg. Ammonia, water, OH^-, Br^-, Cl^-
- electrophile (e^- poor) eg. H^+ donors, alkyl halides, carbonyl compounds

#140 δ table

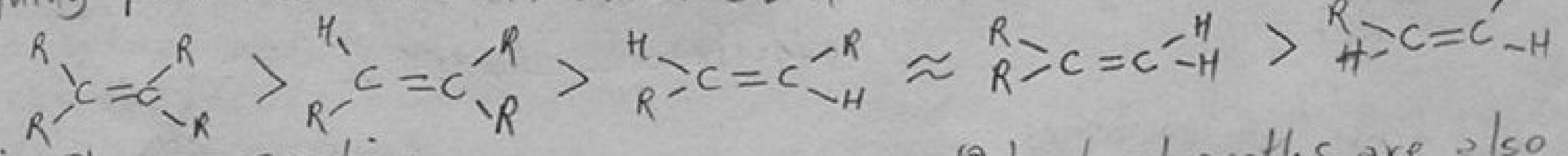
π bonds are accessible e^-, weaker in C=C are nucleophilic

rules for using arrows in polar Rx #147

CH 6 Alkenes: Structure & Reactivity

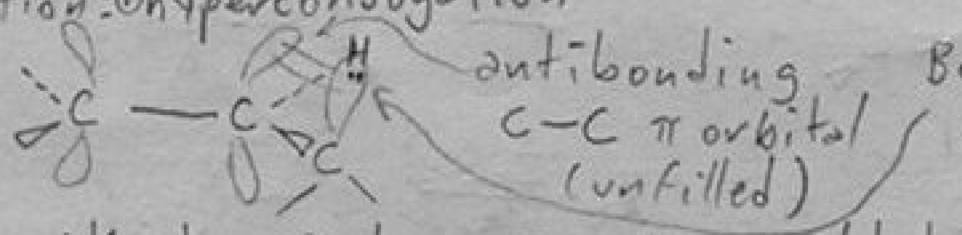
Calculating degree of unsaturation $(2n + 2 - \#H - \#Halogens + \#N) \div 2$ ignore Origen

- when assigning priorities Br > Cl > O > N > C > H this is for naming
- Stability



3 methods
- eq. constant between isomers via chem. transform
- Heats of combust.
- Heats of hydrogenation

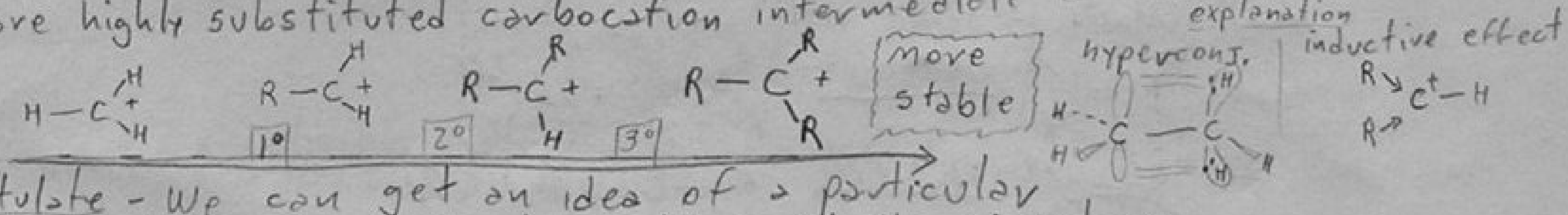
explanation: ① hyperconjugation



② bond strengths are also important. bond between sp^2 C & sp^3 C somewhat stronger than two sp^3 C.

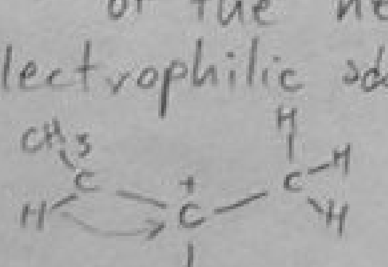
$CH_3-CH=CH-CH_3 > CH_3-CH_2-CH=CH_2$

- Markovnikov's Rule = In the addition of HX to an alkene, the H attaches to the carbon with fewer alkyl substituents and the X attaches to the carbon with more alkyl substituents.
  - if the 2 C atoms have = degree of subst., you get mixed prods.
- Restated → more highly substituted carbocation intermediate is formed. #188
- Carbocation Stability



- Hammond Postulate – We can get an idea of a particular transition state's structure by looking at the structure of the nearest stable species.
- Electrophilic addition: carbocation rearrangements

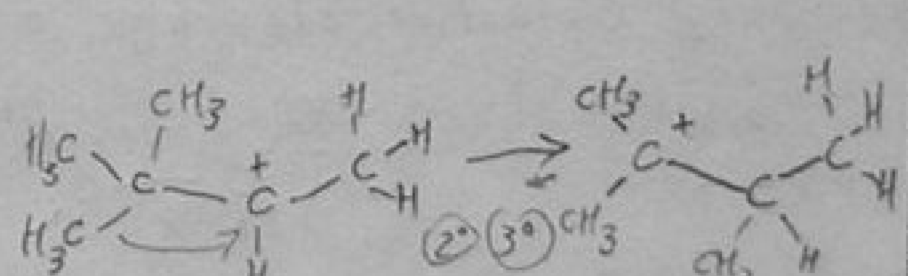
1,2-Hydride shift



H: moves to produce stability

1,2-Alkyl shift

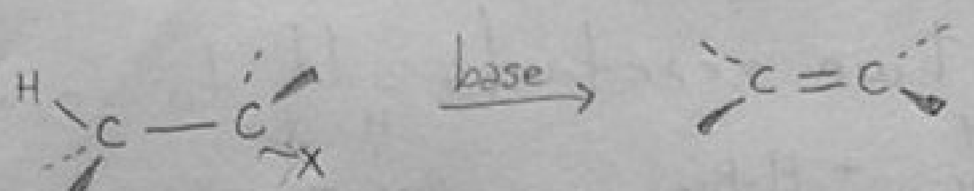
1,2-Methyl shift



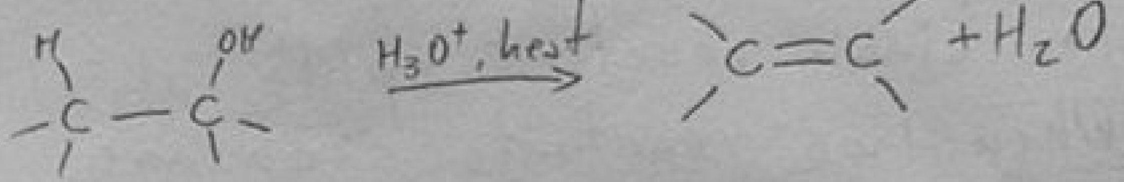
Ch $\boxed{7}$ Alkenes: Reactions & Synthesis

① Synthesis of alkenes

- Dehydrohalogenation of alkyl halides (7.1)

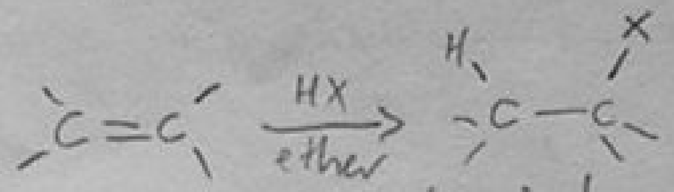


- Dehydration of alcohols (7.1)



② Addition Rx of alkenes

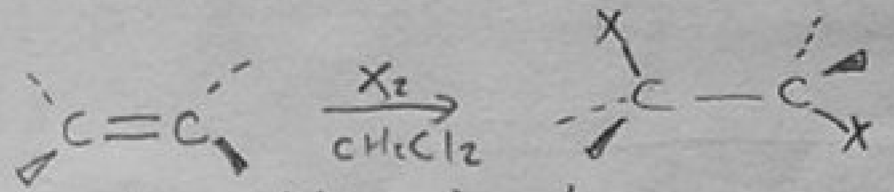
- Addition of HX (6.8 & 6.9)
  X = Cl, Br or I



markovnikov regiochemistry

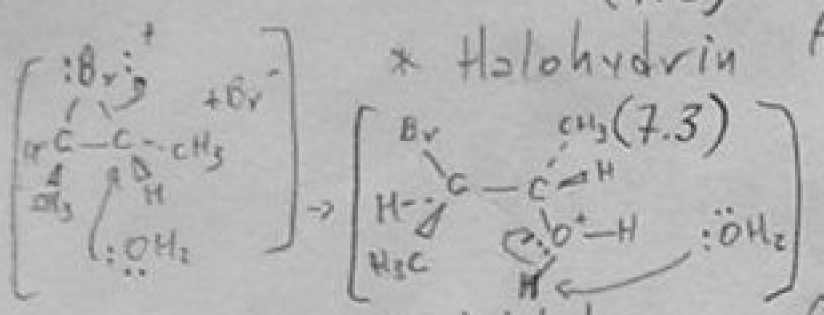
anti-stereochemistry = Br atoms come from opposite faces of the double bond

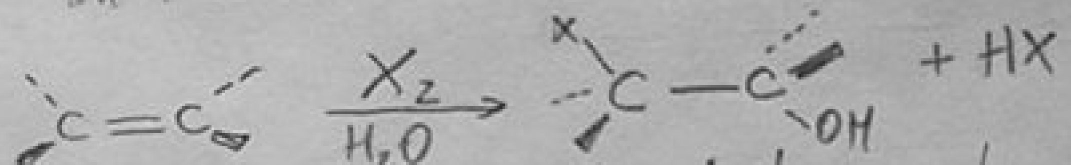
- Addition of halogens
  $X_2 = Cl_2$ or Br_2 (7.2)



anti addition is obs.

- Halohydrin formation (7.3)

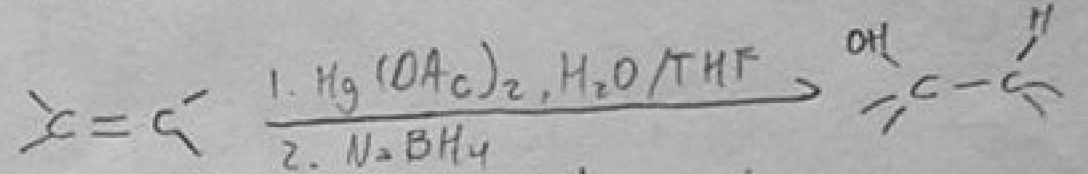




markovnikov regiochemistry and anti stereochemistry are observed.

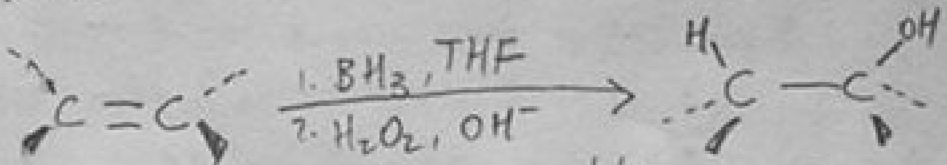
similar to addition of halogens but occurs in the presence of an additional nucleophile. eg. H_2O

- Addition of water by oxymercuration (7.4)



markovnikov regiochemistry w/ OH attaching to more subst. carbon

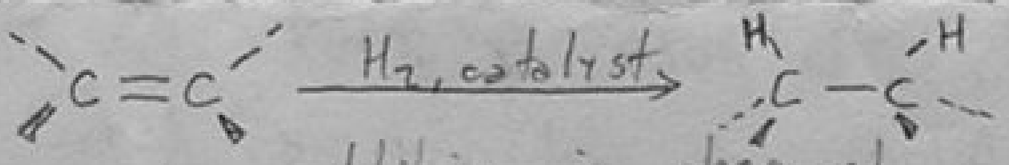
- Addition of water by hydroboration/oxidation (7.5)



non-markovnikov syn addition observed

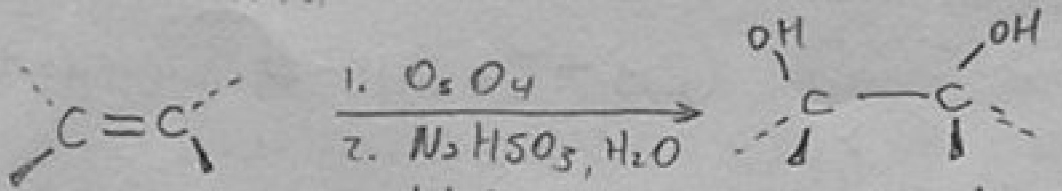
Syn add is the opposite of anti

- Hydrogenation of alkenes (7.7)



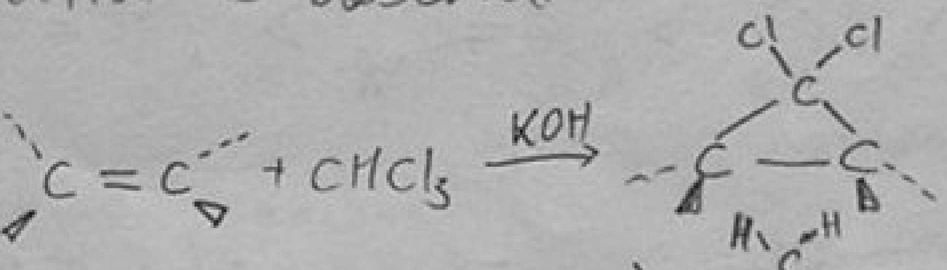
syn addition is observed

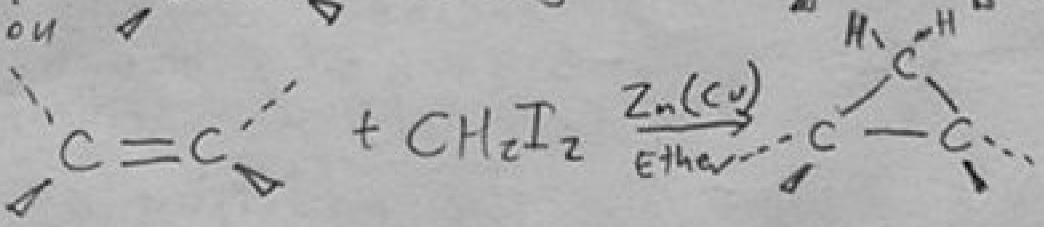
- Hydroxylation of alkenes (7.8)



syn addition is observed

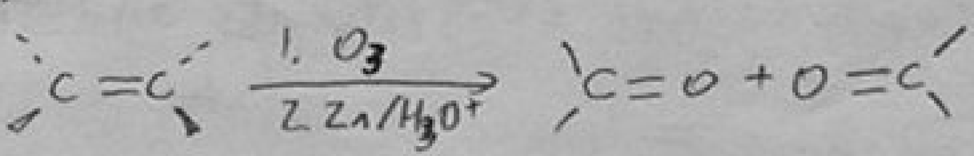
- Addition of carbenes to yield cyclopropanes (7.6)
  1. Dichlorocarbene addition
  2. Simmons-Smith Rx



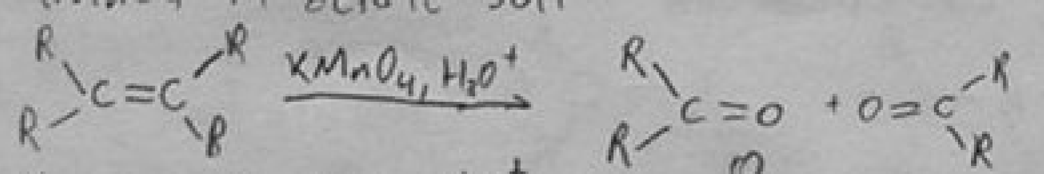


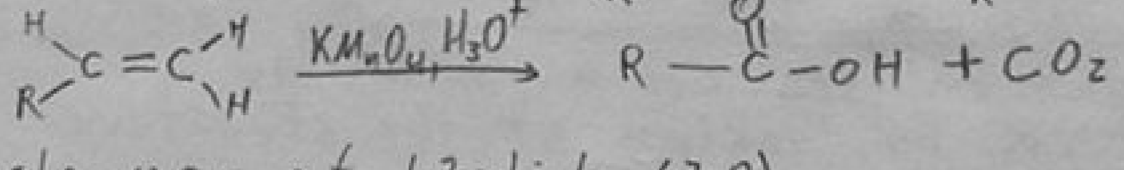
③ Oxidative cleavage of alkenes (7.8)

- Treatment w/ ozone, followed by zinc in acetic acid

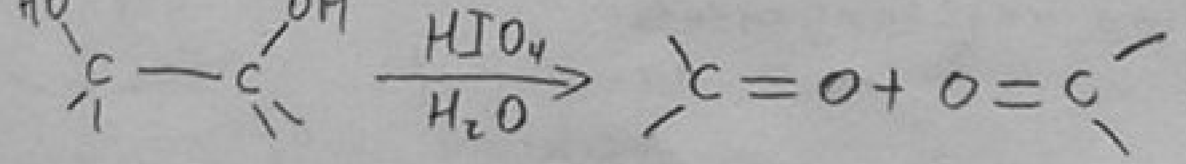


- Rx w/ $KMnO_4$ in acidic soltn





④ Oxidative cleavage of 1,2-diols (7.8)

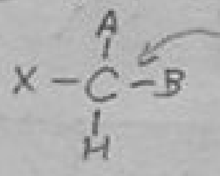


Reagent	Syn/Anti	MarKovniKov
HBr	—	Yes
Br_2	Anti	—
Br_2/H_2O	Anti	Yes
H_2O, H^+	—	Yes
$H_2O, Hg(OAc)_2$	—	Yes
H_2O, BH_3	Syn	Non
$CHCl_3$, NaOH	Syn	—
H_2	Syn	—
OsO_4	Syn	—

reagent	Product
HFO_4	Aldehyde, Ketone
$KMnO_4, H^+$	Acid, Ketone
O_3, Zn	Aldehyde, Ketone

CH $\boxed{9}$ Stereochemistry

- Enantiomers - mirror-image molecules that are not superimposable
- achiral molecules have a plane of symmetry

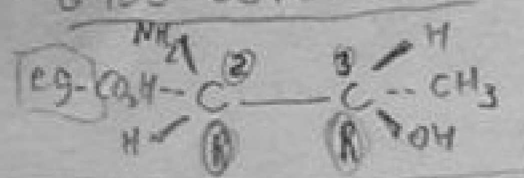


$$X-\overset{A}{\underset{H}{C}}-B$$

chirality center

- when a beam of plane-polarized light passes throught a solution of certain organic molecule, the plane of polarization is rotated. Molecules that exhibit this property are said to be optically active.
- Assigning S or R conf. #283
- diastesteomers - are stereoisomers that are not mirror images of each other

eg-



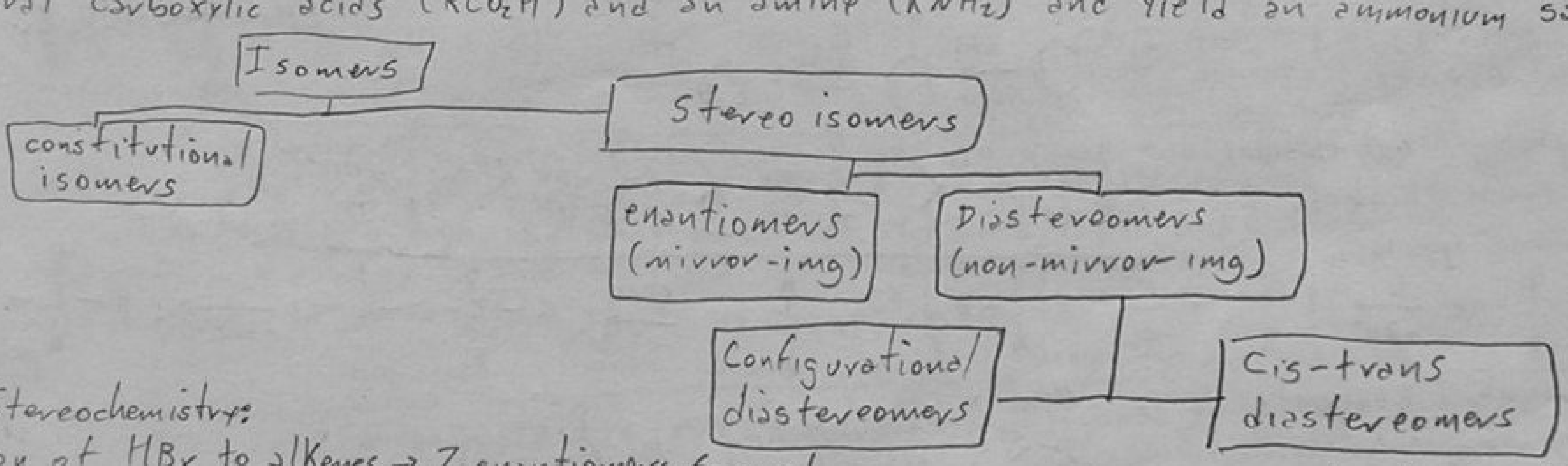
/ enantiomer w/ 2Ⓢ,3Ⓢ / diastereomer w/ 2Ⓡ,3Ⓢ and 2Ⓢ3Ⓡ

- Achiral compounds that contain chirality centers are called <u>meso compounds.</u>
- In general, a molecule with n chirality centers, has a max of 2^n stereoisomers or 2^{n-1} pairs of enantiomers. It can be less depending on the n° of meso comps.
- Physical properties of stereoisomers

eg.

stereoisomer	melt. pt	α	ρ	solub.
(+)	X	+d	D	Z
(-)	X	-d	D	Z
meso	Y	0	C	ω

- <u>Racemic</u> <u>mixture</u> or racemate is a 50:50 mixture of two enantiomers. these mixtures show zero optical rotation. b
- In order to separate (+) & (-) enantiomers, is acid-base reaction between a racemic mixture of chiral carboxylic acids (RCO_2H) and an amine (RNH_2) and yield an ammonium salt #292



Stereochemistry:

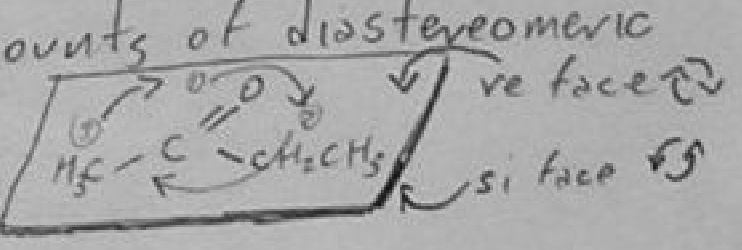
- addition of HBr to alkenes → 2 enantiomers formed

→ Rx between two optically inactive (achiral) partners always leads to an optically inactive product - either racemic or meso.

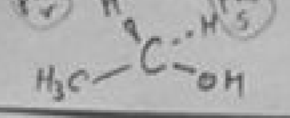
- Br_2 additions #297
- add. of HBr to Chiral alkene

→ Rx of a chiral reactant w/ an achiral reactant leads to unequal amounts of diastereomeric products.

- prochiral molecule can be converted to chiral in one chemical step



prochirality center /



Ch $\boxed{10}$ Alkyl Halides

- radical halogenation of alkanes

eg. $CH_4 + Cl_2 \xrightarrow{h\nu} CH_3Cl + HCl$

$\xrightarrow{Cl_2} CH_2Cl_2 + HCl$

$\xrightarrow{Cl_2} CHCl_3 + HCl$

$\xrightarrow{Cl_2} CCl_4 + HCl$

many product

eg. $CH_3CH_2CH_2CH_3 + Cl_2 \xrightarrow{h\nu}$ $CH_3CH_2CH_2$ … + $CH_3CH_2\overset{Cl}{C}HCH_3$ + dichloro + trichloro + tetrachloro + + +

init. $:\ddot{Cl}-\ddot{Cl}: \xrightarrow[heat]{h\nu \text{ or}} :\ddot{Cl}\cdot + \cdot\ddot{Cl}:$

propag. $H_3C-H + \cdot Cl \longrightarrow H_3C\cdot + H-Cl$

$H_3C\cdot + Cl-Cl \longrightarrow H_3Cl + \cdot Cl$

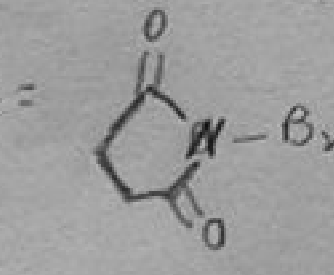
termination $H_3C\cdot + \cdot CH_3 \longrightarrow H_3C-CH_3$

$H_3C\cdot + \cdot Cl \longrightarrow H_3C-Cl$

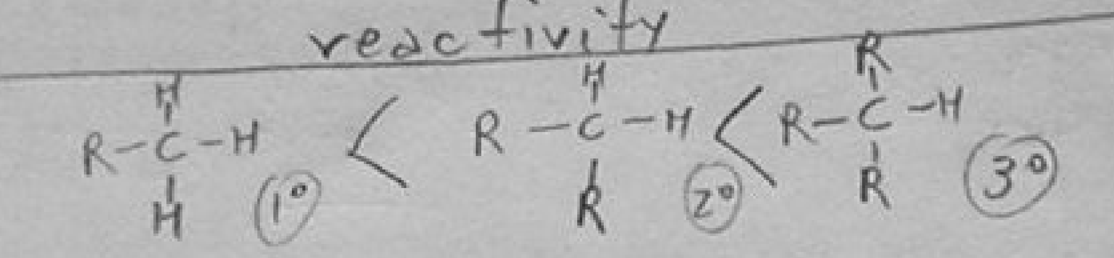
$Cl\cdot + \cdot Cl \longrightarrow Cl_2$

1°H	2°H	3°H
1	3.5	5

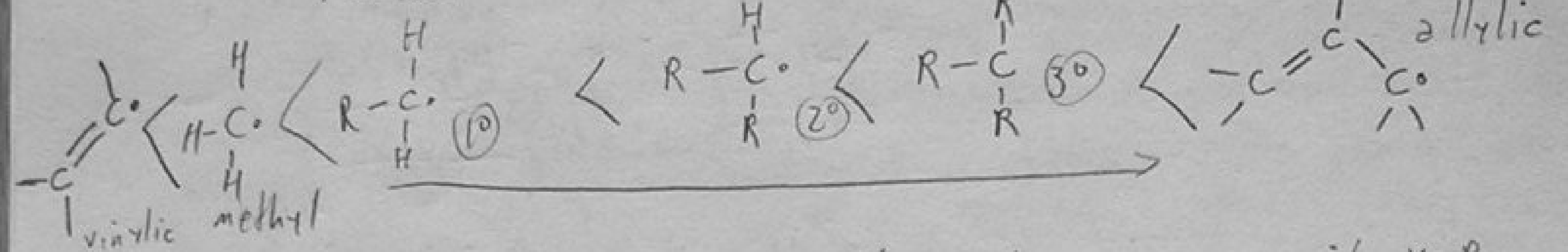
NBS =



reactivity

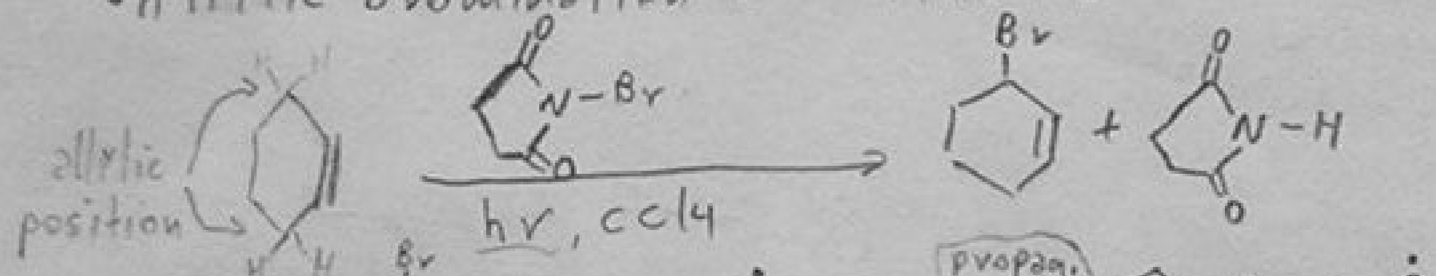


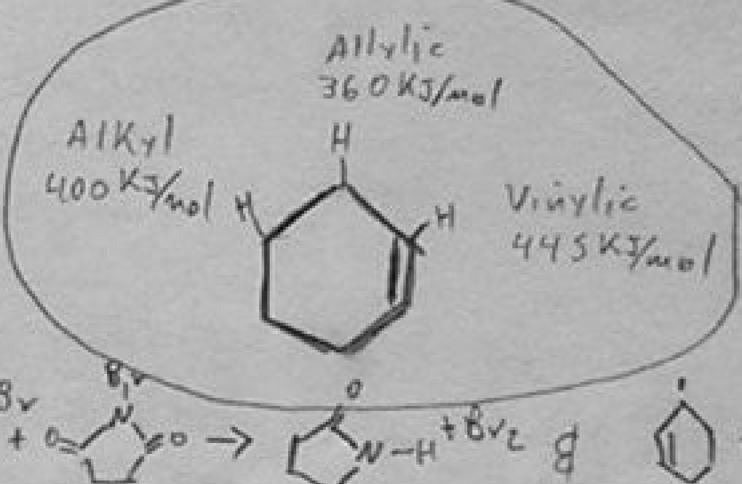
radical stability

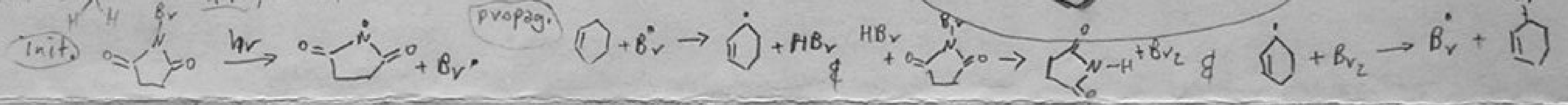


- when reacting $CH_3\overset{CH_3}{C}HCH_3 + X_2 \xrightarrow{h\nu}$ if $x = Cl$ we get a 36:65 mix; if $x = Br$ we get a 99:1 mix ∴ Rx w/ Br is much more selective ∵ Rx w/ Br is less exerg… so transition state resembles alkyl radical more closely #323

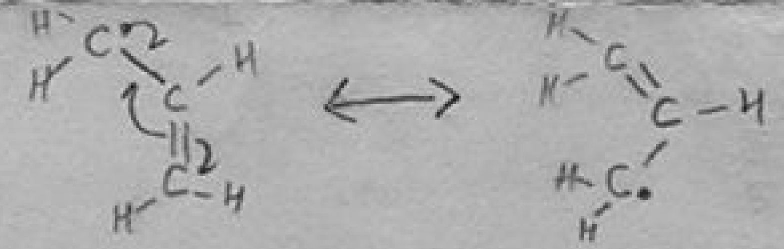
- Allylic Bromination of Alkenes







- Stability of the allyl radical (resonance)



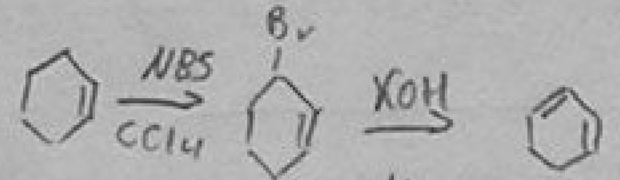
The stability of the allyl radical is due to the fact that unpaired electron is delocalized, over an extended π orbital.

- when reacting an usymmetrical alkene we often get a mixture of products prod. not formed in equal amounts. Rx at the less hindered primary end is favoured

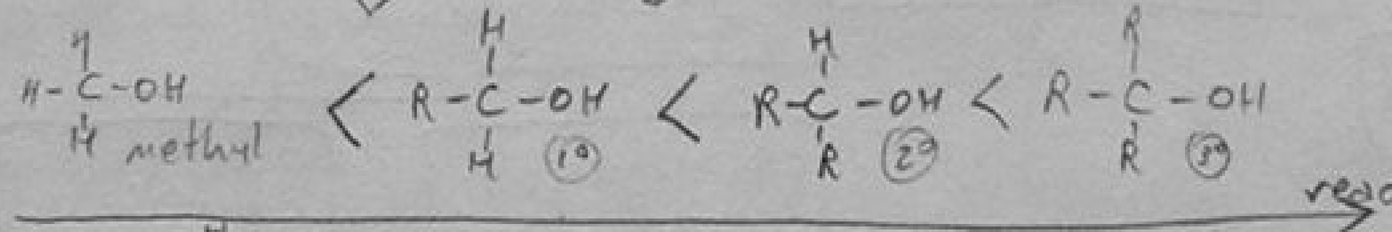
$CH_3CH_2CH_2=CH_2 \xrightarrow[CCl_4]{NBS} CH_3\dot{C}HCH=CH_2 \leftrightarrow CH_3CH=CH\dot{C}H_2 \longrightarrow CH_3\underset{Br}{C}HCH=CH_2 +$

$CH_3CH=CHCH_2Br$ ← more of this

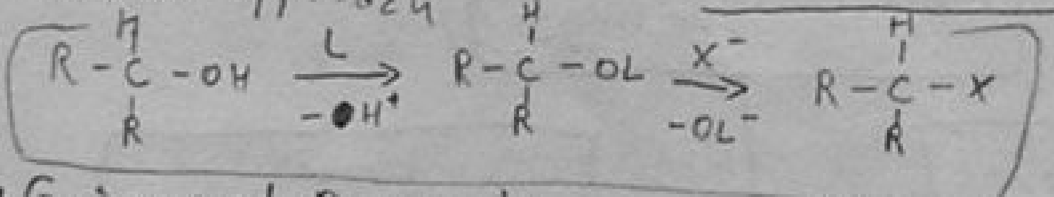
- very useful to produce dienes eg.



- Preparing Alkyl Halides from Alcohols

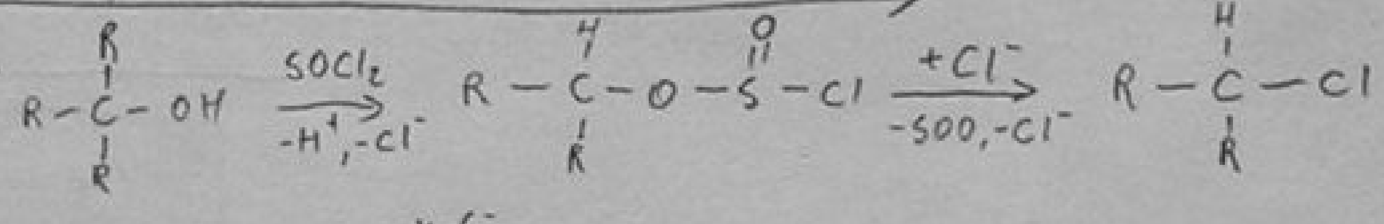


- common approach



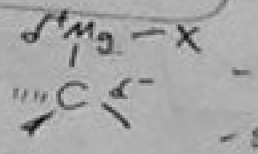
$R-\underset{R}{\overset{H}{C}}-OH \xrightarrow[-H^+]{L} R-\underset{R}{\overset{H}{C}}-OL \xrightarrow[-OL^-]{X^-} R-\underset{R}{\overset{H}{C}}-X$

eg.



$R-\underset{R}{\overset{R}{C}}-OH \xrightarrow[-H^+,-Cl^-]{SOCl_2} R-\underset{R}{\overset{H}{C}}-O-\overset{O}{\overset{\|}{S}}-Cl \xrightarrow[-SOO,-Cl^-]{+Cl^-} R-\underset{R}{\overset{H}{C}}-Cl$

- Grignard Reagents (organomagnesium halides)



- nucleophilic
- strong base

vs

- electrophilic

→Rx

$R-X + Mg \xrightarrow[\text{or } (THF)]{ether} R-Mg-X$

∴ it reacts w/ weak acids to form Hydrocarbons →

eg. $\overset{\delta^-}{HO}-\overset{\delta^+}{H} + CH_3\overset{\delta^-}{C}H_2-\overset{\delta^+}{Mg}Br \rightarrow CH_3-CH_3 + Mg(OH)Br$

H_2O $K_a = 10^{-15.7}$

RCO_2H $K_a \approx 10^{-5}$

R_2NH $K_a \approx 10^{-38}$

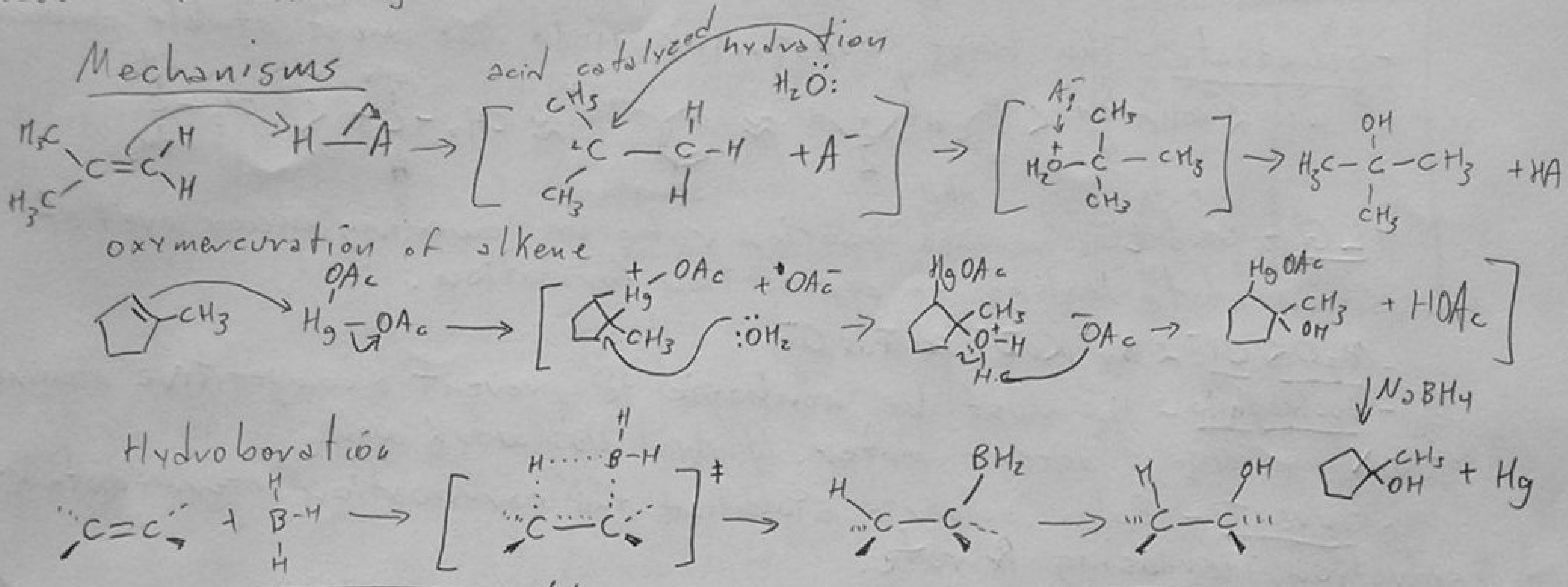
ROH $K_a \approx 10^{-16}$

any acid w/ less than $pK_a = 51$ reacts w/ it

Ch $\boxed{10}$.10 Oxidation & Reduction in organic compounds

- Oxidation Rx - results in a loss of e^- density by a carbon, often caused by bond formation between "C" and a more electronegative atom (O, N, Halogen, etc) or bond breaking between "C" and a less δ^- atom (usually H)
- Reduction Rx - Carbon gain e^- density.

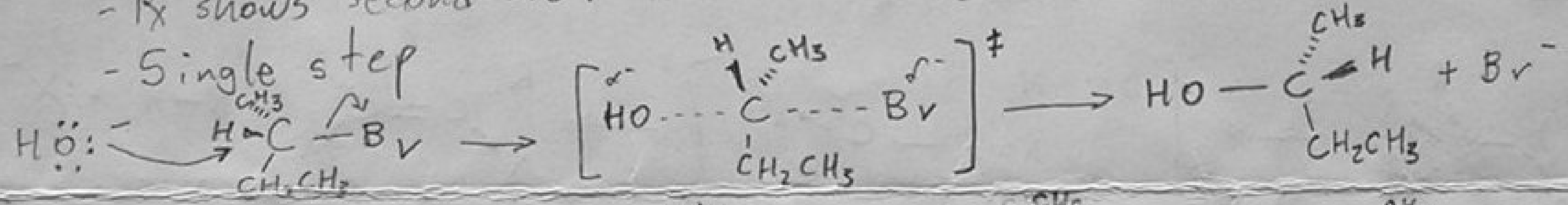
Mechanisms

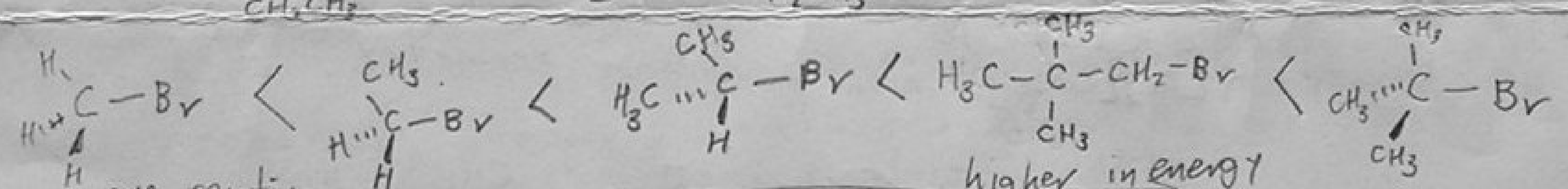


CH $\boxed{11}$ Rx of Alkyl Halides:

• S_N2 Rx $\boxed{11.4}$

- Rx occurs w/ inversion of stereochemistry at the carbon atom
- Rx shows second-order Kinetics → Rate = K [RX][Nu:⁻]
- Single step





more reactive → higher in energy, less reactive

relative reactivity	2,000,000	40,000	500	1	<1

- The nucleophile is important, it can be neutral or negatively charged, as long as it has an unshared pair of electrons. If Nu: is ⊖ charged the product is neutral, if Nu: is neutral the product is ⊕ charged.

Nu:	H_2O	$CH_3CO_2^-$	NH_3	Cl^-	OH^-	CH_3O^-	I^-	CN^-	HS^-
relative reactivity	1	500	700	1000	16000	25000	100000	125000	125000

→ more reactive

- nucleophilicity ∥ to basicity. increases as you go down the periodic table. ∴ $I^- > Br^- > Cl^-$. ⊖ charged tend to be more reactive.
- The leaving group, the best ones are the ones that best stabilize the negative charge. ∴ the best LG are the weaker bases.

OH^-, NH_2^-, OR^-	F^-	Cl^-	Br^-	I^-	$TosO^-$
<<1	1	200	10000	30000	60000

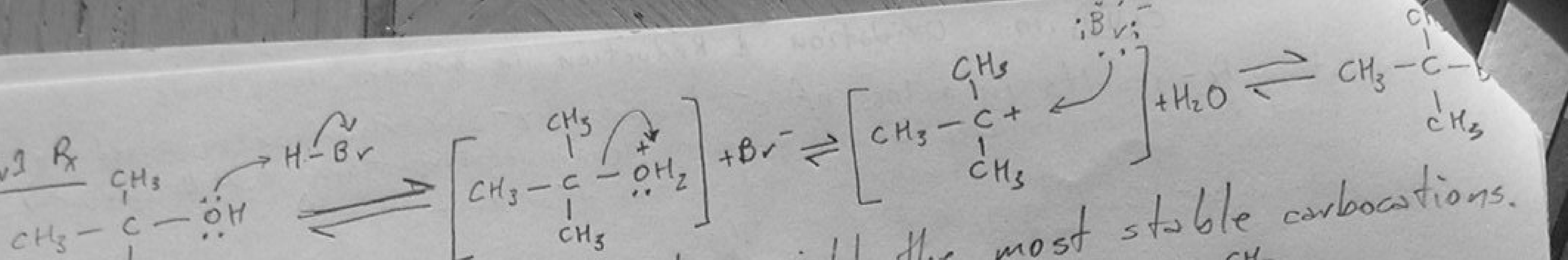
→ more reactive

- Polar aprotic solvents are prefered. (strong dipole) except -OH or -NH groups. these solvents raise the ground state energy of nucleophile. examples are

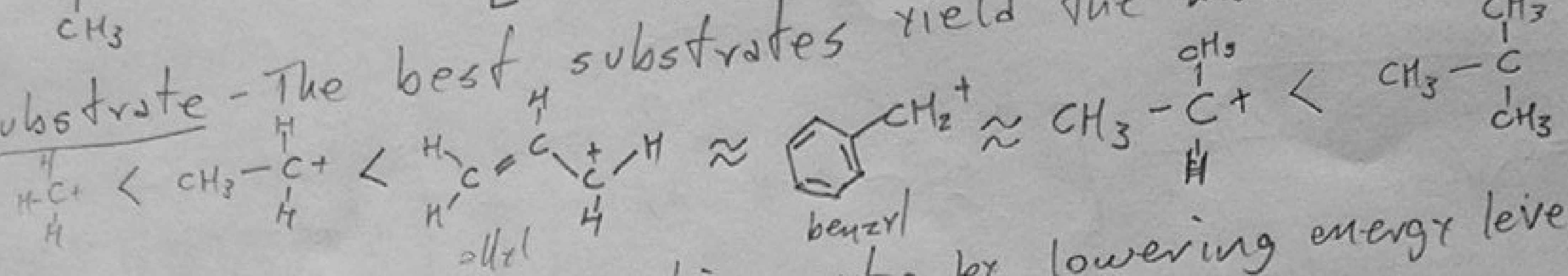
CH_3OH	H_2O	DMSO	DMF	CH_3CN	HMPA
1	7	1300	2800	5000	200 000

→ more reactive

11.8 • S_N1 R_x



- Substrate - The best substrates yield the most stable carbocations.



- LG - Good LGs increase reaction rate by lowering energy level of transition state leading to carbocation formation.

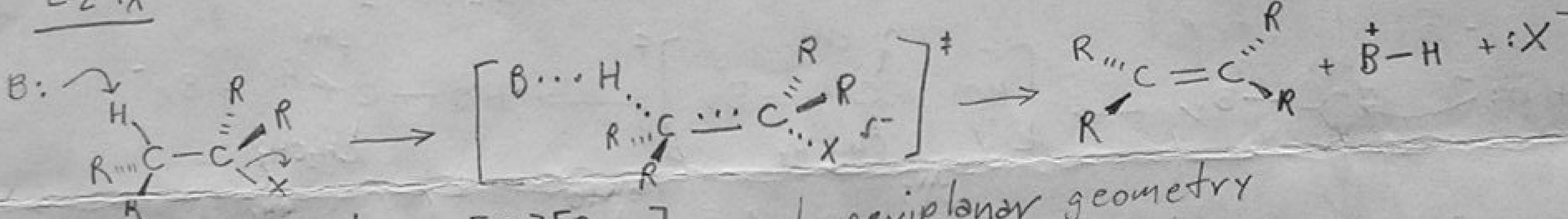
$H_2O < Cl^- < Br^- < I^- \approx$ Tos O^-

- Nucleophile - Nu: must be nonbasic to prevent a competitive elimination of HX, otherwise it doesn't mater. Neutral Nu: work well.

- Solvent - Polar solvents stabilize the carbocation intermediate by solvation, increasing Rx rate.

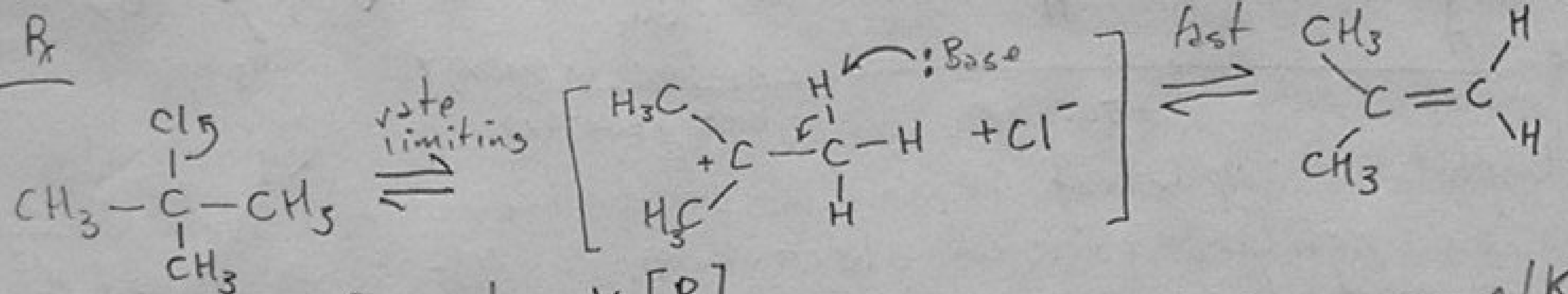
R_x rate = $k[R_x]$

11.11 • E_2 R_x



R_x rate = $k[R_x][Base]$ need periplanar geometry

11.14 • E_1 R_x

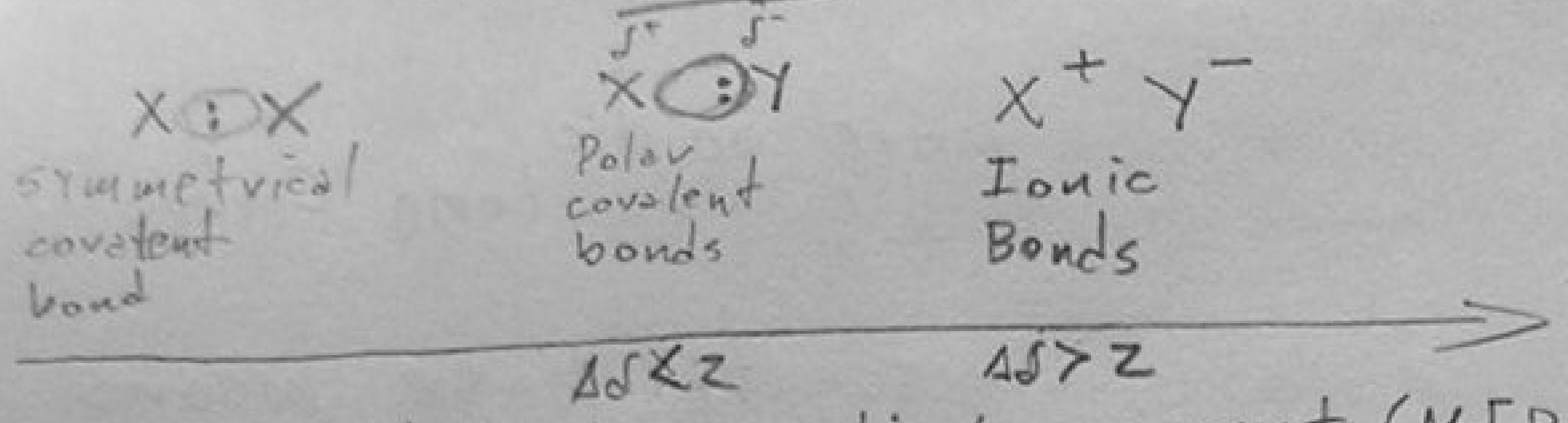


R_x rate = $k[R_x]$

Zaitsev's Rule - In the elimination of HX from an alkyl halide, the more highly substituted alkene product predominates

Halide type	S_N2	S_N1	E_2	E_1
CH_3X	Only	DNO	DNO	DNO
RCH_2X primary	Highly favoured	Does not occur	Occurs if strong big bases are used	DNO
R_2CHX secondary	Occurs in compet. w/ E_2 R_x. Weak bases, polar aprotic s.	Can occur w/ benzylic and allylic halides, polar protic weak Nu:	Favored when strong bases are used	Can occur w/ benzylic and allylic halides polar protic / weak Nu:
R_3CX tertiary	DNO	Favoured w/ hydroxylic solvents and poor Nu:	Favored when bases are used (OH^-, $\underline{RO^-}$)	Occurs in competition w/ S_N1 R_x poor Nu:

Ch $\boxed{2}$ Polar Covalent Bonds; Acids & Bases



* Inductive Effect - shifting of e^- in a bond in response to the electronegativity of nearby atoms.

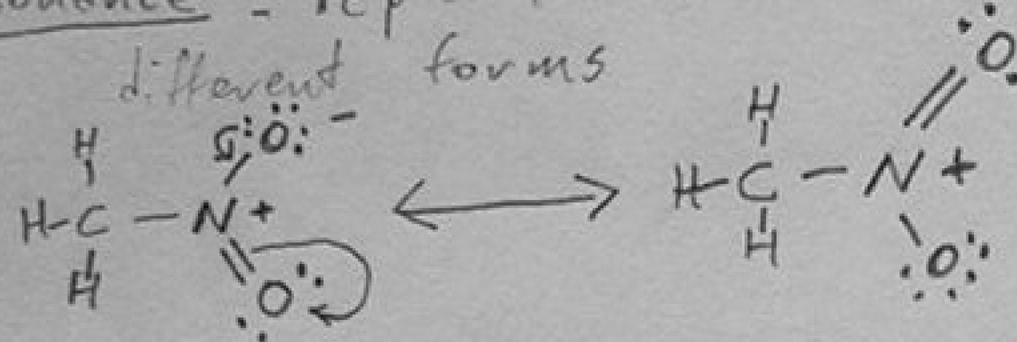
table δ^- #30	
C - 2.5	I - 2.5
O - 3.5	Li - 1.0
H - 2.1	S - 2.5
N - 3.0	B - 2.0
Cl - 3.0	Na - 0.9
Br - 2.8	

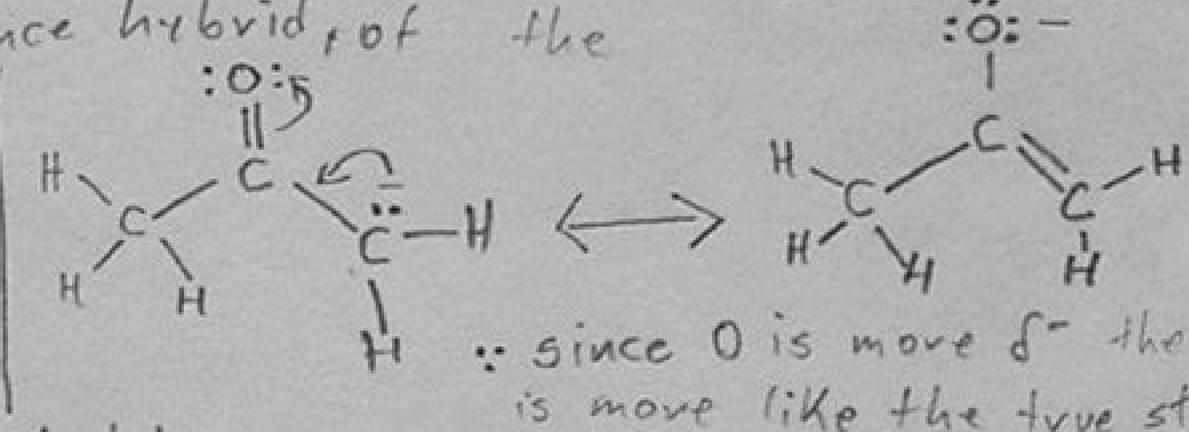
Polar covalent bonds have dipole moment (μ[D = C·m]) represented by ⟼

Formal Charge = (# of valence e^- in free atom) - (# of valence e^- in bound atom) =

= (# of valence e^-) - (½ bondin electrons) - (# of non banding e^-)

$\boxed{2.4 \; 2.5}$ Resonance - representation of a resonance hybrid, of the different forms





∴ since O is more δ^- the 2nd resonance is more like the true structure.

resonance generally leads to stability

$\boxed{2.7}$ Acids & Bases

Brønsted-Lowry acid - substance that donates a hydrogen ion (H^+)

Brønsted-Lowry base - substance that accepts a H^+

$$\underset{\text{acid}}{H-A} + \underset{\text{base}}{:B} \rightleftharpoons \underset{\text{conjugate base}}{A:^-} + \underset{\text{conjugate acid}}{H-B^+}$$

To measure the strength of an acid/base we use pK_a ($-\log K_a$), being K_a an acidity constant. Stronger acid has a larger K_a and small pK_a.

weak acid ↓ stronger ↓ strongest ↓

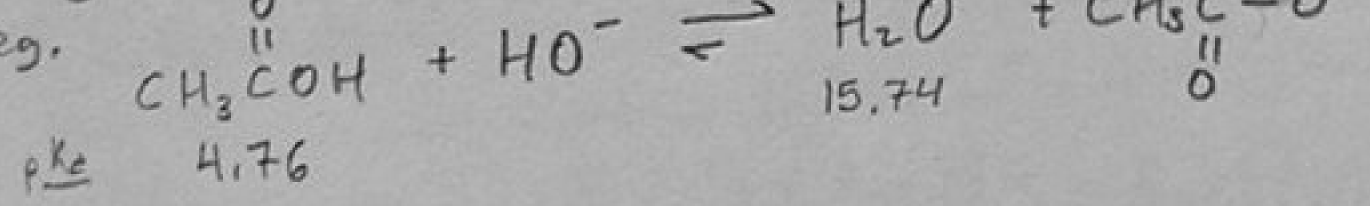
		pK_a	conj. base
Ethanol	CH_3CH_2OH	16	$CH_3CH_2O^-$
Water	H_2O	15.74	HO^-
	HCN	9.31	CN^-
	CH_3CO_2H	4.76	$CH_3CO_2^-$
	HF	3.45	F^-
	HNO_3	-1.3	NO_3^-
	HCl	-7.0	Cl^-

↑ Stronger base ↑ Weaker Base

It is possible to predict Rx between acids and bases from pK_a values

- An acid will donate a proton to the conjugate base of any acid that has a ↑ pK_a

the conjugate base of an acid will remove a proton from any acid that has a lower pK_a. eg.



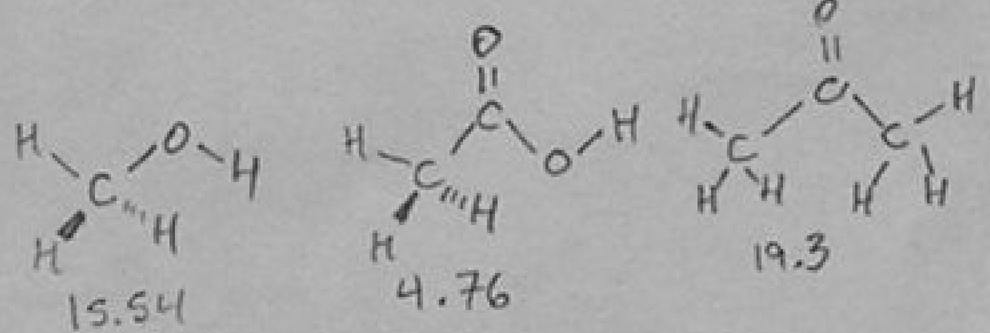
$$\underset{pK_a\ 4.76}{CH_3\overset{O}{\overset{\|}{C}}OH} + HO^- \rightleftharpoons \underset{15.74}{H_2O} + CH_3\underset{\underset{O}{\|}}{C}-O^-$$

$\boxed{2.10}$ Organic Acids

O. Acids have positively polarized hydrogen atom

- anions are usually stabilized by ⊖ charge being on a highly δ^- atom. Resonance is another mech used

eg.



Lewis Acid is a substance that accepts an e^- pair

Lewis Base is a substance that donates an e^- pair

L. Acid eg. H_2O, HCl, HBr, OH, H_2SO_4, Mg^{2+}, Br^+, Li^+, $AlCl_3$, BF_3

L. Bases eg. alcohols, ethers, aldehydes, Ketone, ... #53

- What acid is the strongest?

- e^- withdrawing groups make a substance more acidic
- e^- donating groups make substance less acidic, like long Carbon chains
- Resonance increases acidity, a stable conjugate base means the acid was quite acidic.