LEC (1) CHEM 30A October 1st

(1) WHO/WHEN/WHERE/HOW ?
(2) WHAT ?

HMK
READ Ch 1, sections 1 – 1.4
PROBLEMS 1.1-1.5, 1.19-1.22

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(1) Me

– Office 3077D YOUNG HALL

– E-mail & WEBSITE → ANNOUNCEMENTS
EXAM KEYS
USE VOH for QUESTIONS

– LECTURES 9 am - SUCKS (BUT I HAVE NO CHOICE) [LECTURE NOTES]
MODEL KITS

– QUESTIONS IN CLASS OK

– DON'T FAIL, I TEACH 30A ALL YEAR !

– ENGLISH, ENGLISH

– 26th LETTER, ALUMINIUM, FOOTBALL 13TH
– WAITLIST

TAs

Adam, Phil, Cari, Heather

OH / Discussions posted on WEBSITE
all OH in 3077F Young Hall

Discussions begin MONDAY
Discussion II now in BOELTER 5419
(THURS 9am)

TEXTBOOK BROWNE & POTE 3rd ED
+ HMK/READING assignments

EXAMS

3 QUIZZES	100	(3 x 35)
2 MIDTERMS	200	(2 x 115)
1 FINAL	200	(1 x 230)
	500	

FINAL IS COMPREHENSIVE

PENCIL = NO REGRADES
(READ EXAM POLICY)

CHEATING - DON'T EVEN THINK ABOUT IT

SYLLABUS — tentative...

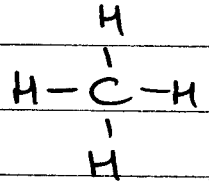
WHAT – ORGANIC CHEMISTRY

ORGANIC – CHEMISTRY OF COMPOUNDS FROM LIVING THINGS AS OPPOSED TO INORGANIC COMPOUNDS

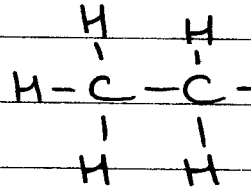
– STUDY OF COMPOUNDS CONTAINING CARBON

SIMPLEST COMPOUNDS

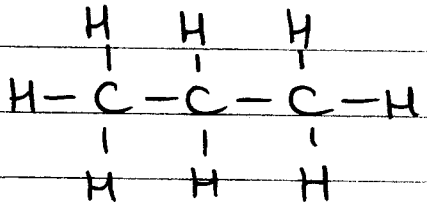
CARBON + HYDROGEN ⟶ HYDROCARBONS



CH_4 methane



C_2H_6 ethane



C_3H_8 propane

} ALKANES

Hydrocarbons serve as a framework from which to dangle functional groups

– FUNCTIONAL GROUPS

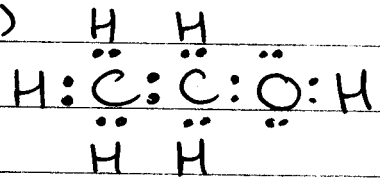
SPECIFIC COMBINATIONS OF ATOMS IN PRECISE ARRANGEMENTS –

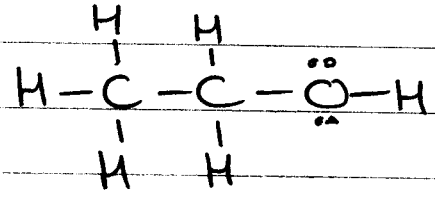
(i) DIVIDE ORGANIC COMPOUNDS INTO CLASSES
(ii) PROVIDE A BASIS FOR NAMING COMPOUNDS
(iii) PREDICTABLE CHARACTERISTIC REACTIVITY

ALCOHOLS $CH_3CH_2\underline{OH}$

ethanol

DRAWING MOLECULES

(i) 

(ii) 

(iii) CH_3CH_2OH

(iv) C_2H_5OH

(v) EtOH

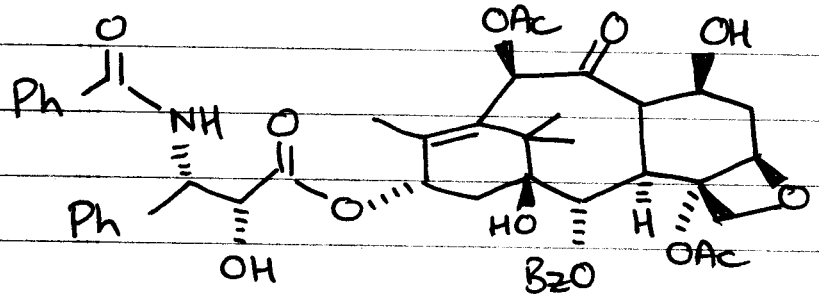
(vi) 

Line formula

Atoms other than C, H

$\Longrightarrow$ HETEROATOMS

O, N, S, P, F, Cl, Br, I



TAXOL

- FUNCTIONAL GROUPS
- STEREOCHEMISTRY
- COMMON ABBREVIATIONS
- LINE FORMULAE

- most promising anti-tumor agent developed in three decades

1998 Sales $1.2 BILLION

Where from - NOT LIKE IT GROWS ON TREES

Well, yes it does, BARK of PACIFIC YEW

Six 100 yr old trees (KILLS TREES) $\longrightarrow$ 1 patient

- SYNTHESIS ⇒ making molecules

⇓

REACTIONS (A + B → C)

⇓

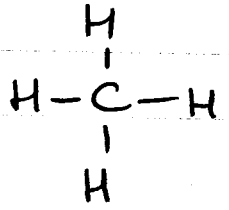
MECHANISMS HOW IT WORKS

To figure all this out - need to understand molecules

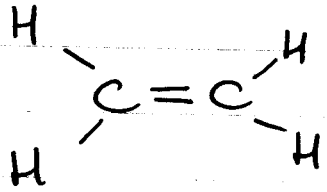
- STRUCTURE
- BONDING → ELECTRONS
  ORBITALS

NOT ABSOLUTE, BUT IN GENERAL
(and in charge neutral species)

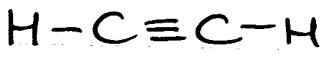
- H forms 1 BOND
- C forms 4 BONDS



methane
(ALKANE)

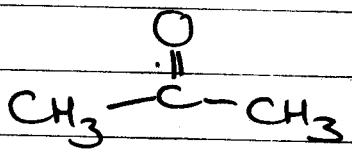
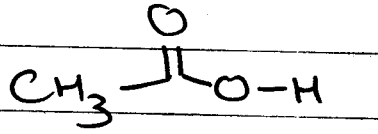
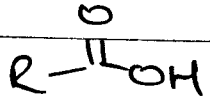


ethylene
(ALKENE)

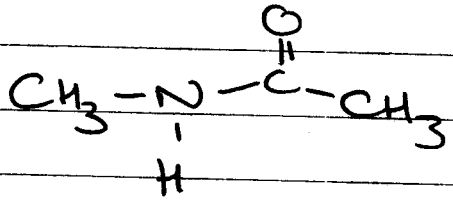
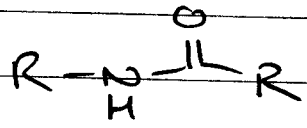


acetylene
(ALKYNE)

- O forms 2 BONDS
- Hal forms 1 BOND
  (F, Cl, Br, I)

CH_3CH_2-O-H	alcohol	R-OH
CH_3-O-CH_3	ether	R-O-R
	ketone	
	carboxylic acid	
CH_3CH_2-Cl	alkyl chloride	R-Cl

- N forms 3 BONDS

CH_3-NH_2	amine	$R-NH_2$
	amide	

- S, P ⟹ variable.

LEC (2) CHEM 30A Oct 4th

1. CHEMICAL BONDING
2. LEWIS STRUCTURES
3. FORMAL CHARGE
4. SHAPES OF MOLECULES
5. DRAWING ORGANIC STRUCTURES
6. DIPOLE MOMENTS
7. RESONANCE

HMK Read FUNCTIONAL GROUPS Sect 1.3
1.6-1.14, 1.23-1.49

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(1) Chemical Bonding

Valence electrons (outer shell electrons)
⇒ these are what form bonds

1	2		3	4	5	6	7	8	# valence e⁻
H								He	
Li	Be	d-BLOCK	B	C	N	O	F	Ne	
Na	Mg		Al	Si	P	S	Cl	Ar	

ELECTRONEGATIVITY (EN) — AN ATOM'S ATTRACTION FOR ELECTRONS IT SHARES IN A CHEMICAL BOND WITH ANOTHER ATOM

F has HIGHEST VALUE AT 4.0

decreases ← F

↓

decreases

PAULING SCALE
(Linus Pauling 1901–1994)
CHEM 1954
PEACE 1962

WEDNESDAY

~$1M DEC 10TH (NOBEL DEATH)

Organic chemistry – mainly concerned w/ COVALENT BONDS

EN differences < 2

Na F → NaF or $Na^+ F^-$
0.9 4 ionic salt
(3.1)

O H → δ^- δ^+ polar
3.5 2.1 O–H covalent
(1.4)

C C → C–C nonpolar covalent
2.5 2.5
(0)

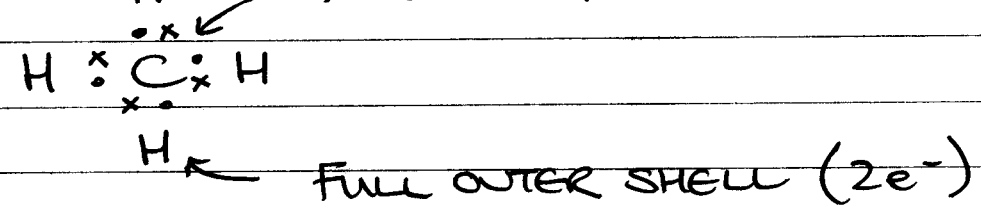
EN difference < 0.5 ⇒ NON POLAR

C–H (TABLE 1.5 pg 7)
2.5 2.1
↳ know values for common elements

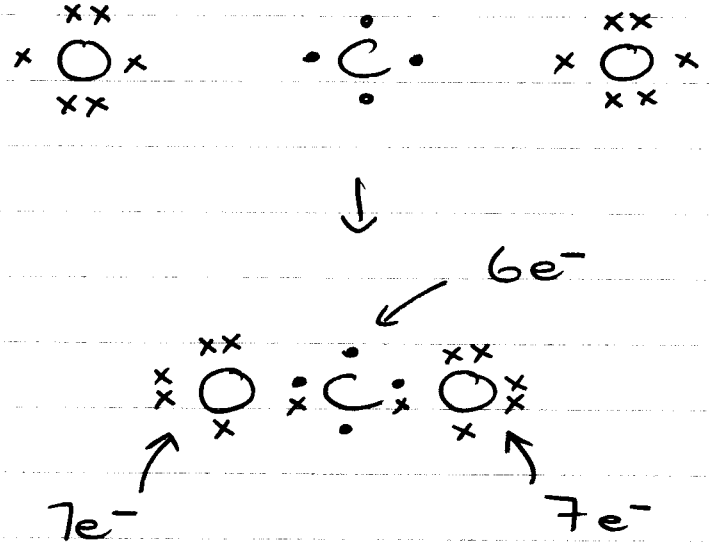
② LEWIS STRUCTURES

- # of VALENCE ELECTRONS ON EACH ATOM
- IN GENERAL, PUT LEAST EN ELEMENT IN THE MIDDLE (ignore H)
- FORM SINGLE BONDS - FILL OCTETS

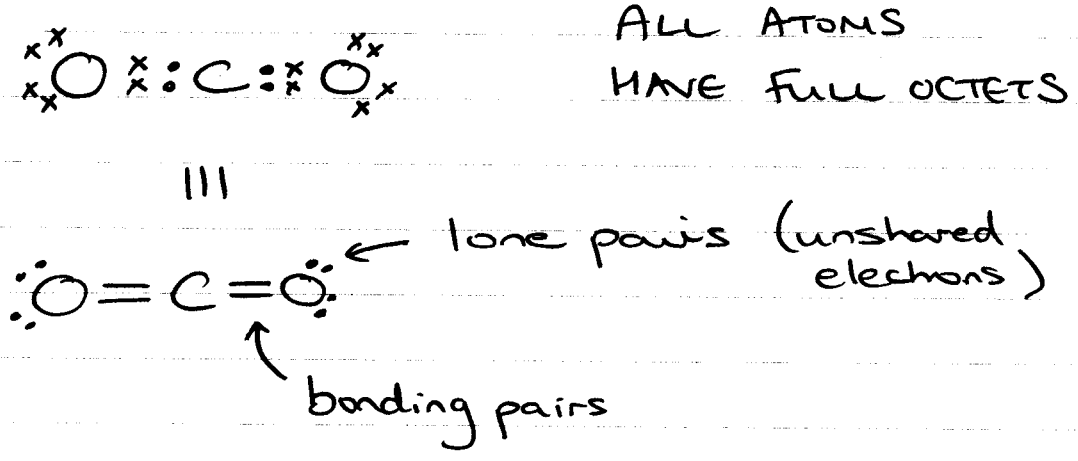
a) CH_4



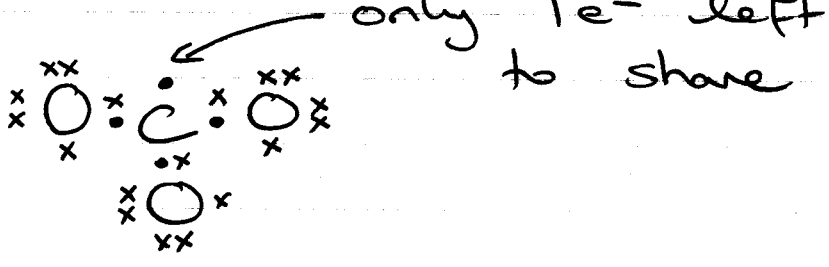
b) CO_2

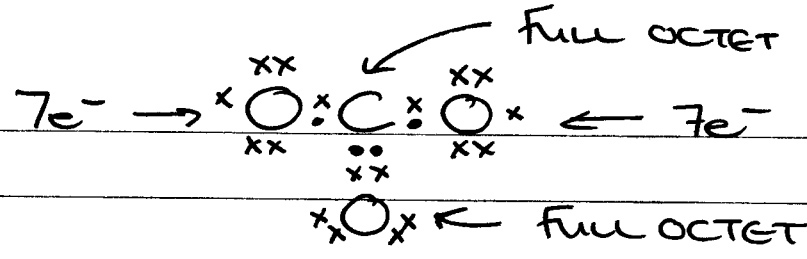


SO, SHARE MORE ELECTRONS

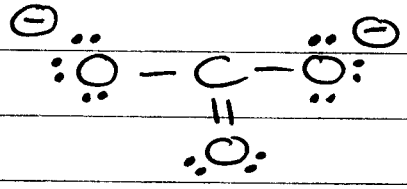


c) CO_3^{2-} (ANION)

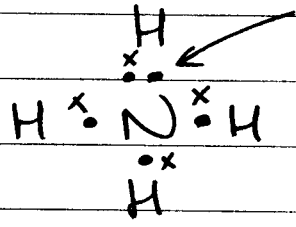




BUT 2^- SO ADD TWO ELECTRONS (DRAW THEM IN ABOVE)

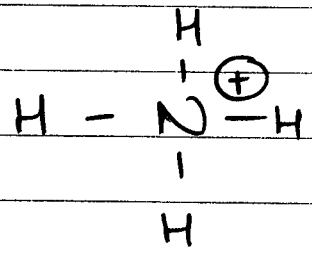


d) NH_4^+ (CATION)



VIOLATES OCTET RULE

So, get rid of it. (ERASE IT)



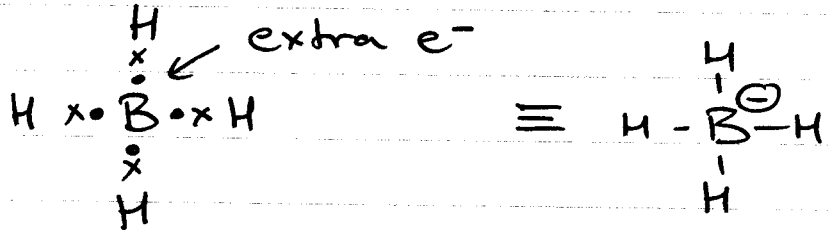
③ FORMAL CHARGE

- DRAW LEWIS STRUCTURE

For each atom's valence shell,
ADD # of NON-BONDING electrons
$\frac{1}{2}$ # of BONDING electrons

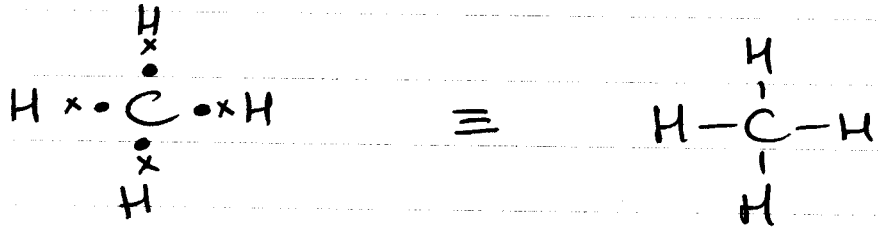
FORMAL CHARGE = # VALENCE ELECTRONS IN ISOLATED NEUTRAL ATOM − THIS NUMBER

a) $BH_4^{\ominus}$



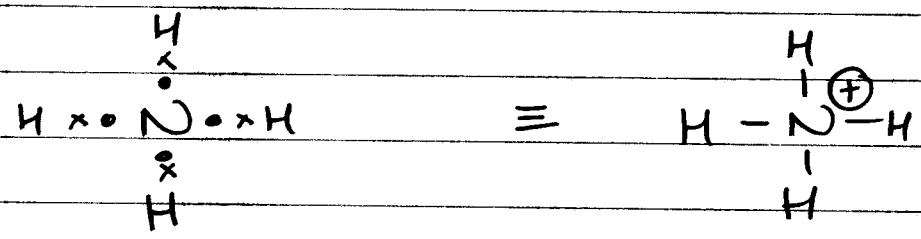
$(3 - 8/2) = -1$

b)



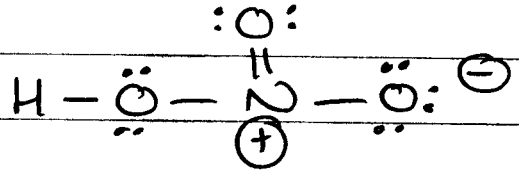
$(4 - 8/2) = 0$

c) NH_4^+
(already seen)



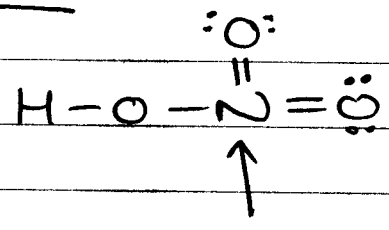
$(5 - {}^8/_4) = +1$

d) HNO_3 (nitric acid)



$N\,(5 - {}^8/_2) = +1$
$O\,(6 - ({}^2/_2 + 6)) = -1$

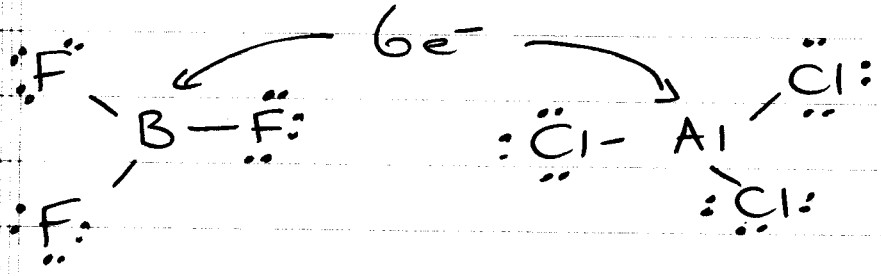
NOT



$10e^-$ VIOLATES
OCTET RULE

Note: EXCEPTIONS TO OCTET RULE

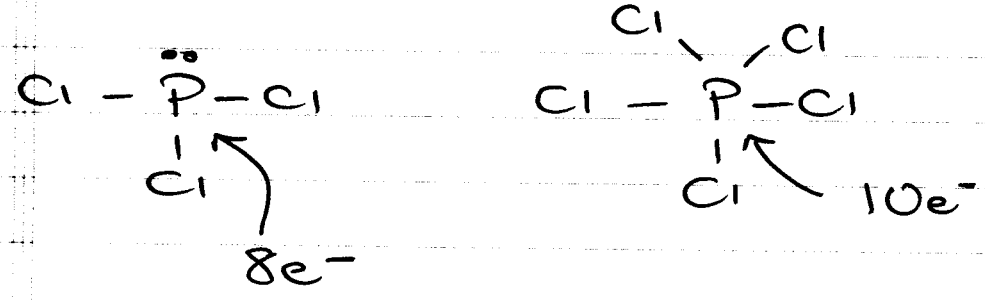
GROUP 3



3rd Row ELEMENTS (P & S)

– d orbitals ⇒ EXPAND OCTET

PCl_3 and PCl_5



④ SHAPES OF MOLECULES

Valence Shell Electron Pair Repulsion THEORY (VSEPR)

Simplified model

Geometry determined by valence shell ELECTRON PAIRS (σ and lp not π) arranging to minimize electrostatic repulsions.

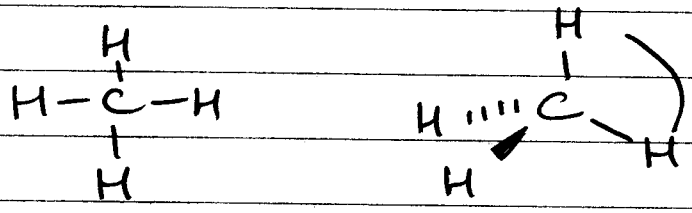
other considerations

lp − lp > lp − bp > bp − bp

and

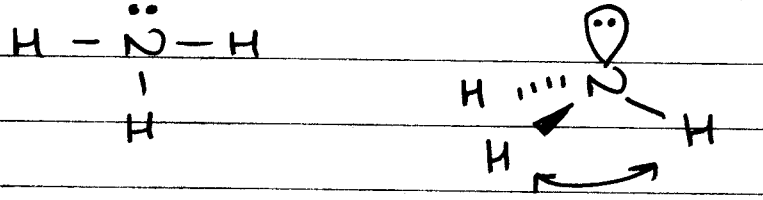
A ≡ B > A = B > A − B

So



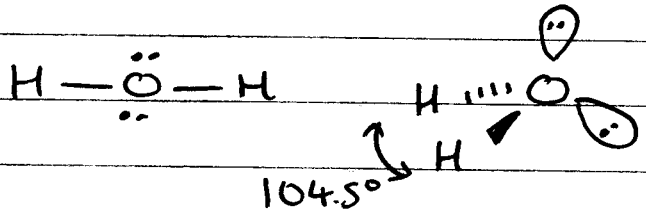
REGULAR TETRAHEDRON

tetrahedral



PYRAMIDAL

Compressed

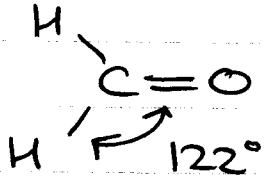


BENT

more compressed

linear

linear

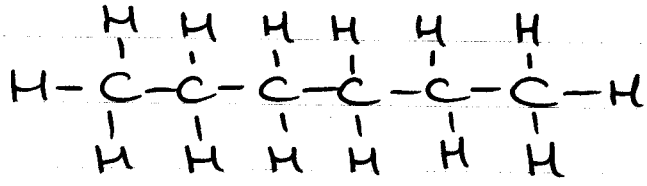


trigonal planar

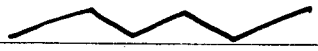
2 LINEAR
3 TRIGONAL PLANAR
4 TETRAHEDRAL
5 TRIGONAL BIPYRAMIDAL
6 OCTAHEDRAL

(5) DRAWING ORGANIC STRUCTURES

- Draw chains of atoms as a zigzag
- Miss out H atoms from C atoms (not from heteroatoms)
- Miss out Cs of C atoms
- Draw all lone pairs



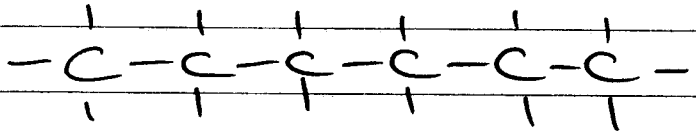
HEXANE (naming later)



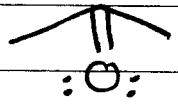
DO NOT WRITE

C–C–C–C–C–C WRONG

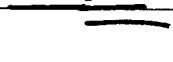
or

 WRONG

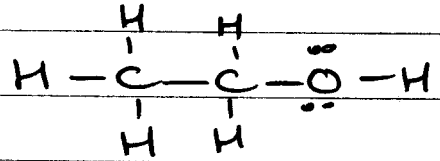
Try to be as true to molecular shape as possible

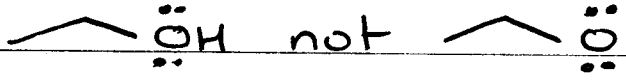
 BAD  GOOD

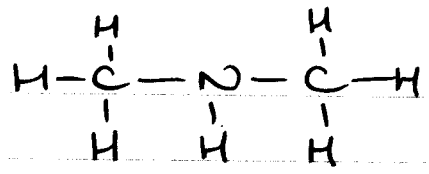
 BAD  GOOD

 BAD  GOOD

HETEROATOMS







not

C_5H_{12}

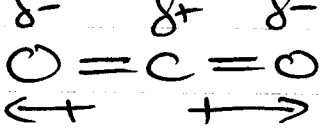
all C_5H_{12}

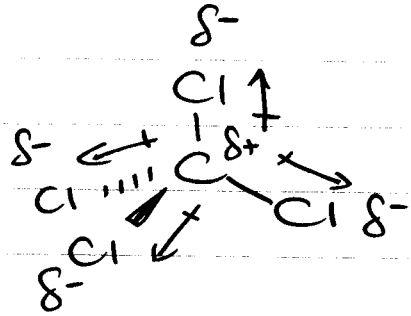
CONSTITUTIONAL ISOMERS
- same molecular formula, different arrangements of atoms

QUICKER TO DRAW

⑥ DIPOLE MOMENTS

Vector Sum of BOND dipoles

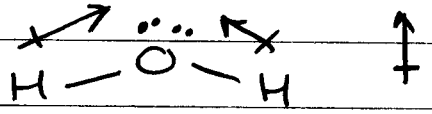




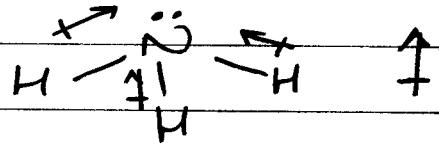
μ = 0D

μ = 0D

D = debye



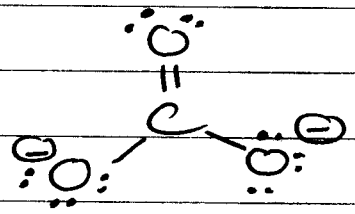
$\mu = 1.85$ D



$\mu = 1.47$ D

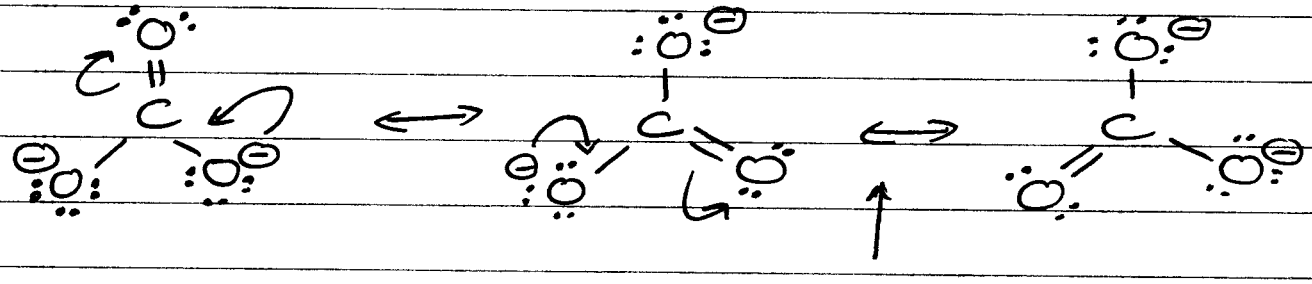
(7) RESONANCE

consider CO_3^{2-}



one C=O bond
two C–O bonds

However all carbon–oxygen bonds are the same

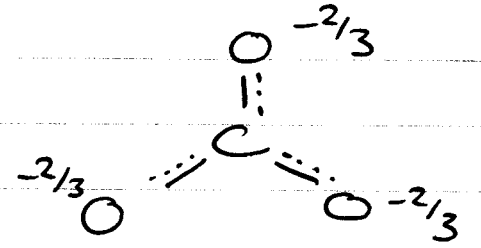


means RESONANCE

↷ movement of pair of electrons

THREE RESONANCE CONTRIBUTORS
(ALL EQUIVALENT)

NONE OF THEM ARE REAL



RESONANCE HYBRID

- NON EQUIVALENT CONTRIBUTORS

DIFFERENT ENERGIES

- RULES FOR DRAWING RESONANCE STRUCTURES

- RULES FOR DETERMINING IMPORTANCE OF CONTRIBUTING STRUCTURES

LEC (3) CHEM 30A Oct 6th

(1) SHAPES OF MOLECULES
(2) DRAWING ORGANIC STRUCTURES
(3) RESONANCE

HMK Problems 1.15 – 1.17
1.50 – 1.54

Read the rest of Chapter 1

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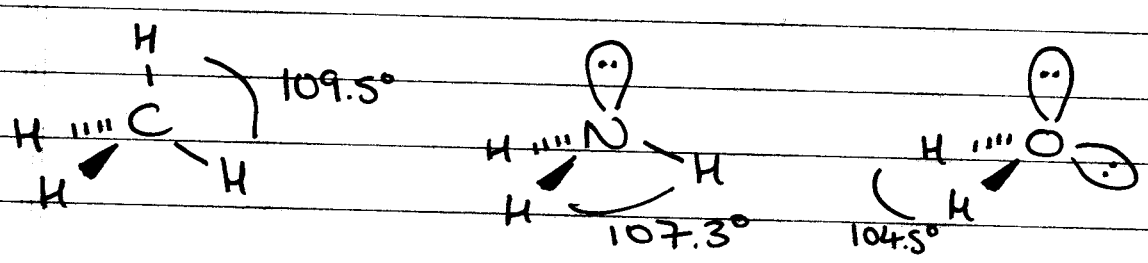
(1) SHAPES OF MOLECULES

- PAIRS OF ELECTRONS IN VALENCE SHELL BONDED & NON-BONDED



TETRAHEDRAL PYRAMIDAL BENT

BUT: GEOMETRY AROUND C, N, O is STILL DESCRIBED AS TETRAHEDRAL

REPULSION NB-NB > NB-B > B-B

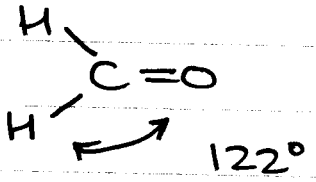
of e^- pairs

2 LINEAR
3 TRIGONAL PLANAR
4 TETRAHEDRAL
5 TRIGONAL BIPYRAMIDAL
6 OCTAHEDRAL

FOR SAKE OF GEOMETRY TREAT MULTIPLE BONDS AS SINGLE BONDS, i.e. JUST 1 e^- PAIR

$O=C=O$ LINEAR

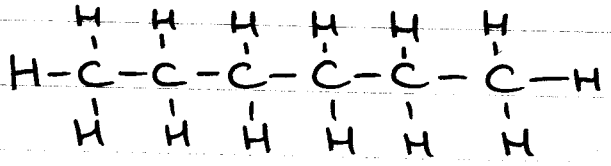
$H-C\equiv C-H$ LINEAR



TRIGONAL PLANAR

$A\equiv B > A=B > A-B$

(2) DRAWING ORGANIC STRUCTURES



HEXANE

STRUCTURAL FORMULA

– CONDENSED FORMULA

$CH_3CH_2CH_2CH_2CH_2CH_3$

– LINE FORMULA

- DRAW CHAINS AS ZIG-ZAGS
- LEAVE OUT ANY Hs ATTACHED TO Cs
- DRAW NON-BONDED ELECTRONS (LONE PAIRS)

a)

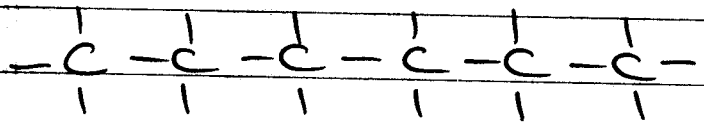
THIS IS A C ATOM (2 Hs ON IT)

THIS IS A C ATOM (THERE ARE 3 Hs ON IT)

DO NOT WRITE

C – C – C – C – C – C

OR



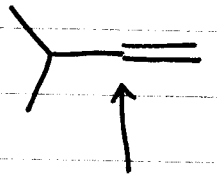
b) CH_3

$CH - CH = CH_2$

CH_3

(DRAW THIS ONE FIRST)

$(CH_3)_2CHCHCH_2$



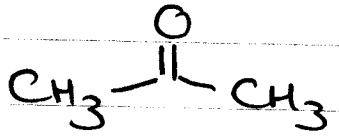
MAYBE YOU WOULD DRAW THIS

GEOMETRY OF THIS C ATOM?

TRIGONAL PLANAR, SO:

TRY TO BE AS TRUE TO MOLECULAR SHAPE AS POSSIBLE

$CH_3(CO)CH_3$

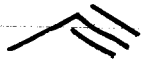


GOOD

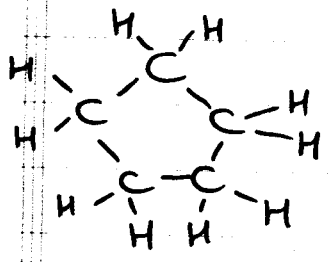
TRIGONAL PLANAR

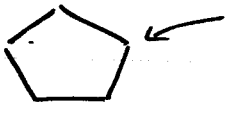
BAD

CH_3CCH $CH_3-C\equiv C-H$

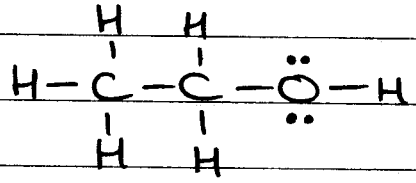
not  but 

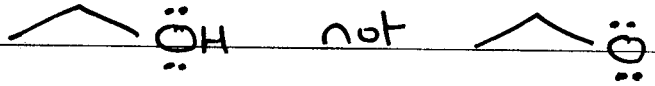
— RINGS

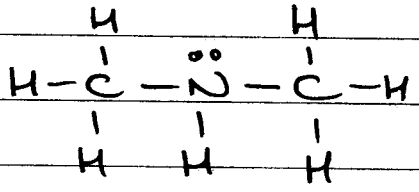


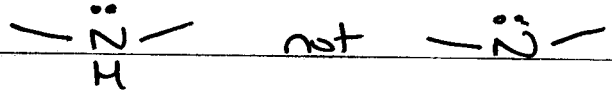
≡  ← each one of these is a CH_2

- HETEROATOMS







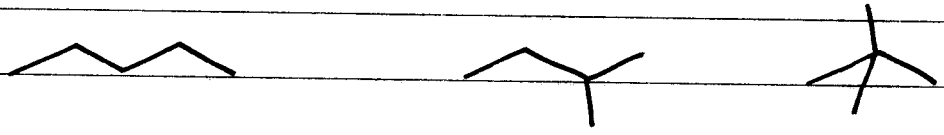


DRAW Hs ON HETEROATOMS

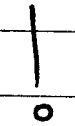
- EXAMPLE

C_5H_{12}

DRAW ALL REASONABLE STRUCTURES WITH THIS FORMULA

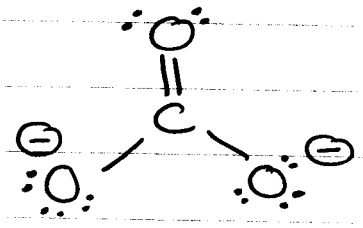


CONSTITUTIONAL ISOMERS - same formula different arrangements of atoms

R GROUPS 

③ RESONANCE

consider CO_3^{2-}

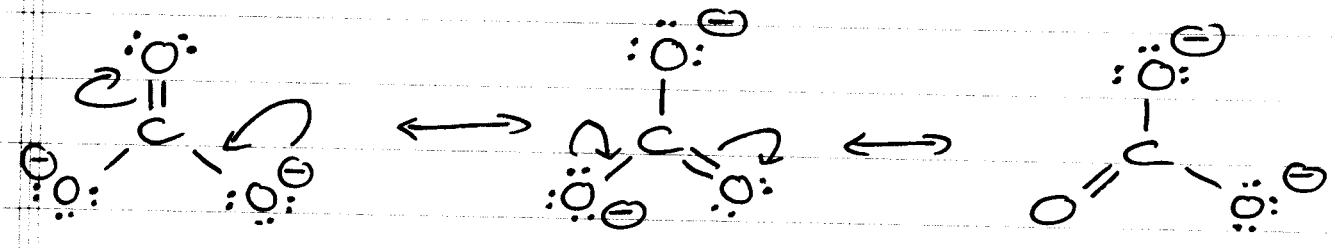


one C=O BOND
two C-O BONDS

C=O SHORTER THAN C-O
(STRONGER)

IN CO_3^{2-} HOWEVER, ALL CARBON-OXYGEN BONDS ARE IDENTICAL

WHY?



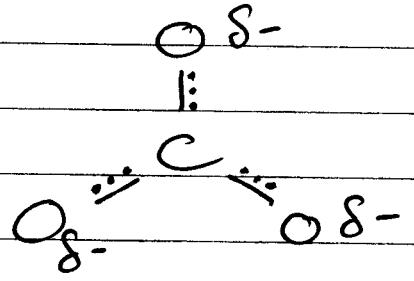
RESONANCE CONTRIBUTORS
(ALL EQUIVALENT)

ARROWS

$\longleftrightarrow$ SEPARATES RESONANCE CONTRIBUTORS

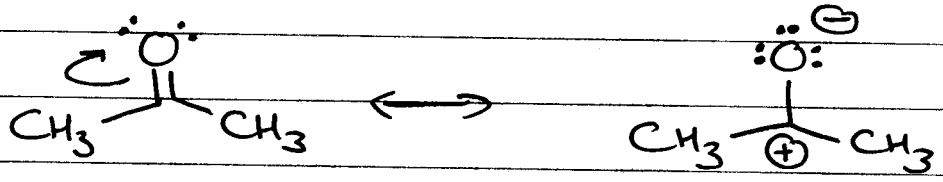
CURLY ARROW - MOVEMENT OF A PAIR OF ELECTRONS

NONE OF THESE CONTRIBUTORS ACTUALLY EXIST!!



RESONANCE HYBRID

NOT ALL RESONANCE CONTRIBUTORS ARE NECESSARILY EQUIVALENT

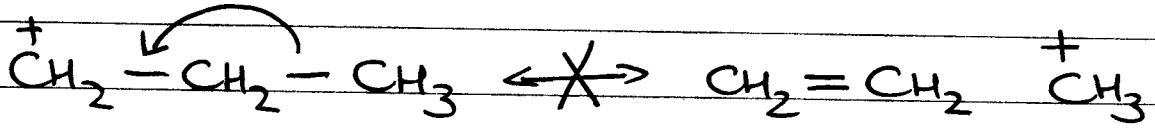


WHICH ONE OF THESE IS MOST STABLE?

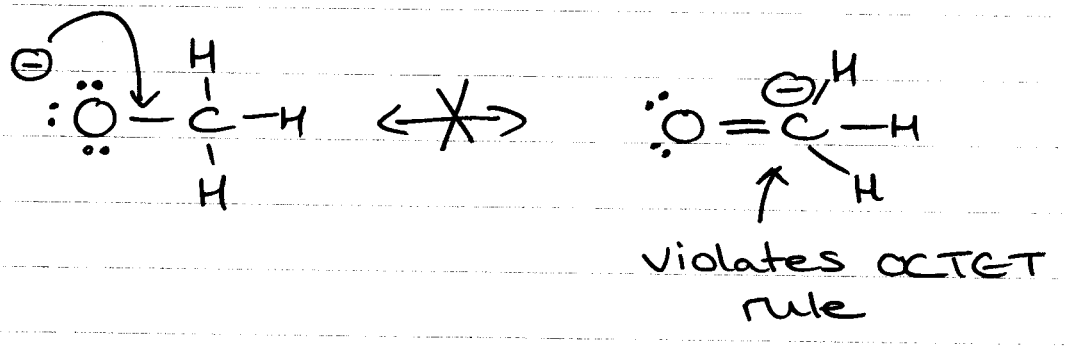
– RULES FOR WRITING RESONANCE STRUCTURES

<u>DO NOT</u>

(1) BREAK ANY SINGLE BONDS



② DO NOT VIOLATE THE OCTET RULE



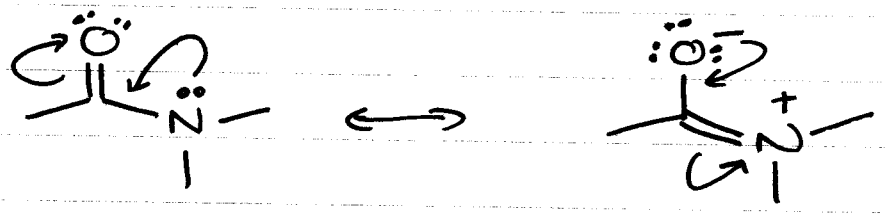
– DRAWING RESONANCE STRUCTURES

We cannot break single bonds, so we can only move electrons from double bonds, triple bonds (π) and lone pairs

PATTERS

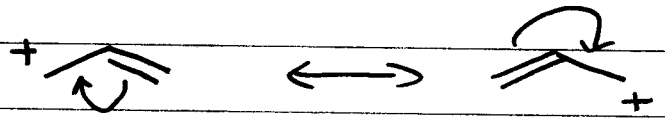
① LONE PAIR NEXT TO π BOND

"NEXT TO" MEANS ONE SINGLE BOND AWAY

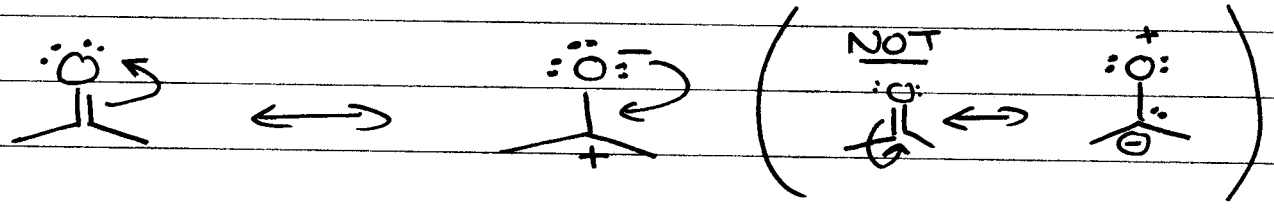


② LONE PAIR NEXT TO +VE CHARGE

(3) π BOND NEXT TO A +ve CHARGE

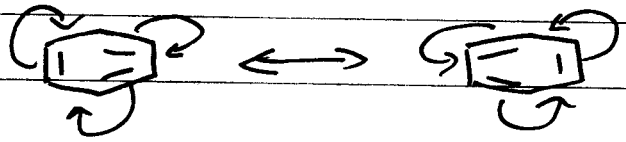


(4) π BOND BETWEEN TWO ATOMS WHERE ONE IS QUITE ELECTRONEGATIVE



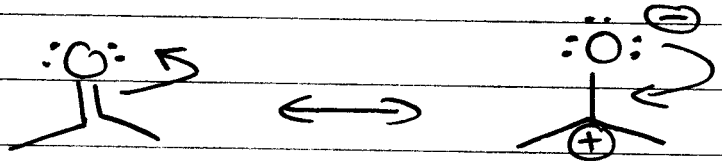
ELECTRONS GO TO MORE ELECTRONEGATIVE ATOM

(5) ALTERNATING π BONDS IN A RING



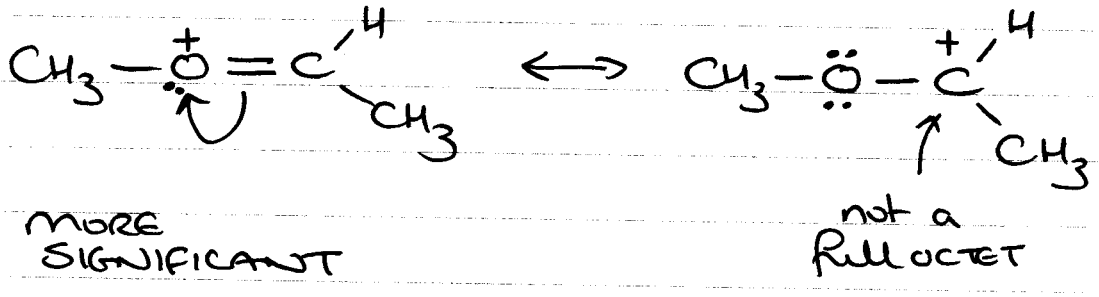
RELATIVE IMPORTANCE OF CONTRIBUTING STRUCTURES

(1) MINIMIZE CHARGES



MORE SIGNIFICANT

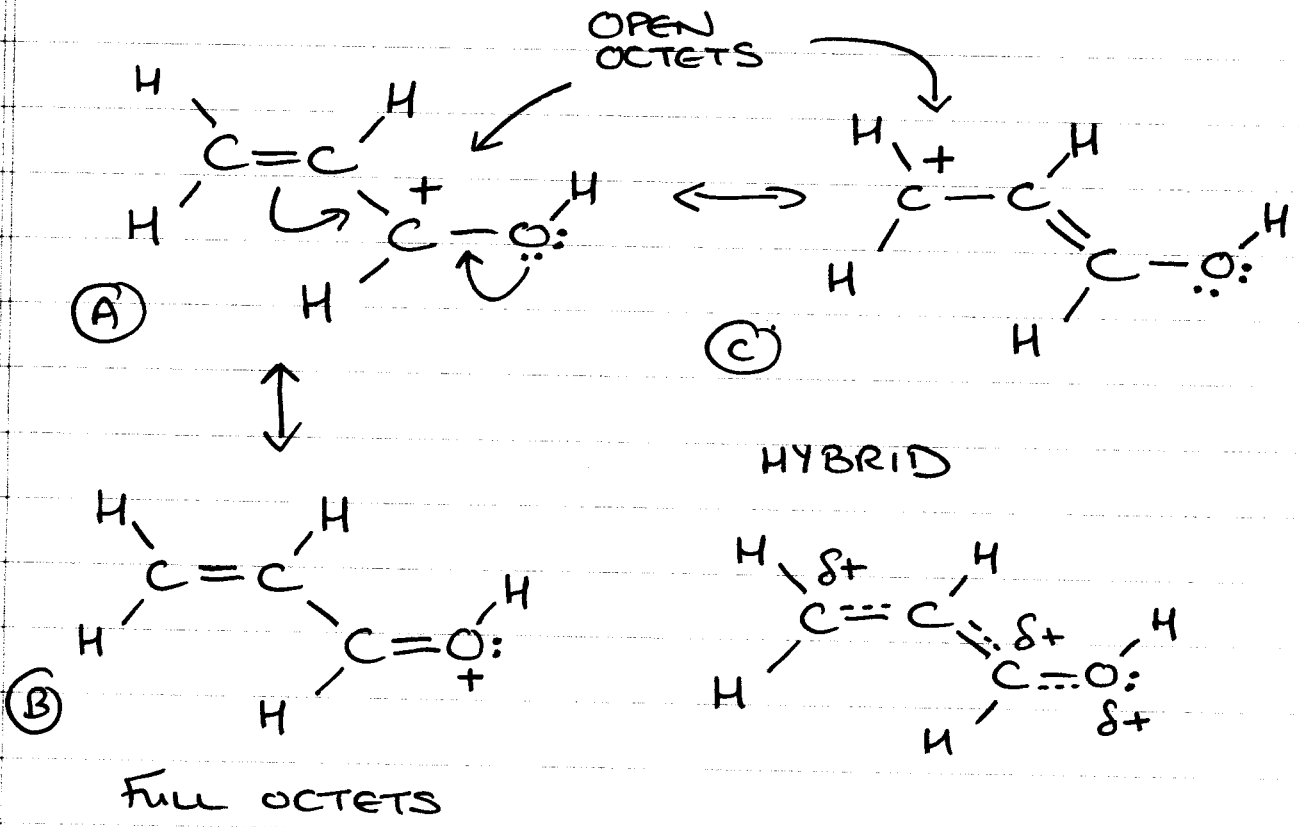
(2) MAXIMIZE OCTETS



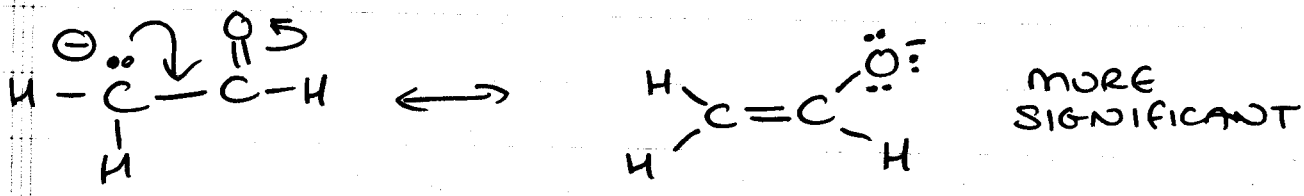
MORE SIGNIFICANT

not a FULL OCTET

EXAMPLE



(3) NEGATIVE CHARGE ON MORE EN ELEMENT



MORE SIGNIFICANT

LEC 4 CHEM 30 A Oct 8th

1. RESONANCE
2. ATOMIC ORBITALS
3. MOLECULAR ORBITALS
4. HYBRIDIZATION

HMK 1.18, 1.55-1.70

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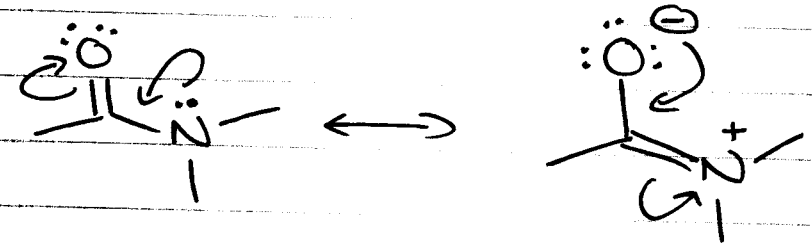
1 RESONANCE CONTINUED...

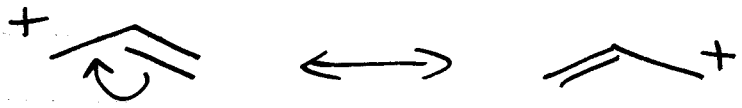
Patterns

1 LONE PAIR / π-BOND

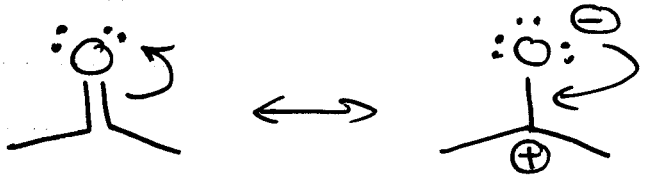


2 LONE PAIR / ⊕ve charge

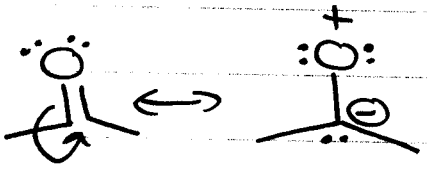
(3) π BOND / ⊕ve charge



(4) π BOND between two atoms where one is quite electronegative



NOT



e^- go to more EN ATOM

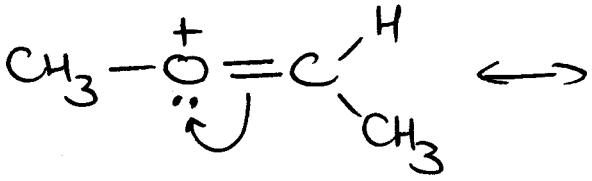
(5) ALTERNATING π BONDS IN A RING

RELATIVE IMPORTANCE OF CONTRIBUTING STRUCTURES

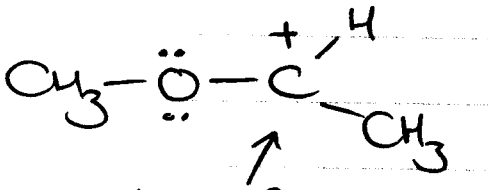
(1) MINIMIZE CHARGES

more significant

② MAXIMIZE OCTETS

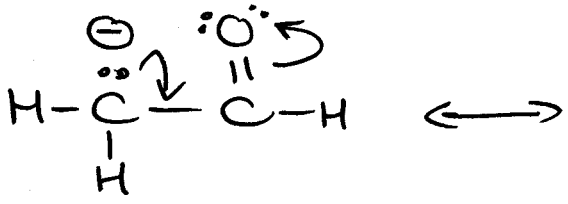


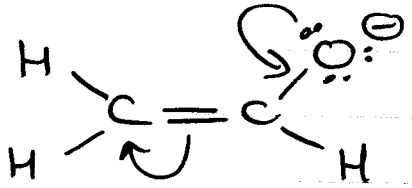
MORE SIGNIFICANT



not a full octet

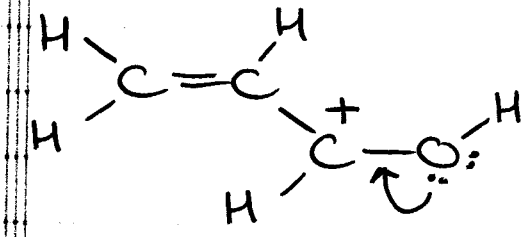
③ NEGATIVE CHARGE ON MORE EN ELEMENT

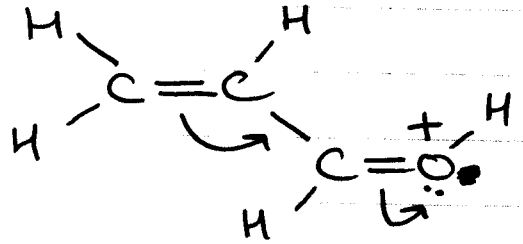




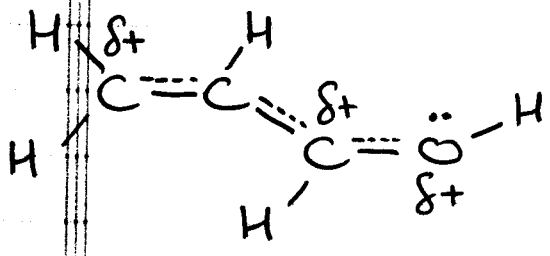
more significant

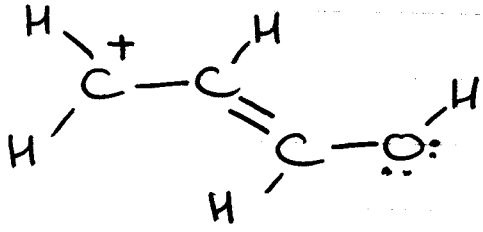
EXAMPLE





HYBRID





(2) ATOMIC ORBITALS

SCHRÖDINGER EQUATION

⇓

PROBABILITY DISTRIBUTIONS OF ELECTRON DENSITY

⇓

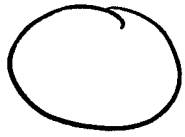
SHAPES OF ORBITALS

⇓

s, p, d, f

sharp, principal, diffuse, fundamental

1s 

2s 

2p ORBITALS

Px

Py

Pz

(3) MOLECULAR ORBITALS

Molecules => many atoms => many atomic orbitals

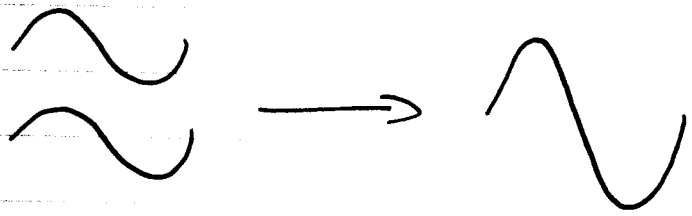
- LCAO (linear combination of atomic orbitals)

n AOs $\longrightarrow$ n MOs

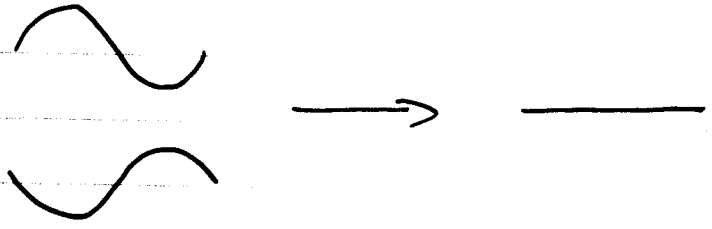
Same filling rules

- AUFBAU PRINCIPLE (lowest energy first)
- PAULI EXCLUSION PRINCIPLE (2 e⁻ OPP SPIN)
- HUND'S RULE (don't pair until you must)

Orbitals $\Rightarrow$ Wavefunctions
- combine like waves

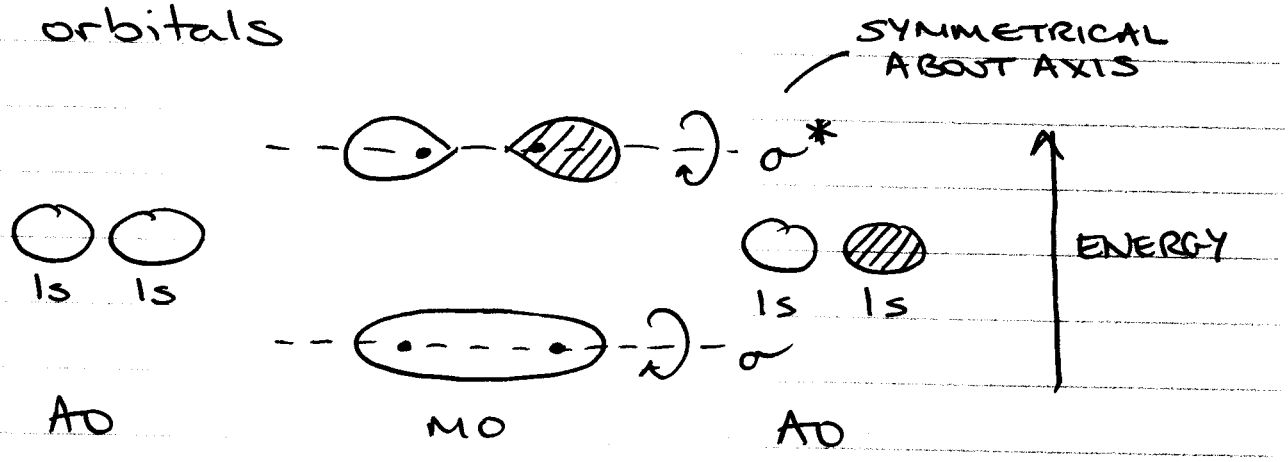


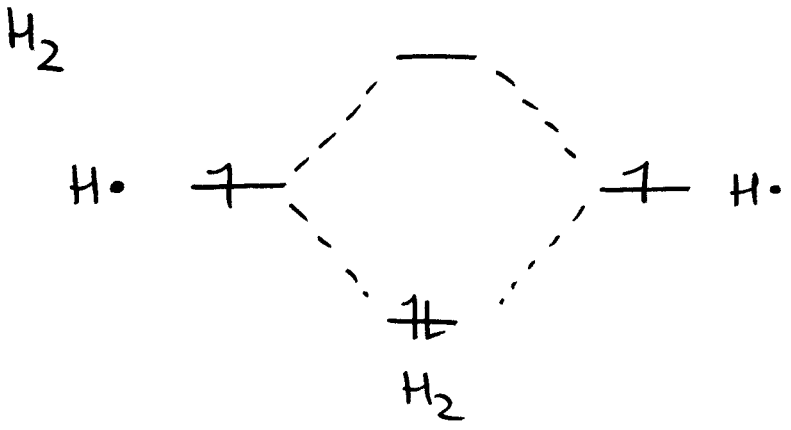
in phase (constructive)



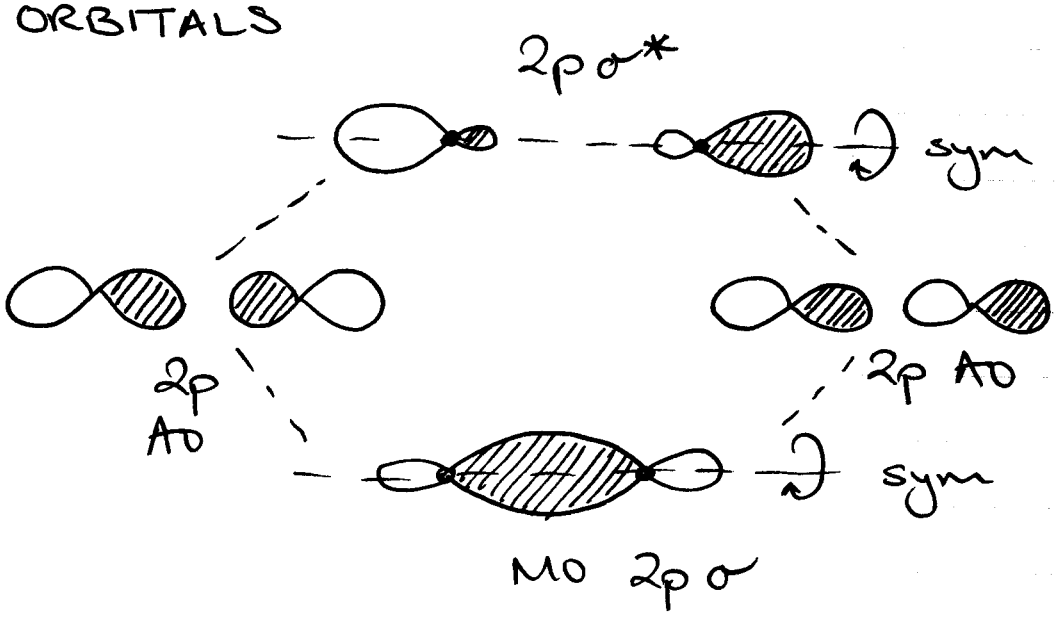
out of phase (destructive)

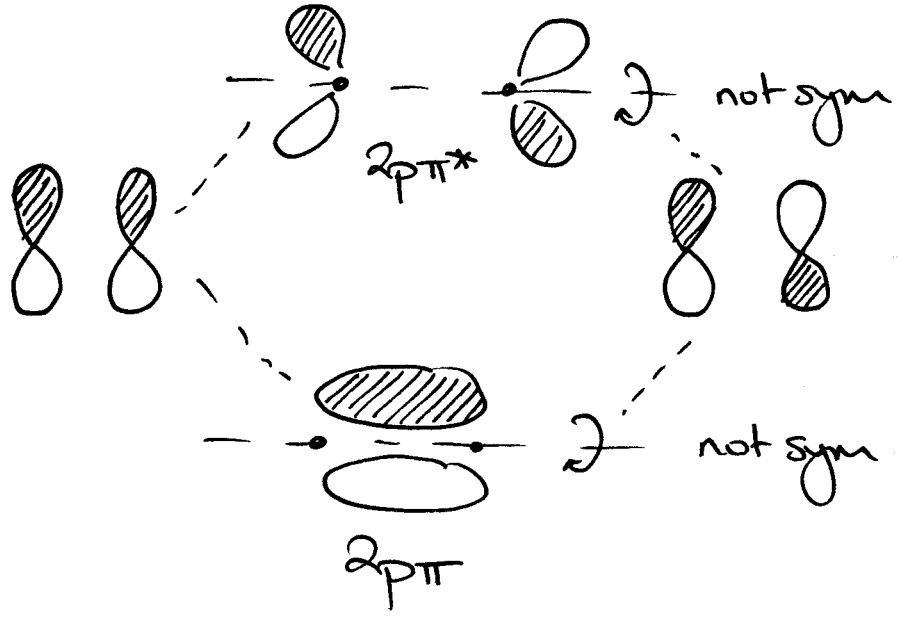
- S orbitals





p ORBITALS





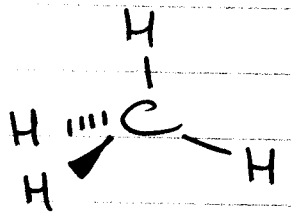
σ BONDS STRONGER THAN π BONDS — MORE OVERLAP

④ HYBRIDIZATION

C $1s^2\ 2s^2\ 2p^2$

$1s^2\ 2s^2\ 2p_x^1\ 2p_y^1\ 2p_z^0$

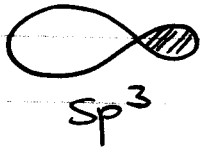
ONLY 2 unpaired electrons
and p orbitals are 90° apart

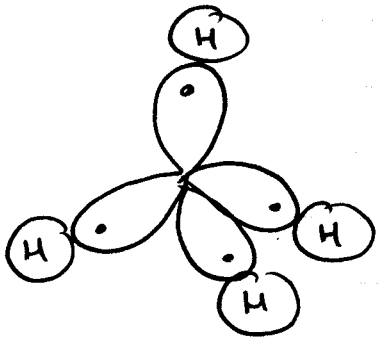
So, how do we explain 

HYBRID ORBITALS (PAULING)

sp^3 1 x 2s 3 x 2p ⟹ 4 x sp^3

equiv hybrid orbitals



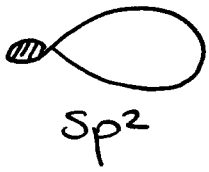


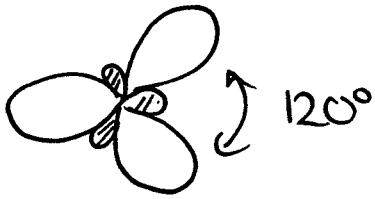
CH_4

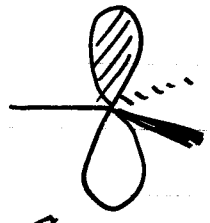
4 x 1s – $2sp^3$ σ BONDS

sp^2 1 × 2s and 2 × 2p

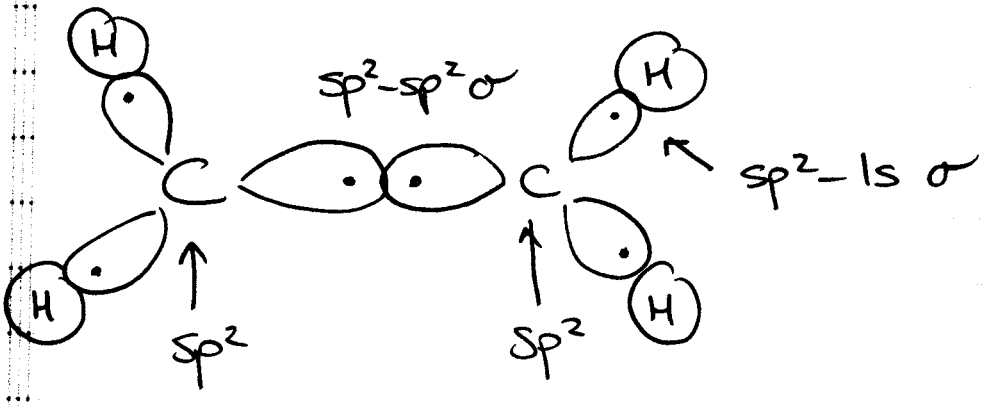
$\Rightarrow$ 3 × sp^2 orbitals







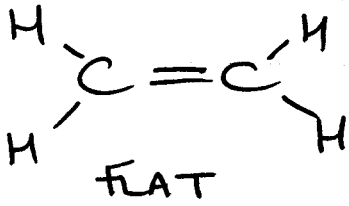
one left over p orbital



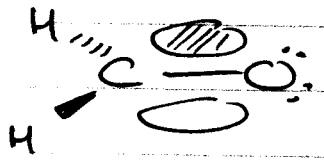
σ BOND FRAMEWORK

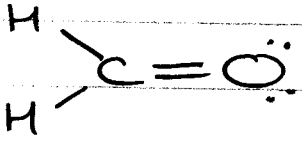
π BOND

≡

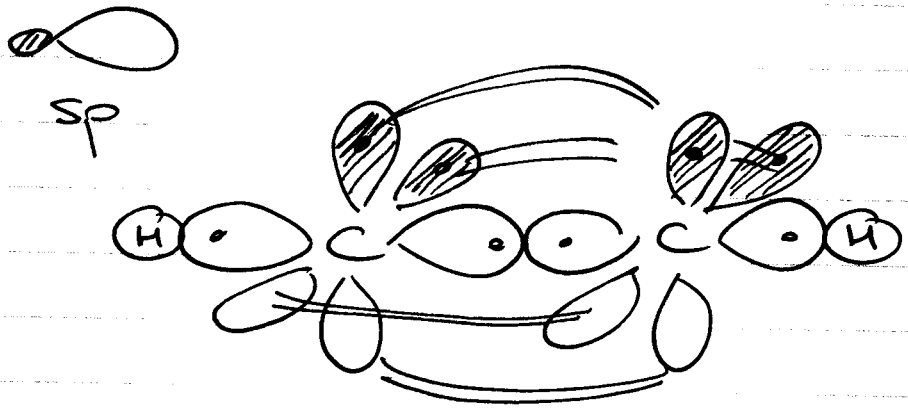


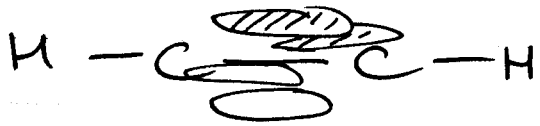
FLAT





sp 1 x 2s and 1 x 2p





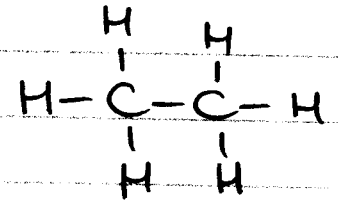
$H-C\equiv C-H$

↑

1 x sp–sp σ

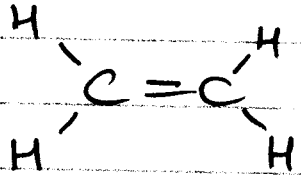
2 x $2p_{\pi}$

CONSIDER



C–C
1.53 Å
88 kcal mol^{-1}

C–H
sp^3–1s σ
1.11 Å
98 kcal/mol



not ×2

C=C
1.34 Å
146 kcal mol^{-1}

C–H
sp^2–1s σ
1.10 Å
104 kcal/mol

not ×3

H–C≡C–H

C≡C
1.21 Å
200 kcal mol^{-1}

C–H
sp–1s σ
1.09 Å
125 kcal/mol

Å = 10^{-10} m

More S character
→ electrons closer to nucleus
→ stronger / shorter bonds

So, to determine HYBRIDIZATION

ADD # of BONDED ATOMS TO # LONE PAIRS

4 → sp^3
3 → 3 × sp^2 + 1 × p
2 → 2 × sp + 2 × p

LEC (5) CHEM 30A Oct 11th

(1) HYBRIDIZATION

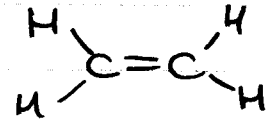
Chapter 2

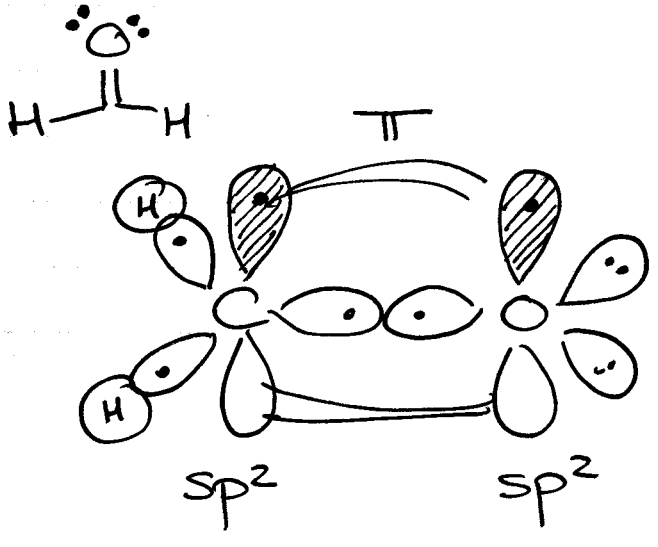
(2) ALKANES
- STRUCTURE
- ISOMERS
- NOMENCLATURE
- CONFORMATION
- PROPERTIES

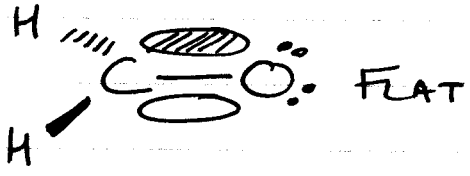
HMK: Reading Ch2
Problems: 2.1, 2.2, 2.8, 2.17–2.21, 2.24–2.26

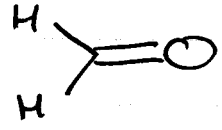
QUIZ ON WEDNESDAY IN CLASS

(1) HYBRIDIZATION cont: sp^2



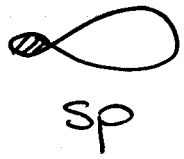


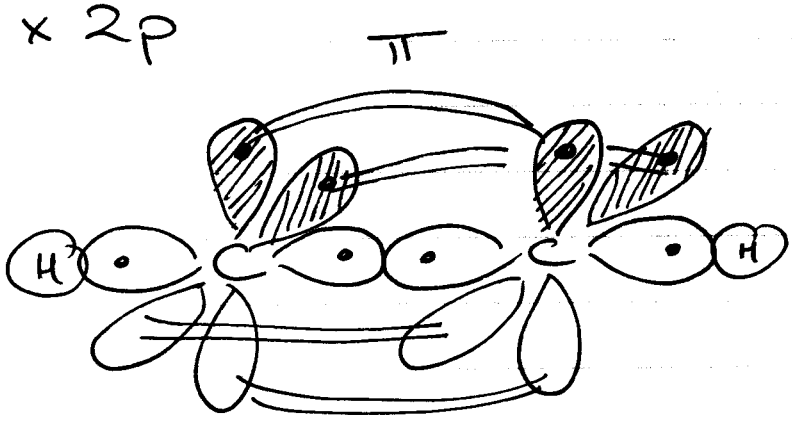




sp HYBRIDIZATION

1 x 2s and 1 x 2p



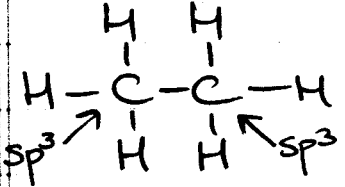


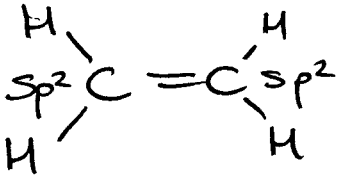
$\Rightarrow$ H–C≡C–H

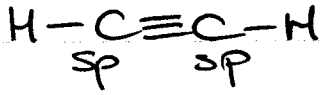
1x sp – sp σ

2x 2p – 2p π

CONSIDER







C–C	1.53 Å	1.34 Å	1.21 Å (10^{-10} M)
	88 kcal mol^{-1}	146 kcal mol^{-1} (not ×2)	200 kcal mol^{-1} (not ×3)
	σ stronger than π		
C–H	1.11 Å	1.10 Å	1.09 Å
	98 kcal/mol	104 kcal mol^{-1}	125 kcal mol^{-1}

More s character in hybrid orbital

↳ e^- closer to nucleus

↳ stronger/shorter bonds

SIMPLE WAY TO DETERMINE HYBRIDIZATION

ADD # BONDED ATOMS TO # LONE PAIRS

four

4 → sp^3

3 → three sp^2 and one p

2 → two sp and two p

② ALKANES

(i) STRUCTURE

SATURATED HYDROCARBONS

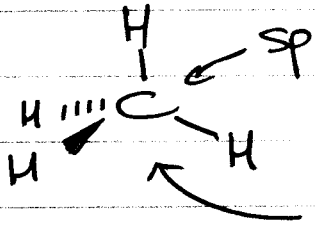
⇓ ⇓

ONLY C & H

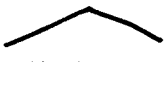
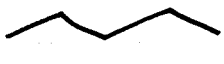
EACH C

HAS MAX # H

General formula C_nH_{2n+2} (without rings)



METHANE

CH_4	methane	CH_4
CH_3-CH_3	ethane	C_2H_6
	propane	C_3H_8
	butane	C_4H_{10}
	pentane	C_5H_{12}
	hexane	etc, etc C_6H_{14}

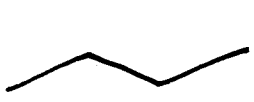
$CH_3(CH_2)_n CH_3$

(ii) ISOMERS

- same molecular formula, different attachment of atoms
  CONSTITUTIONAL ISOMERS

CH_4, C_2H_6, C_3H_8
each has only ONE possible arrangement

How ABOUT C_4H_{10}



butane 2-methyl propane

Do C_6H_{14} for HMR (5 structures)

(iii) NOMENCLATURE

International Union of Pure and Applied Chemistry (IUPAC)

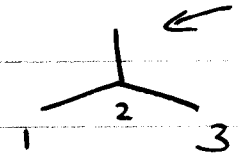
SYSTEMATIC NAMING

- STRAIGHT CHAINS (DONE) ✓

- BRANCHED STRUCTURES

① IDENTIFY LONGEST CHAIN

② EACH SUBSTITUENT GETS A NAME AND NUMBER

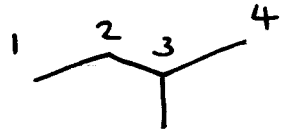


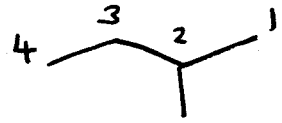
2-METHYL PROPANE

ALKYL GROUPS

CH_3- methyl
CH_3CH_2- ethyl
$CH_3CH_2CH_2-$ propyl
$CH_3CH_2CH_2CH_2-$ butyl etc

③ MINIMIZE SUBSTITUENT NUMBER

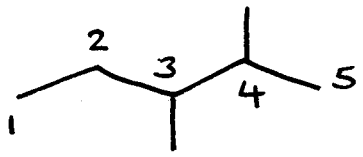


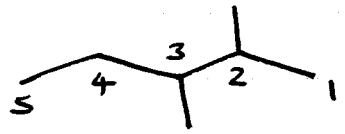


3 METHYL BUTANE ✗

2 METHYL BUTANE ✓

④ SAME SUBSTITUENT MORE THAN ONCE

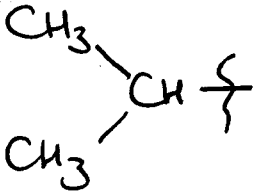




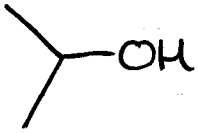
2,3- DIMETHYL PENTANE

After this, it gets SILLY.

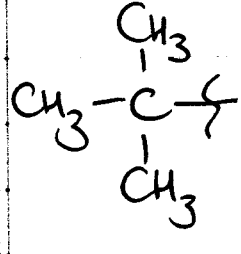
Common names



isopropyl

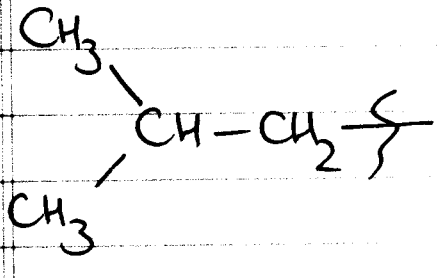


isopropyl alcohol

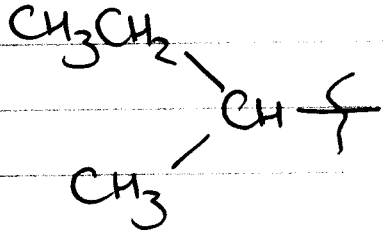


tert-butyl

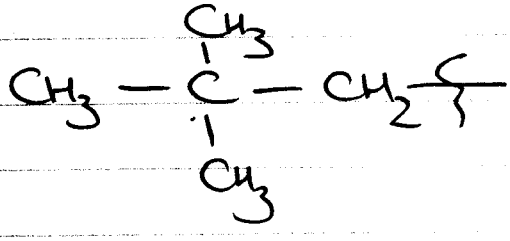
t-butyl alcohol



isobutyl



sec-butyl



neo-pentyl

CYCLOALKANES

CYCLOPROPANE C_3H_6

CYCLOBUTANE C_4H_8

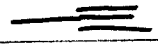
CYCLOPENTANE C_5H_{10}

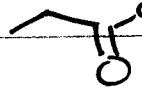
CYCLOHEXANE C_6H_{12}

BICYCLOALKANES — FORGET IT!

PREFIX – INFIX – SUFFIX

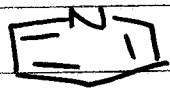
PROP AN E
3Cs single bonds hydrocarbon

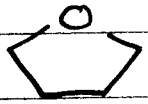
INFIX – AN-  PROPANE
(double) – EN-  PROPENE
(triple) – YN-  PROPYNE

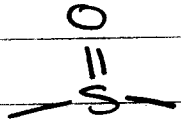
SUFFIX – E  PROPANE
– OL  PROPANOL
– AL  PROPANAL
(– AMINE)*  PROPYL AMINE*
– ONE  PROPANONE
– OIC ACID  PROPANOIC ACID

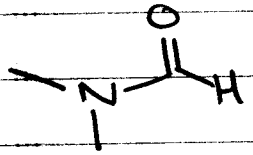
COMMON STRUCTURES/NAMES/ACRONYMS
(keep a notebook)

 acetone

 pyridine

 tetrahydrofuran (THF)

 dimethyl sulfoxide (DMSO)

 dimethylformamide (DMF)

 acetic acid AcOH

LEC (6) CHEM 30A Oct 18th

(1) NOMENCLATURE
(2) CONFORMATION } ALKANES
(3) PROPERTIES

A PENCIL
B ELECTRONIC
C STOP WRITING

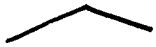
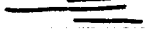
HMK: READ: 2 – 2.6
PROBLEMS: 2.9, 2.27, 2.28

---

(1) NOMENCLATURE

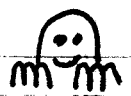
PREFIX – INFIX – SUFFIX

PROP — 3 Cs
AN — single bonds
E — hydrocarbon


INFIX
- AN –  PROPANE
- EN –  PROPENE
- YN –  PROPYNE

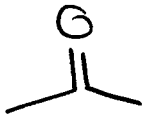
SUFFIX
- –E  PROPANE
- –OL  PROPANOL
- –AL  PROPANAL
- (–AMINE)  PROPYL AMINE
- –ONE PROPANONE
- –OIC ACID  PROPANOIC ACID

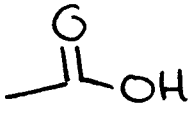
N – HERE YOU GO – S

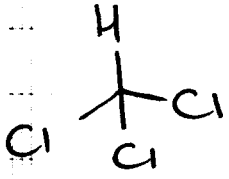


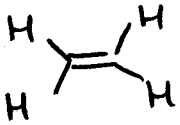
- COMMON NAMES / STRUCTURES / ACRONYMS

- KEEP A NOTEBOOK

 ~~PROPANONE~~ ACETONE

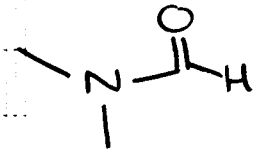
 ~~ETHANOIC~~ ACETIC ACID

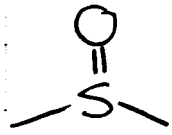
 ~~TRICHLOROMETHANE~~ CHLOROFORM

 ~~ETHENE~~ ETHYLENE

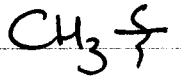
ALL ABOUT COMMON NAMES

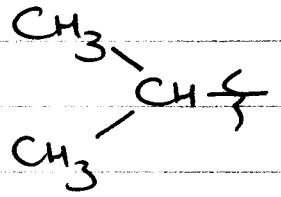
 TETRAHYDROFURAN THF

 DIMETHYLFORMAMIDE DMF

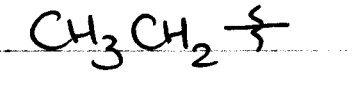
 DIMETHYLSULFOXIDE DMSO

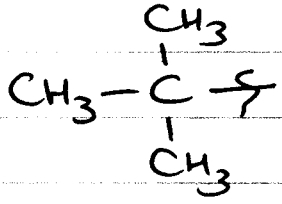
- other common abbreviations

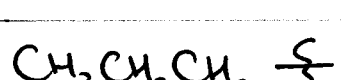
 Me

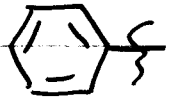
 ^{i}Pr

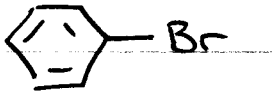
 Et

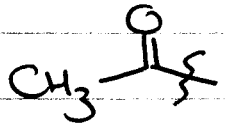
 Pr

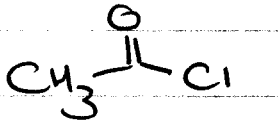
 ^{t}Bu

 Bu

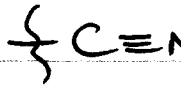
 Ph
PHENYL

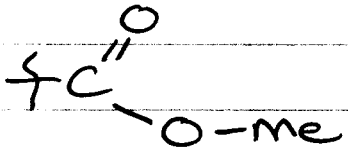
i.e.  = PhBr

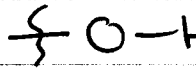
 Ac
ACETYL

i.e.  = AcCl

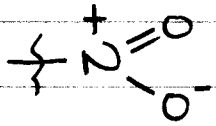
- functional groups

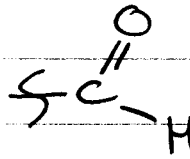
 - CN

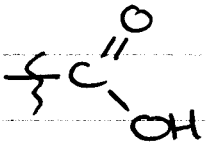


 - OH

- CO_2Me

 - NO_2

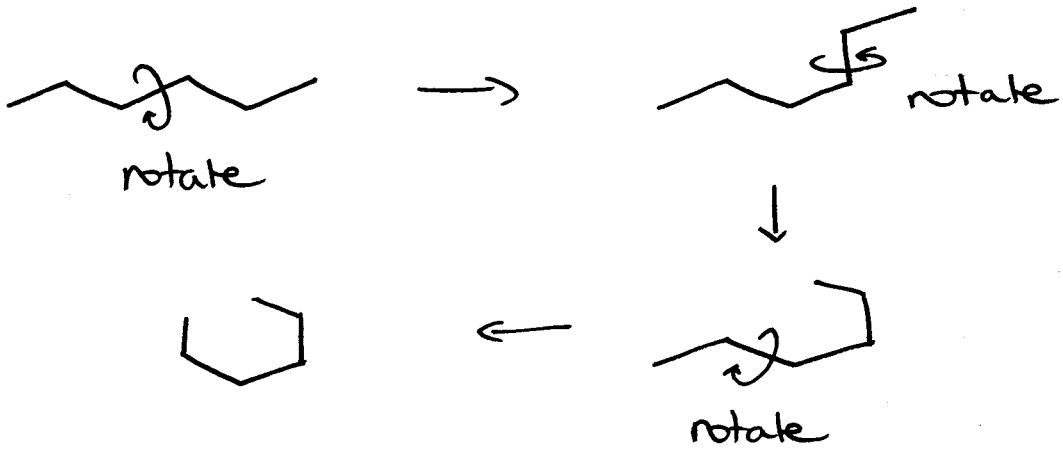


 - CO_2H

- CHO

(2) CONFORMATIONAL ANALYSIS

- consider HEXANE

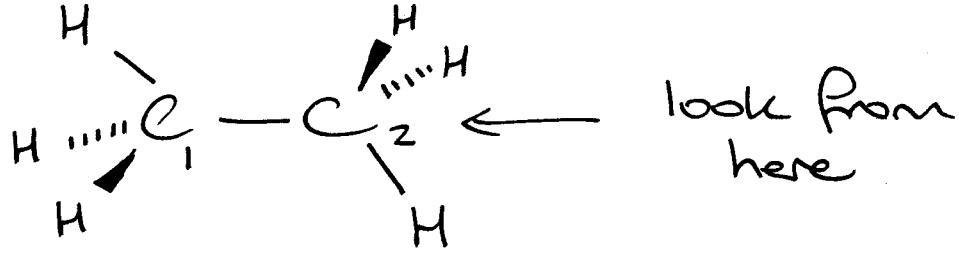


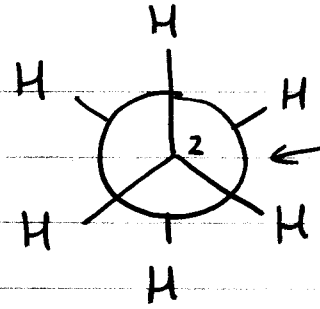
THESE ARE ALL THE SAME MOLECULE

Different arrangements of atoms that result from ONLY single bond rotations are called CONFORMATIONS

At room temp, all single bonds are constantly rotating

Consider C_2H_6





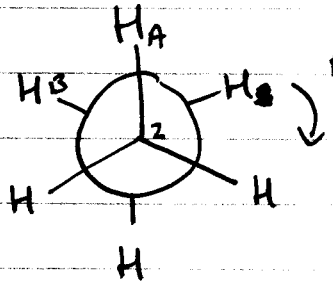
← C_1 is at back

LOOKING DOWN C–C bond

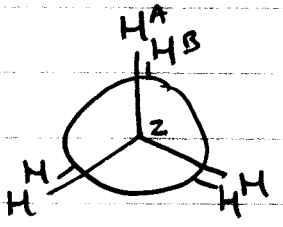
NEWMAN PROJECTION

- TWO METHYL GROUPS CAN ROTATE WRT ONE ANOTHER i.e. 0 – 360° (INFINITE NUMBER OF CONFORMATIONS)
- AT RT, rate of rotation ~ 7000000 s^{-1} ! or 10000000000 s^{-1} !

HOWEVER, rotation is not completely unhindered



rotate 60°



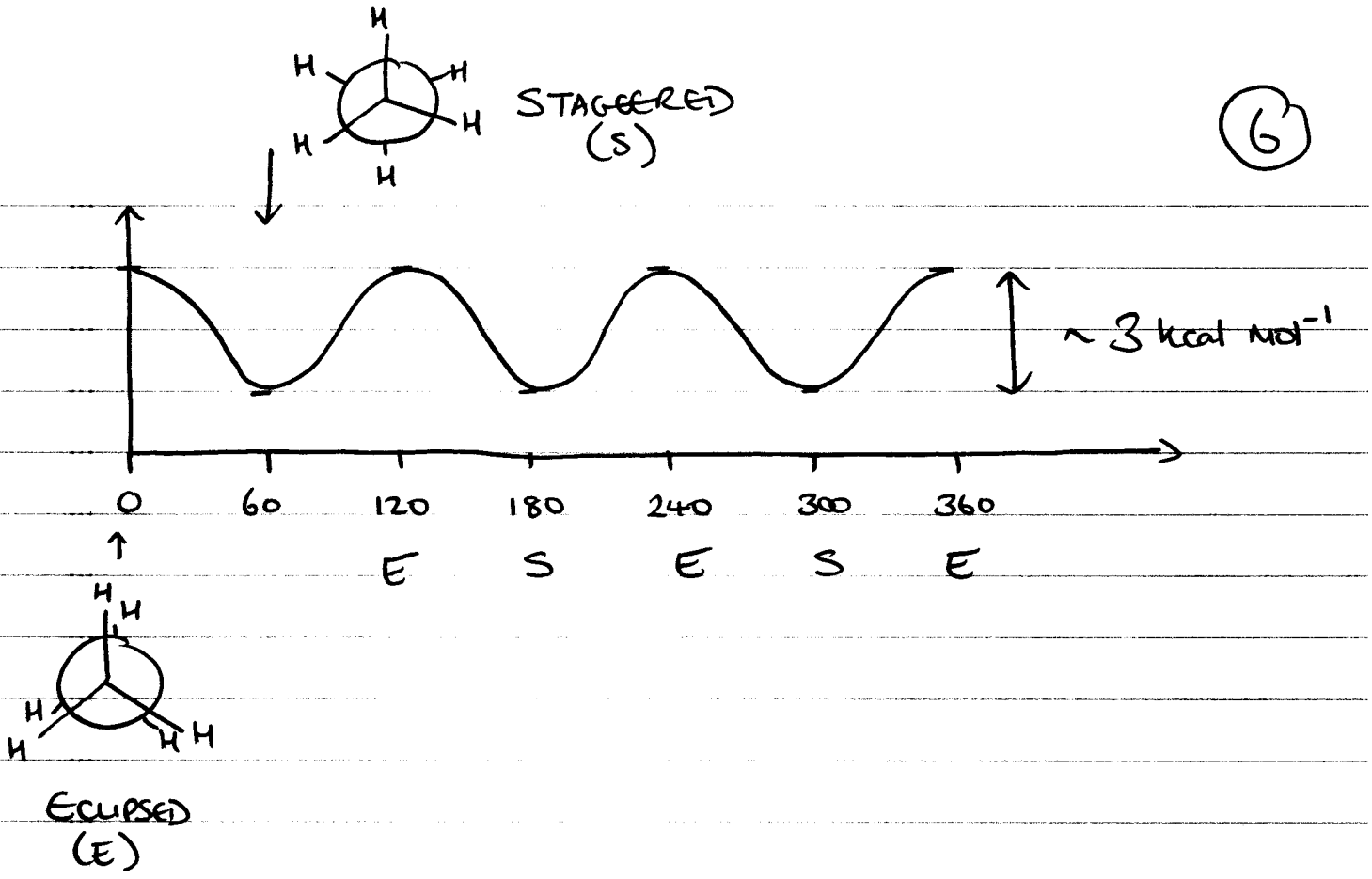
HIGHER ENERGY by ~ 3kcal mol^{-1}

STAGGERED ECLIPSED

DIHEDRAL ANGLE – angle between two intersecting planes (Θ)

$H_A C_2 C_1$
$H_B C_1 C_2$ 60°

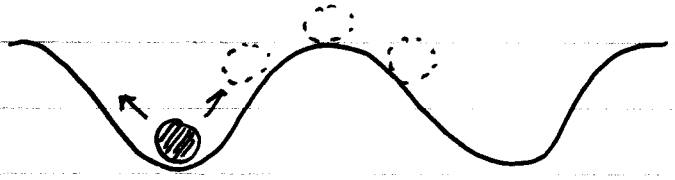
0°



Energy barrier is also called TORSIONAL STRAIN

Any given molecule will spend most of its time in a staggered or nearly staggered conformation, (LOWEST ENERGY) and will only briefly pass through the eclipsed conformation on its way to the next staggered conformation

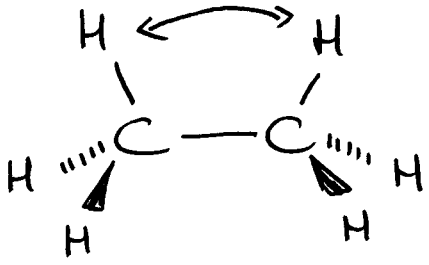
EQUILIBRIUM



Enough energy → will go over barrier, but won't spend a lot of time there

WHY IS THERE A BARRIER?

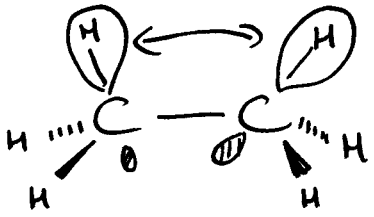
(i) STERIC INTERACTION?



BUT H ATOMS are VERY SMALL

STERICS ACCOUNT FOR ~ 10% of BARRIER

(ii) ELECTRON PAIR REPULSION

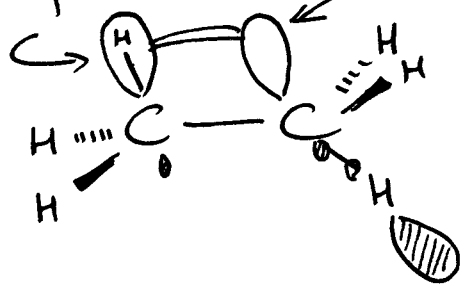


(iii) ATTRACTIVE INTERACTIONS

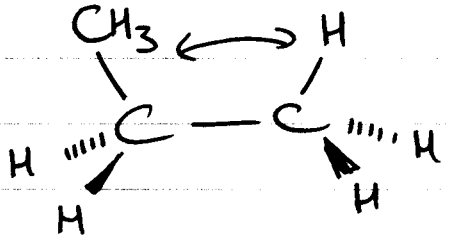
$C_{sp^3}-H_{1s}$ σ

$C_{sp^3}-H_{1s}$ σ^*

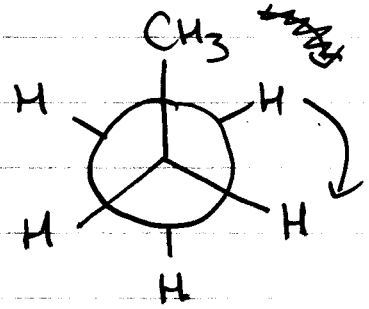
EMPTY ANTIBONDING ORBITAL



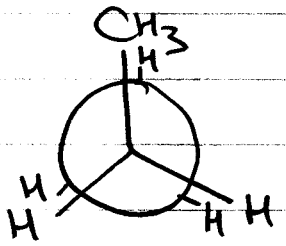
– CONFORMATIONS OF PROPANE



Bigger repulsive interaction than C–H C–H



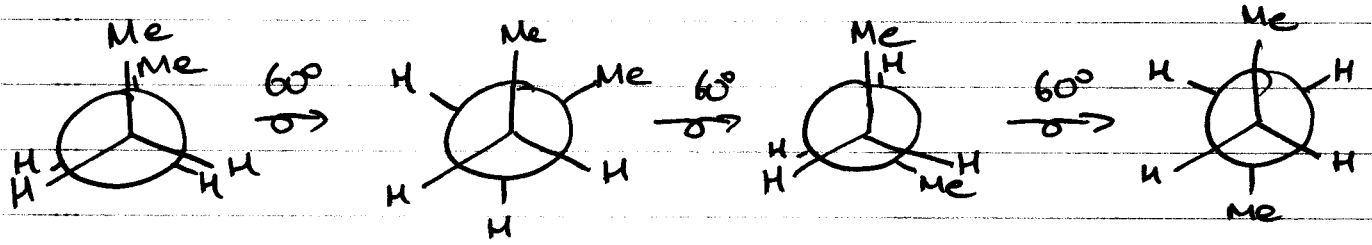
STAGGERED



ECLIPSED

So, same energy profile as ETHANE, but barrier is now 3.4 kcal mol^{-1} (cf 3.0 kcal mol^{-1})

– CONFORMATIONS OF BUTANE



ECLIPSED 1 STAGGERED 1 ECLIPSED 2 STAGGERED 2

GAUCHE ANTI

LEC 7 CHEM 30A Oct 18th

1. CONFORMATIONAL ANALYSIS
2. PROPERTIES

QUIZ 1: AVERAGE 26/30
Readings: Rest of Chapter 2
Problems: NO NEW ONES

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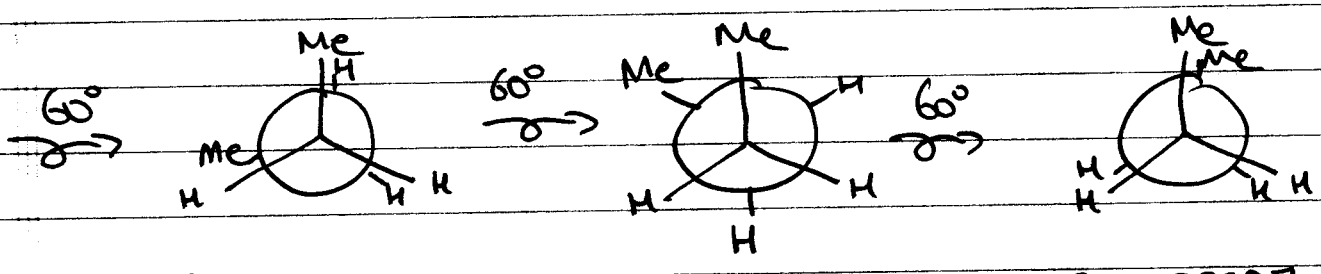
1. CONFORMATIONAL ANALYSIS

- start at Pg 4 from lecture 6

(1 kcal = 4.18 kJ)

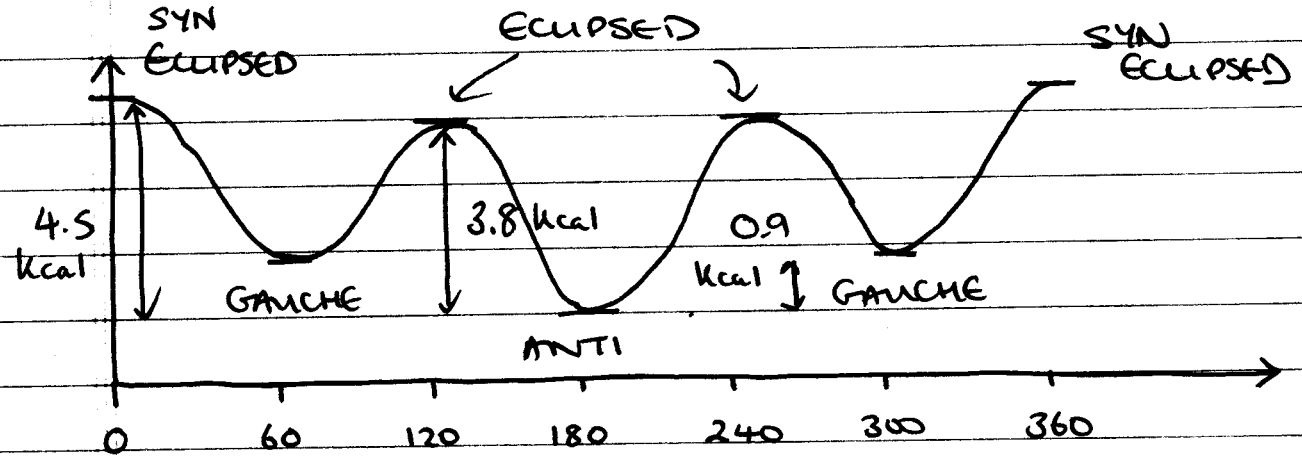
continue from end of Pg 8 Lec 6



ECLIPSED 2 STAGGERED 1 ECLIPSED 1

(Mirror image) to other ECLIPSED 2

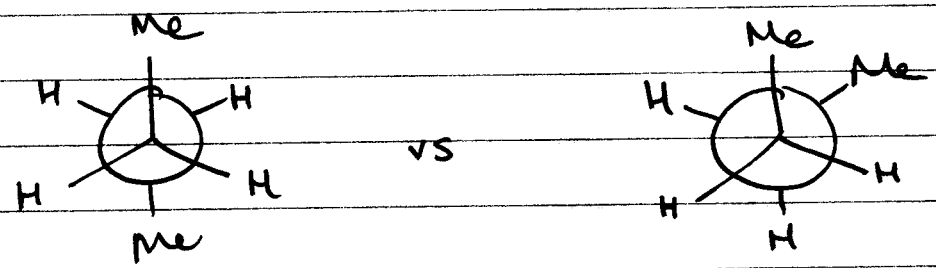
(Mirror image) to other STAGGERED 1



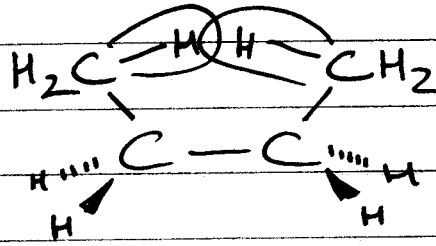
Each eclipsed conformer is a MAXIMA
Each staggered conformer is a MINIMA

<u>BUT</u> different MINIMA / MAXIMA ENERGIES

Consider



Neither is ECLIPSED, but ANTI is MORE STABLE THAN GAUCHE — difference in energy is due to STERIC STRAIN



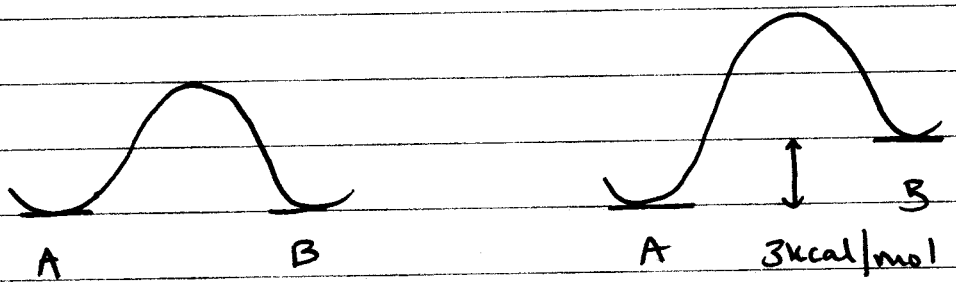
↓
forcing atoms closer together than atomic radii allow

At room temperature, BUTANE is rapidly equilibrating between conformers

~80 : 20 anti : gauche

NOTE: v. small differences in energy barriers result in very different ratios of conformational isomers

At room temp:



50 : 50 99 : 1

equilibrium constant

$$A \underset{}{\overset{k}{\rightleftharpoons}} B \qquad k = \frac{[B]}{[A]}$$

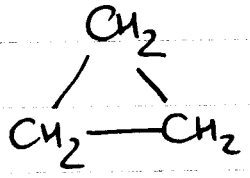
↖ in equilibrium with

$$\Delta G^\circ = -RT \ln k$$

↓

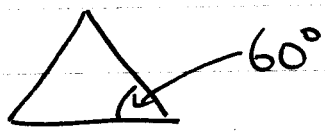
energy difference (free energy)

- CYCLOALKANES



Cyclopropane

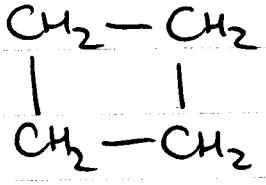
Ring strain of ~ 28 kcal/mol



TETRAHEDRAL
109.5°

ANGLE STRAIN - most

eclipsed C–H bonds, and cannot be any other way ⇒ TORSIONAL STRAIN



Cyclobutane

If planar, all C–Hs are eclipsed, so ring is puckered → reduces TORSIONAL STRAIN

<u>BUT</u> increases ANGLE STRAIN

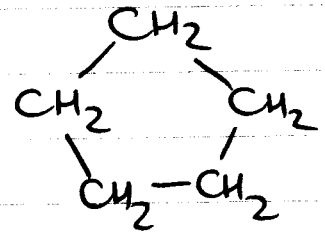
Ring Strain is ~26 kcal/mol

CYCLOBUTANE PLANAR

ALL CYCLOALKANES LARGER THAN CYCLOPROPANE ADOPT NONPLANAR CONFORMATIONS

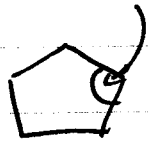
PUCKERED CYCLOBUTANE

C-C BOND ANGLES ~ 88°



cyclopentane

If it was planar, internal angles would be 108°

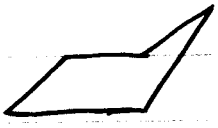


cf 109.5° for tetrahedral

⇓

VERY LITTLE ANGLE STRAIN

<u>BUT</u> again, all C-H bonds would be eclipsed



4 in PLANE, 1 OUT

ENVELOPE CONFORMATION (GIVE EQUIVALENT ONES) EQUILIBRIUM

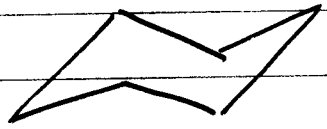
Ring strain is ~ 7 kcal/mol

cyclohexane

⇒ would lead to angle strain & torsional strain,

BUT CYCLOHEXANE is almost strain free

CHAIR CONFORMATION

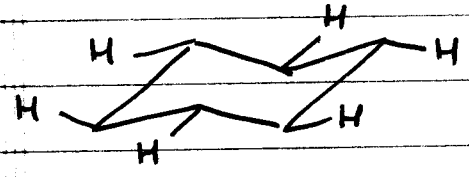


C–C–C angles ~ 109.5°

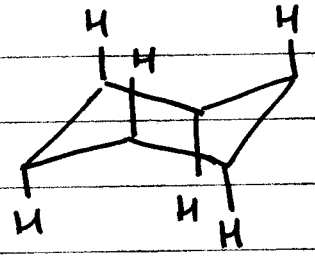
NO ANGLE STRAIN

HYDROGENS on ADJACENT CARBONS ARE STAGGERED — NO TORSIONAL STRAIN

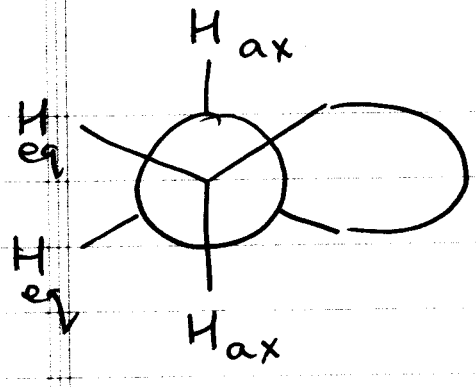
NO STERIC STRAIN



EQUATORIAL



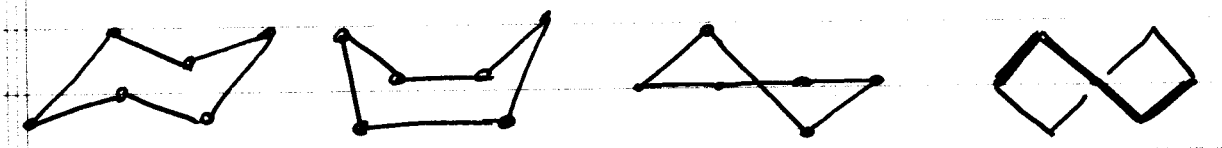
AXIAL

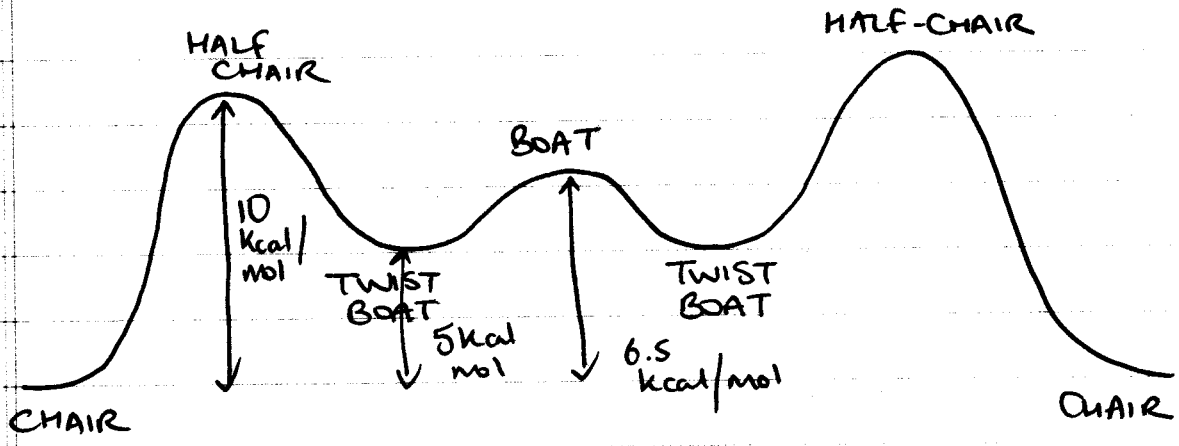


LOOKING DOWN ANY C–C AXIS

NEWMAN PROJ

- other CYCLOHEXANE CONFORMATIONS





ROOM TEMP – CHAIR >99.99% of equilibrium mixture

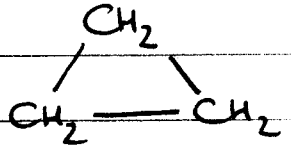
DYNAMICS OF THE CYCLOHEXANE RING

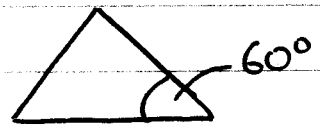
LEC (8) CHEM 30A Oct 18th

(1) CYCLOALKANES

Problems 2.10 - 2.15, 2.31 - 2.45
Reading: Review Ch 2.

CYCLOPROPANE





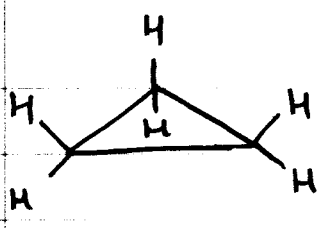
60° VERY DIFFERENT FROM TETRAHEDRAL ANGLE 109.5°

⇒ ANGLE STRAIN

Total ring strain ~ 28 kcal/mol

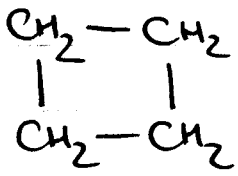
- most of this is angle strain, but also all C-H BONDS ARE ECLIPSED

⇒ TORSIONAL STRAIN

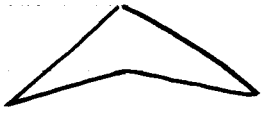


ALL ECLIPSED

- CYCLOBUTANE



If planar, all C-H's would be eclipsed, so ring puckers to avoid TORSIONAL STRAIN

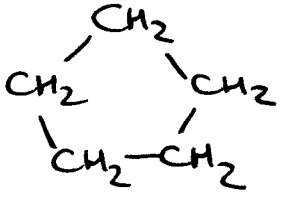


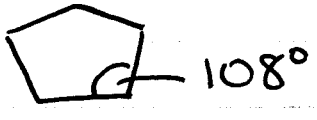
BUT, C-C-C bond angles are now 88°, even worse than 90°, ANGLE STRAIN is INCREASED

Total ring strain is ~ 26 kcal/mol

- IN ALL CYCLOALKANES LARGER THAN CYCLOPROPANE, NON PLANAR CONFORMATIONS ARE FAVORED

- CYCLOPENTANE





If cyclopentane was planar, there would be virtually no angle strain 108 vs 109.5°

<u>BUT</u> again, all C-H BONDS would be eclipsed

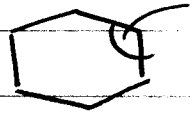
ENVELOPE CONFORMATION

4Cs in plane, 1 out (EQUILIBRIUM) (ANGLES 105°)

Reduces TORSIONAL STRAIN

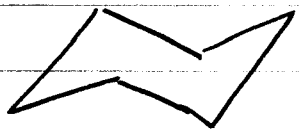
Total ring strain is ~ 7 kcal mol^{-1}

- CYCLOHEXANE



PLANAR structure would lead to angle strain and torsional strain

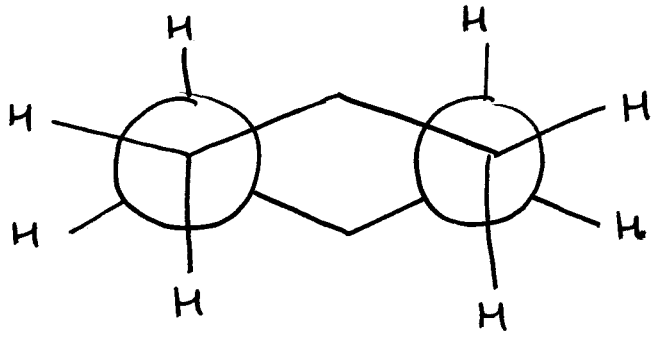
<u>BUT</u> CYCLOHEXANE is virtually STRAIN FREE



CHAIR CONFORMATION

C-C-C ANGLES 109.5°

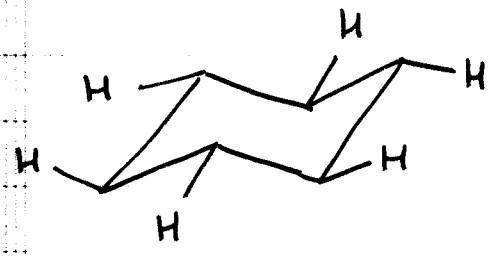
ALSO, Hs on ADJACENT CARBONS are STAGGERED ⇒ NO TORSIONAL STRAIN



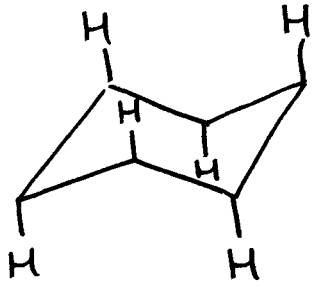
NEWMAN PROJECTION

- ALSO NO STERIC STRAIN (NON BONDED INTERACTION STRAIN)

TWO DIFFERENT ORIENTATIONS FOR C–H BONDS

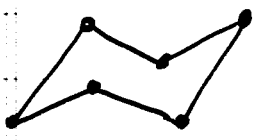


EQUATORIAL



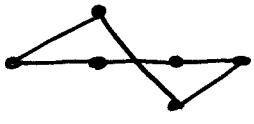
AXIAL

- other CYCLOHEXANE CONFORMATIONS

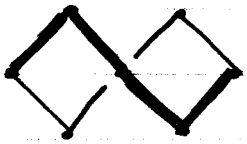


CHAIR

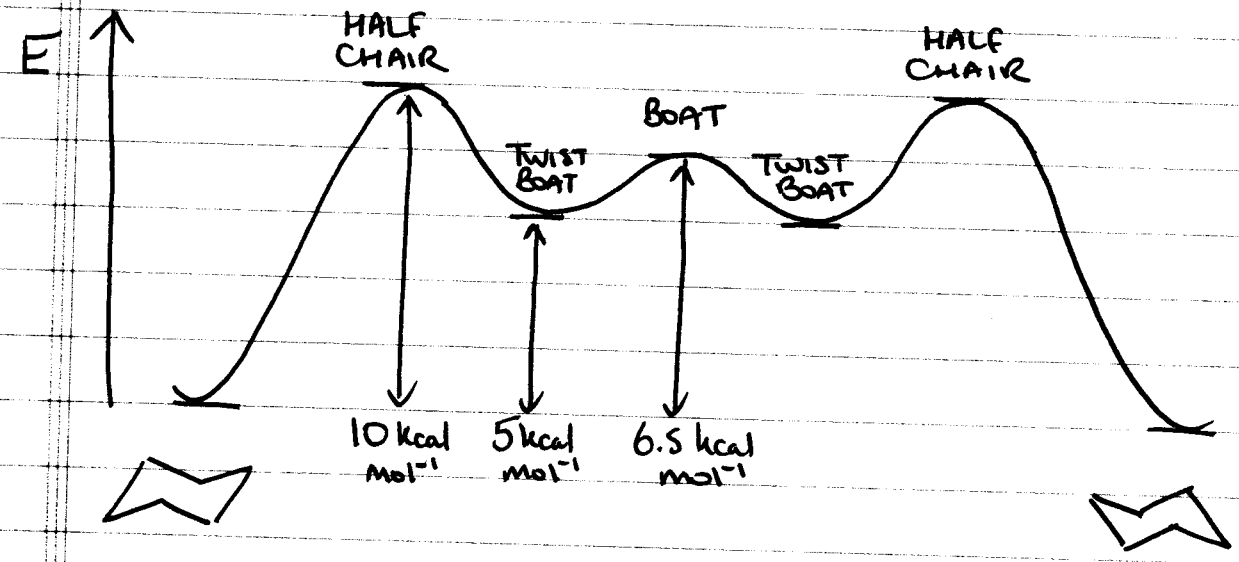
BOAT



HALF-CHAIR

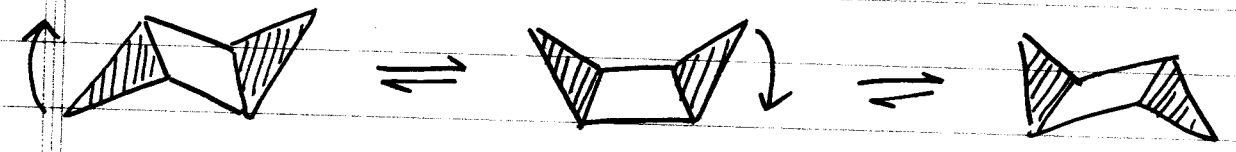


TWIST BOAT

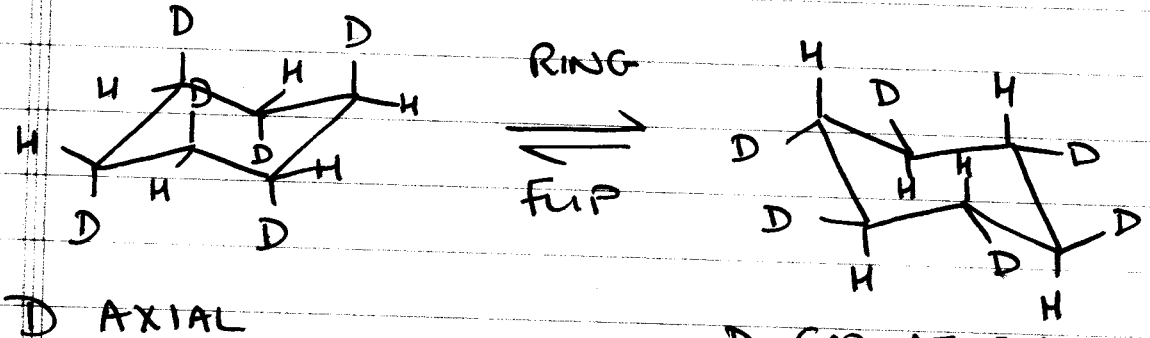


At Room Temp Chair > 99.99% of Equilibrium Mixture

Chair Inversion (Ring-Ring Flipping)



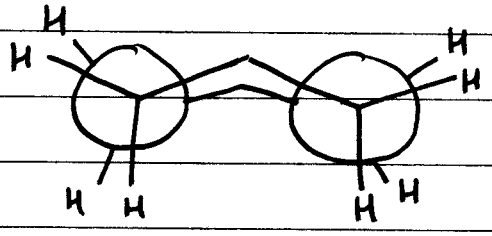
Switches Axial & Equatorial Positions



D Axial
H Equatorial

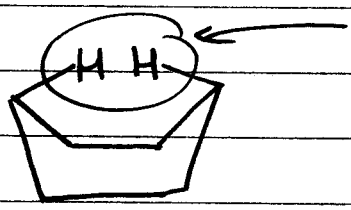
D Equatorial
H Axial

BOAT CONFORMATION



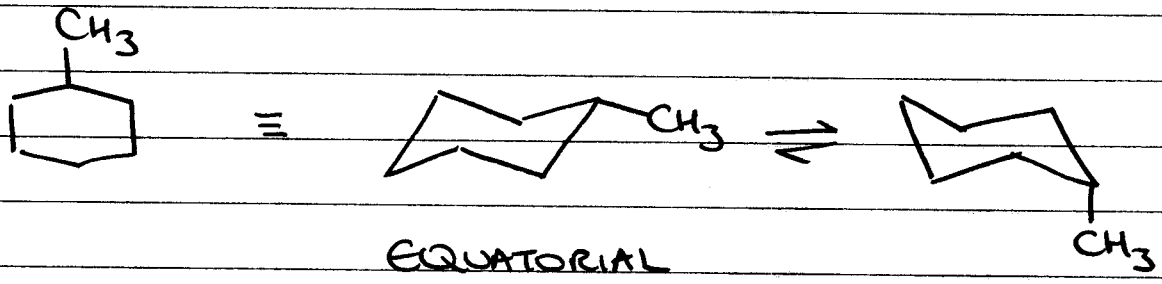
← ECLIPSED C–Hs

also



← NON BONDED (STERIC) INTERACTIONS

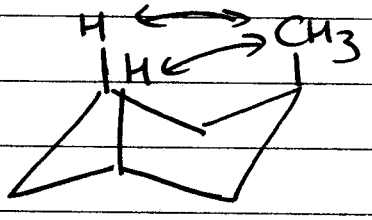
Consider METHYL CYCLOHEXANE



EQUATORIAL AXIAL

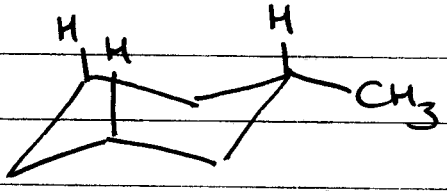
WHICH IS MORE STABLE?

(i) 1,3 DIAXIAL INTERACTIONS

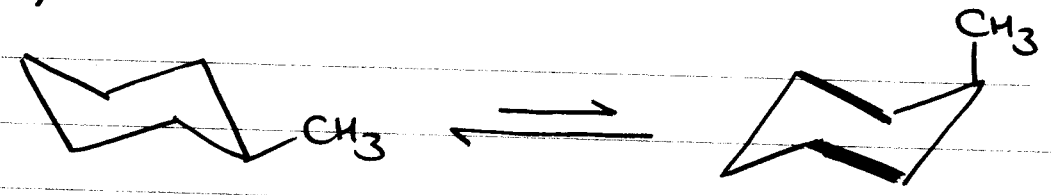


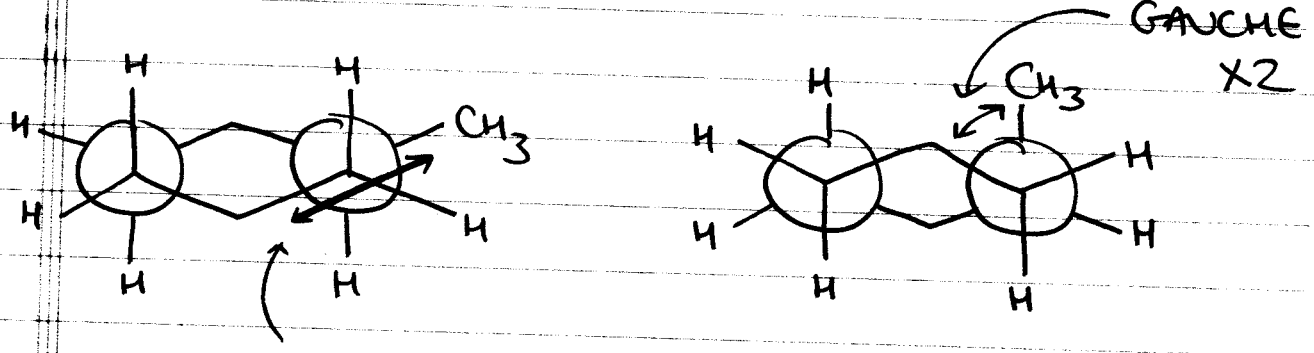
NON BONDED INTERACTION STRAIN

VS

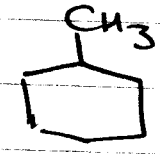


(ii)





Generally, conformer in which the largest substituent is equatorial will be the most stable

For  , equatorial is more stable by ~ 1.74 kcal mol^{-1}

A values → measure of preference for the equatorial position

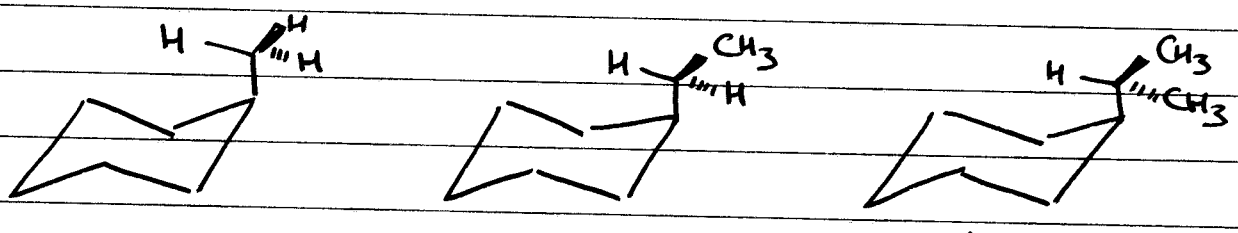
$A = -\Delta G$ change from axial → equatorial

So A values are usually positive

$-CH_3$	$-CH_2CH_3$	$-CH(CH_3)_2$	$-C(CH_3)_3$
1.74	1.75	2.15	> 5

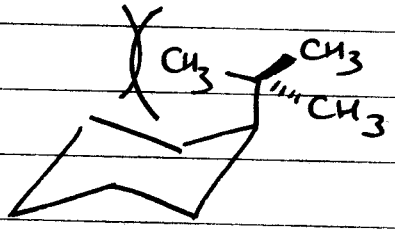
Note:

small differences for Me, Et, ^{i}Pr



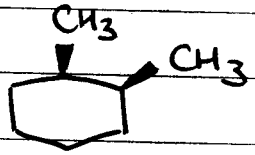
Me Et ^{i}Pr

^{t}Bu $^{+}$Bu



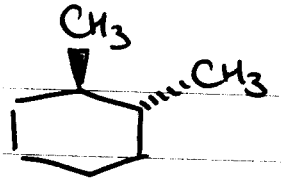
$^{+}$Bu considered a locking group, OVERWHELMING PREFERENCE FOR EQUATORIAL POSITION

— DISUBSTITUTED CYCLOHEXANES



Same side CIS

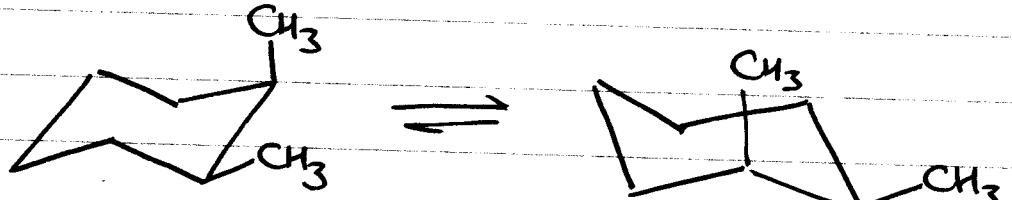
1,2 DIMETHYLCYCLOHEXANE



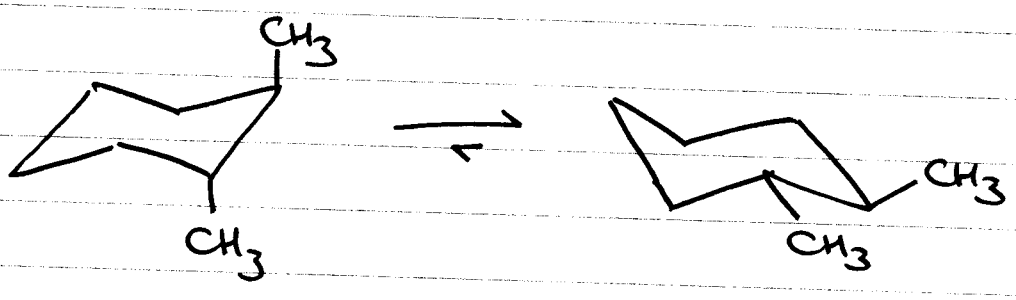
opposite sides trans

1,2 DIMETHYLCYCLOHEXANE

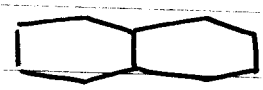
cis



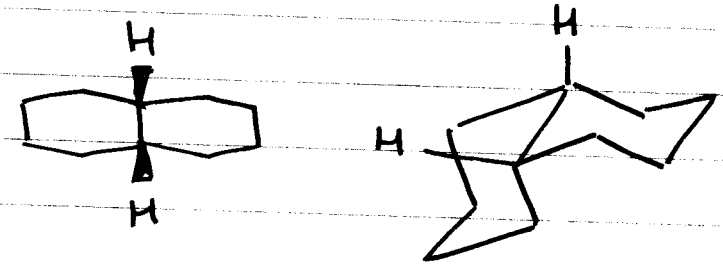
trans



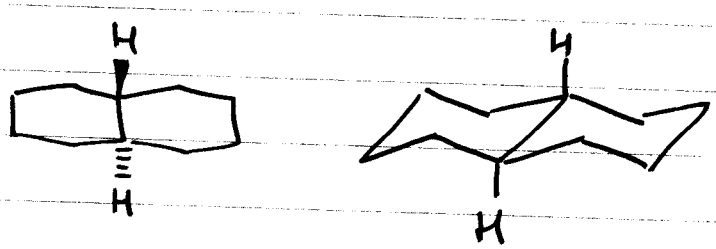
- DECALIN



cis decalin



trans decalin



LEC (9) CHEM 30A Oct 20th

(1) PROPERTIES OF ALKANES
(2) REACTIONS / SOURCES / IMPORTANCE

CHAPTER 3
(3) STEREOCHEMISTRY
(4) CHIRALITY

Reading 2.9 – 3.4
Hmk 2.16, 2.46 – 2.61, 3.1 – 3.5, 3.10 – 3.23
(Ch2 Probs on FRIDAY)

---

(1) PROPERTIES OF ALKANES

As mw increases, mp & bp increase

Intermolecular Interactions

- Ionic Interactions
- Hydrogen Bonding
- Dipole – Dipole
- Dipde – Induced Dipole
- Induced Dipole – Induced Dipole
  ↳ DISPERSION FORCES / LONDON FORCES

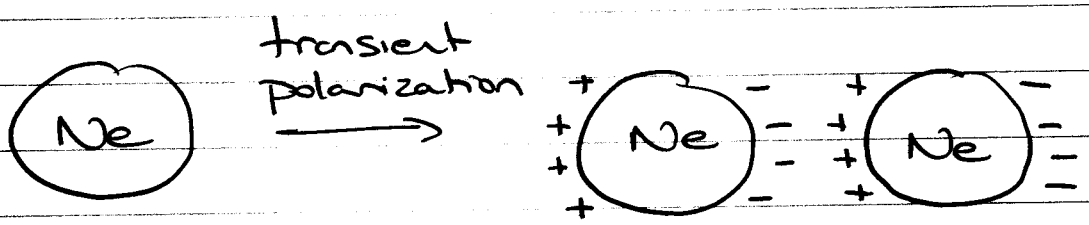
↓ DECREASING STRENGTH

The fact that LOW MW nonpolar substances can be LIQUEFIED

$\Rightarrow$ DISPERSION FORCES

e.g. He 4K
Ne 27K

Bigger electron clouds, stronger forces



Symmetrical electron density distribution

temporary electrostatic attraction

- Consider


bp 36°C


28°C


10°C

ISOMERS

more branching
↓
more compact shape
↓
less surface area
↓
less molecule/molecule contact, fewer DISPERSION interactions

(2) Reactions / Sources / Importance

↳ Read sections 2.9 / 2.10 and answer questions

(3) STEREOCHEMISTRY

ISOMERS → different compounds with the same molecular formula

CONSTITUTIONAL ISOMERS ⇓

Different connectivity

e.g. CH_3OCH_3

CH_3CH_2OH

or

STEREOISOMERS (configurational isomers) ⇓

Same connectivity, different geometry

STEREOISOMERS →
- ENANTIOMERS (non-superimposable) mirror images
- DIASTEREOISOMERS (non-superimposable) non-mirror images →
  - CONFIGURATIONAL DIASTEREOISOMERS
  - CIS/TRANS DIASTEREOISOMERS

(4) CHIRALITY

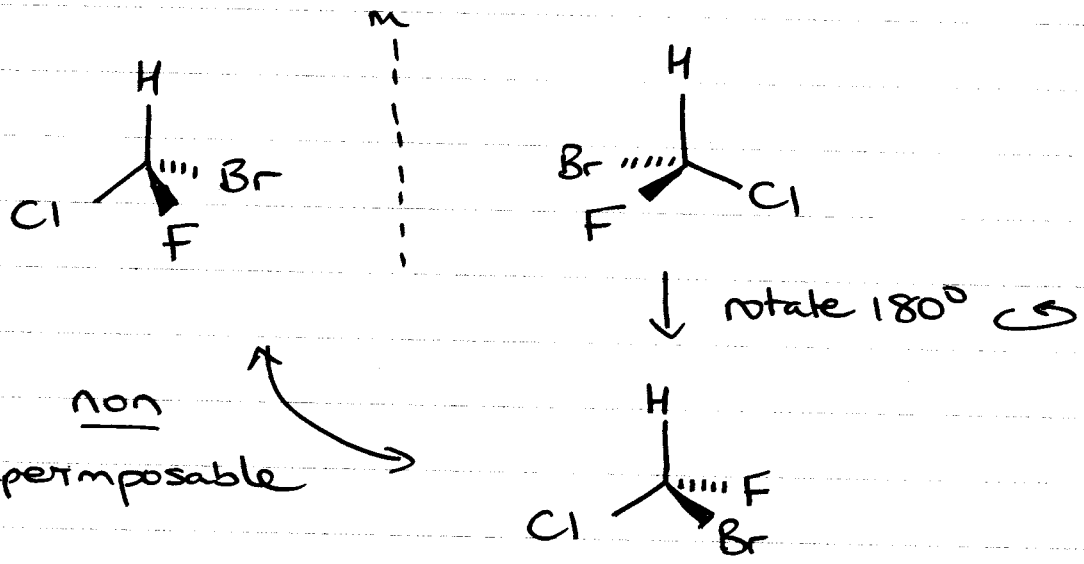
An object that is not superimposable on its

mirror image is said to be CHIRAL

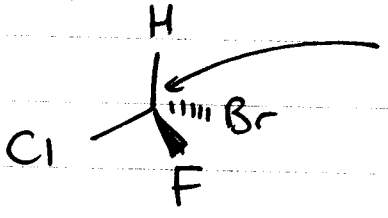
from greek cheir meaning hand

So, a molecule is an object ⟹

e.g.



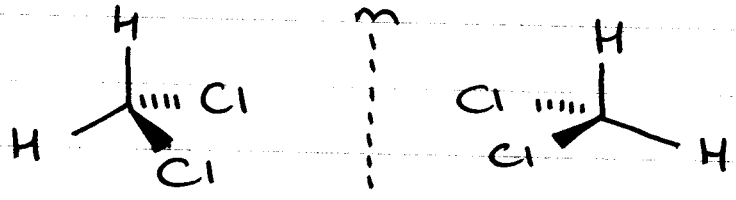
So both of these molecules are chiral, and they are ENANTIOMERS



called a CHIRAL center
or
STEREOGENIC center

If an OBJECT or MOLECULE is not CHIRAL, it is referred to as ACHIRAL

i.e.



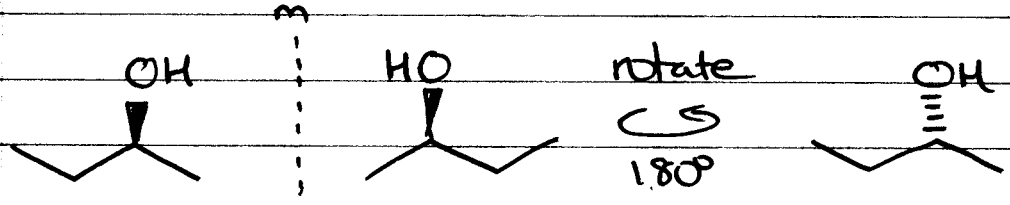
SAME

One of the most common causes of chirality in organic molecules is a TETRAHEDRAL atom (usually C) bonded to four different groups

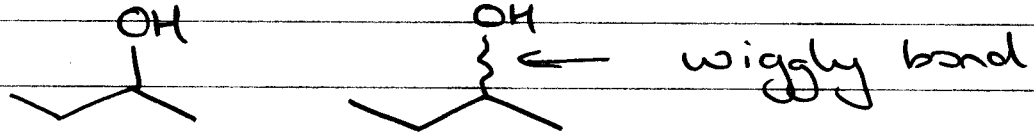
e.g. 

THIS is a CHIRAL molecule

ENANTIOMERS ALWAYS COME IN PAIRS



If no stereochemistry is indicated in a structure

i.e., 

MEANS ONE OF TWO THINGS

(1) We have an equal mixture of enantiomers (RACEMIC MIXTURE or RACEMATE)
(2) We have a single enantiomer, but of UNKNOWN stereochemistry.

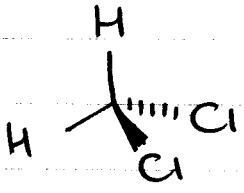
TIPS FOR IDENTIFYING CHIRAL OBJECTS

If a molecule can be drawn with

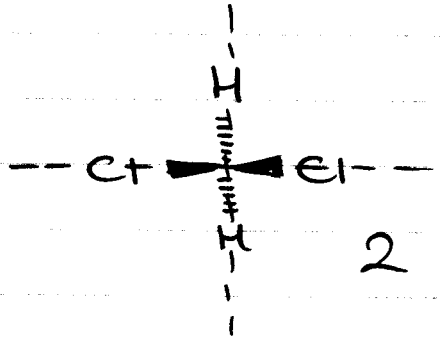
(i) a PLANE of symmetry or
(ii) an inversion center

IT IS ACHIRAL

e.g. (i)



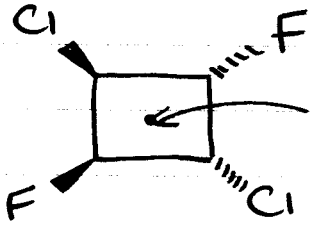
ACHIRAL



2 PLANES!

You will see this more than:

(ii)



center of inversion
NO PLANE

ACHIRAL

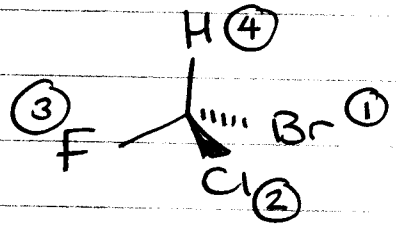
Centre of inversion → identical groups lie equidistant of a point, on opposite sides of that point

Distinguishing ENANTIOMERS

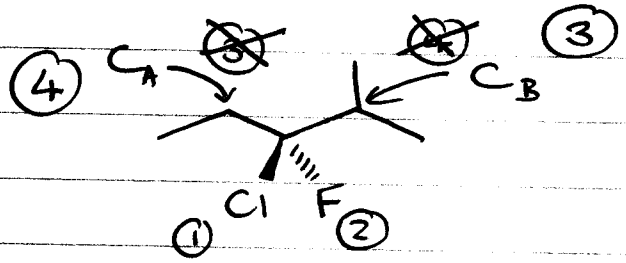
R,S designation

① Assigning priority

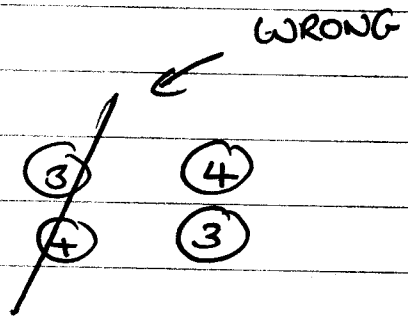
(i) ATOMIC WEIGHT of atoms attached to stereocenter



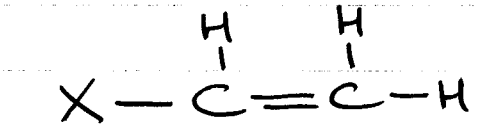
(ii) KEEP going until the first point of difference



Attached to C_A C, H, H
Attached to C_B C, C, H

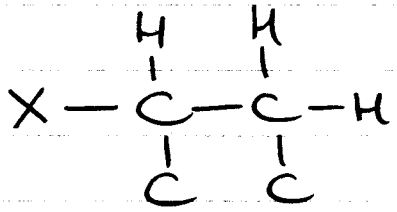


(iii) MULTIPLE BONDED ATOMS count as the equivalent number of singly bonded atoms, i.e.,

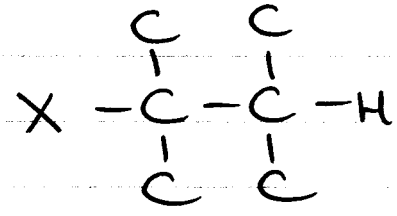


chiral center

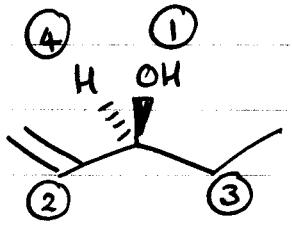
counts as



counts as



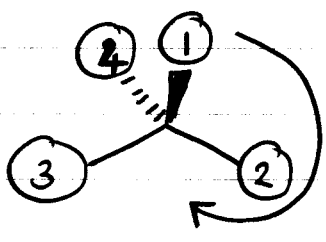
So



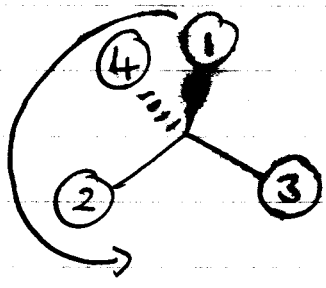
(2) Arrange in the following orientation:

- PUT (4) in the back, pointing away from you, so you get either

CLOCKWISE (R)

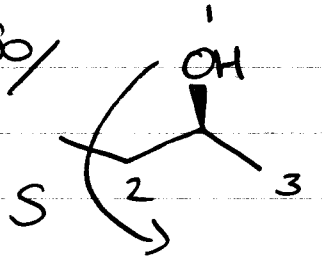


OR

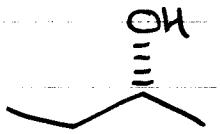


COUNTER-CLOCKWISE (S)

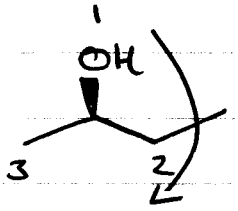
So/



S-2- BUTANOL



rotate 180



R-2- BUTANOL

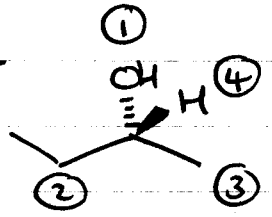
or

If you have trouble rotating molecules

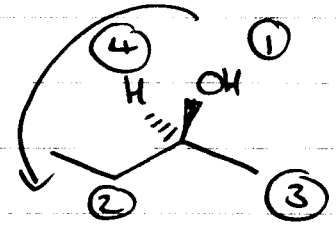
TRICK

- switch the ④ group with whatever group is in the back
- assign stereochemistry R or S
- switch the stereochemistry

eg.

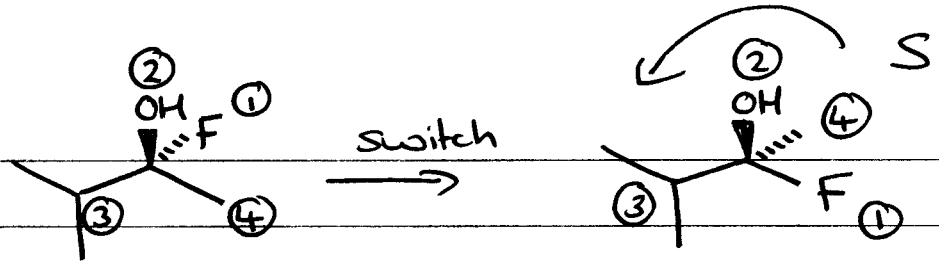


switch →



Rosis (S)

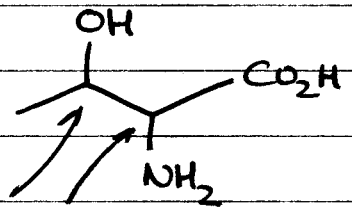
So original cmpd was (R)



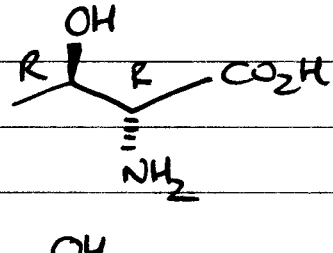
So, this one over here, is (R)

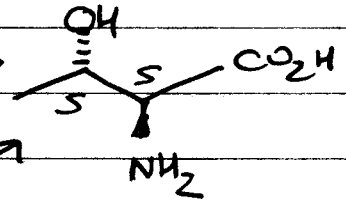
- More than ONE STEREOCENTER

amino acid THREONINE

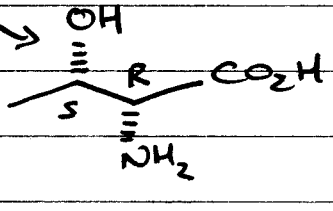


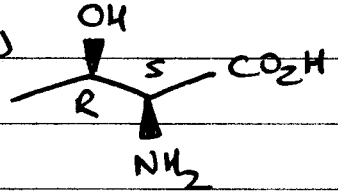
Chiral centers





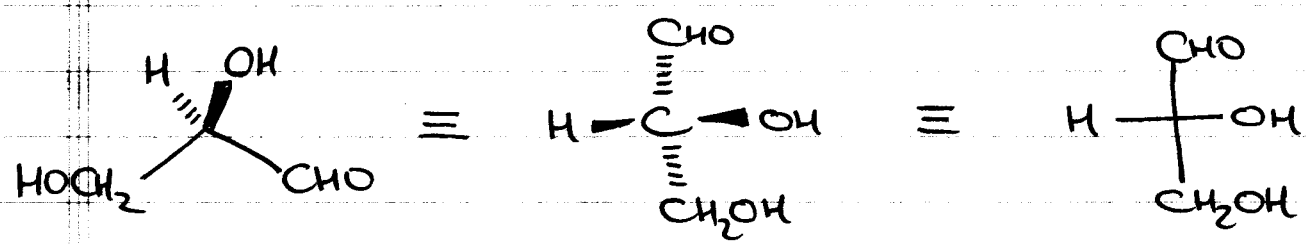
PAIRS OF DIASTEREOISOMERS (STEREOISOMERS, BUT NOT MIRROR IMAGES)





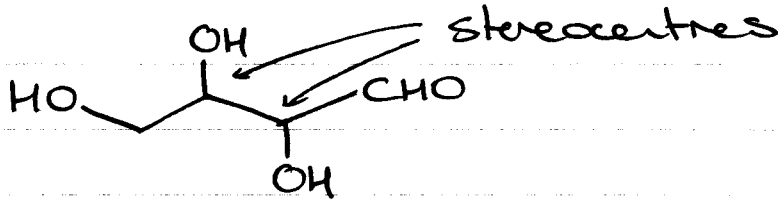
NATURALLY OCCURRING IN PLANTS / ANIMALS

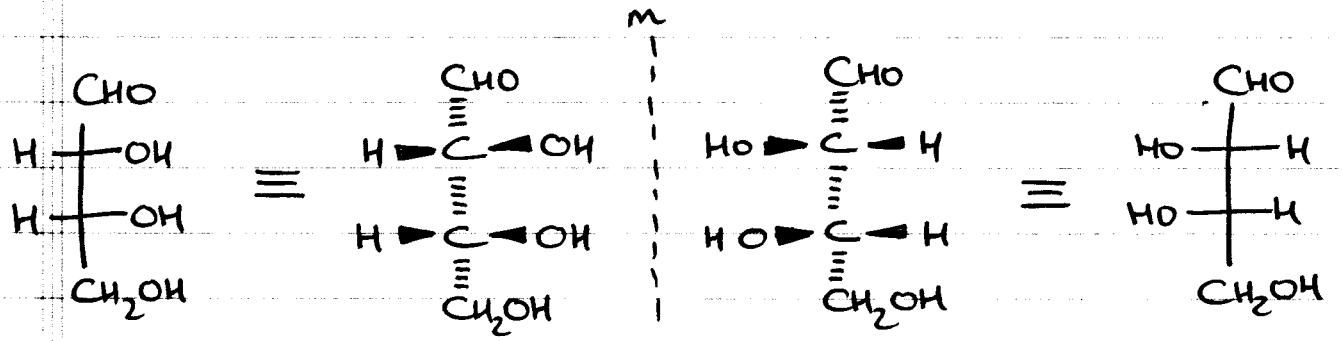
FISCHER PROJECTIONS



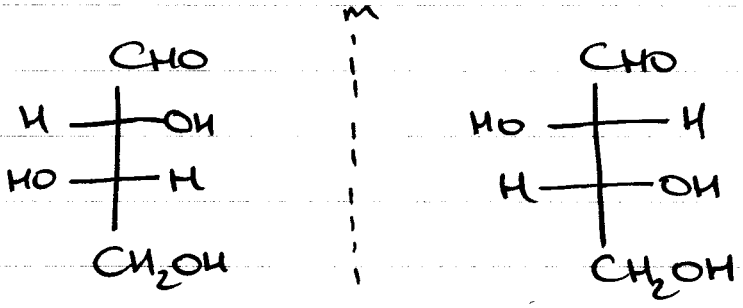
Glyceraldehyde

2,3,4 Trihydroxybutanal





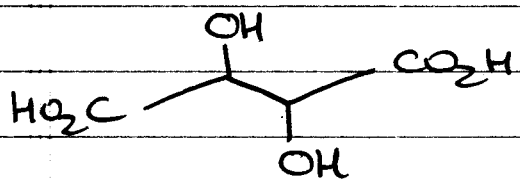
ENANTIOMERS



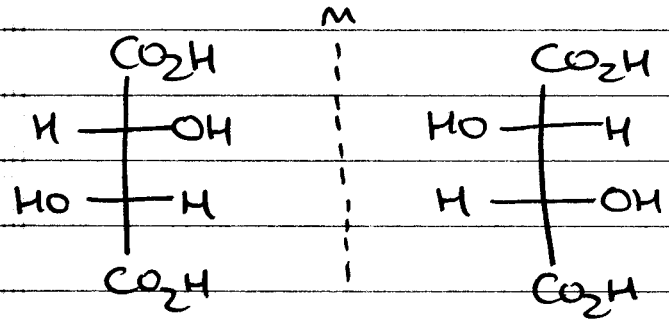
ANOTHER PAIR OF ENANTIOMERS

A molecule with n chiral centers can have a max number of stereoisomers $= 2^n$

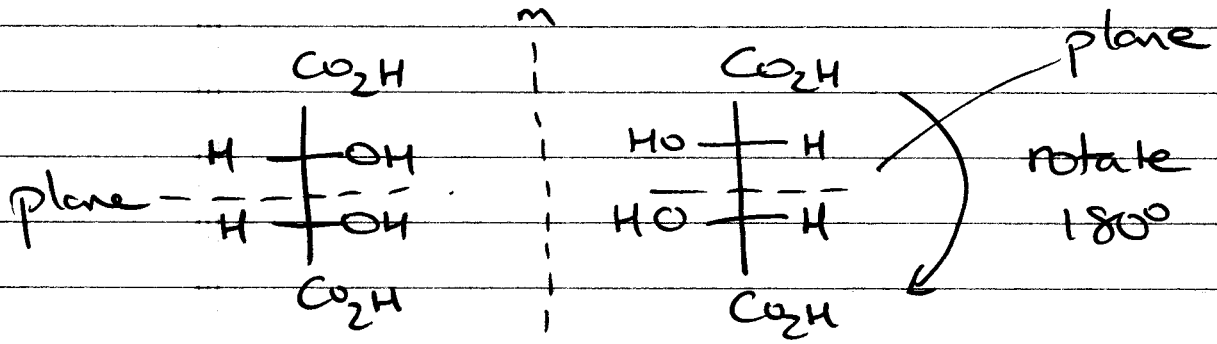
– MESO COMPOUNDS



TARTARIC ACID



ENANTIOMERS



SAME

So – Cmpd with stereocenters, but is achiral ⇒ MESO

LEC (10) CHEM 30A Oct 22nd

(1) R/S DESIGNATION
(2) FISCHER PROJECTIONS
(3) CIS/TRANS DIASTEREOISOMERS
(4) CONSEQUENCES OF CHIRALITY

Problems: HANDOUTS 3.6-3.9, 3.24-3.36
Reading: REVIEW Ch 3

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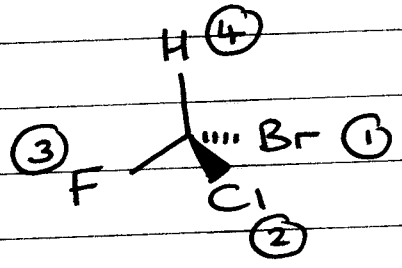
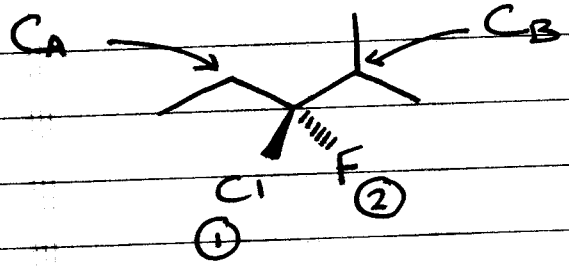
(1) R/S DESIGNATION

- assigning priority

(i) ATOMIC WEIGHT

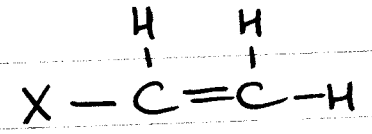
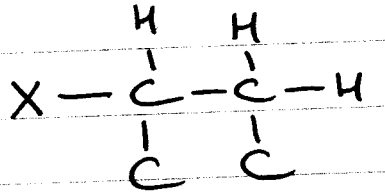


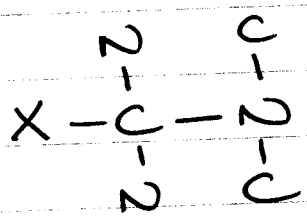
(ii) First POINT of DIFFERENCE

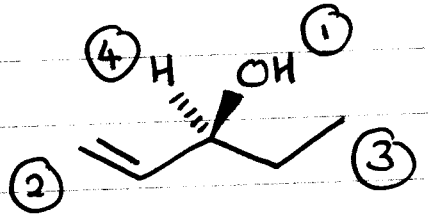


C_A C, H, H (4)
C_B C, C, H (3)

(iii) MULTIPLE BONDS = EQUIVALENT # of SINGLE BONDS

So,  is 

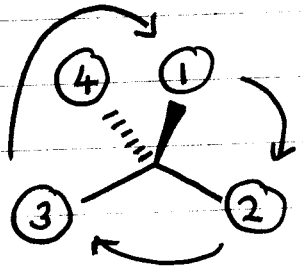
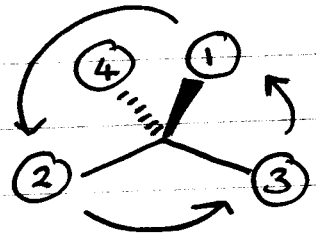
 is 

so 

- determining R/S

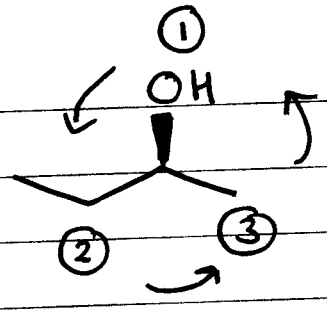
Rotate molecule to put lowest priority group in the background →

TWO POSSIBLE ORIENTATIONS

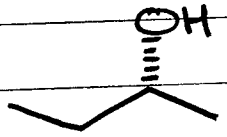
 or 

CLOCKWISE (R) COUNTERCLOCKWISE (S)

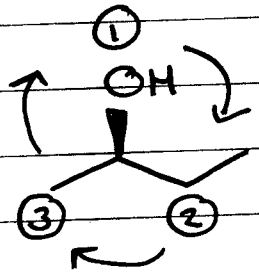
So



S-2-BUTANOL



rotate 180°



small group is not in the back

R-2-BUTANOL

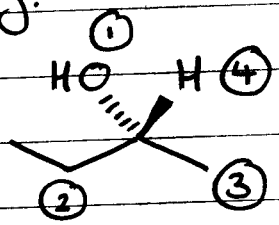
or if you have trouble rotating molecules...

TRICK

SWITCH LOWEST PRIORITY GROUP (4) WITH THE GROUP THAT IS IN THE BACK

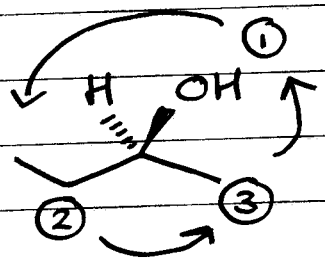
ASSIGN R/S, REALISING THAT THE STEREOCHEMISTRY OF THE ORIGINAL MOLECULE IS THE OPPOSITE...

e.g.



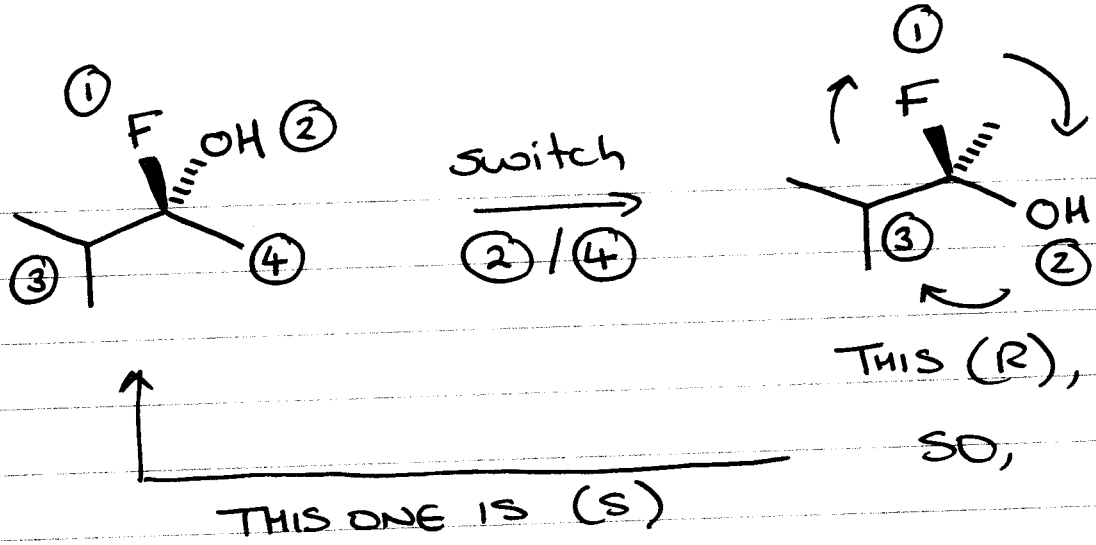
switch

1 / 4



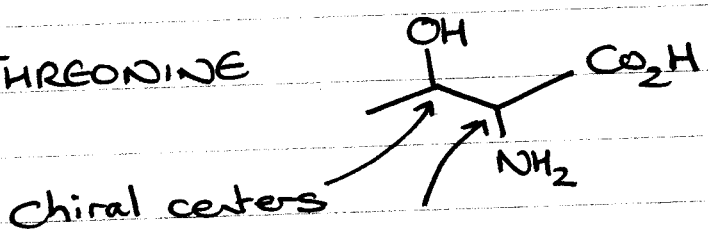
(S)

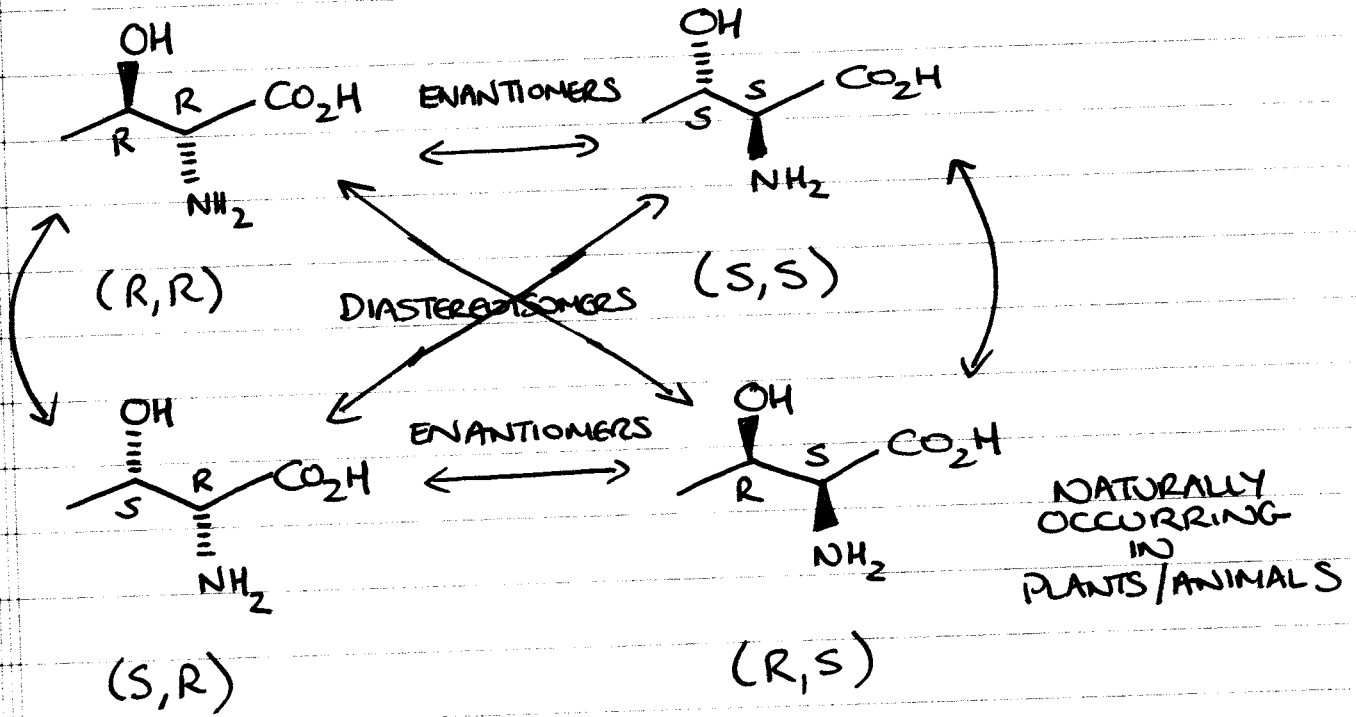
SO THIS MUST BE (R)



- COMPOUNDS W/ MORE THAN ONE STEREOCENTER

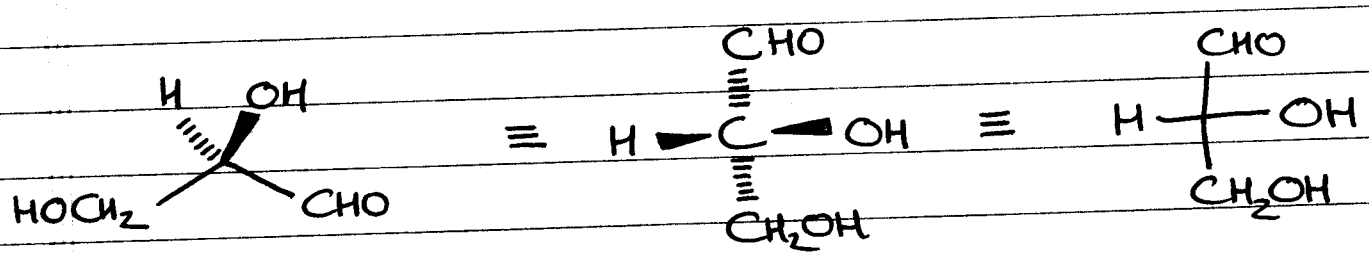
amino acid THREONINE





DIASTEREOISOMERS – NON MIRROR IMAGE STEREOISOMERS

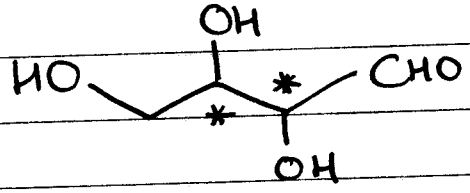
- FISCHER PROJECTIONS

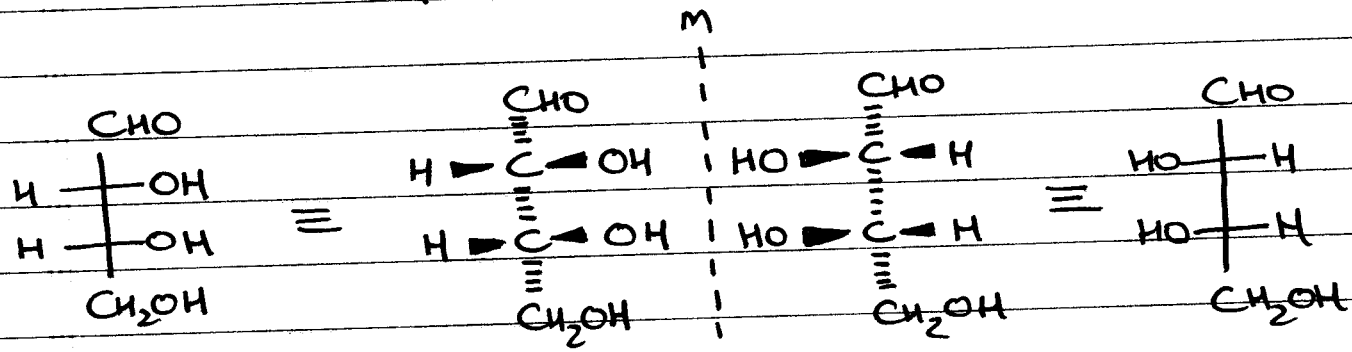


Glyceraldehyde

Useful for compounds with many continuous stereocenters

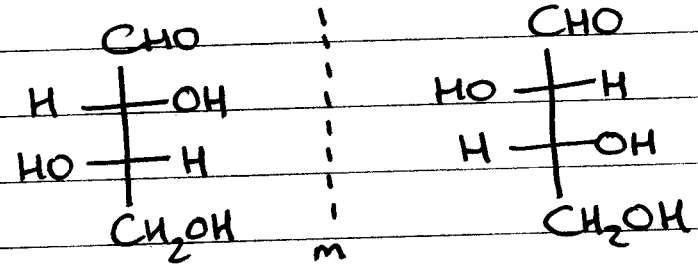
2,3,4-trihydroxybutanal



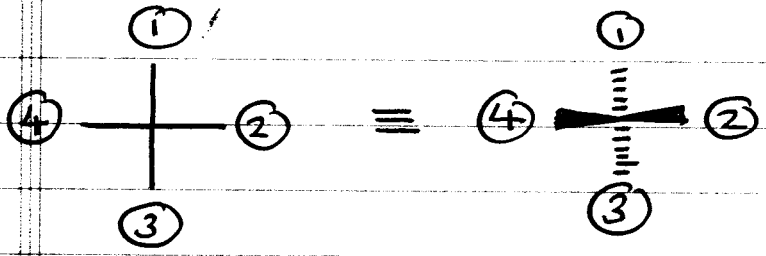


ENANTIOMERS

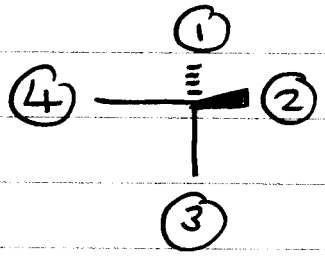
ANOTHER PAIR OF ENANTIOMERS



Determing Stereocenter Configuration in FISCHER projections



SWITCH one wedge and one dash for straight lines



⇐ assign R/S

THIS ONE IS (S)

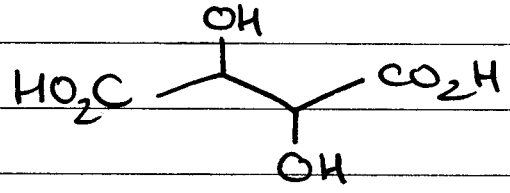
GO BACK and determine R/S for 2,3,4 trihydroxybutanal

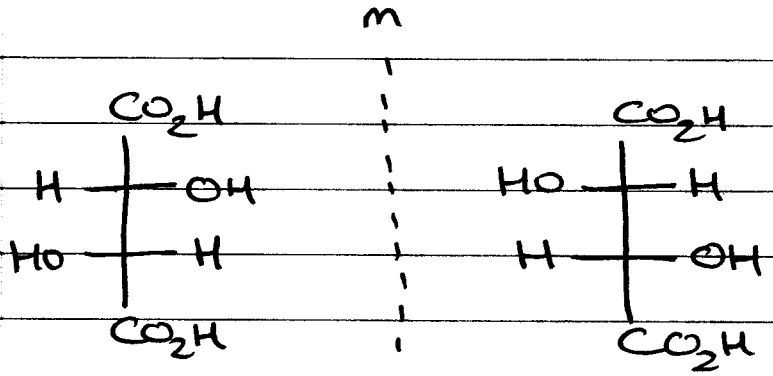
- A molecule with n chiral centers can have a maximum number of stereoisomers = 2^n

i.e., 2,3,4 trihydroxybutanal has 2 stereocenters and

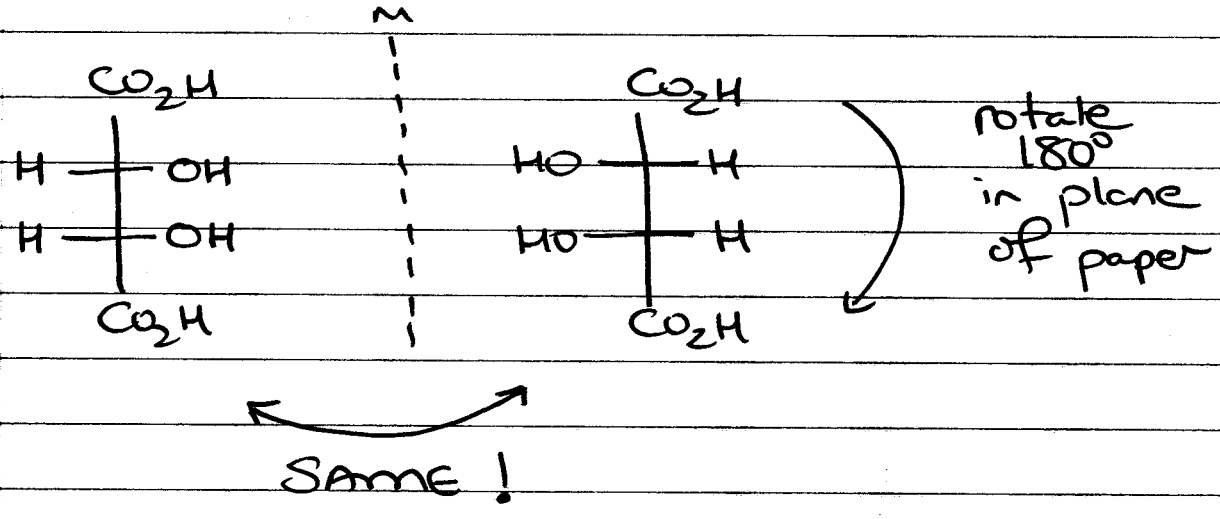
$2^2 = 4$ stereoisomers

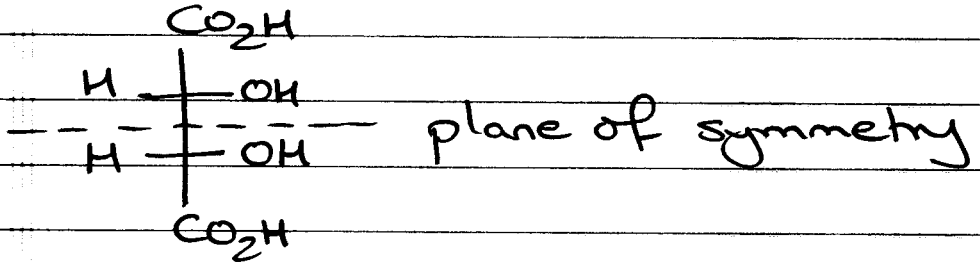
Consider TARTARIC ACID





ENANTIOMERS





Cmpd with stereocenters, but is achiral
=> MESO

ENANTIOMERS ✓

DIASTEREOISOMERS → CONFIGURATIONAL ✓

DIASTEREOISOMERS → CIS/TRANS → RINGS, ALKENES

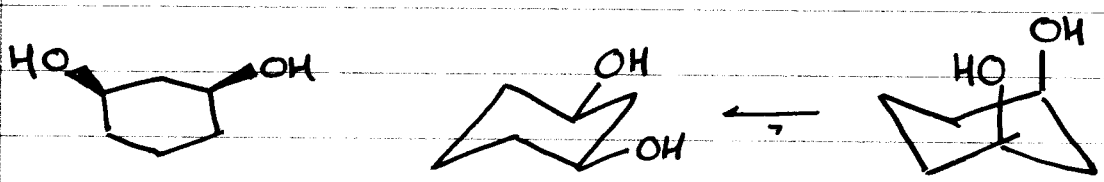
RINGS

cis (meso) | trans | trans

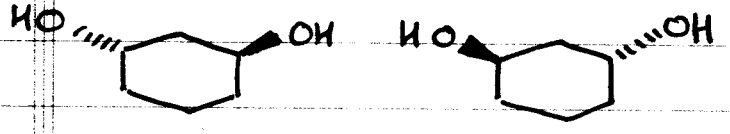
trans, trans: ENANTIOMERS

CONSIDER CYCLOHEXANES

1,3



cis (meso)

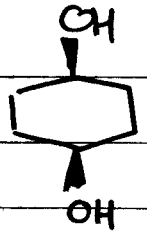


ENANTIOMERS

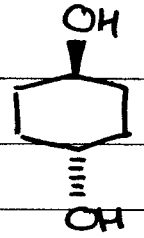
DRAW CHAIR FOR EACH AND DO RING FLIP

FOR EACH ENANTIOMER CHAIRS ARE IDENTICAL

1,4



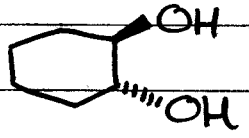
cis



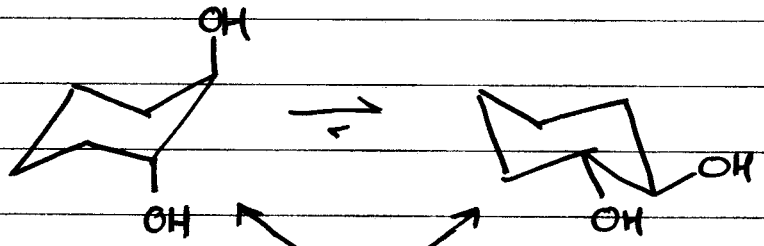
trans

BOTH ACHIRAL

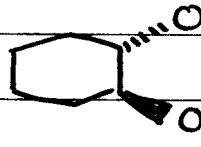
1,2

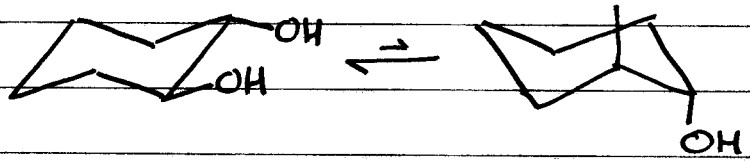


trans

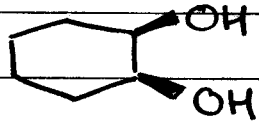


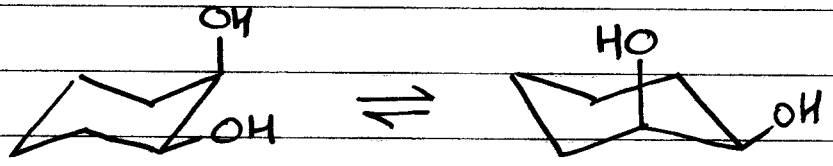
MIRROR IMAGES





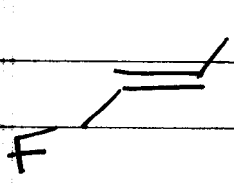
cis



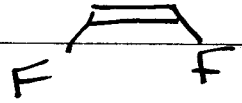


MIRROR IMAGES

ALKENES

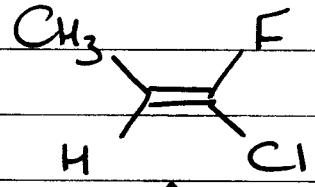


trans



cis

DIASTEREOISOMERS

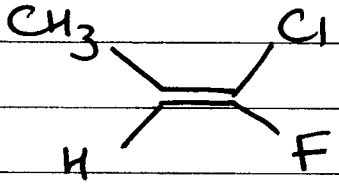


cis/trans ? (E)

↑

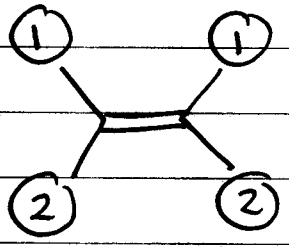
DIASTEREOISOMERS

↓

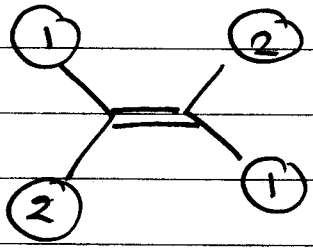


? (Z)

Use same priorities as for R/S on each C of double bond

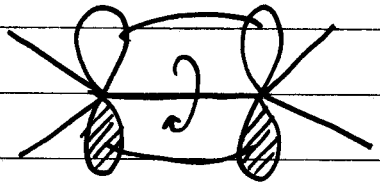


Z



E

WHY NO ROTATION ABOUT DOUBLE BONDS ?



ROTATION WOULD REMOVE OVERLAP (BREAK π BOND) AND THIS DOESN'T HAPPEN UNDER NORMAL CONDITIONS

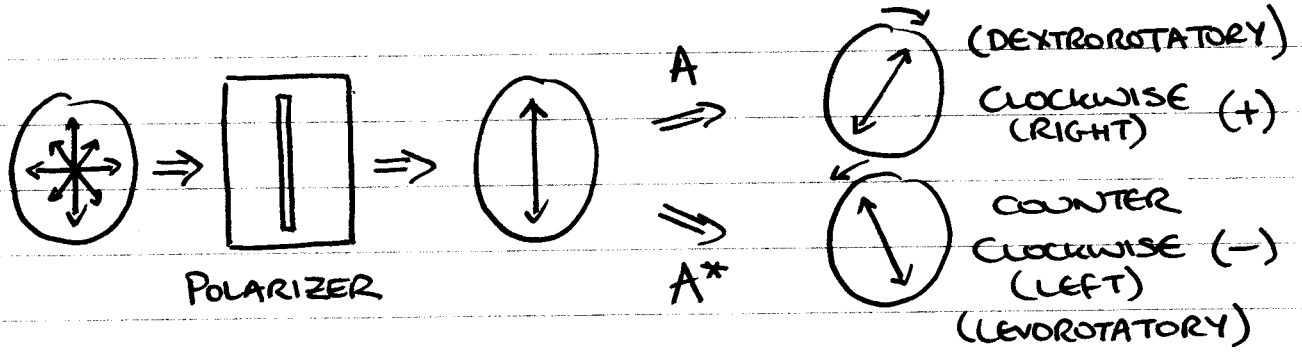
(3) PROPERTIES OF STEREOISOMERS

ENANTIOMERS – Identical PHYSICAL & CHEMICAL PROPERTIES (in an achiral environment)

e.g. mp, bp, solubility in water etc

DIASTEREOISOMERS – DIFFERENT....

OPTICAL ACTIVITY
– ROTATION OF PLANE POLARIZED LIGHT



$$\text{Specific rotation } [\alpha]_{\lambda}^{T} = \frac{\text{Obs rotation (°)}}{\text{Length (dm)} \times \text{Conc (g/mL)}}$$

T = temperature (°C)
λ = wavelength of light

Racemic mixture → specific rotation = ϕ ($\pm$)

NO RELATIONSHIP B/WEEN R/S +/–

ENANTIOMERIC EXCESS (ee)

$$ee = \frac{[R]-[S]}{[R]+[S]} \times 100$$

$$= \%R - \%S$$

e.g. if a sample is 90% R and 10% S,

the ee = 90 − 10 = 80%

READ SECTIONS 3.8 / 3.9

CHIRALITY IN THE NATURAL WORLD
(DNA, PROTEINS, ENZYMES, DRUGS)

LEC (11) CHEM 30A Oct 25th

(1) CIS/TRANS DIASTEREOISOMERS
(2) CONSEQUENCES OF CHIRALITY

CHAPTER 4 – ACIDS & BASES
(3) INTRO
(4) ACID STRENGTH

HMM: MIDTERM ON WEDNESDAY...

MIDTERM
EXTRA OFFICE HRS: TUES 1-2, 4-5pm
ROOMS: A-J BUNCHE 1209B K-Z CS50
BOOKS:
NO CALCULATORS

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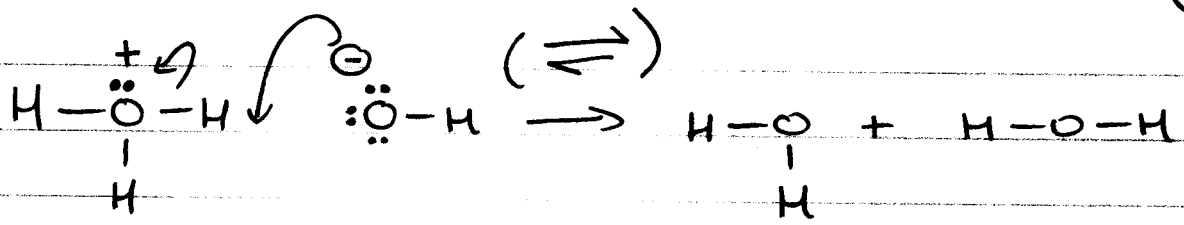
(1)/(2) Start Page (8) Lecture (10)

(3) CHAPTER (4)

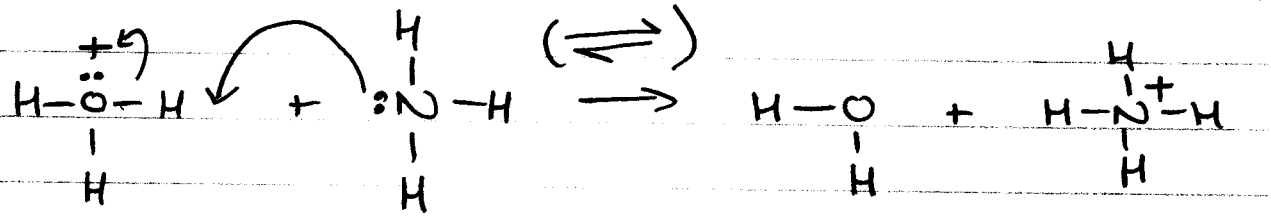
ACIDS & BASES

BRONSTED-LOWRY ACID H^+ DONOR
BASE H^+ ACCEPTOR



ACID (H⁺ DONOR) — Hydronium ion

BASE (H⁺ ACCEPTOR) — Hydroxide ion



ACID — BASE — CONJUGATE BASE — CONJUGATE ACID

(2) ACID DISSOCIATION CONSTANTS

- Quantify acid strength

$$HA + H_2O \rightleftharpoons A^- + H_3O^+$$

$$K_{eq} = \frac{[H_3O^+][A^-]}{[HA][H_2O]}$$

← changes very little - huge xs

$$K_a = K_{eq}[H_2O] = \frac{[H_3O^+][A^-]}{[HA]}$$

e.g. for acetic acid $CH_3\overset{\overset{O}{\|}}{C}-OH$

$K_a = 1.74 \times 10^{-5}$

most organic acids have K_a values with -ve exponents, so we often compare pK_a values

$pK_a = -\log_{10} K_a$

$pK_a\ (CH_3COOH) = 4.76$

LARGER pK_a VALUE $\longrightarrow$ WEAKER ACID

ALSO:

STRONG ACID $\equiv$ WEAK CONJUGATE BASE

WEAK ACID $\equiv$ STRONG CONJUGATE BASE

Scan through table Page 141

→ Position of acid/base equilibrium

$HA + B^{\ominus} \rightleftharpoons A^{\ominus} + HB$

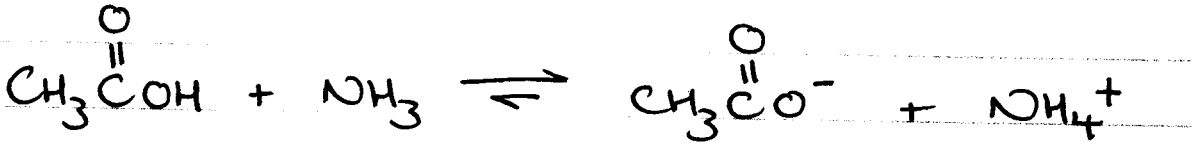
Competition between B^- and A^- for the H^+

$$K_{eq} = \frac{[A^-][BH]}{[HA][B^-]}$$

$$\times \frac{[H_3O^+]}{[H_3O^+]}$$

$$K_{eq} = \frac{[A^-][H_3O^+]}{[HA]} \times \frac{[BH]}{[B^-][H_3O^+]}$$

$$K_{eq} = \frac{K_{AH}}{K_{BH}} \quad \begin{matrix} \text{(ACID)} \\ \text{(CONJUGATE ACID)} \end{matrix} \qquad \left[pK_{eq} = pK_{HA} - pK_{BH} \right]$$



pka 4.76 pka 9.24

$$pK_{eq} = 4.76 - 9.24 = -4.48$$

$$K_{eq} = 10^{-pK_{eq}}$$

$$= 3 \times 10^4$$

PUT STRONGER ACID ON LEFT, $K_{eq} > 1$

STRONGER ACID + STRONGER BASE ⟹ WEAKER ACID/BASE

Lec (12) CHEM 30A Oct 29th

(1) ACID/BASE EQUILIBRIA
(2) STRUCTURE AND ACIDITY
(3) PROTONATING ORGANIC STRUCTURES
(4) LEWIS ACIDS/BASES

READING: CH4
HMK: DO THE MIDTERM AGAIN!
: 4.1 → 4.45

MIDTERM: HIGH 98, LOW 13, MEAN 52
"HOW-TO" GUIDE

---

(1) ACID/BASE EQUILIBRIA

$$HA + H_2O \rightleftharpoons A^- + H_3O^+$$

$$K_a = \frac{[H_3O^+][A^-]}{[HA]}$$

$$pK_a = -\log_{10} K_a$$

LARGER pK_a → WEAKER ACID
AND STRONG ACID ≡ WEAK CONJUGATE BASE
WEAK ACID ≡ STRONG CONJUGATE BASE

Scan through pka table Page 141

Acid/Base Equilibrium

$$HA + B^{\ominus} \rightleftharpoons A^{\ominus} + HB$$

Competition between $B^{\ominus}$ and $A^{\ominus}$ for the H^+

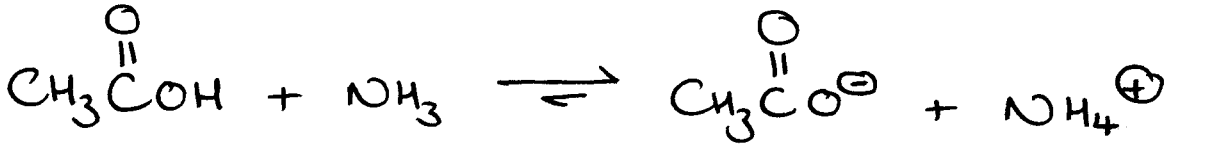
$$K_{eq} = \frac{[A^-][HB]}{[HA][B^-]}$$

multiply by $\frac{[H_3O^+]}{[H_3O^+]}$

$$K_{eq} = \frac{[A^-][H_3O^+]}{[HA]} \times \frac{[HB]}{[B^-][H_3O^+]}$$

$$K_{eq} = \frac{K_{HA}}{K_{HB}} \quad \begin{matrix}(\text{ACID}) \\ (\text{CONJUGATE ACID})\end{matrix}$$

$$pK_{eq} = pK_{HA} - pK_{HB}$$



pka 4.76

pka 9.24

So,

$$pK_{eq} = 4.76 - 9.24 = -4.48$$

$$K_{eq} = 10^{-pK_{eq}}$$

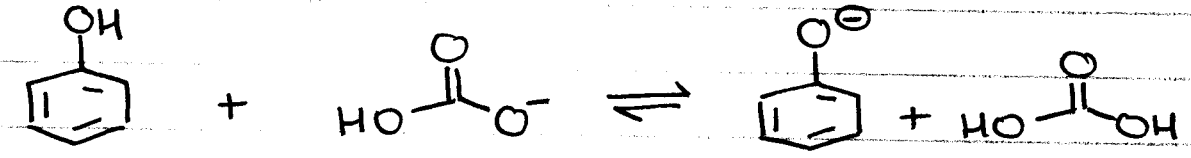
$$= 3 \times 10^{4}$$

STRONGER ACID AND STRONGER BASE REACT TO GIVE WEAKER ACID + WEAKER BASE

If stronger acid is on left side of equation, K_{eq} will be > 1

If stronger acid is on the right side of equation, K_{eq} will be < 1

For example:



$pK_a \sim 10$ STRONGER ACID $\Rightarrow pK_a \sim 6.4$

So equilibrium lies to the left, and

$$K_{eq} = 10^{-3.6}$$

(2) STRUCTURE AND ACIDITY

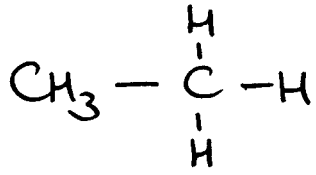
$$HA \rightleftharpoons H^+ + A^-$$

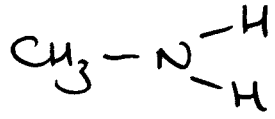
all about A^-

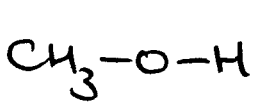
The more stable A^-, the more acidic HA is.

a) Electronegativity

Consider

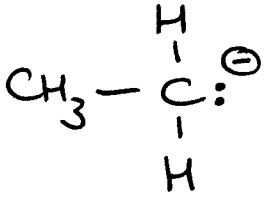


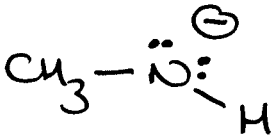


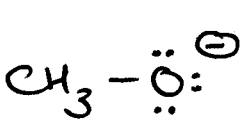


pKa 51 38 16

⟶ INCREASING ACIDITY







Conjugate bases

⟵ INCREASING BASICITY

C	N	O
2.5	3.0	3.5

Bigger EN, electrons held more strongly, A^- is more stable $\longrightarrow$

THIS TREND holds within any given row of the periodic table.

b) ATOM SIZE

Consider

CH_3-S-H vs CH_3-O-H

pka 7 16

$CH_3-S^{\ominus}$ $CH_3-O^{\ominus}$

↑

more stable

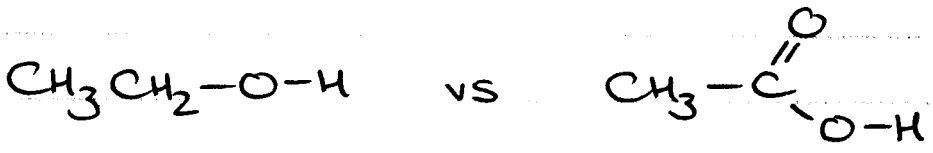
NEGATIVE CHARGE IS SPREAD OVER A LARGER VOLUME (lower charge density)

So for HALOGEN ACIDS

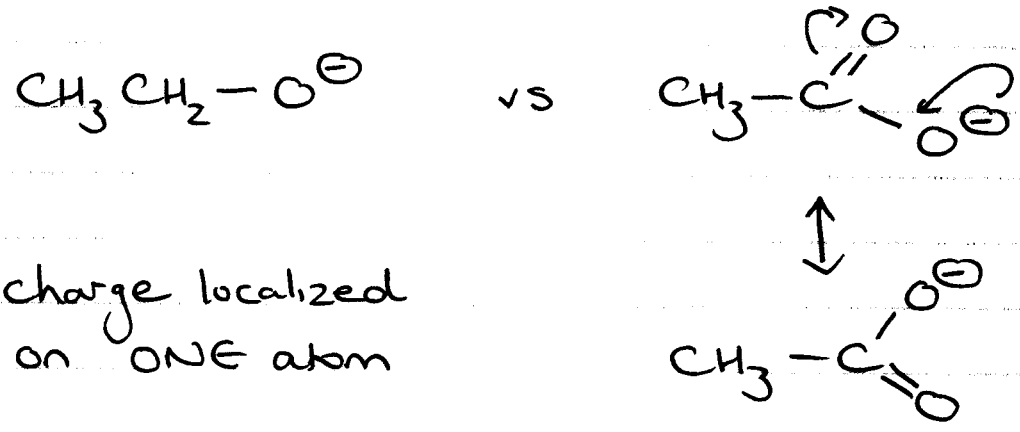
$HI > HBr > HCl > HF$

c) RESONANCE

Consider:

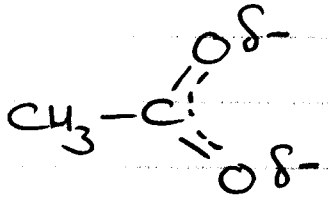


pka 16 vs 5



charge localized on ONE atom

charge delocalized



DELOCALIZATION ≡ STABILITY

(HOT POTATO ANALOGY)

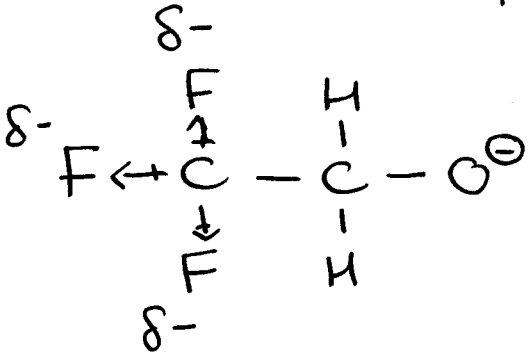
d) INDUCTIVE EFFECT

Consider: CH_3CH_2-O-H CF_3CH_2-O-H

pka 15.9 12.4

So,

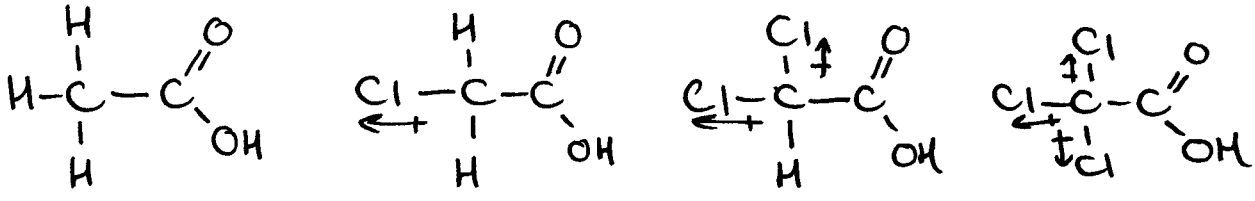
$CF_3CH_2O^{\ominus}$ is more stable than $CH_3CH_2O^{\ominus}$



THROUGH BOND – FALLS OFF RAPIDLY WITH DISTANCE

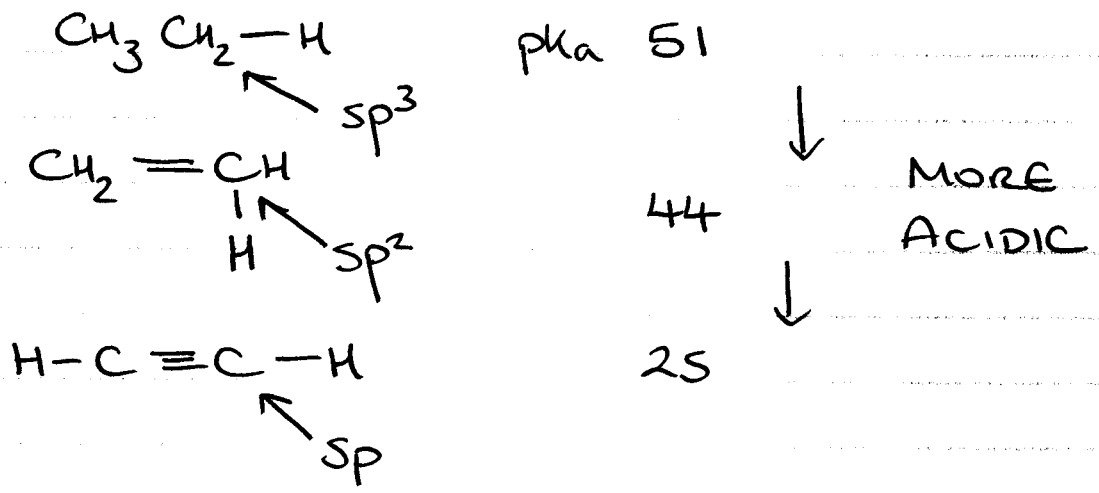
CF_3CH_2OH	$CF_3CH_2CH_2OH$	$CF_3CH_2CH_2CH_2OH$
12.4	14.6	15.4

Same effect on carboxylic acids



4.75	2.85	1.48	0.64

e) HYBRIDIZATION



S character of orbital

25% → 33% → 50%

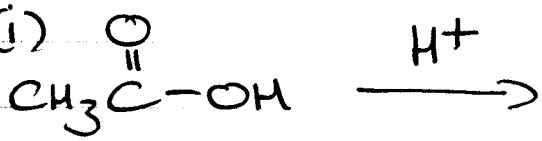
⟶

- electrons held closer to the nucleus
  - more stable anion
  - more acidic

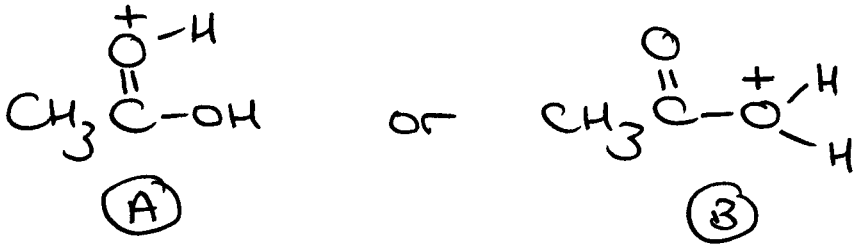
IMPORTANCE OF EFFECT → in order presented

Atom / (Size) / Resonance / Induction / Orbital

③ ORGANIC STRUCTURES

(1) 

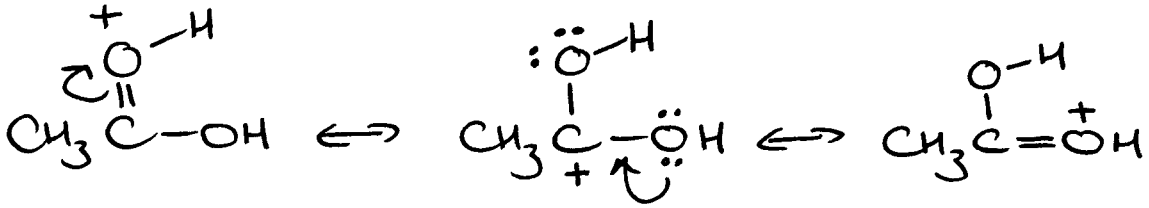
(9)



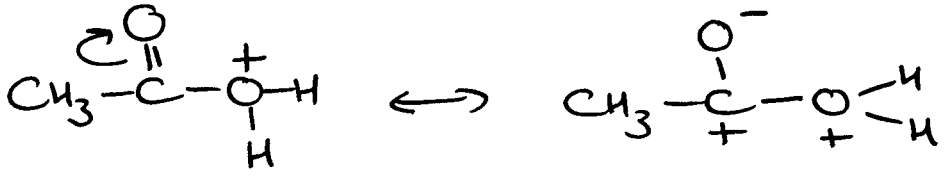
(A) or (B) ?

Consider resonance

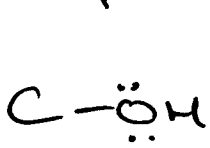
(A)

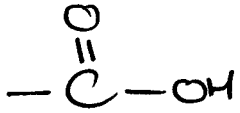


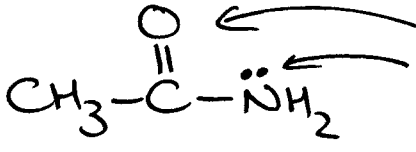
(B)



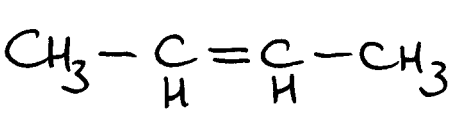
not a good resonance form

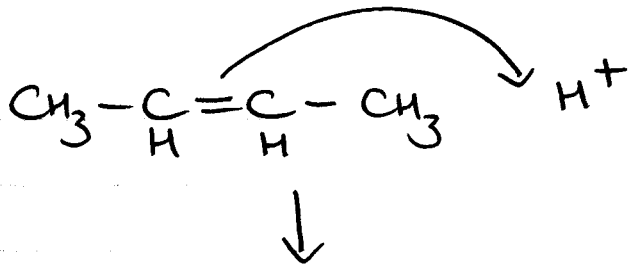
So,  more basic than 

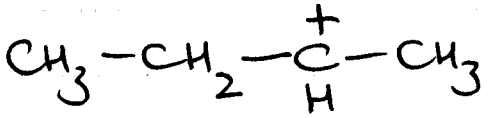
in 

HMK  which is more basic

(ii)

 + H^+ ⟶ ?





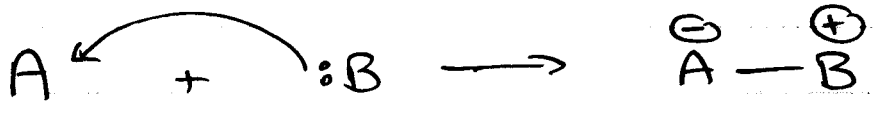
CARBOCATION

(See these a lot more — soon)

(4) LEWIS ACIDS / BASES

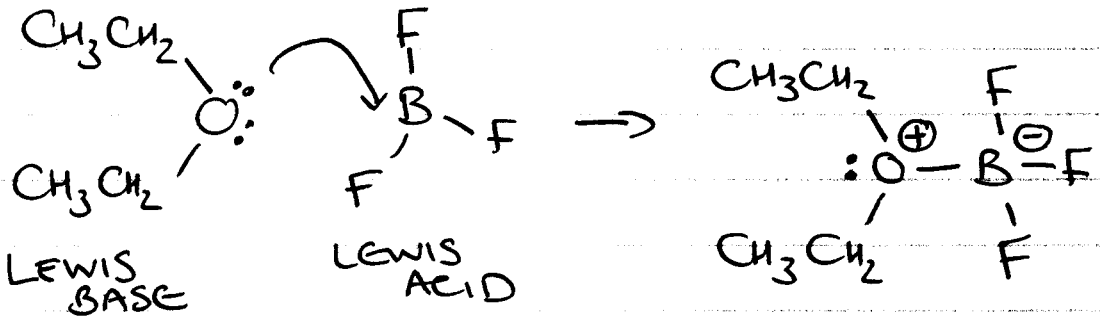
About e^- pairs, not H^+

LEWIS ACID accepts an e^- pair
LEWIS BASE donates an e^- pair



LEWIS ACID — LEWIS BASE

e.g.



LEWIS BASE — LEWIS ACID

LEC (13) CHEM 30A Nov 1st

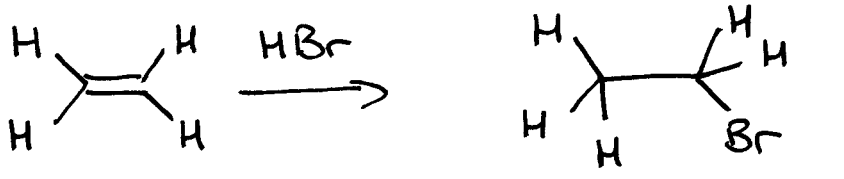
ORGANIC REACTIONS

① TYPES
② MECHANISMS
③ ENERGY DIAGRAMS

READ: Ch5 6.1–6.3 PBLMS: 5.2, 5.6–5.10, 5.13–5.19 6.1, 6.2

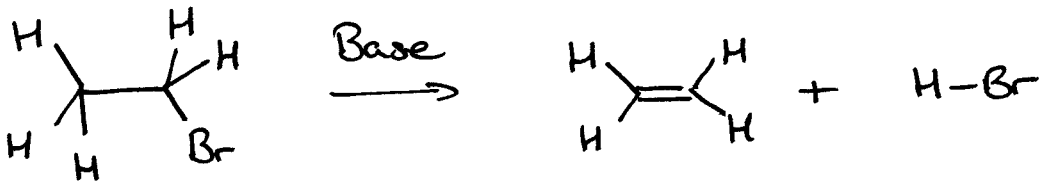
① TYPES OF REACTIONS

a) ADDITION (A + B ⟶ C)

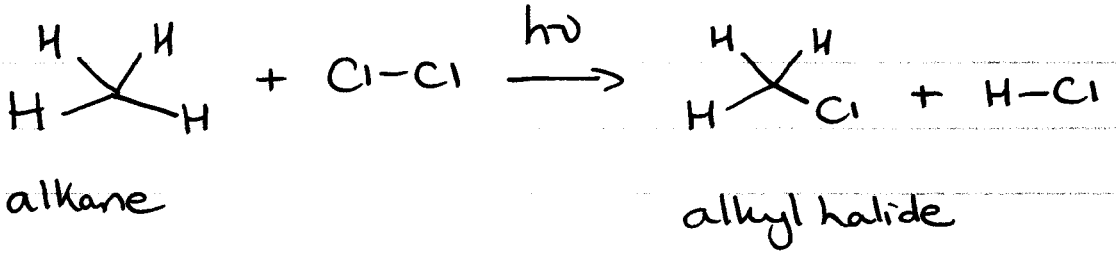
e.g 

alkene alkylhalide

b) ELIMINATION (A ⟶ B + C)

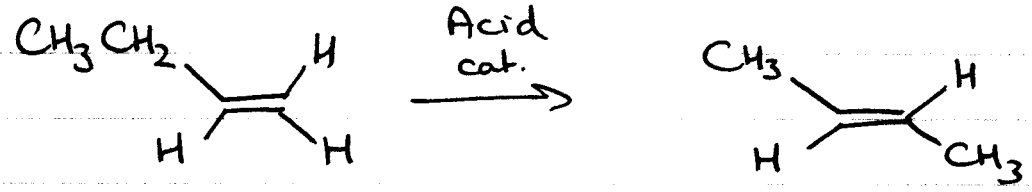
e.g. 

c) SUBSTITUTION (A-B + C-D → A-C + B-D)

e.g. 

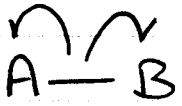
alkane — alkyl halide

d) REARRANGEMENT (A → B)

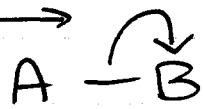


(2) MECHANISMS

BOND MAKING / BOND BREAKING

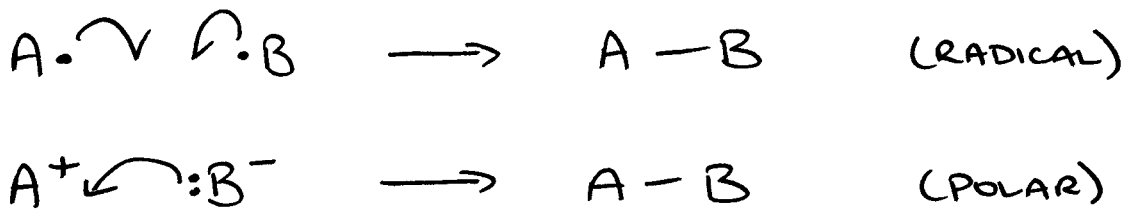
1e⁻ ARROW →  HOMOLYTIC → A• + B•

Radical reactions → radical is a neutral chemical species that contains a single unpaired electron

2e⁻ ARROW →  HETEROLYTIC → $A^+ + :B^-$

POLAR REACTIONS

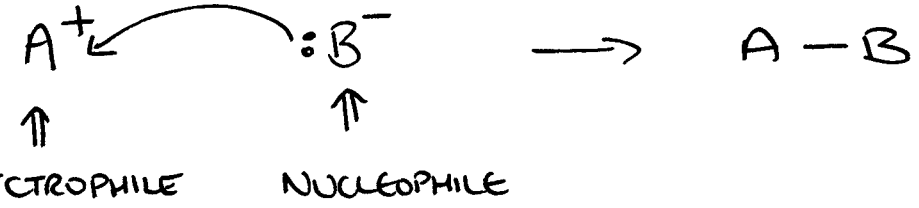
BOND MAKING



(RADICAL RXNS LATER IN COURSE)

- POLAR REACTIONS

e⁻ rich sites in one molecule react with e⁻ poor sites in another molecules

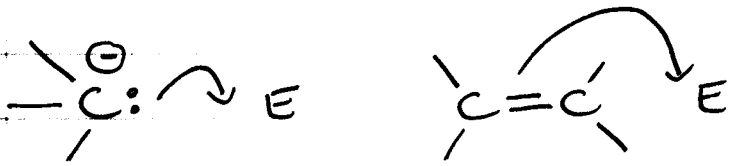


Nucleophiles: have an e⁻ rich atom and are NEUTRAL or −VELY charged.

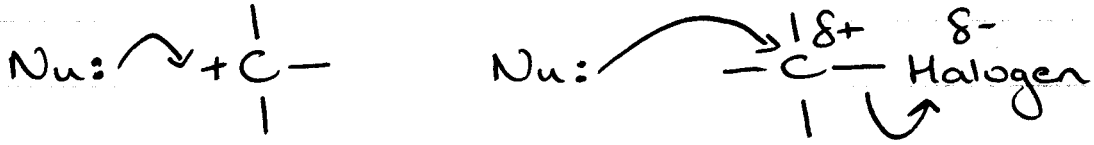
Electrophiles: have an e⁻ poor atom and are NEUTRAL or +VELY charged

Patterns

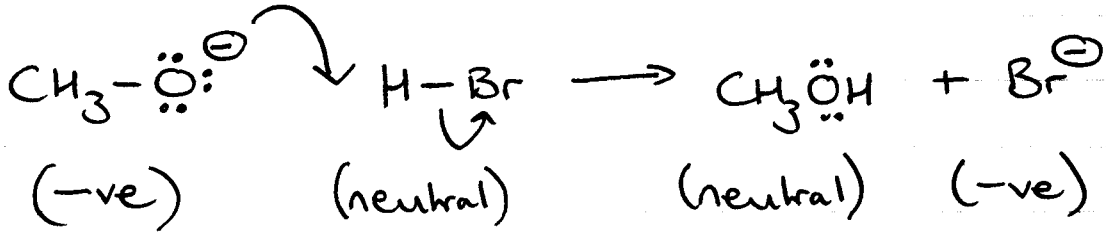
Electrons flow from nucleophiles :

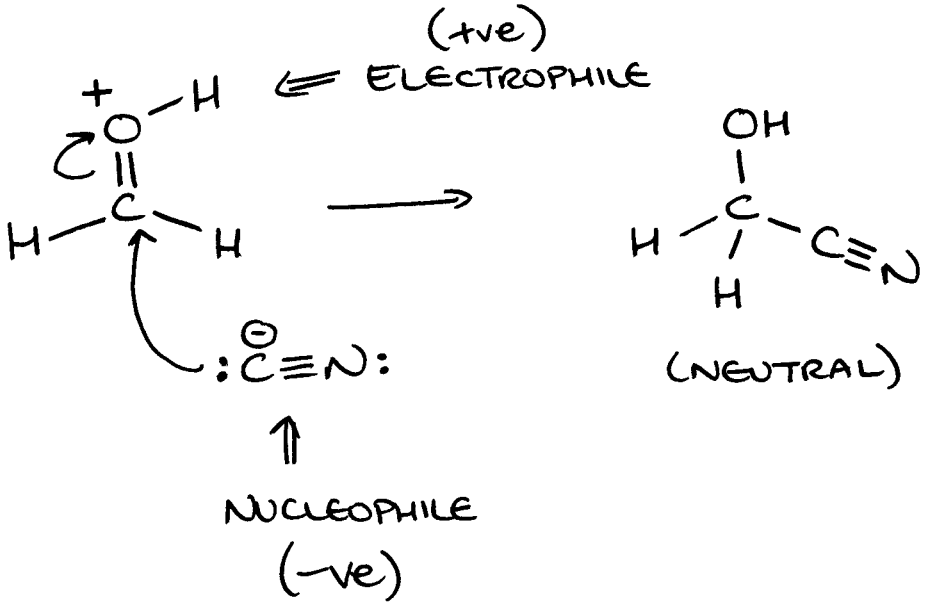


Electrons flow to electrophiles :

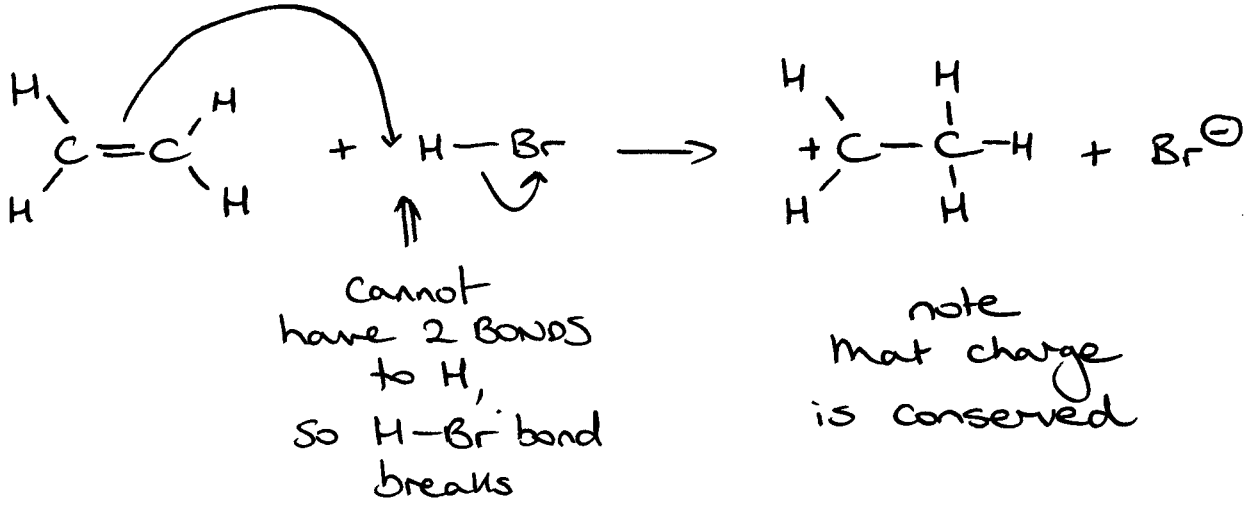


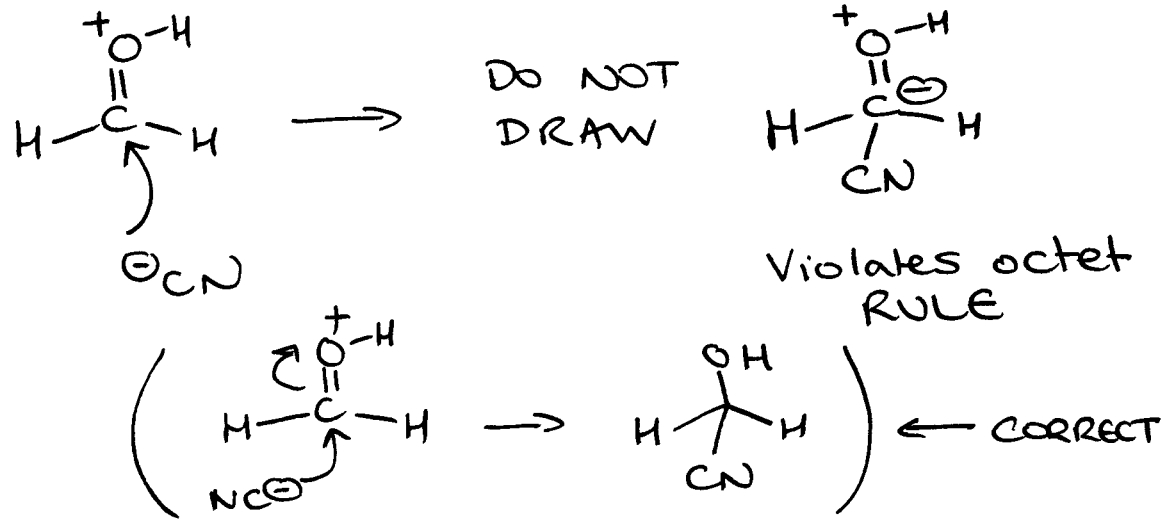
Conserve charge:





Octet Rule must be followed

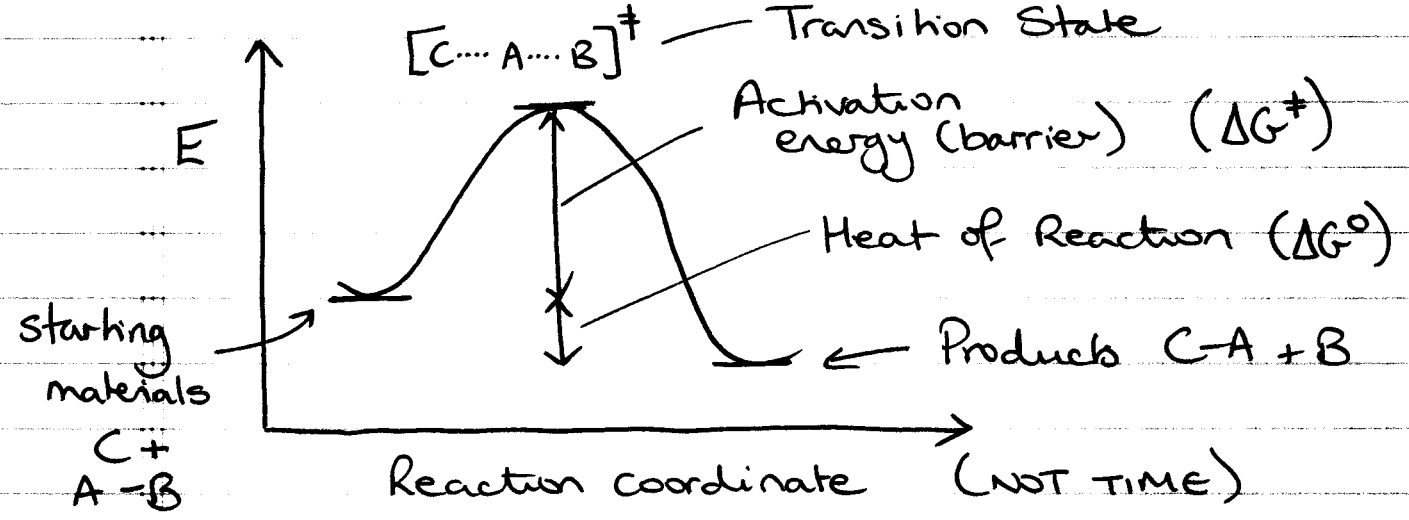




(3) ENERGY DIAGRAMS

- ONE-STEP REACTION

$C + A-B \longrightarrow C-A + B$



For a reaction to occur as written,

$\Delta G^\circ < 0$ (proceeds spontaneously)

If $\Delta G^\circ > 0$ reaction does not proceed

- Heat of reaction

$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$ ← change in entropy (more significant at higher T)

↑ change in enthalpy (CAN BE MEASURED DIRECTLY)

ΔH° -ve EXOTHERMIC Reaction
ΔH° +ve ENDOTHERMIC Reaction

- Transition State

Energy maximum on reaction co-ordinate

- definite geometry and arrangement of atoms

CANNOT BE ISOLATED, STRUCTURE CANNOT BE DETERMINED

- sometimes we can infer structure, or use computational techniques

- Activation energy

Difference in energy between starting materials and the transition state

$\Delta G^\ddagger$ or E_A

Arrhenius equation

$$K = Ae^{\left(\frac{-E_A}{RT}\right)}$$

pre-exponential factor

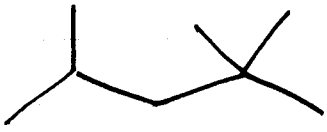
K: reaction rate constant

KINETICS vs THERMODYNAMICS

↓ How fast will it happen

↓ Will a reaction happen?

e.g.



isooctane

$+ O_2 \rightleftharpoons 8CO_2 + 9H_2O$

$\Delta G^\circ = -1000\ kJ\ mol^{-1}$

$K_{eq} = 10^{175}$ at 298K

(10^{86} atoms in the observable universe)

<u>BUT</u>

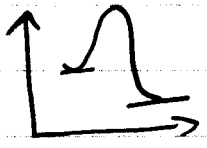
ISOOCTANE is stable

(YOU PUT IT INTO YOUR CAR)

So, energy is required to start reaction

⇒ activation energy

DRAW GRAPH

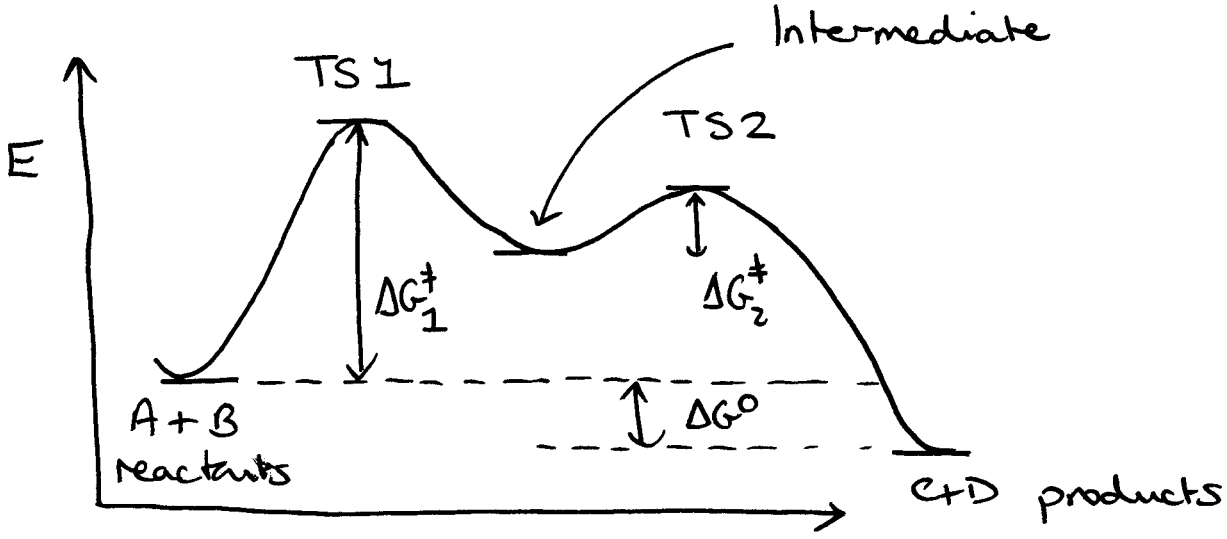


So, octane + oxygen

THERMODYNAMICALLY UNSTABLE BUT KINETICALLY STABLE

By contrast, if you applied the same burst of energy to the H_2O and CO_2 that is formed, it WILL NOT revert back to octane and oxygen.

TWO-STEP REACTION



Reaction intermediate → energy minimum between two transition states

SLOWEST step in a multi-step reaction (one with highest barrier) is called the RATE DETERMINING STEP (RDS)

LEC (14) CHEM 30A Nov 3rd

1. KINETICS vs THERMODYNAMICS
2. ADDITION TO ALKENES
   - HX
   - H_2O
3. CARBOCATION REARRANGEMENT
4. ADDITION OF Br_2 / Cl_2

HMK: Read 6-6.5
Problems 6.3 - 6.8, 6.14 - 6.16

---

1. KINETICS vs THERMODYNAMICS

↓	↓
How fast will it happen	will a reaction happen

e.g.

$$+ \; O_2 \rightleftharpoons 8CO_2 + 9H_2O$$

isooctane $\Delta G^\circ = -1000\ kJ\ mol^{-1}$

$K_{eq} = 10^{175}$ at 298K

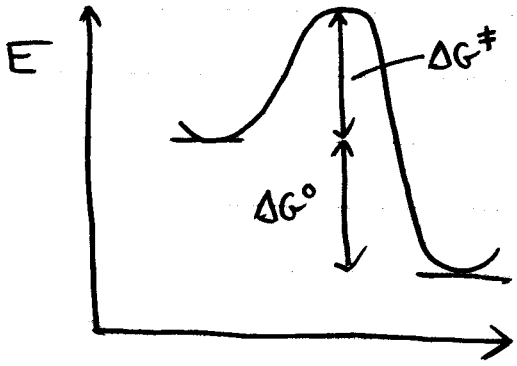
(10^{86} atoms in the observable universe)

BUT

Isooctane is stable
(you put it in your car...)

Energy is required to start the reaction
⇒ ACTIVATION ENERGY

→ spark plug



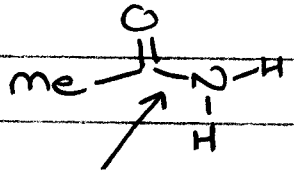
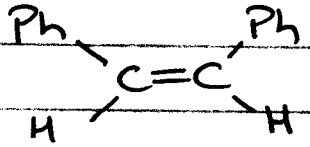
So isooctane + oxygen

THERMODYNAMICALLY UNSTABLE
BUT KINETICALLY STABLE

However → apply burst of energy to $H_2O + CO_2$, they will not reconvert to octane and oxygen.

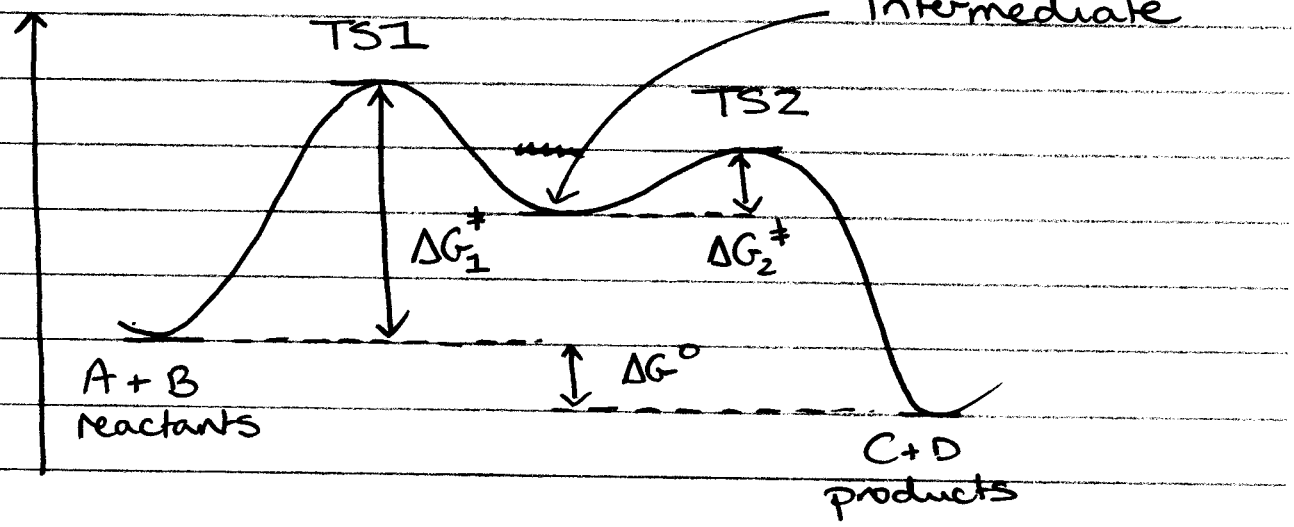
ENERGY BARRIERS & RATE

(Consider BOND ROTATION - same principles apply to reactions)

	E_A (kcal/mol)	k (s^{-1}) (298 K)	$t_{1/2}$
H_3C-CH_3	3	5×10^{10}	0.02 ns
Cl_3C-CCl_3	11	8×10^{4}	10 μs
	17	3	0.2 s
	45	2×10^{-19}	~ 10^{11} years

(AGE of the EARTH ~ 4.6×10^9 years)

- TWO-STEP REACTION

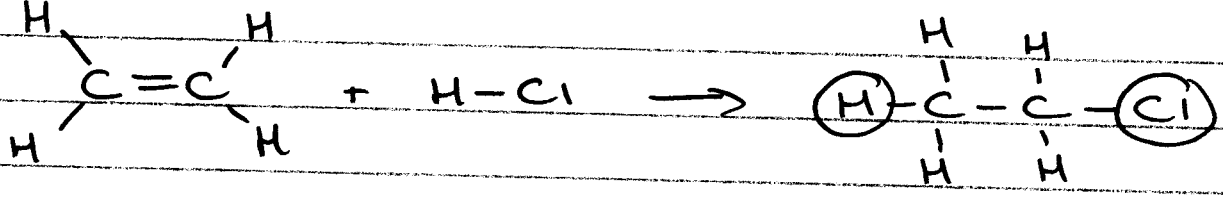


Reaction Intermediate
=> localized energy minimum between two transition states

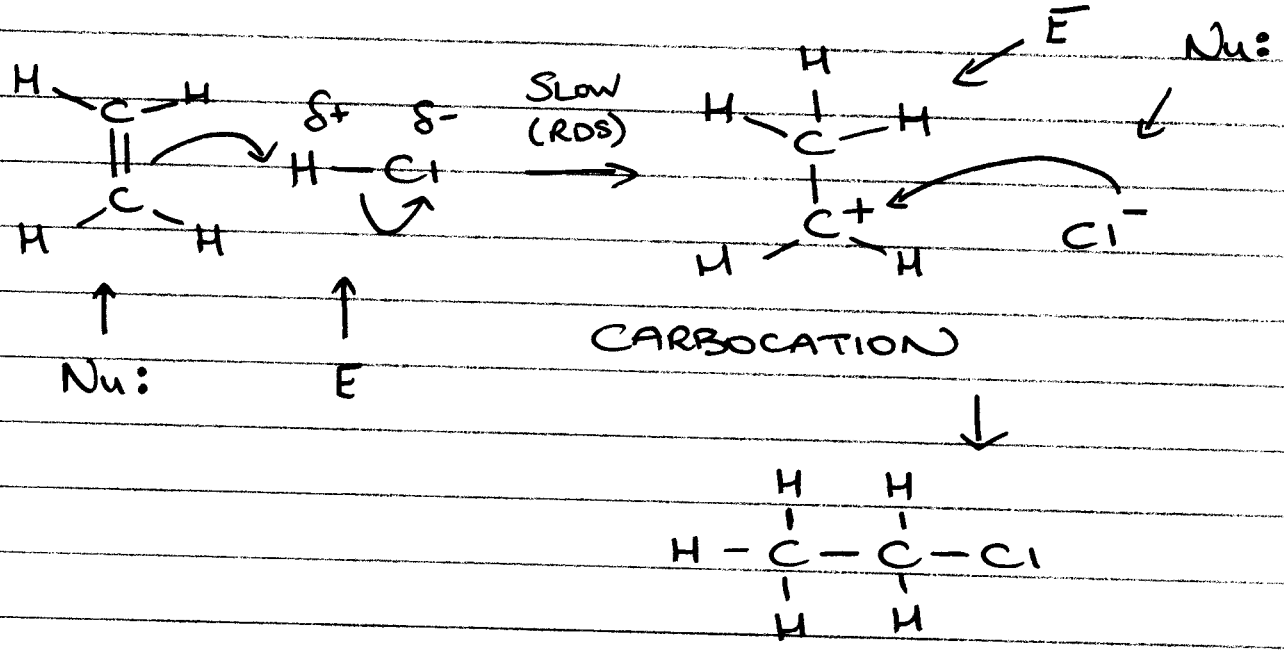
(sometimes possible to isolate)

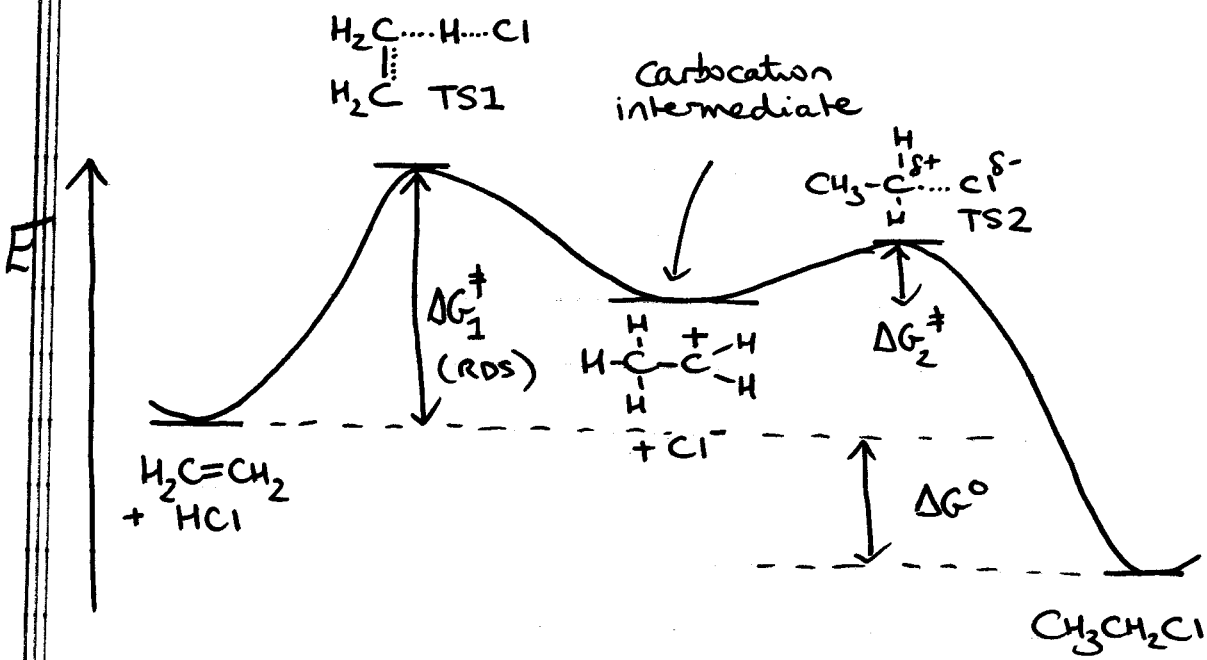
Slowest step in a MULTISTEP reaction (one with highest barrier) is called the rate determining step (RDS)

(2) ELECTROPHILIC ADDITION TO ALKENES

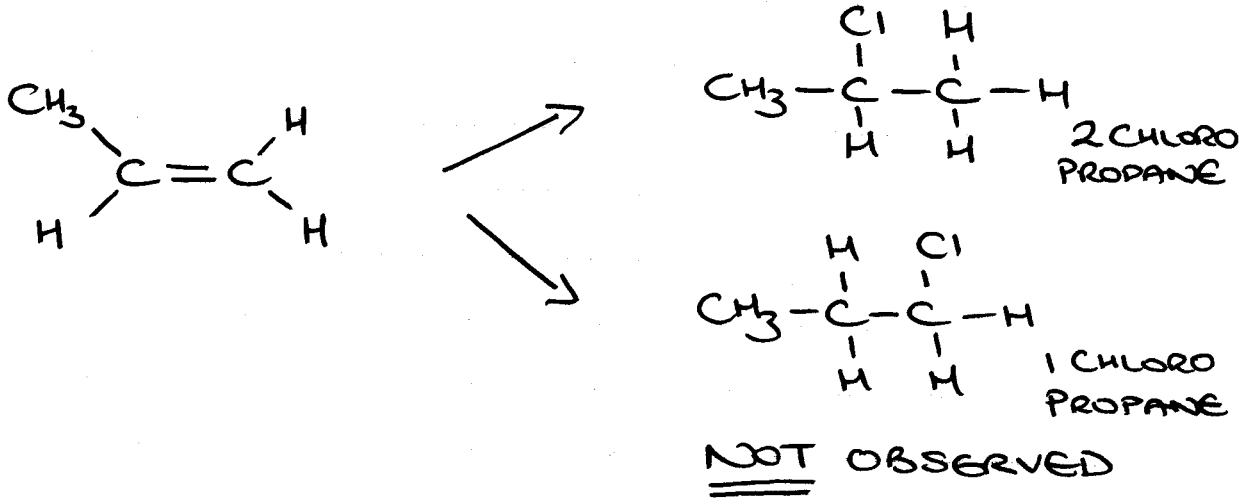


Mechanism





NOW CONSIDER:



NOT OBSERVED

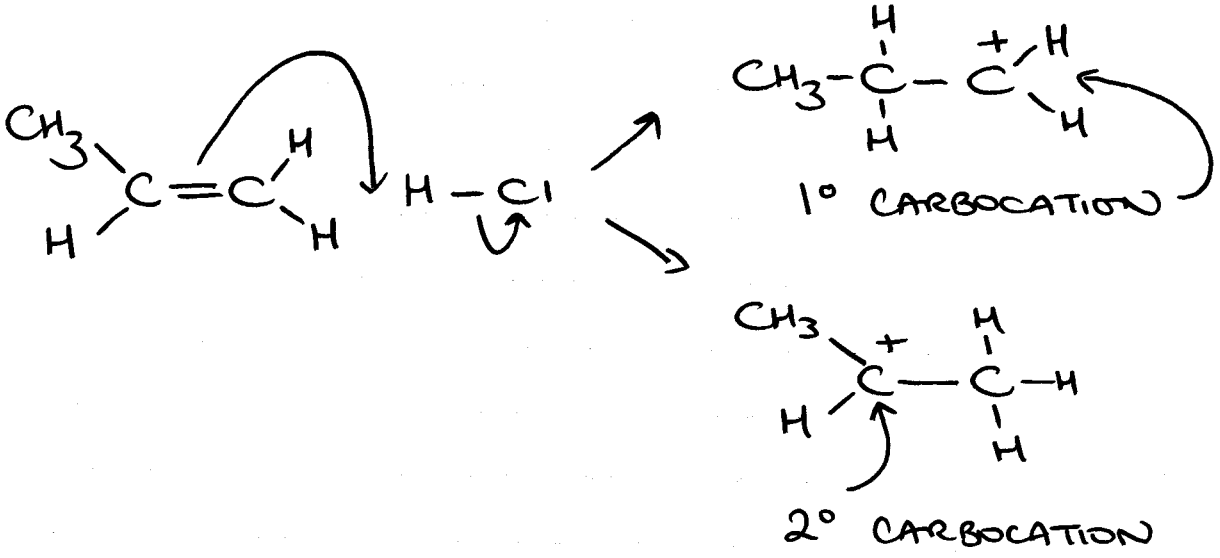
Example of a REGIOSELECTIVE reaction

MARKOVNIKOV'S RULE —

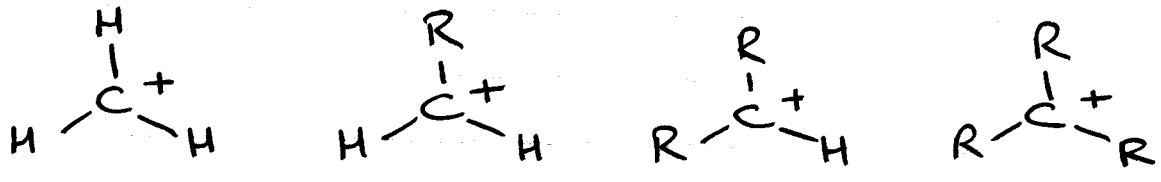
Addition of H–X to an ALKENE, H adds to double-bonded C atom with greatest # of H atoms

WHY?

CARBOCATIONS



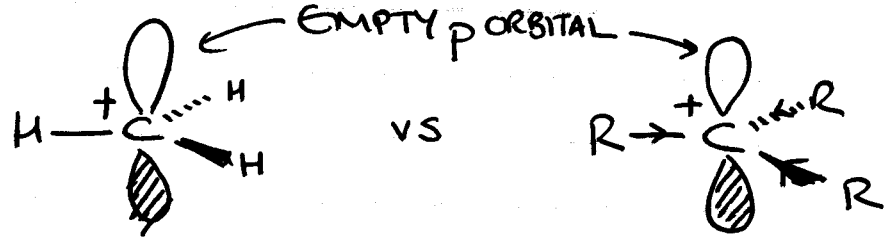
STABILITY (R = ALKYL)



INCREASING STABILITY →

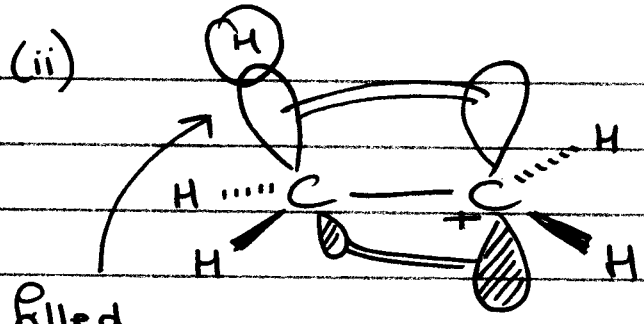
TWO FACTORS: (i) INDUCTIVE EFFECT
(ii) HYPERCONJUGATION

(i)



ALKYL GROUPS ARE INDUCTIVELY DONATING

(ii)



filled sp^3–1s σ orbital

↖ empty p orbital

DELOCALIZATION of adjacent σ BOND e^- into the empty p-orbital

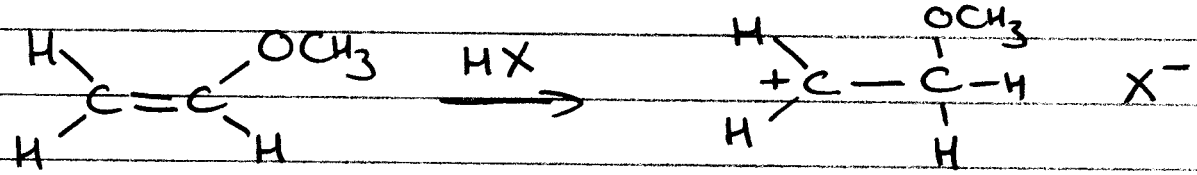
– HYPERCONJUGATION

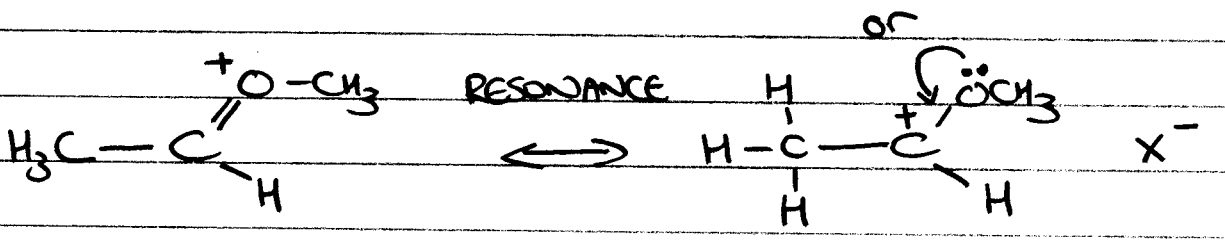
– the more C–H bonds, the more significant the interaction, so

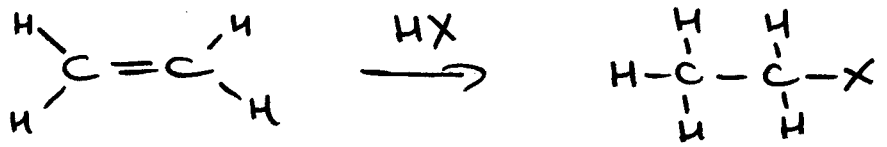
$Me^+ < 1° < 2° < 3°$

.... AND ANOTHER FACTOR → RESONANCE

consider

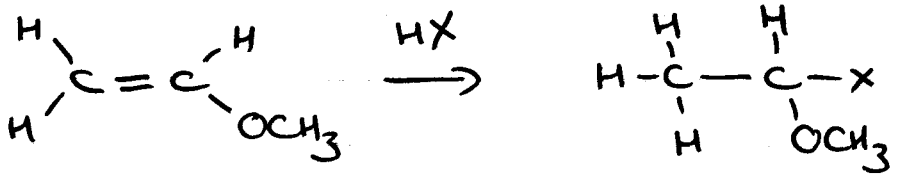






1

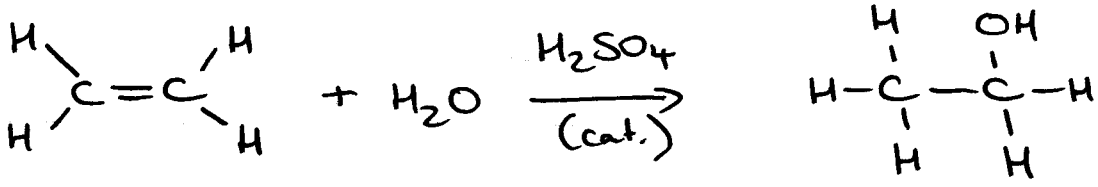
2×10^6



5×10^{14}

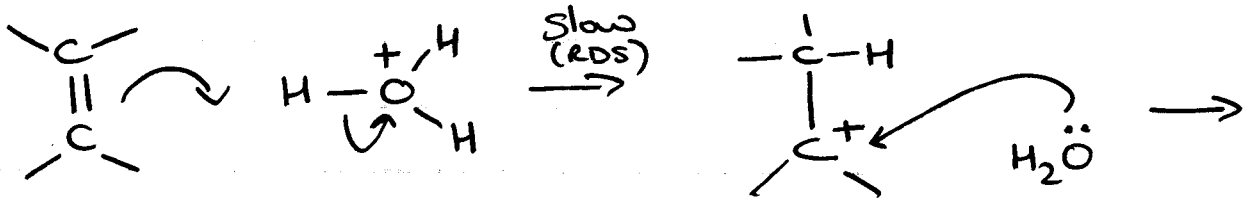
RELATIVE RATES of ADDITION at 298K

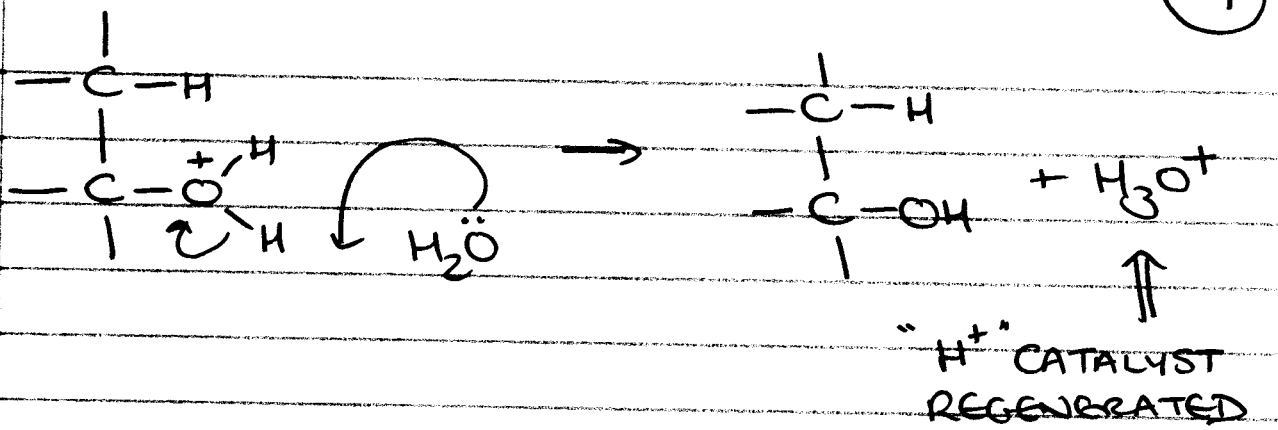
ADDITION OF H_2O (acid catalyst)
(HYDRATION)



H_2O cannot protonate a C=C bond like HCl or HBr, but

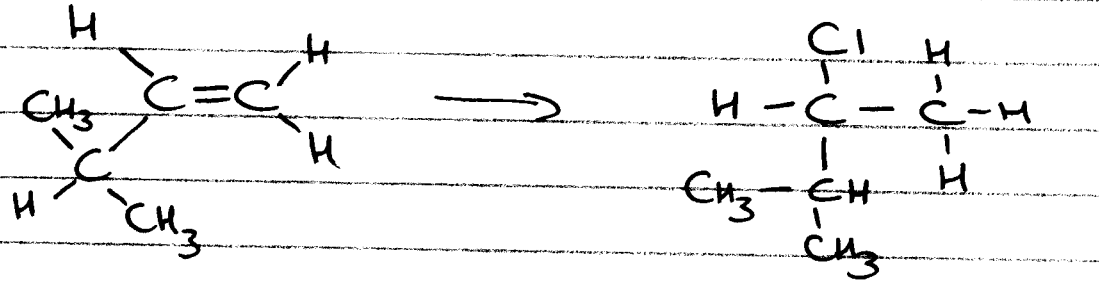
$$H_2SO_4 + H_2O \rightleftharpoons H_3O^+ + HSO_4^-$$





Mechanism involves a carbocation, so proceeds with MARKOVNIKOV selectivity.

③ CARBOCATION REARRANGEMENT

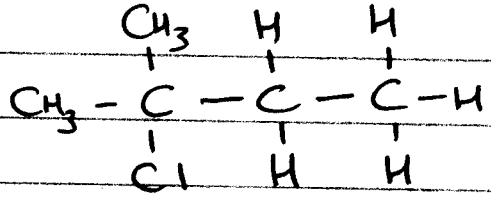


Expected product

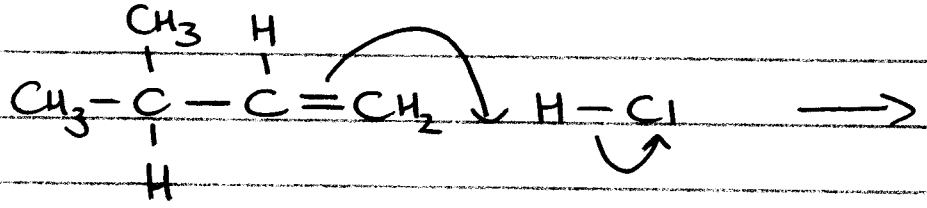
~ 40%

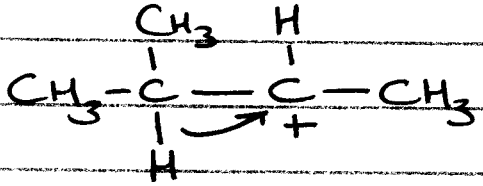
2CHLORO-3-METHYL BUTANE

other 60% ?

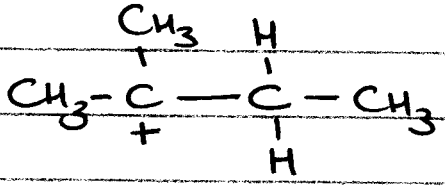


2 CHLORO-2-METHYL BUTANE





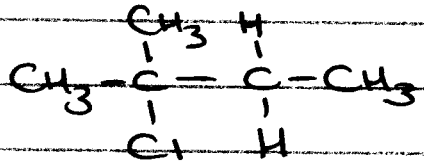
1,2 HYDRIDE SHIFT



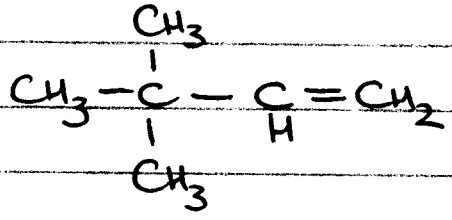
Secondary carbocation

tertiary carbocation (more stable)

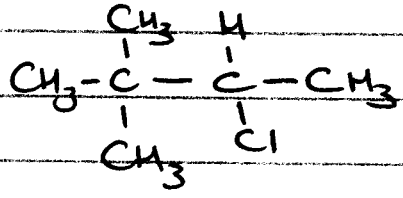
Cl^-



Can also happen in ACID CATALYSED HYDRATION

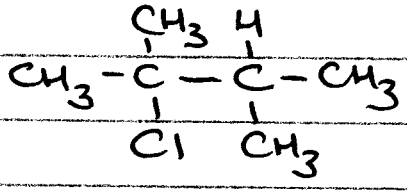


HCl



MINOR PRODUCT (20%)

INVOLVES A 1,2 METHYL SHIFT



MAJOR PRODUCT (80%)

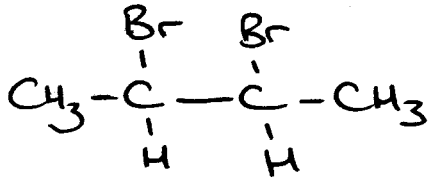
SHOW WHY THIS HAPPENS

2° CARBOCATIONS → 3° CARBOCATIONS

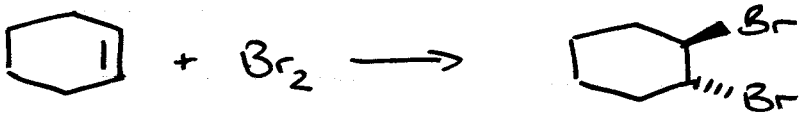
(RARELY REARRANGE IN THE OPPOSITE DIRECTION)

We don't really worry about 1° C+, as they don't form in reactions in solution as they are UNSTABLE.

(4) ADDITION of Br_2 / Cl_2

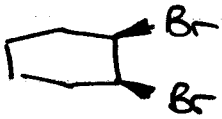
$CH_3CH=CHCH_3 + Br_2 \longrightarrow$ 

note:



trans
1,2-dibromocyclohexane

AN EXAMPLE OF A STEREOSPECIFIC REACTION

– DO NOT FORM  – WHY?

LEC (15) CHEM 30A Nov 5th

1. CARBOCATION REARRANGEMENT
2. ADDITION OF Br_2 / Cl_2
3. ADDITION OF HOCl / HOBr
4. OXYMERCURATION
5. HYDROBORATION

READ: 6.3 – 6.7
PROBLEMS: 6.9 – 6.11, 6.17 – 6.38

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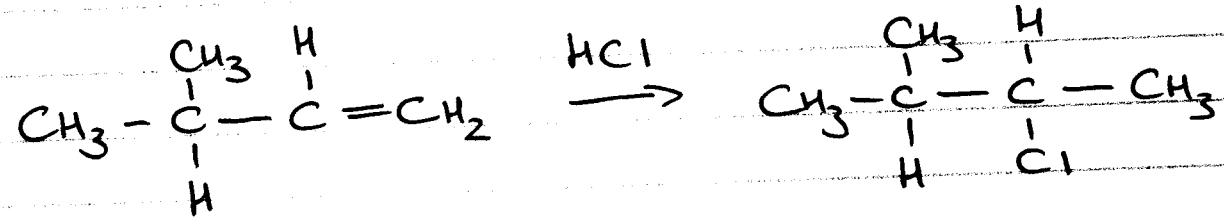
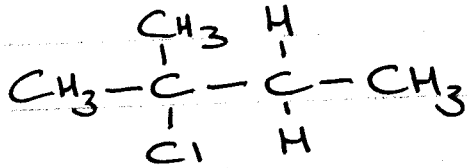
(1) CARBOCATION REARRANGEMENT



expected MARKOVNIKOV product
2 CHLORO-3-METHYL BUTANE
~40%

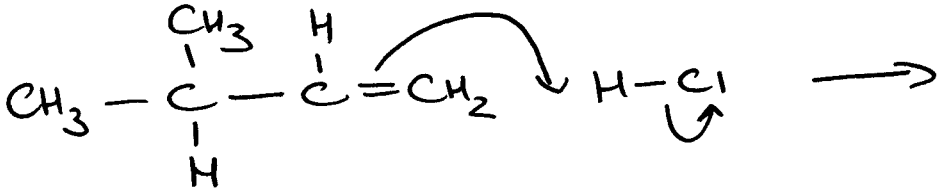
WHAT'S THE OTHER 60% ?

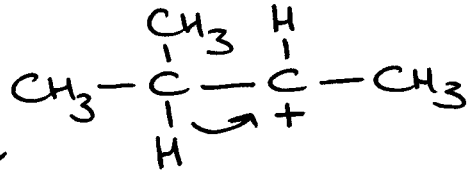


2 CHLORO-2-METHYL BUTANE

WHY? —

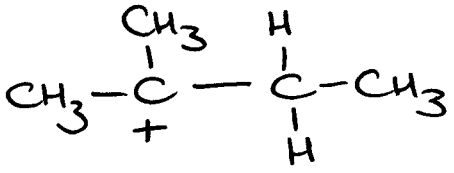
consider mechanism:





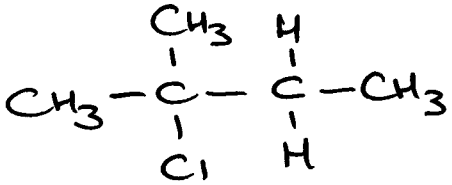
hydride shift

secondary carbocation

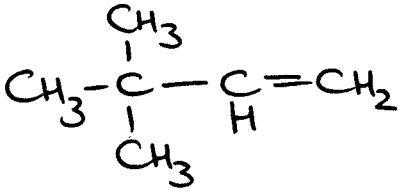


tertiary carbocation (more stable)

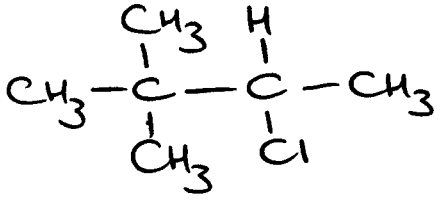
Cl^-



(ACID-CATALYSED HYDRATION ALSO GOES THROUGH A CARBOCATION, SO REARRANGEMENT CAN ALSO HAPPEN IN THAT PROCESS)

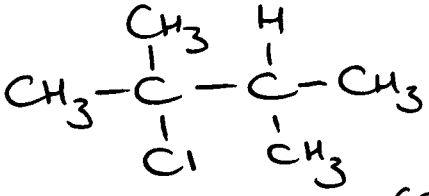


HCl



MINOR PRODUCT (20%)

INVOLVES A 1,2 METHYL SHIFT (SHOW HOW THIS HAPPENS...)



MAJOR PRODUCT (80%)

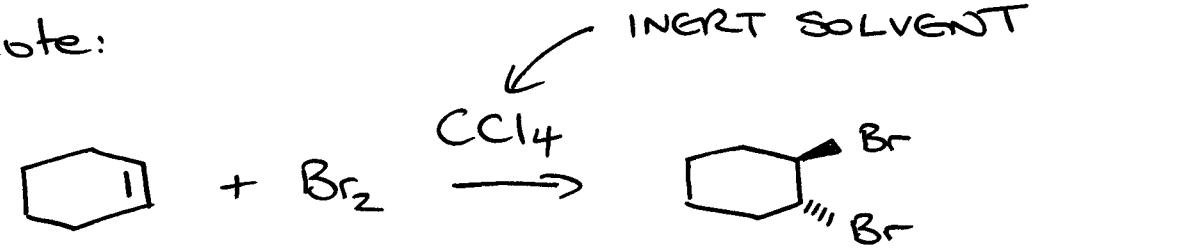
So/ 2° C^+ REARRANGE TO 3° C^+
(RARELY GO IN OPPOSITE DIRECTION)

1° C^+ NOT formed in reactions in solution
(TOO UNSTABLE)

(2) ADDITION OF Br_2/Cl_2

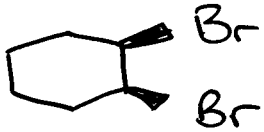
$$CH_3CH=CHCH_3 + Br_2 \longrightarrow CH_3-\underset{H}{\overset{Br}{C}}-\underset{H}{\overset{Br}{C}}-CH_3$$

note:



trans-
1,2-dibromocyclohexane

AN EXAMPLE OF A STEREOSPECIFIC RXN



cis STEREOISOMER is
NOT FORMED

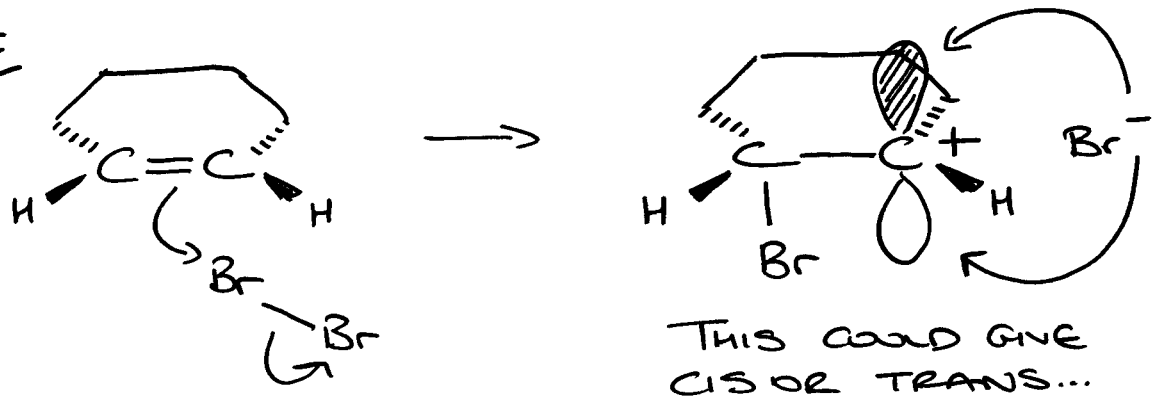
NOTE

STEREOSPECIFIC / STEREOSELECTIVE
exclusion preference

(REGIOSPECIFIC / REGIOSELECTIVE)

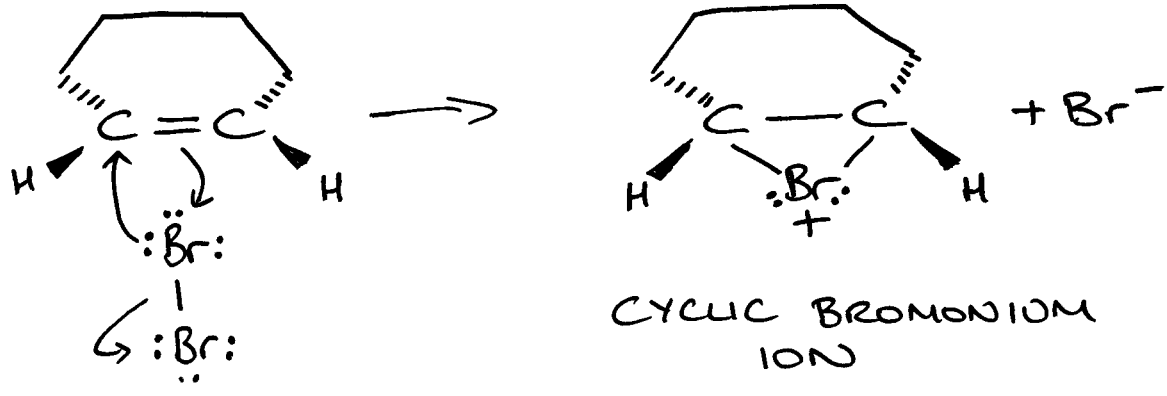
- consider mechanism

IF

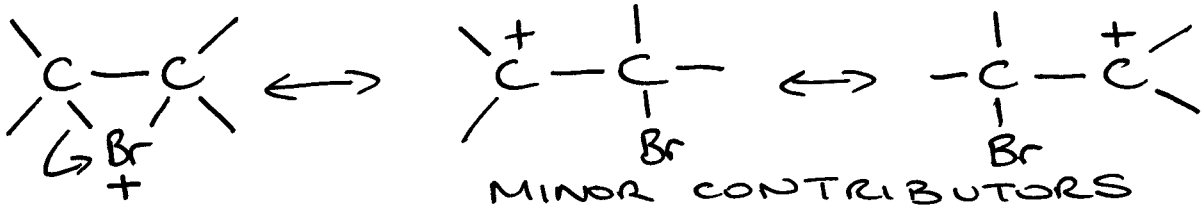


THIS COULD GIVE CIS OR TRANS...

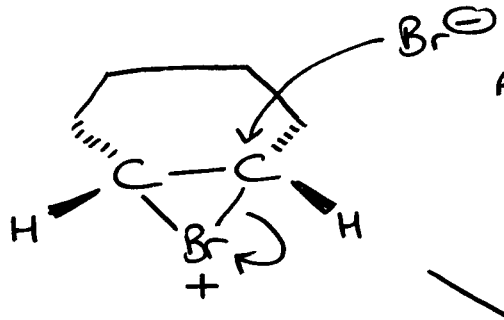
mechanism is:



CYCLIC BROMONIUM ION

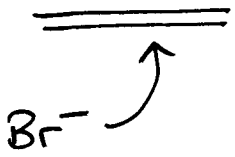


MINOR CONTRIBUTORS

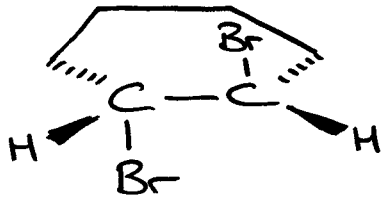


Attack occurs from TOP FACE

(ANTI-STEREOSPECIFICITY)

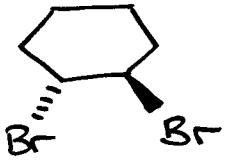


attack blocked



COULD HAVE FORMED BROMONIUM ION ON TOP FACE & ATTACKED FROM BOTTOM

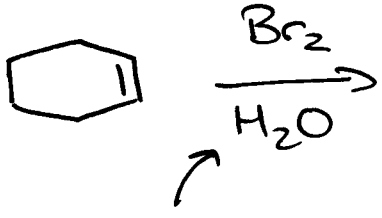
III



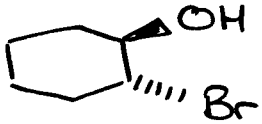
TRANS

IF OTHER C ATOM OF BROMONIUM ION WAS ATTACKED, OTHER ENANTIOMER WOULD BE FORMED

(3) ADDITION OF HOCl / HOBr



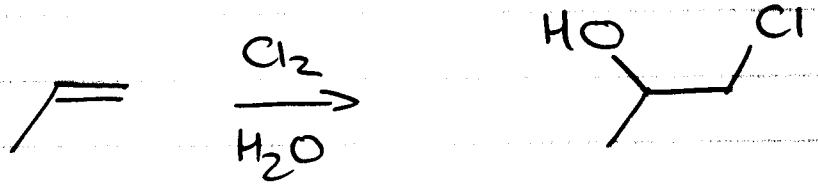
not an INERT SOLVENT



HALOHYDRIN (BROMOHYDRIN)

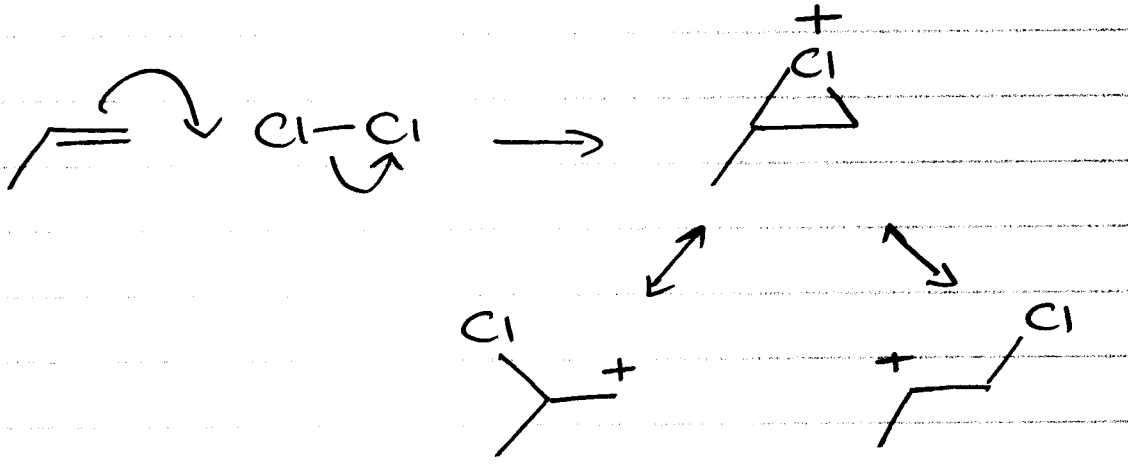
ANTI-STEREO SPECIFIC

ALSO REGIOSPECIFIC

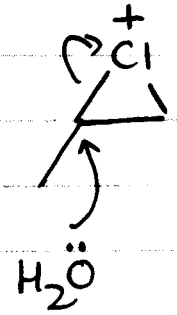


-OH ADDS to more SUBSTITUTED C ATOM OF ALLENE

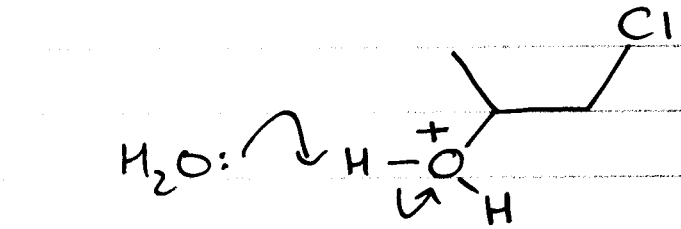
consider mechanism:

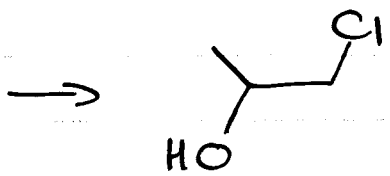


MORE STABLE CARBOCATION

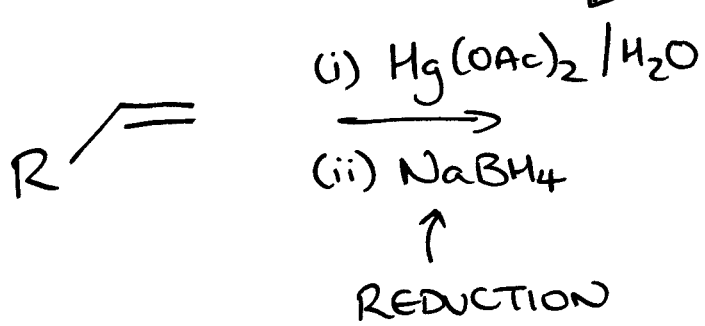


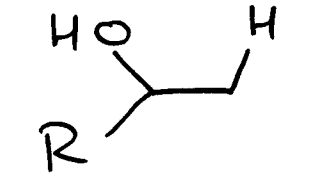
OPENS VIA MOST STABLE C^+





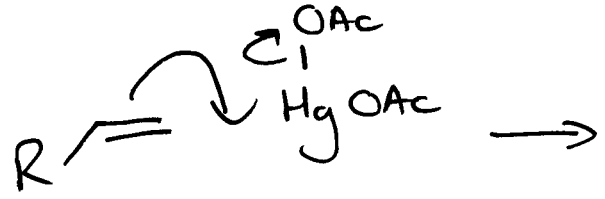
(4) OXYMERCURATION

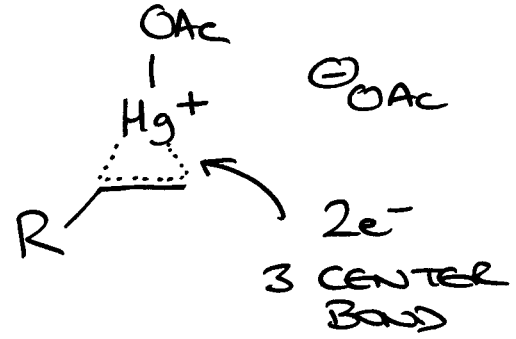




MARKOVNIKOV HYDRATION

mechanism

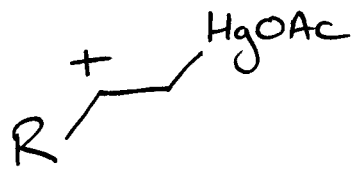




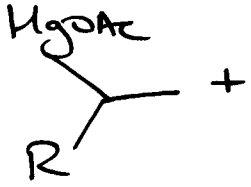
CYCLIC MERCURINIUM ION

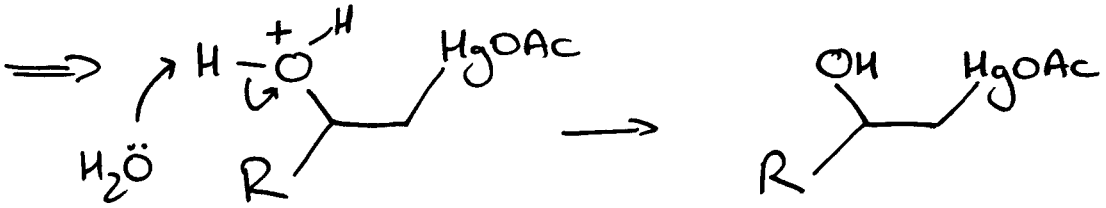
Opens via most stable C^+

So

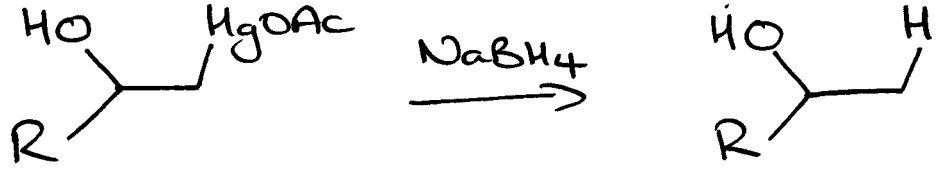


NOT



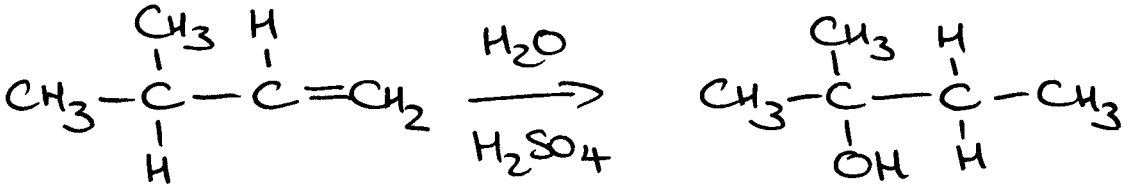


ORGANOMERCURY COMPOUND IS REDUCED WITH $NaBH_4$



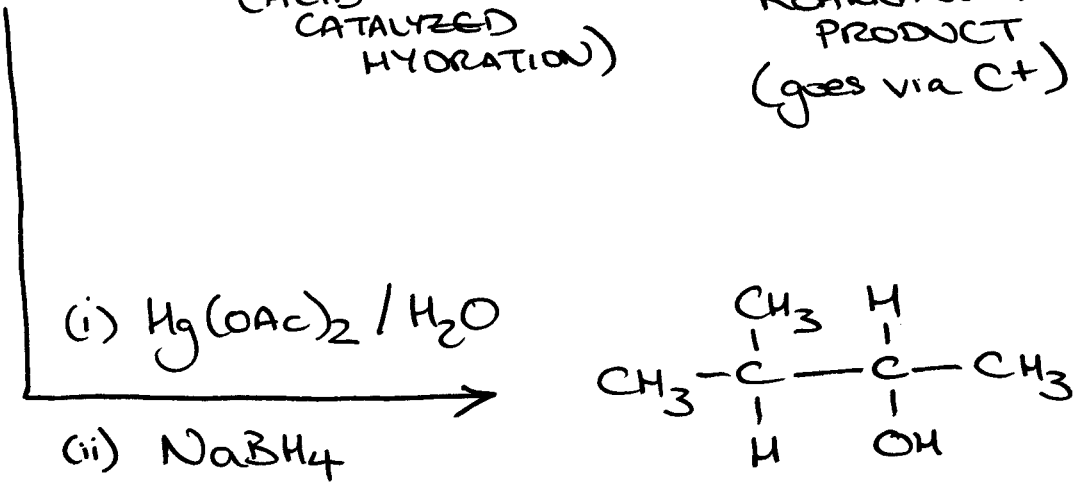
So, why is this useful?

CONSIDER



(ACID CATALYZED HYDRATION)

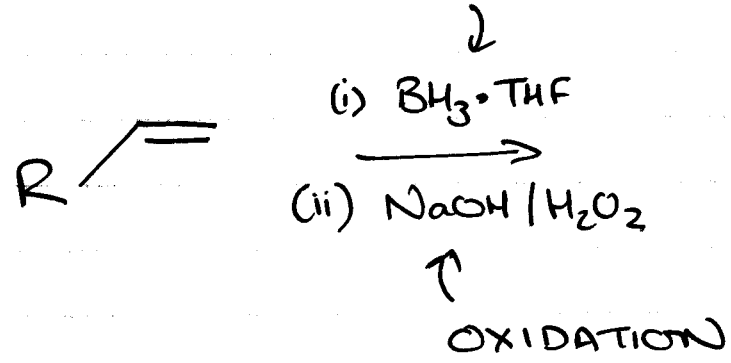
REARRANGED PRODUCT (goes via C+)



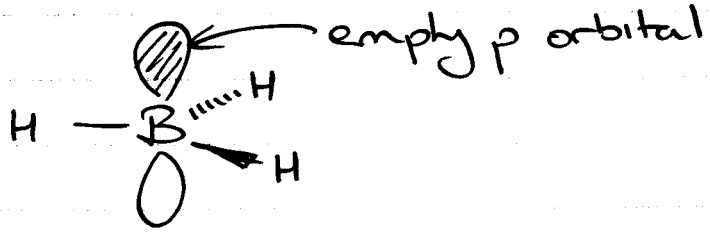
MARKOVNIKOV PRODUCT (NO REARRANGEMENT)

REGIOSPECIFIC w/ ANTI STEREOSPECIFICITY
(similar to addition of Br_2 / Cl_2)

(5) HYDROBORATION

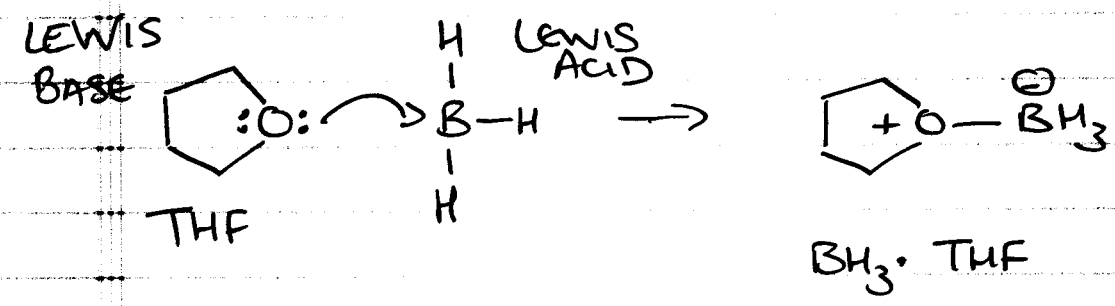


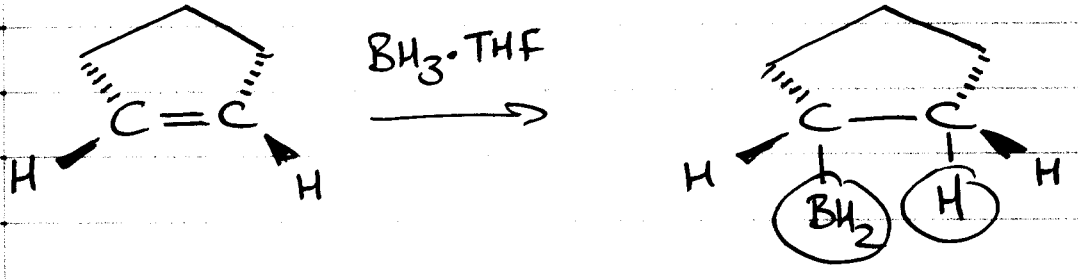
BORANE (BH_3)



(actually exists as B_2H_6)

↳ WHAT IS THE STRUCTURE?

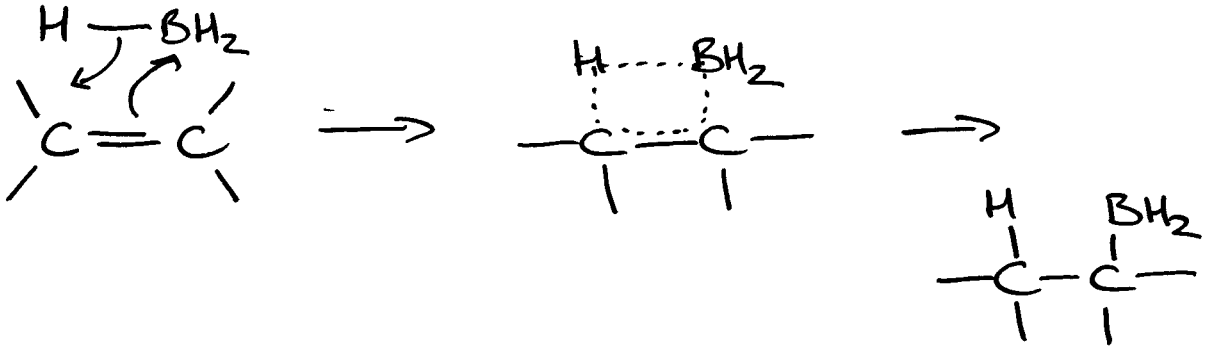




SYN STEREOSPECIFIC

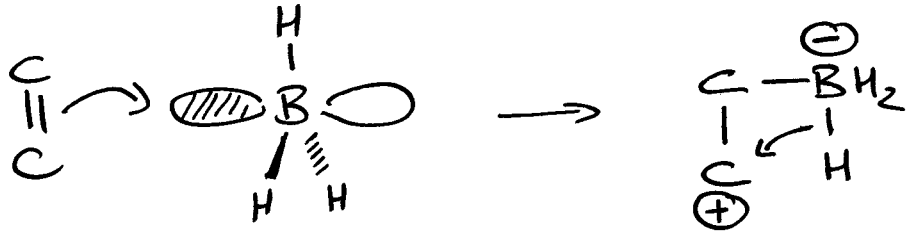
REGIOSELECTIVE

BORON ADDS TO LESS SUBSTITUTED C ATOM



DOES NOT GO THROUGH A C^+

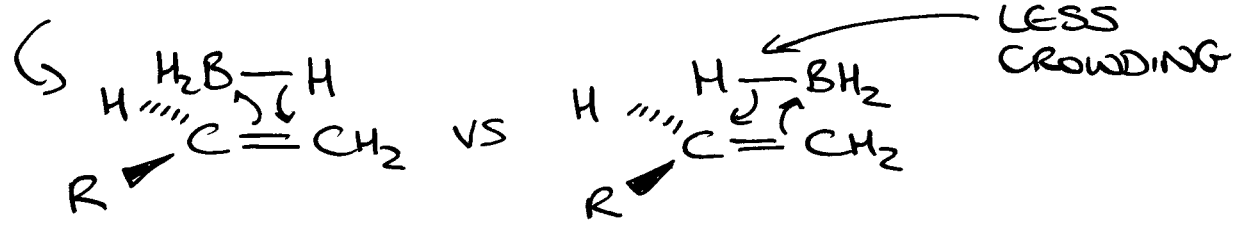
i.e



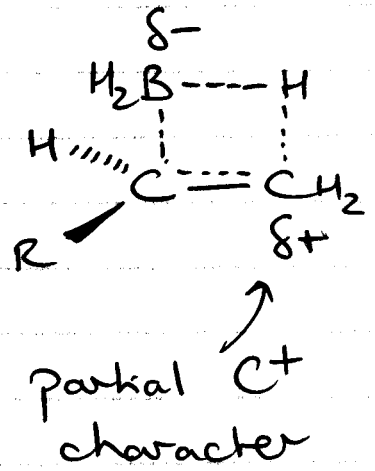
BUT: THERE ARE NO REARRANGEMENTS, AND SO C^+ NOT AN INTERMEDIATE

WHY REGIOSELECTIVE?

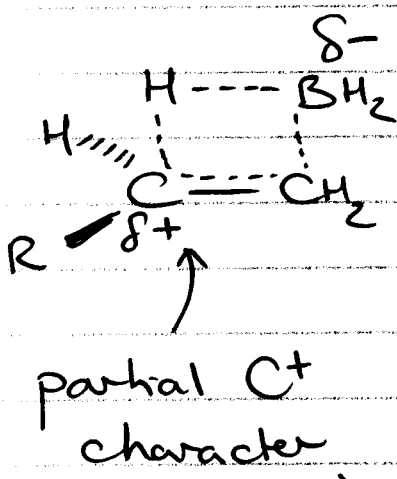
(i) STERICS (ii) ELECTRONICS



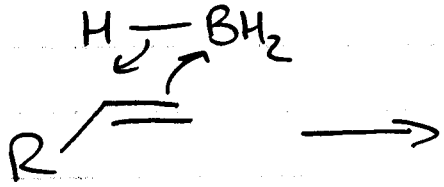
(ii) ELECTRONICS

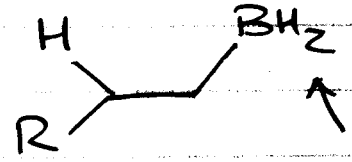


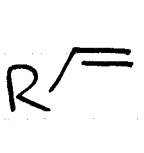
VS



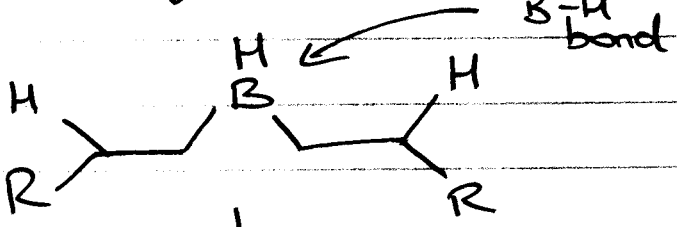
So

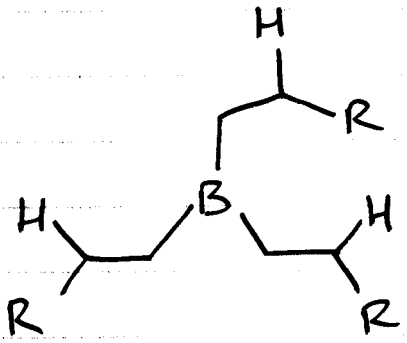




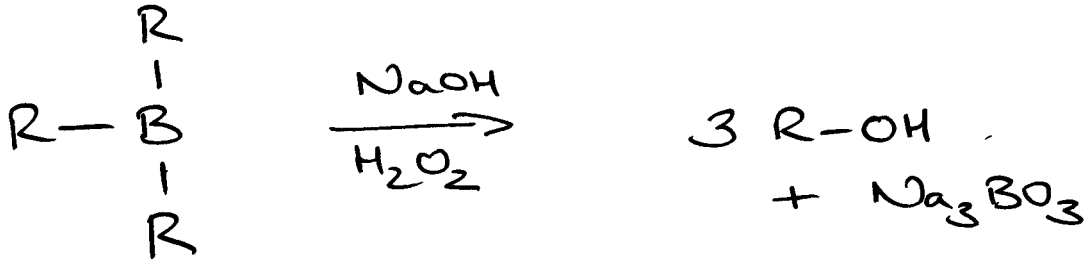


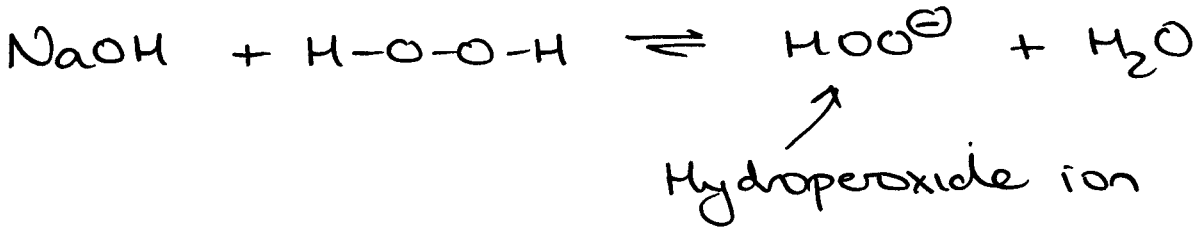
So

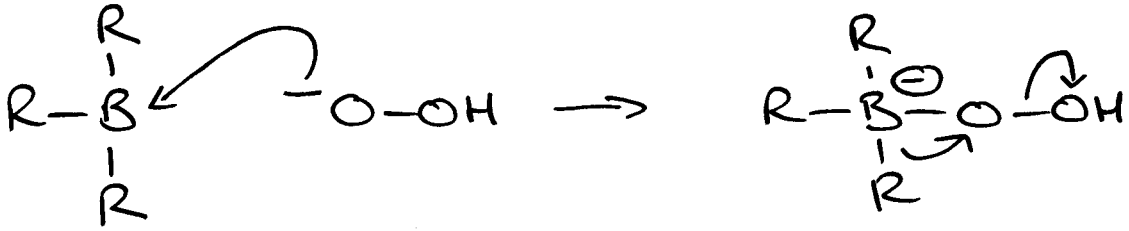


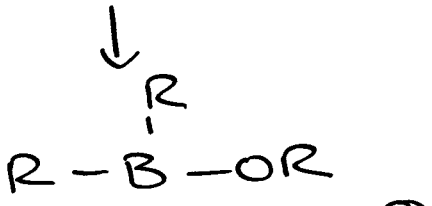


TRIALKYLBORANE

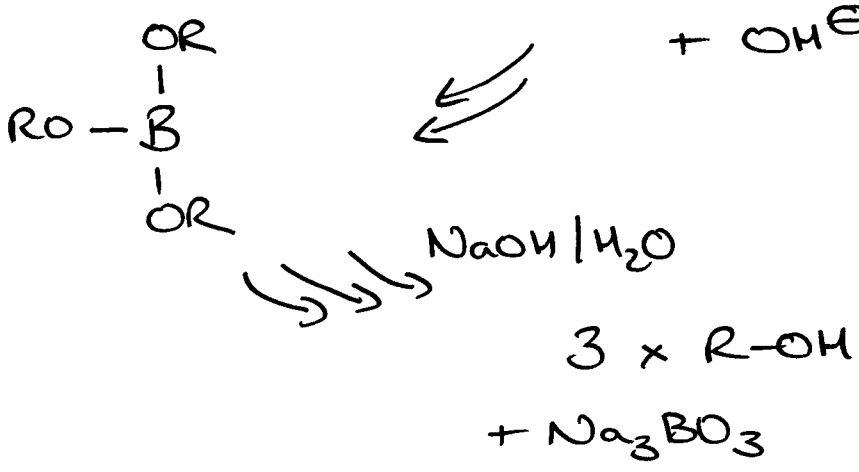








TRIALKYL BORATE



LEC (16) CHEM 30A Nov 8th

1. OXYMERCURATION
2. HYDROBORATION
3. OXIDATION
4. REDUCTION

- Mechanism Guides / Problem Sets on WEB
- READ: Ch 6 esp 6.7
- PROBLEMS 6.13, 6.37 – 6.49

QUIZ ON WEDNESDAY

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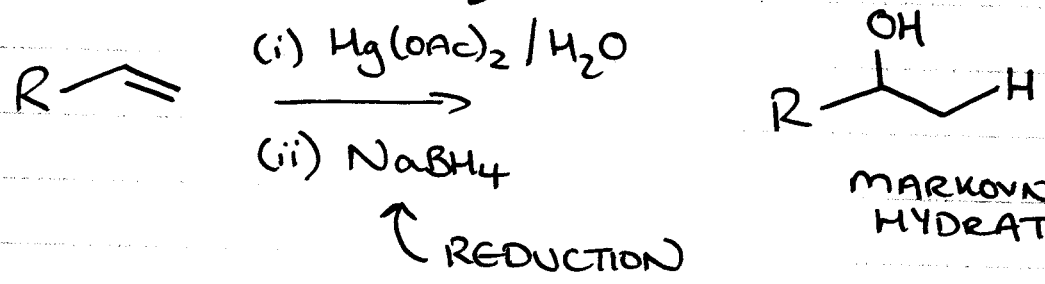
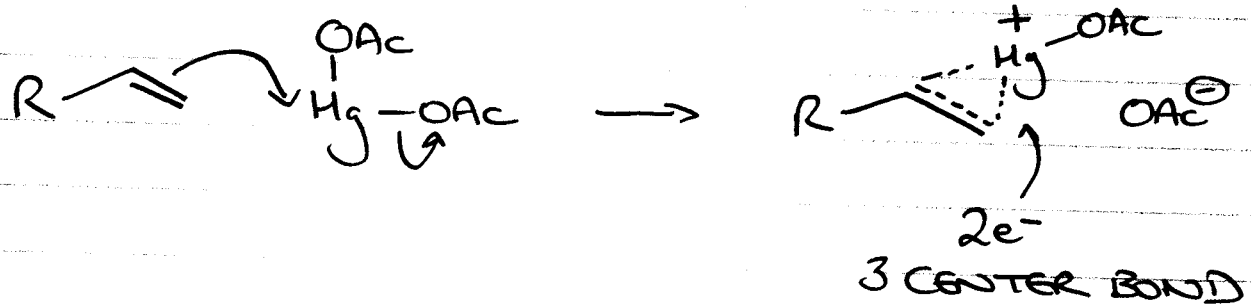
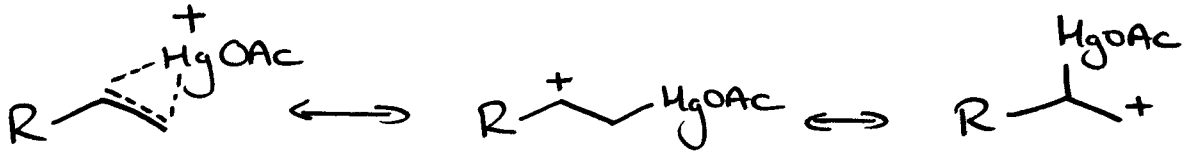
(1) OXYMERCURATION



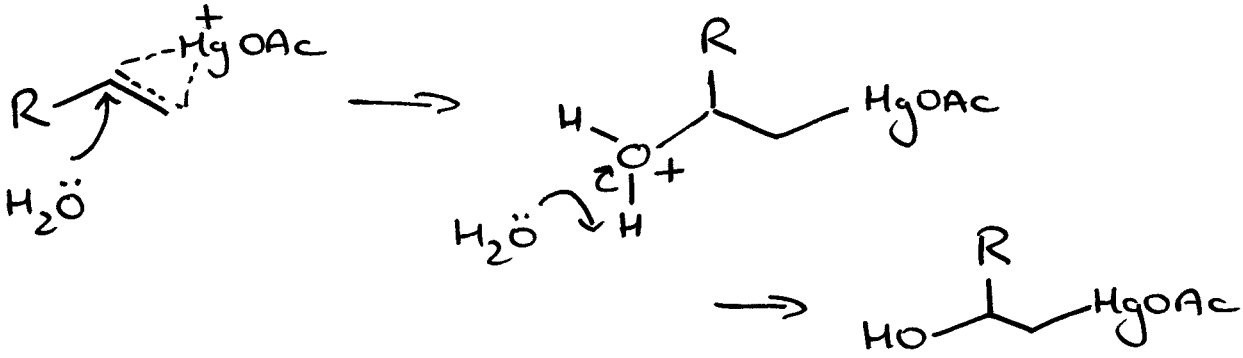


CYCLIC MERCURINIUM ION

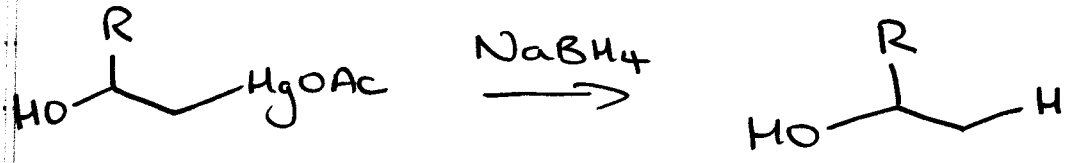
Consider resonance forms



opens via most stable C+



IN SECOND STEP, ORGANOMERCURY IS REDUCED WITH $NaBH_4$

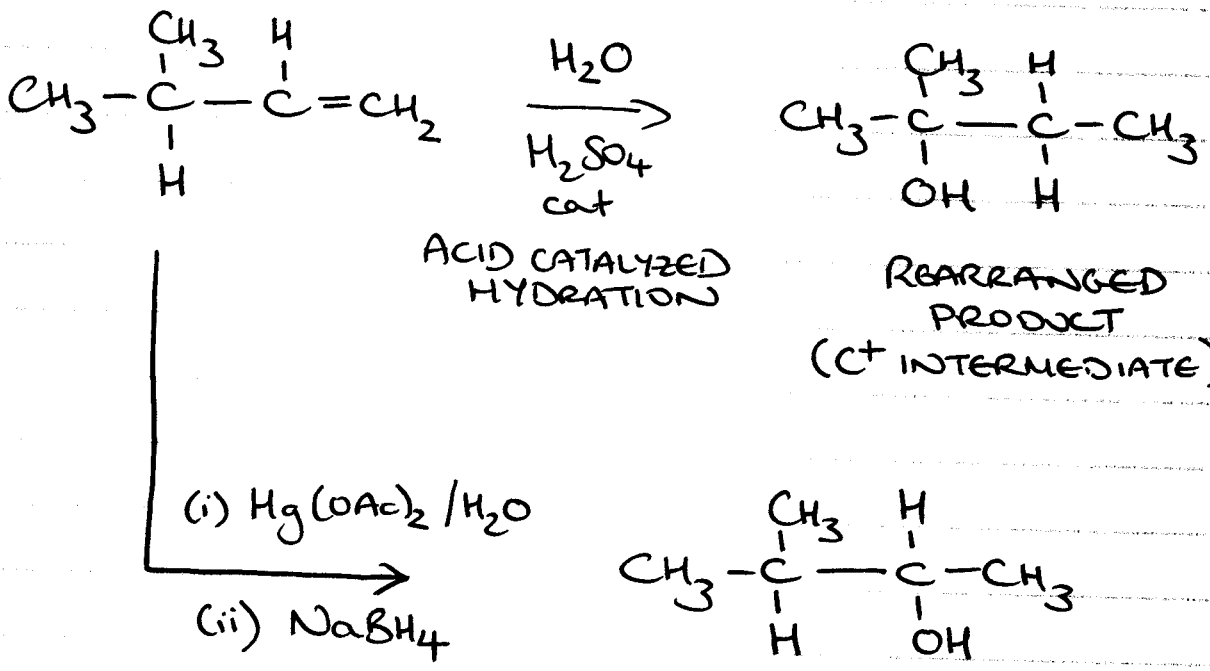


Replaces HgOAc with H

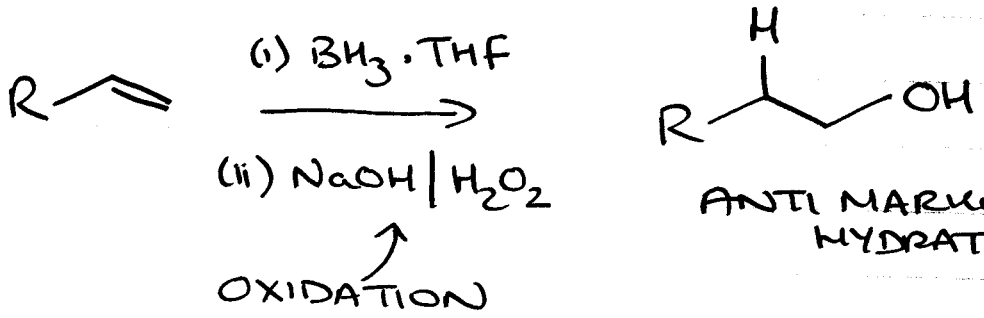
REGIOSPECIFIC w/ ANTI STEREOSPECIFIC OPENING OF MERCURINIUM ION

NO C^+ INTERMEDIATE ⟹ NO REARRANGEMENT

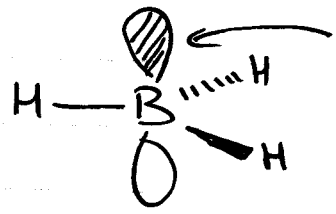
... Why is this useful



(2) HYDROBORATION



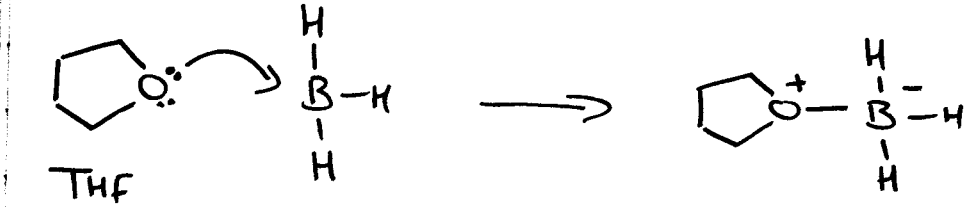
BORANE (BH_3)



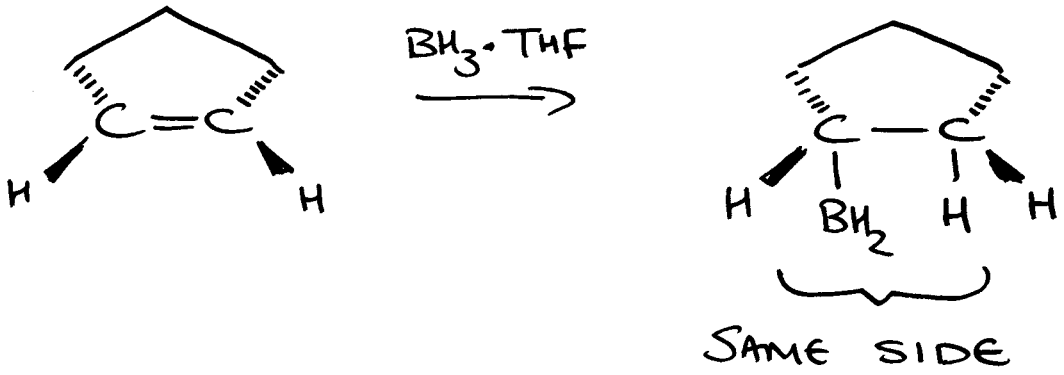
← empty p-orbital

(actually exists as B_2H_6 – DIBORANE)

STRUCTURE?

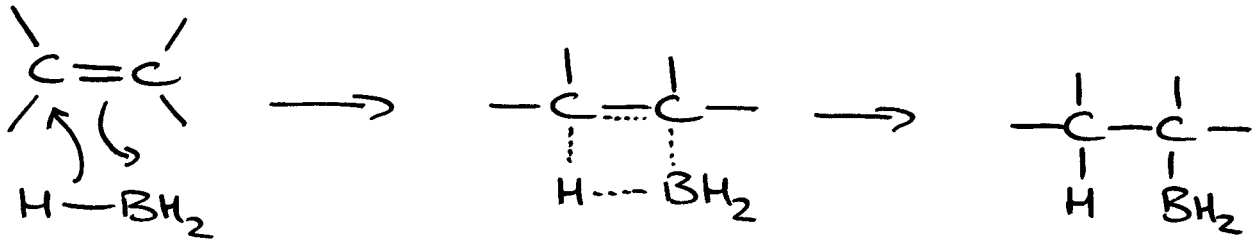


- SYN-STEREOSPECIFIC



- REGIOSELECTIVE

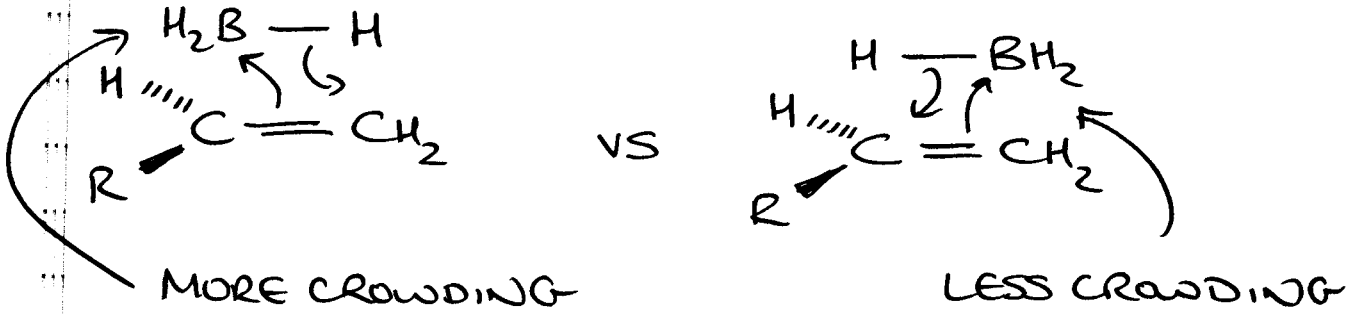
BORON ADDS TO LESS SUBSTITUTED C ATOM



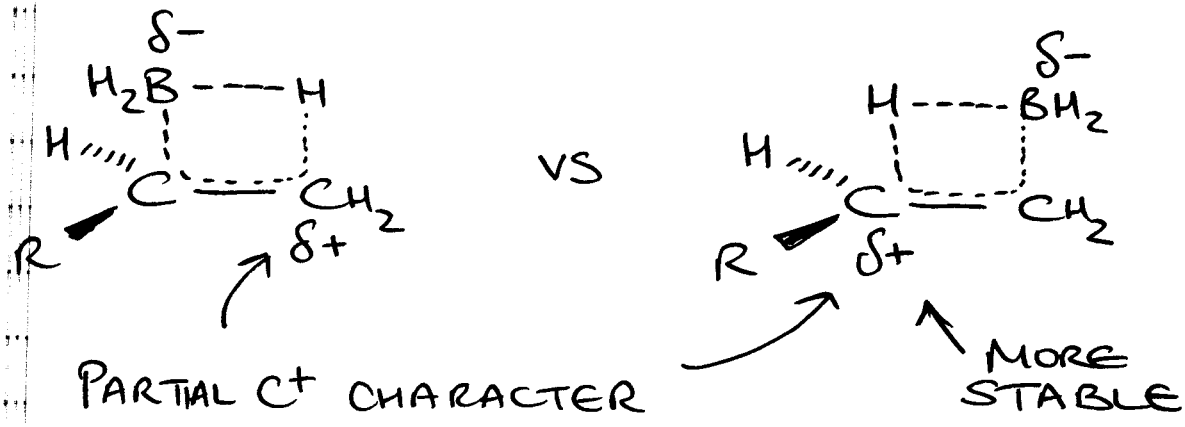
DOES NOT GO THROUGH C^+ INTERMEDIATE
$\Rightarrow$ NO REARRANGEMENTS

WHY REGIOSELECTIVE?

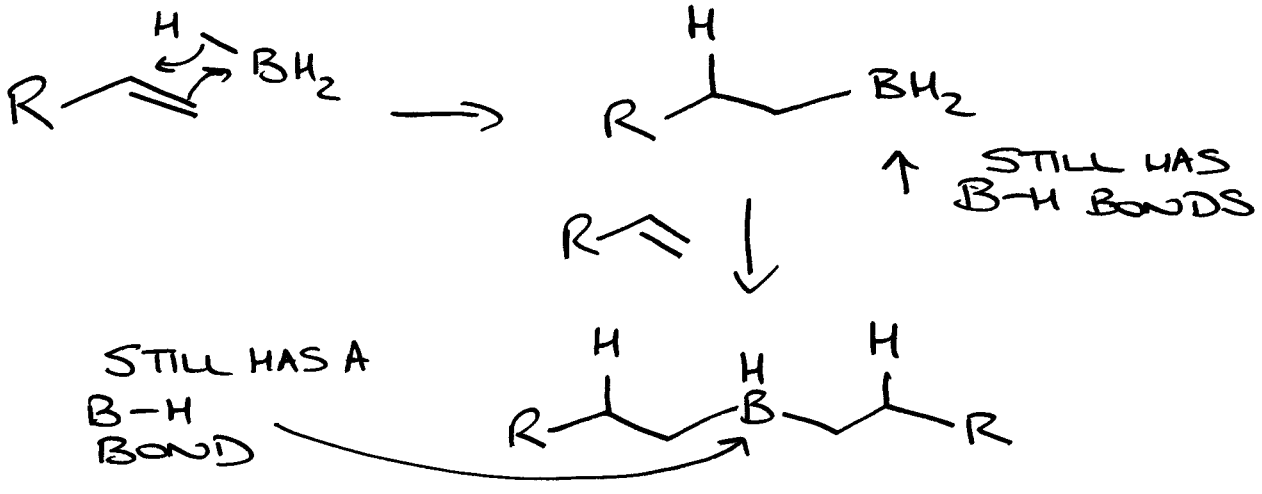
(i) STERICS

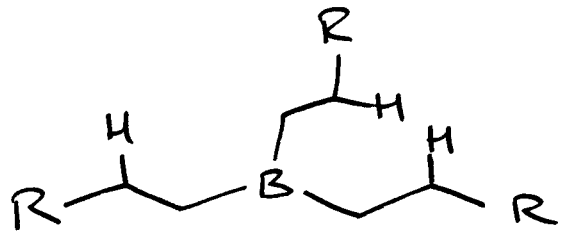


(ii) ELECTRONICS



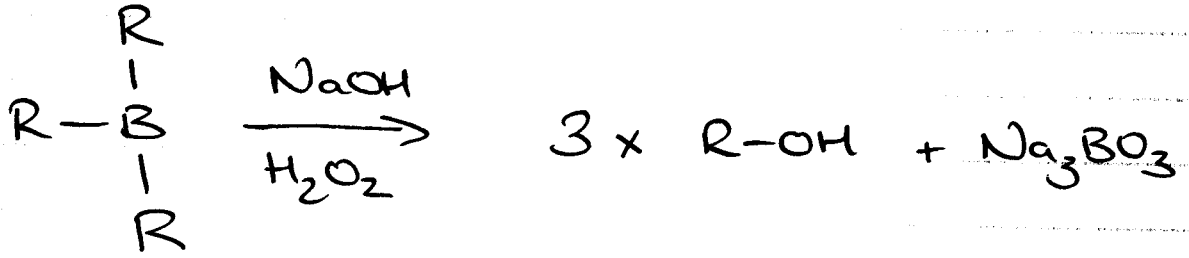
FULL MECHANISM



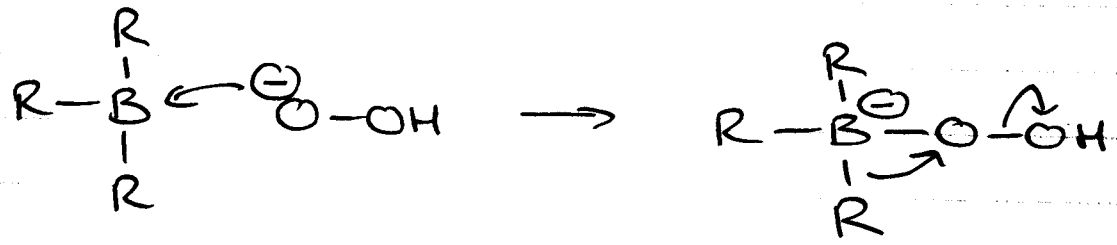


TRIALKYLBORANE

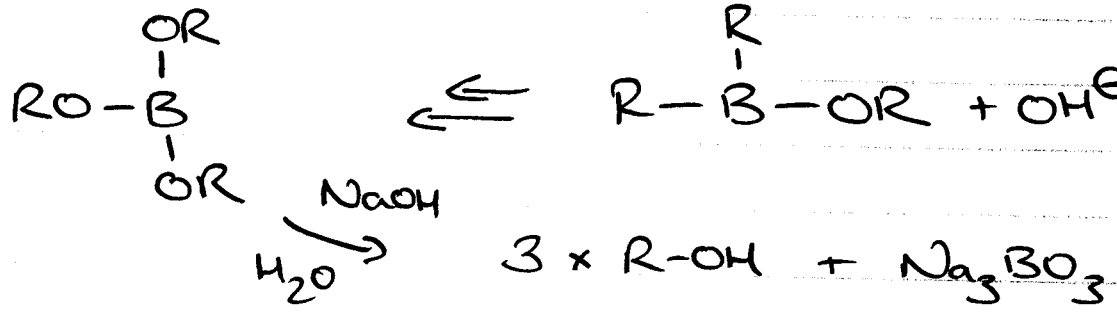
— OXIDATION STEP



HYDROPEROXIDE ION

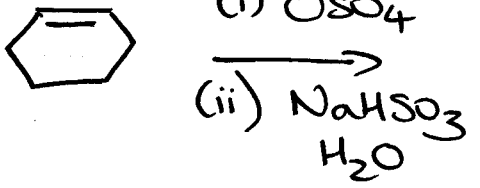


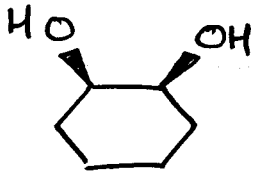
TRIALKYL BORATE



③ OXIDATION

(i) OsO_4 OSMIUM TETROXIDE

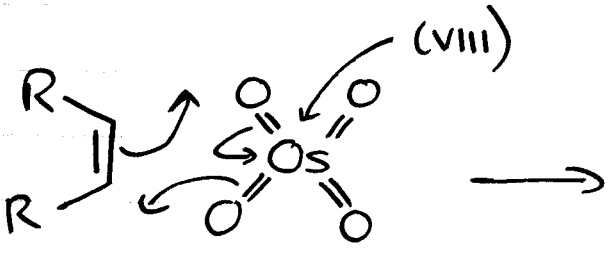


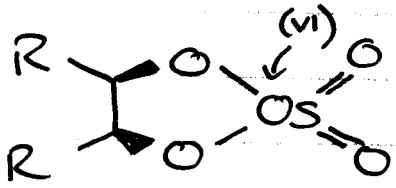


cis diol

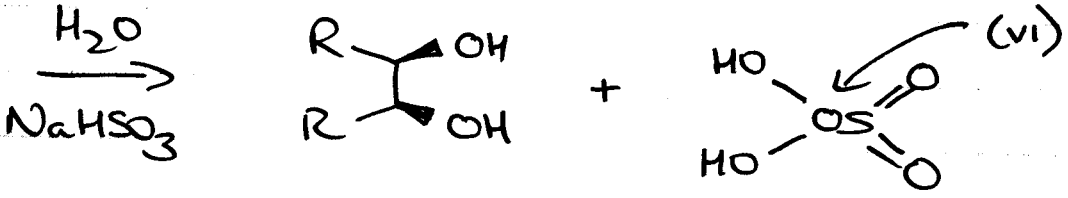
syn-addition

STEREOSPECIFIC





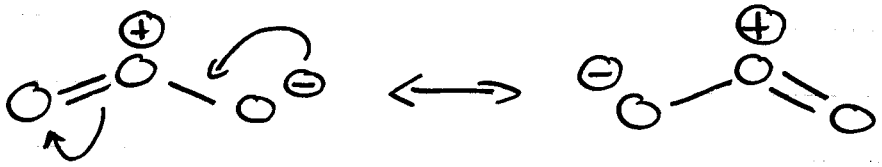
cyclic osmate ester



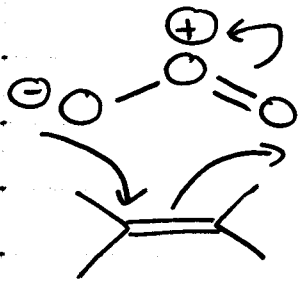
Os reduced (VIII → VI) Alkene oxidized.

(ii) OZONOLYSIS

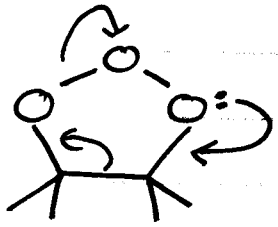
OZONE O_3



Mechanism

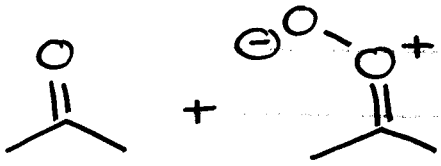


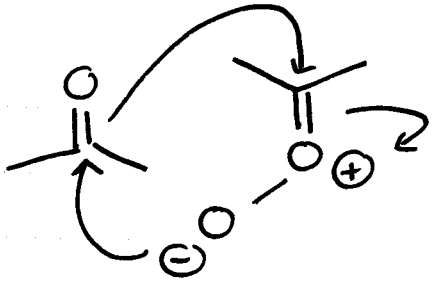
CYCLO ADDITION →



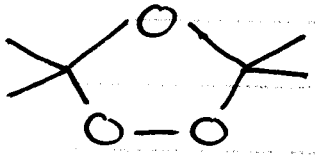
molozonide

↓ REVERSE





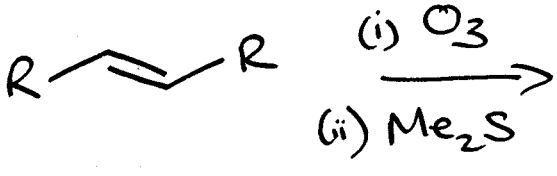
CYCLO ADDITION →



OZONIDE

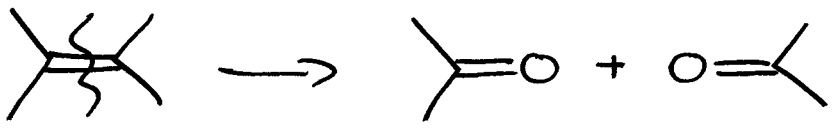
PRODUCT DEPENDS UPON 2nd REAGENT

- most common Me_2S

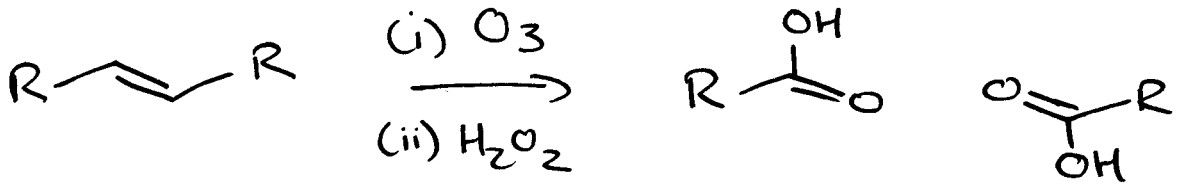


ALDEHYDES

(OR KETONES)



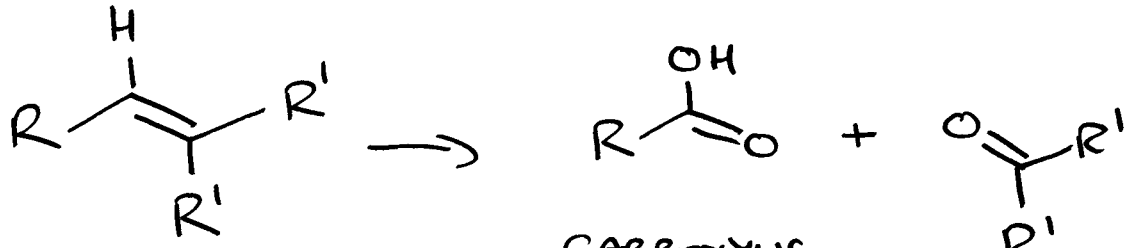
– H_2O_2



CARBOXYLIC ACIDS
(or KETONES)

(must have H on C=C to get ACID)

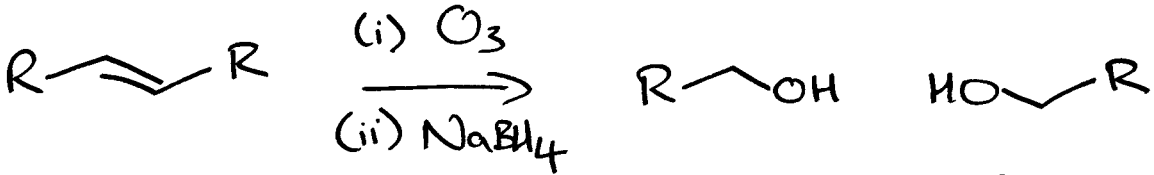
i.e.



CARBOXYLIC ACID

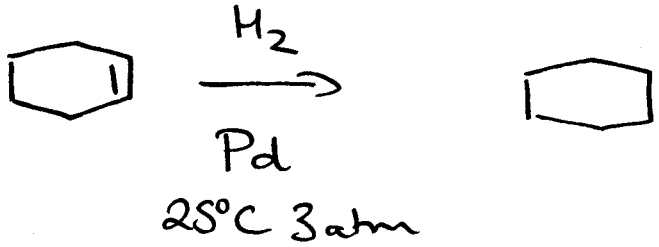
KETONE

– $NaBH_4$



ALCOHOLS

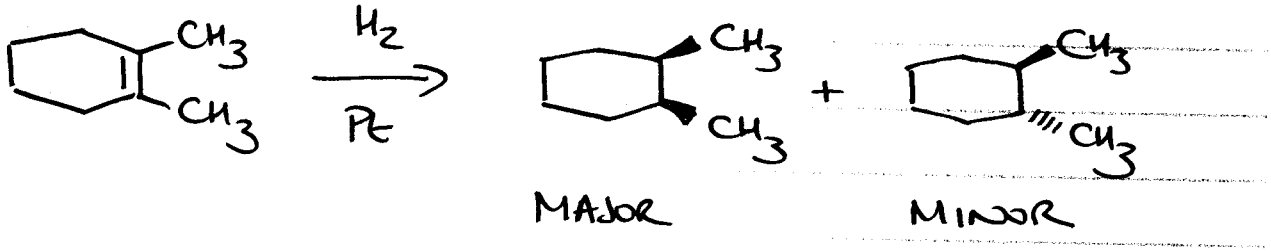
④ REDUCTION



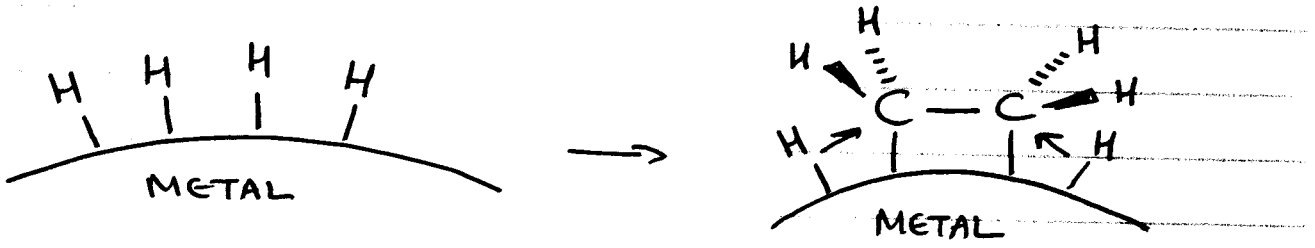
- Transition metal catalyst Pt, Pd, Ru, Ni

- CATALYTIC REDUCTION / HYDROGENATION

- STEREOSELECTIVE



- Mechanism



ADDS SAME SIDE
(SYN ADDITION)

LEC (17) CHEM 30A Nov 10th

(1) OXIDATION
(2) REDUCTION
(3) STEREOCHEMISTRY REVISITED
(4) ADDITION TO ALKYNES

READ 6.6-6.7 & 10.9
PROBLEMS 10.5

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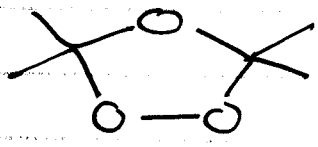
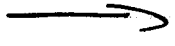
(1) OXIDATION

ozonolysis continued

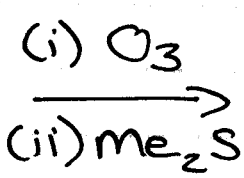


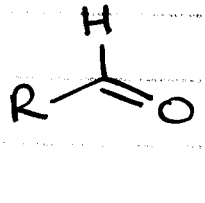
ozonide

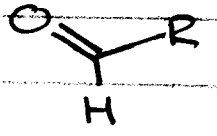


PRODUCTS

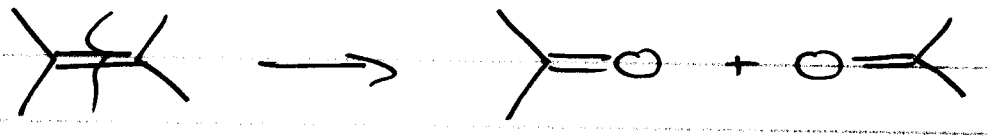
(i) Me_2S



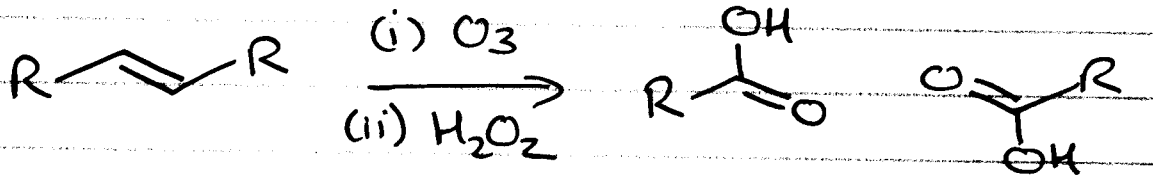




ALDEHYDES (OR KETONES)



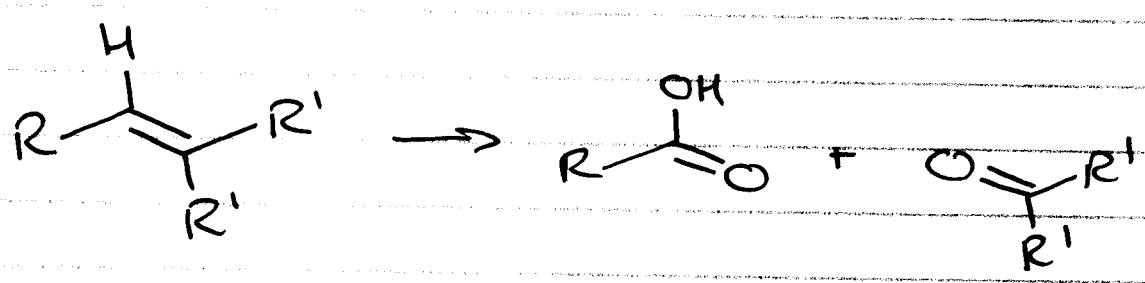
(ii) H_2O_2



CARBOXYLIC ACIDS (KETONES)

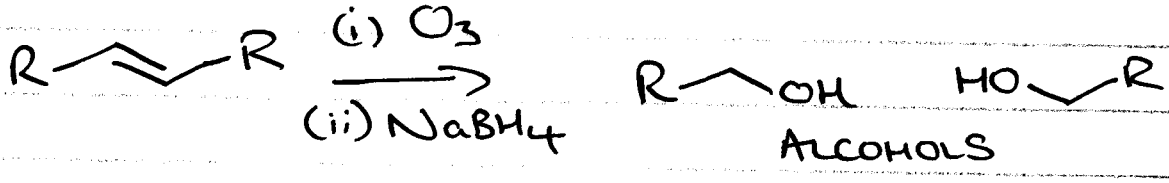
(MUST HAVE H ON C=C TO GET ACID)

i.e.



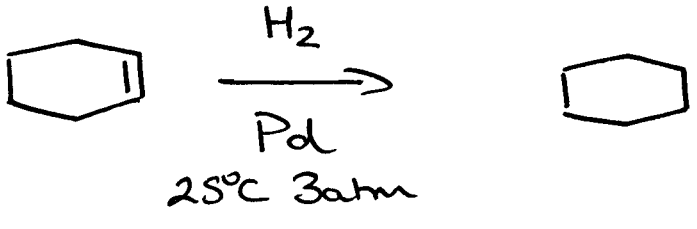
CARBOXYLIC ACID — KETONE

– $NaBH_4$



ALCOHOLS

(2) REDUCTION

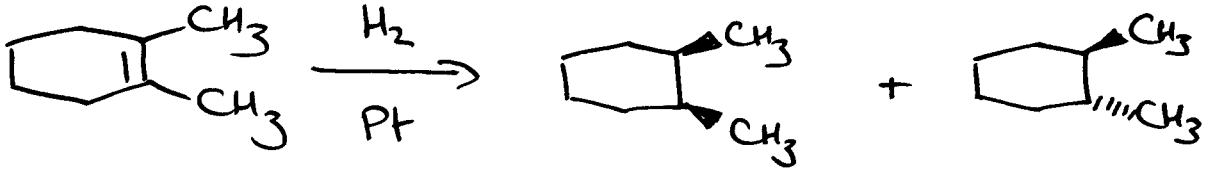


METAL CATALYST
Finely divided on an inert support (charcoal)

Transition metal catalyst Pt, Pd, Ru, Ni:

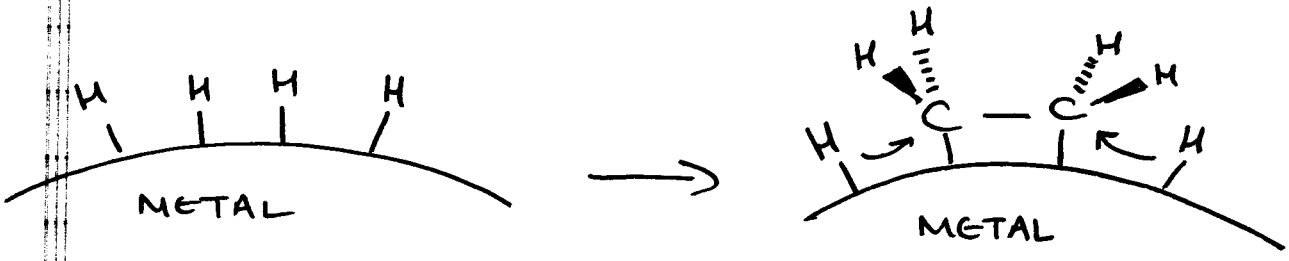
CATALYTIC REDUCTION / HYDROGENATION

- STEREOSELECTIVE



MAJOR MINOR

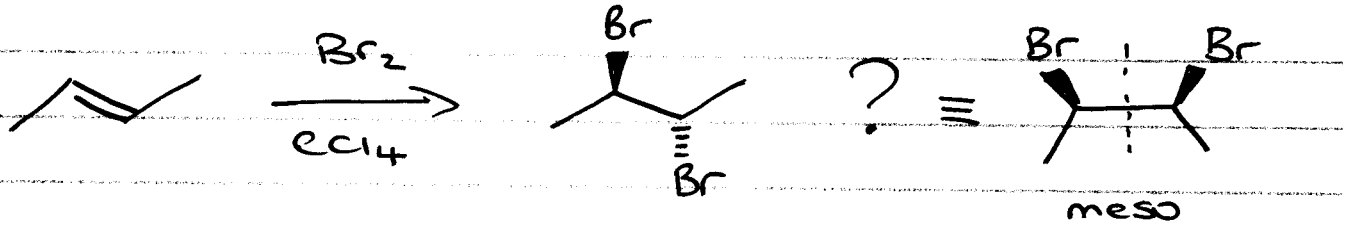
mechanism:

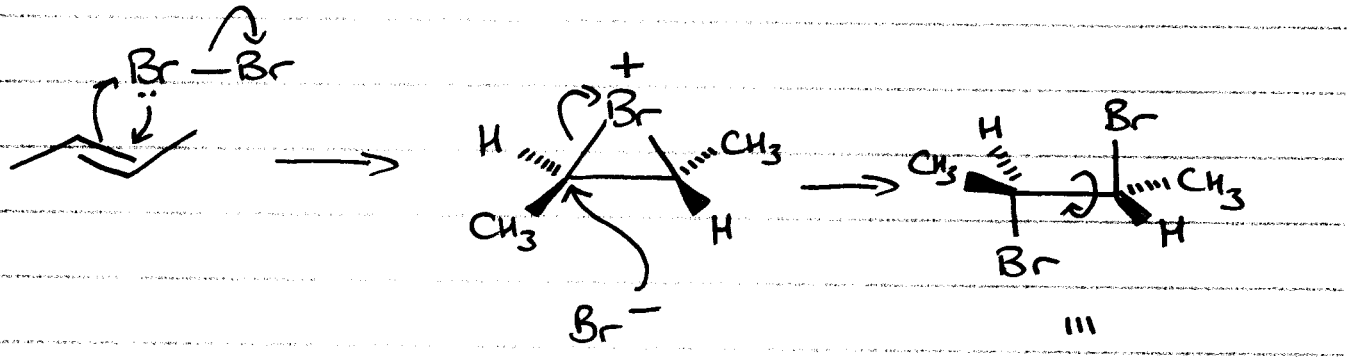


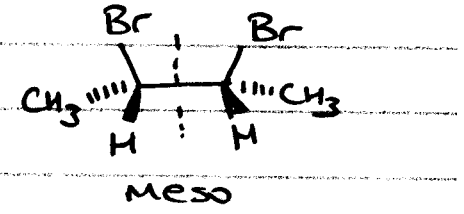
MINOR PRODUCTS RESULT FROM ISOMERIZATION OF THE ALKENE ON THE METAL CATALYST

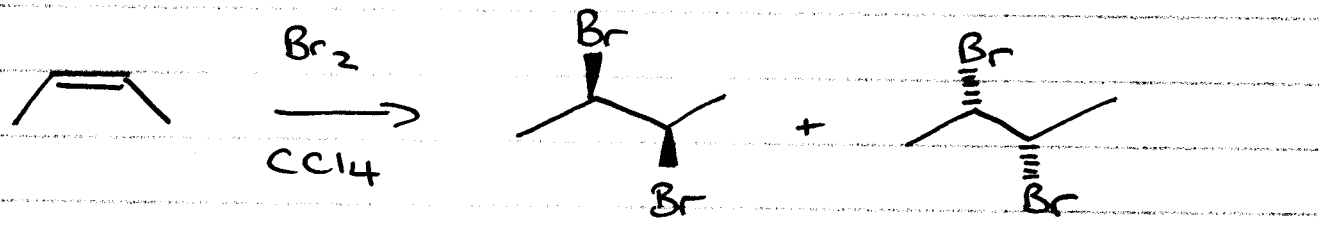
(3) STEREOCHEMISTRY REVISITED

consider

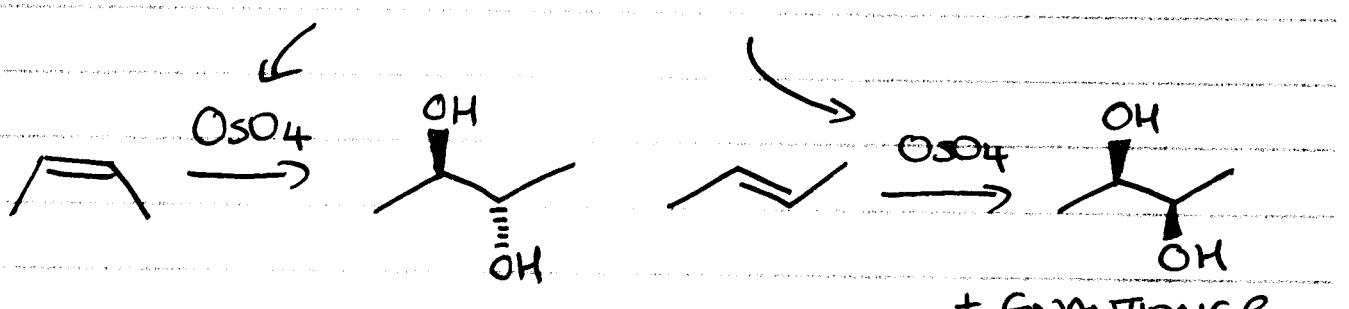






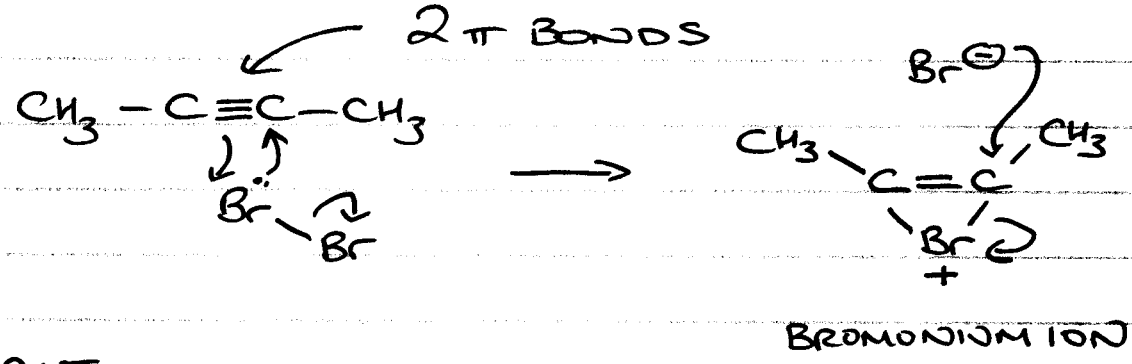


WORK THROUGH MECHANISM



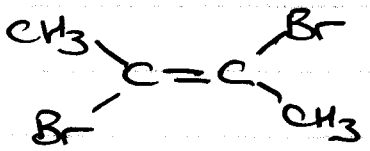
(4) ADDITION TO ALKYNES

(i) X_2 (Br_2 / Cl_2)



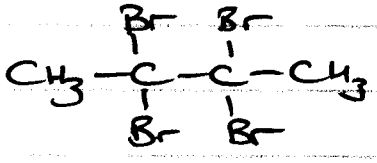
BROMONIUM ION

ANTI STEREO SPECIFICITY →



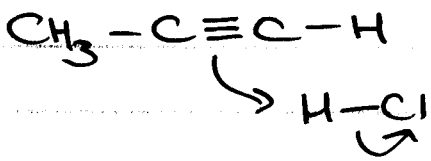
trans dibromide

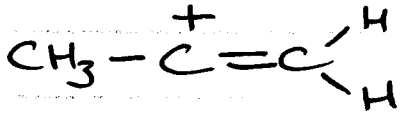
Br_2 →



tetrabromoalkane

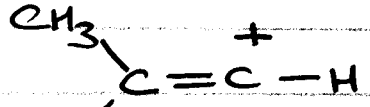
(ii) HX (HCl, HBr, HI)





2°

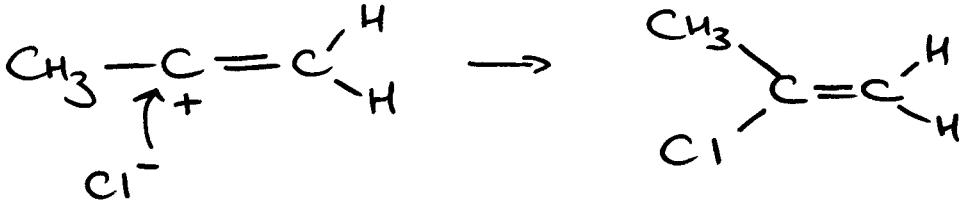
or



1°

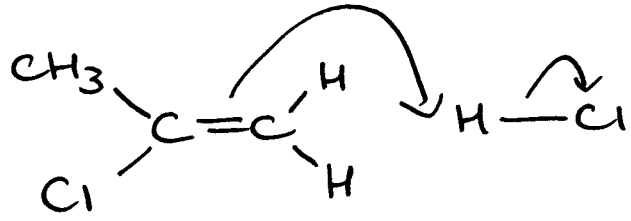
VINYL CARBOCATIONS

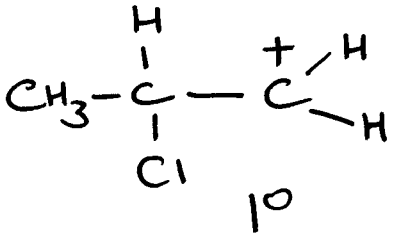
(MORE STABLE)



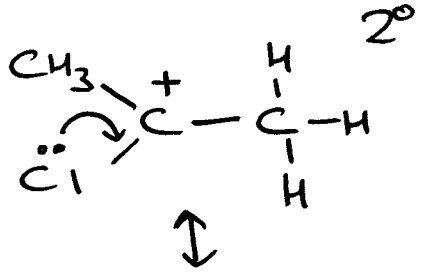
MARKOVNIKOV PRODUCT

ALKENE PRODUCT COMPETES WITH ALKYNE FOR H–Cl IN THE REACTION



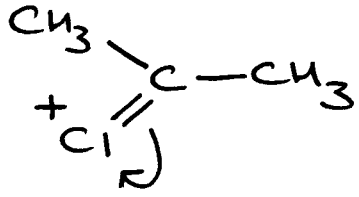


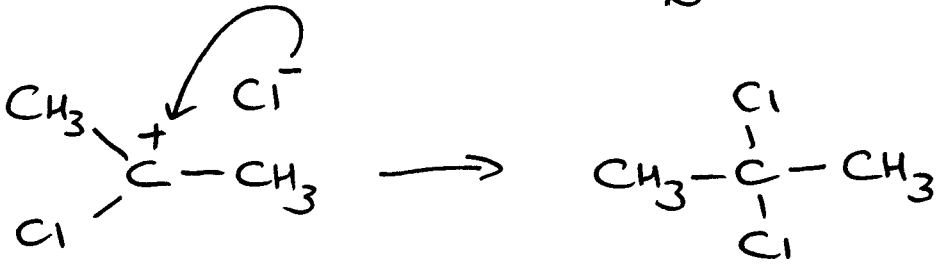
1°



2°

RESONANCE STABILIZED





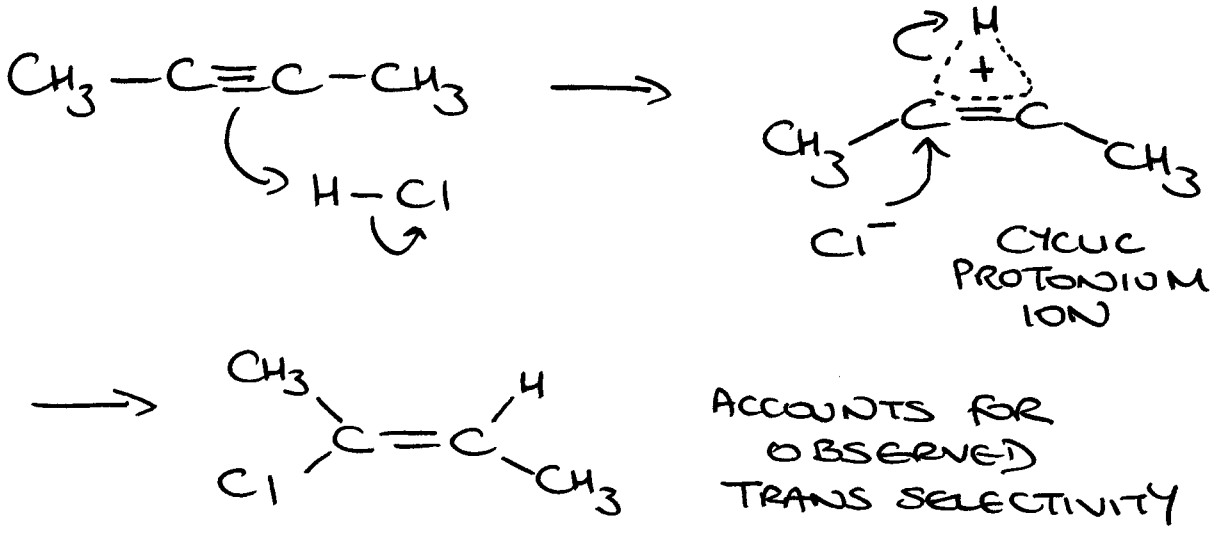
(Mechanisms actually more complicated than this, but these are good models)

VINYLIC C^+ VERY UNSTABLE

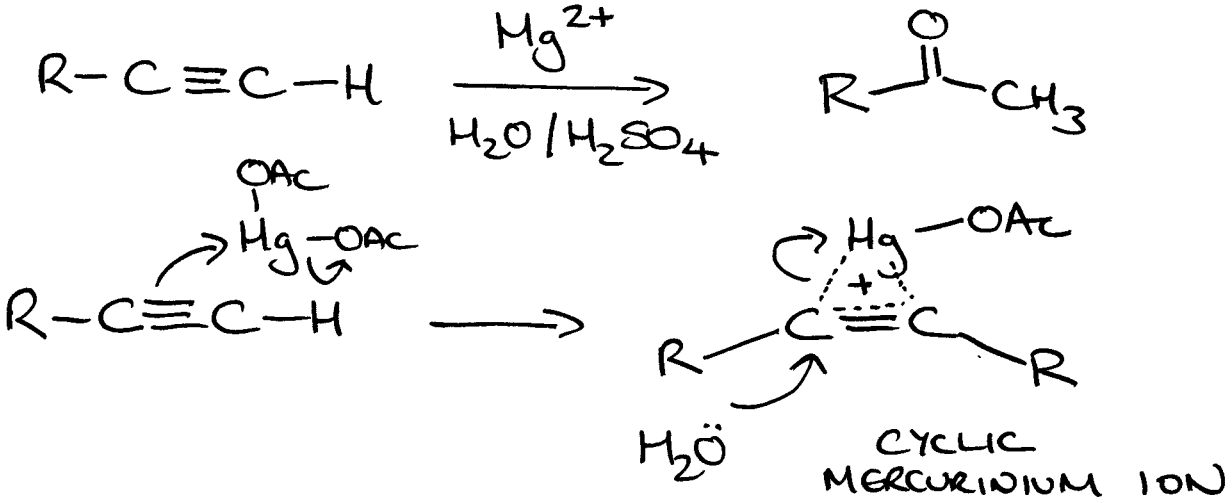
2° VINYLIC C^+ $\simeq$ 1° C^+

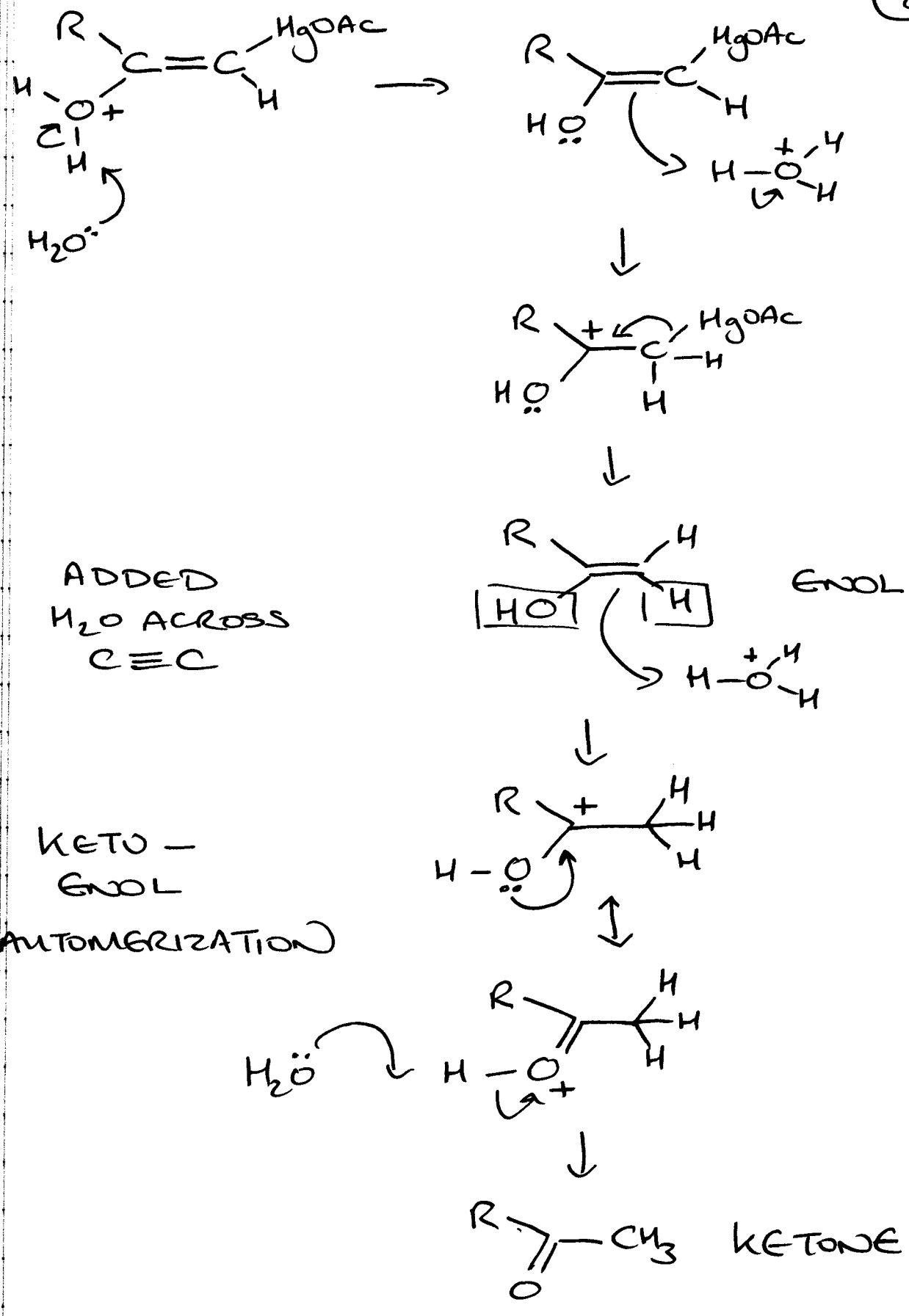
1° C^+ usually considered not to be a viable reaction intermediate

PROPOSED INTERMEDIATE



(iii) OXYMERCURATION




ADDED
H_2O ACROSS
C≡C
KETO –
ENOL
TAUTOMERIZATION
ENOL
KETONE

LEC (18) Chem 30A

(1) ELECTROPHILIC ADDITION TO ALKYNES
- (i) X_2
- (ii) HX
- (iii) OXYMERCURATION (HYDRATION)
- (iv) HYDROBORATION
- (v) REDUCTION

PROBLEMS 10.4, 10.16, 10.17, 10.21-23
READING 10.7-9, 8.1-8.2

QUIZ #2 LOW 0 MEAN 12 HIGH 29

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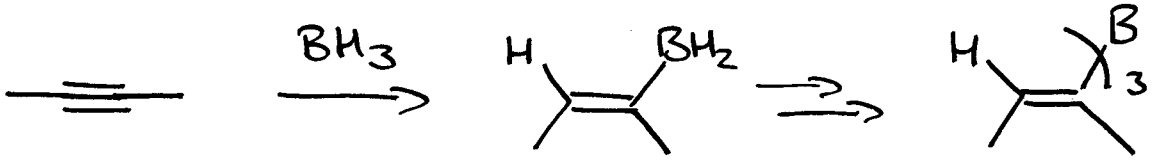
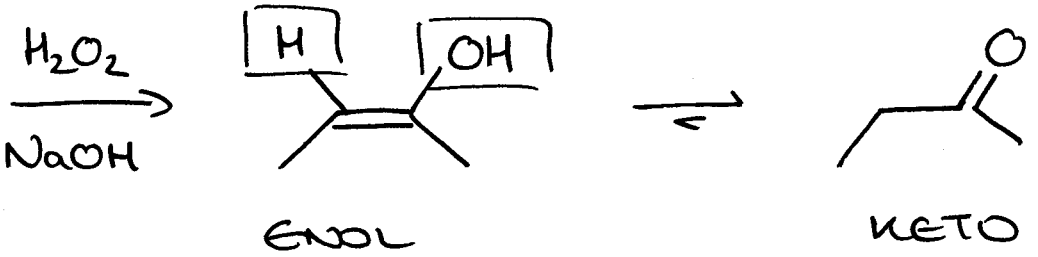
(1) (i) X_2
(ii) HX
(iii) OXYMERCURATION
} see LEC (17) notes pg 5-8

(iv) HYDROBORATION

(R—≡—H terminal R—≡—R non terminal)



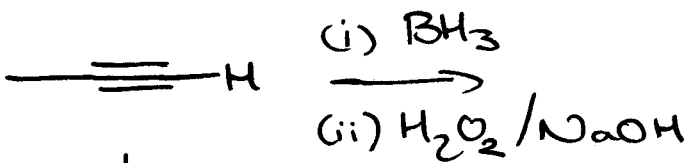
TRIALKENYL BORANE



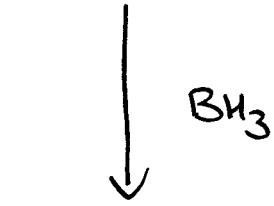
ENOL KETO

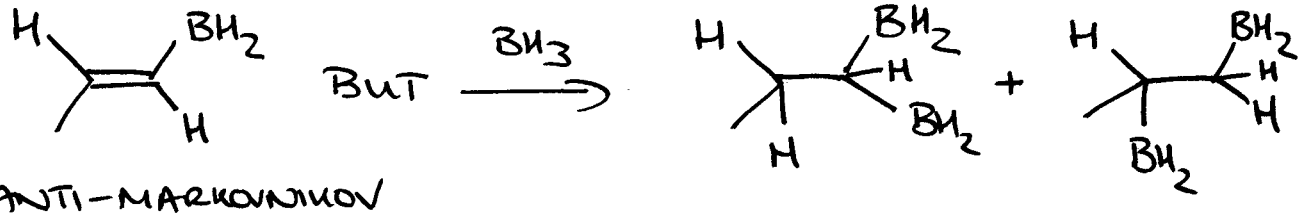
(Same mechanism as for ALKENES)

Terminal alkynes



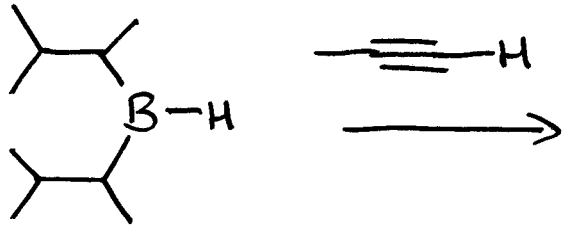
mixture of products

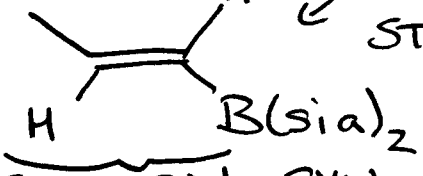




ANTI-MARKOVNIKOV

DISIAMYL BORANE $(sia)_2BH$

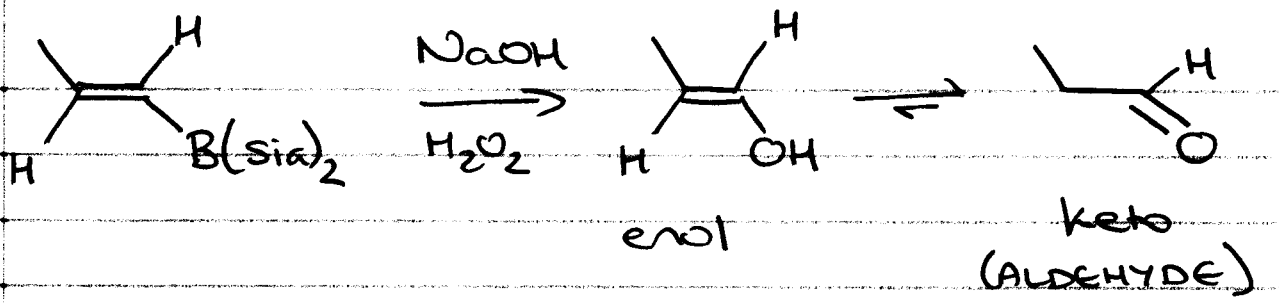




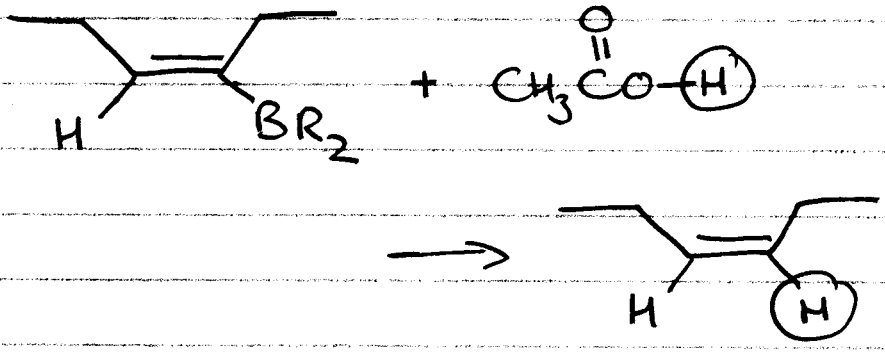
STOPS HERE (only one B–H addition) STERICS

Same side SYN

ANTI MARKOVNIKOV



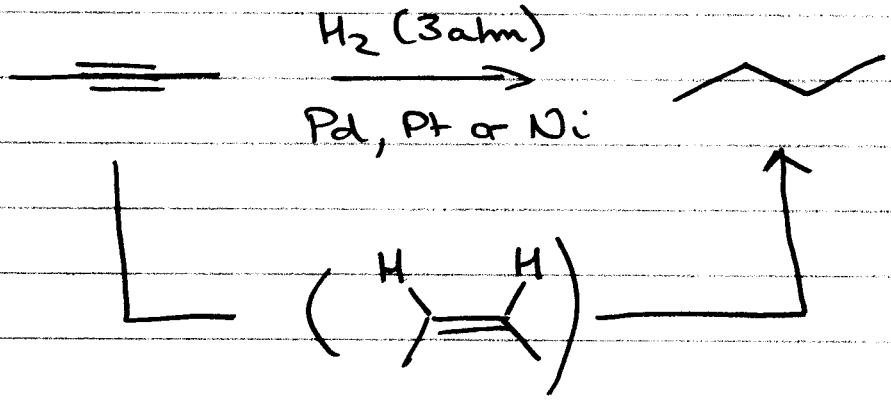
Reaction with acetic acid



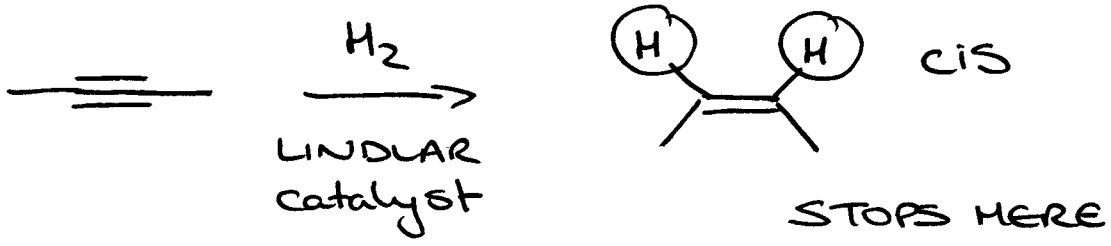
STEREOSPECIFIC (HYDROBORATION/PROTONOLYSIS)

(v) REDUCTION

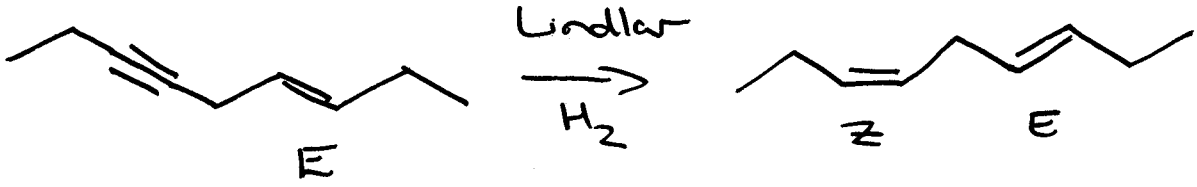
ALKYNE → [ALKENE] → ALKANE



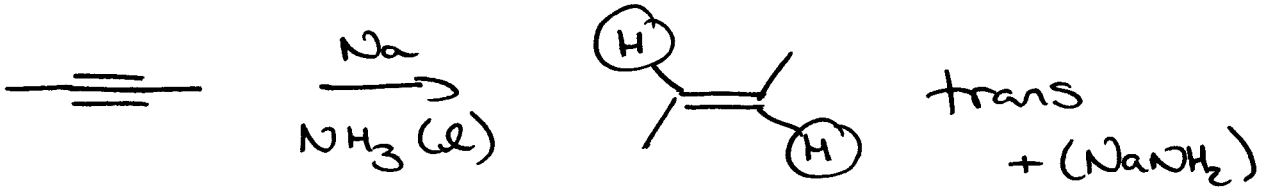
NOT ISOLABLE

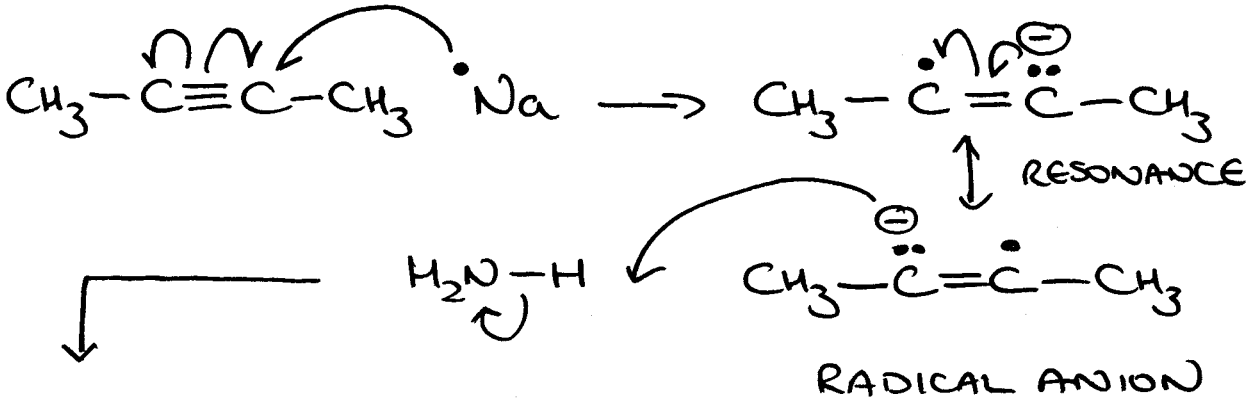


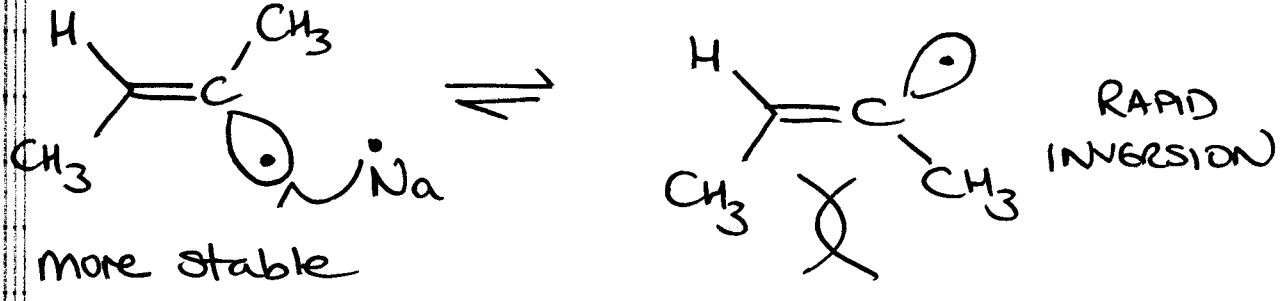
LINDLAR catalyst ($Pd/CaCO_3$ / PbO)
POISONED CATALYST

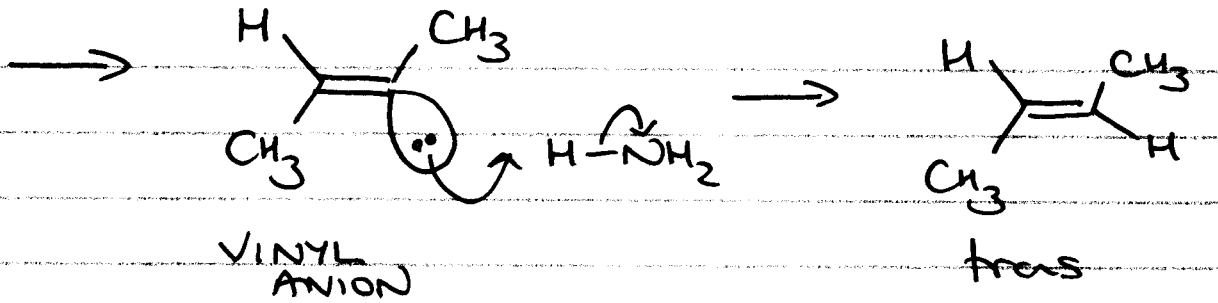


— DISSOLVING METAL REDUCTION





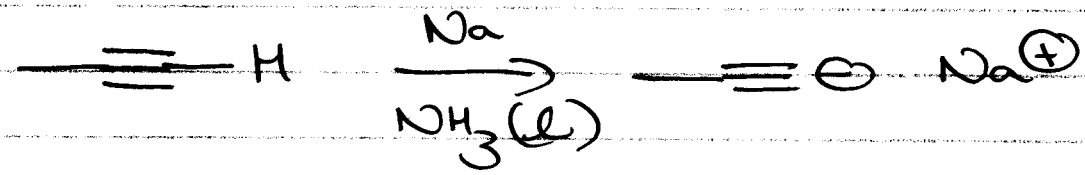




VINYL ANION

trans

Does not work w/ TERMINAL ALKYNES



LEC (19) CHEM 30A Nov 18th

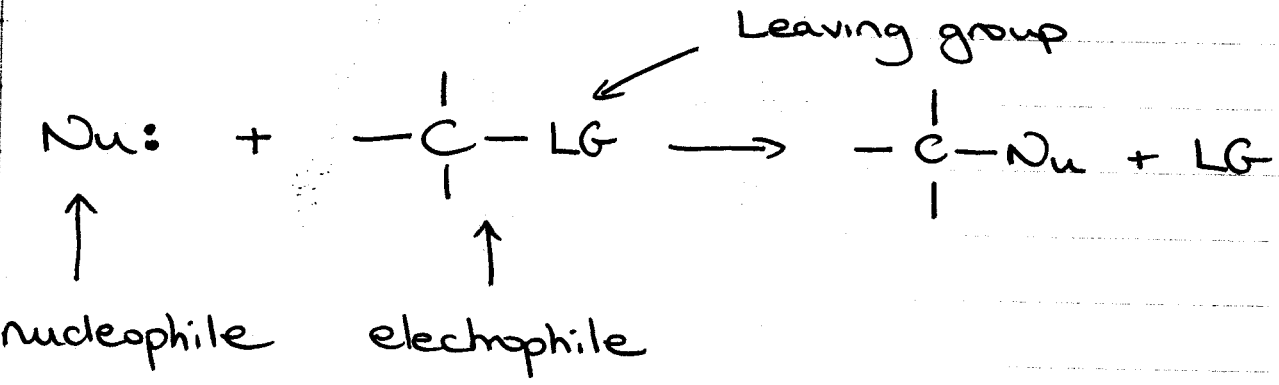
- NUCLEOPHILIC SUBSTITUTION
  1. INTRODUCTION
  2. MECHANISMS
  3. ELECTROPHILE
  4. NUCLEOPHILE

READ 8.1–8.6

PROBLEMS 8.1, 8.2, 8.3, 8.9–8.13

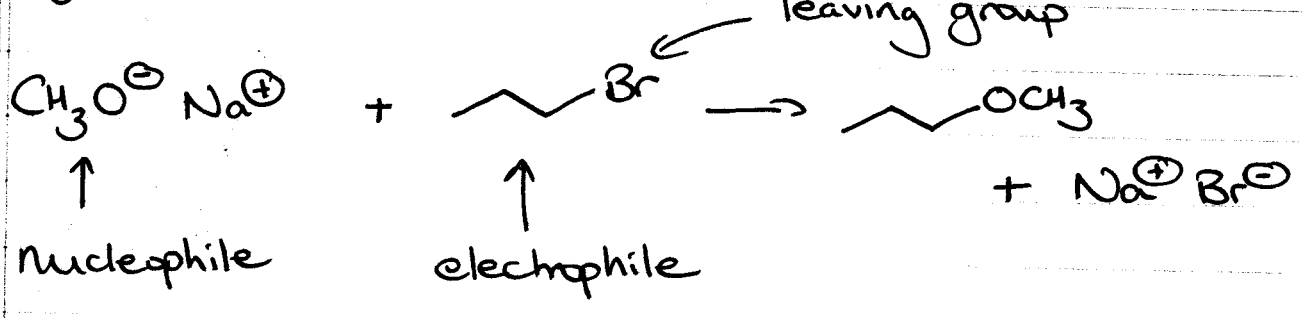
NOTHING ON MIDTERM FROM THIS WEEKS LECTURES

(1) INTRODUCTION



SUBSTITUTION REACTION of Nu Br LG

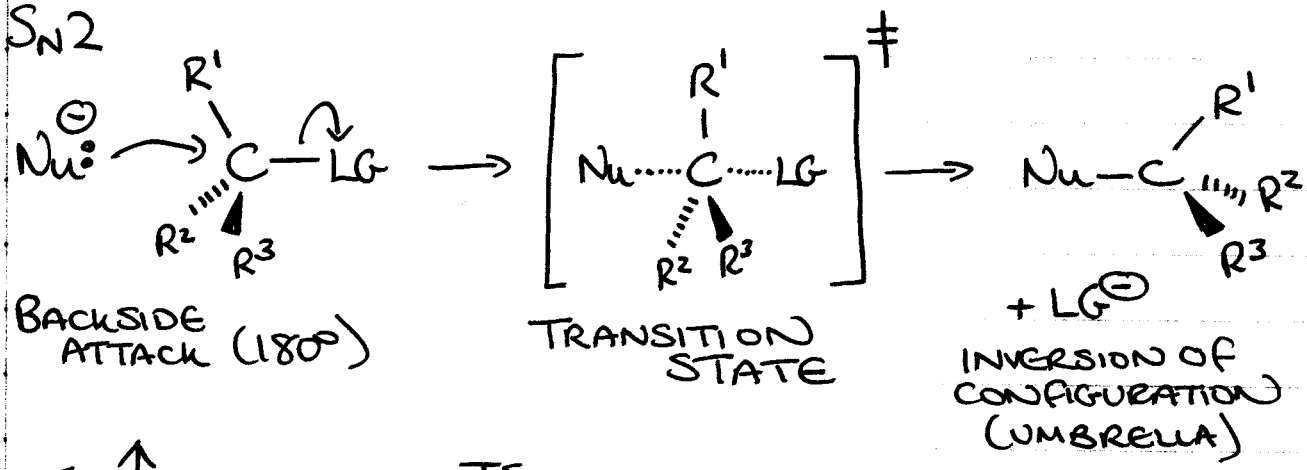
e.g.



(2) MECHANISMS

- TWO LIMITING MECHANISMS

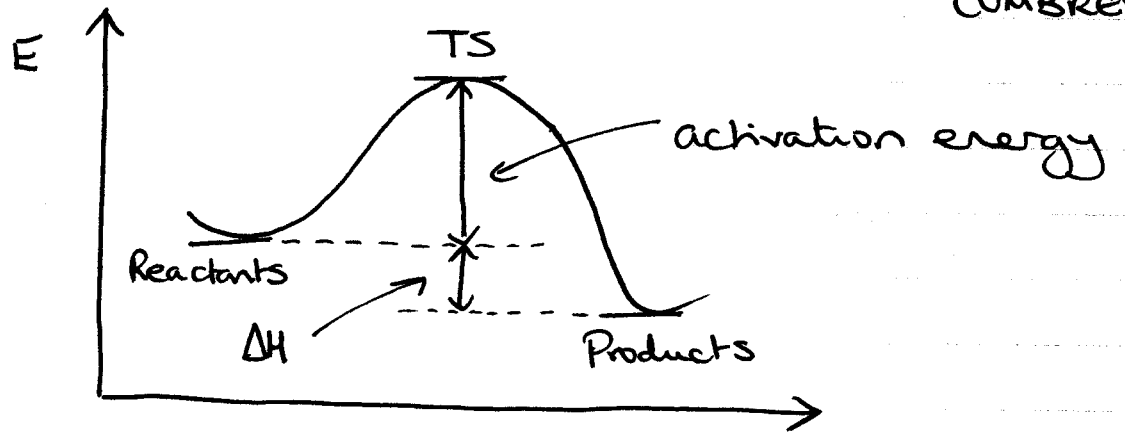
(i) S_N2



BACKSIDE ATTACK (180°)

TRANSITION STATE

INVERSION OF CONFIGURATION (UMBRELLA)



S_N2 = SUBSTITUTION, NUCLEOPHILIC, BIMOLECULAR

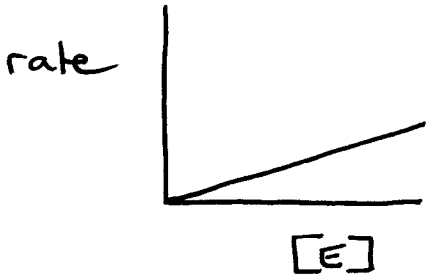
BIMOLECULAR REACTION

- RATE OF REACTION IS DEPENDANT UPON THE CONCENTRATIONS OF BOTH THE NUCLEOPHILE AND THE ELECTROPHILE

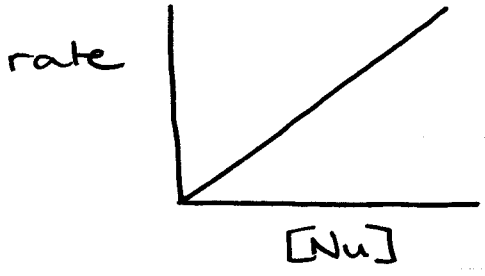
$$\text{rate} = k_2[Nu][E]$$

k_2 ↑ 2nd order rate constant

TWO DIFFERENT EXPERIMENTS



[Nu] constant



[E] constant

rate = k_a [E]

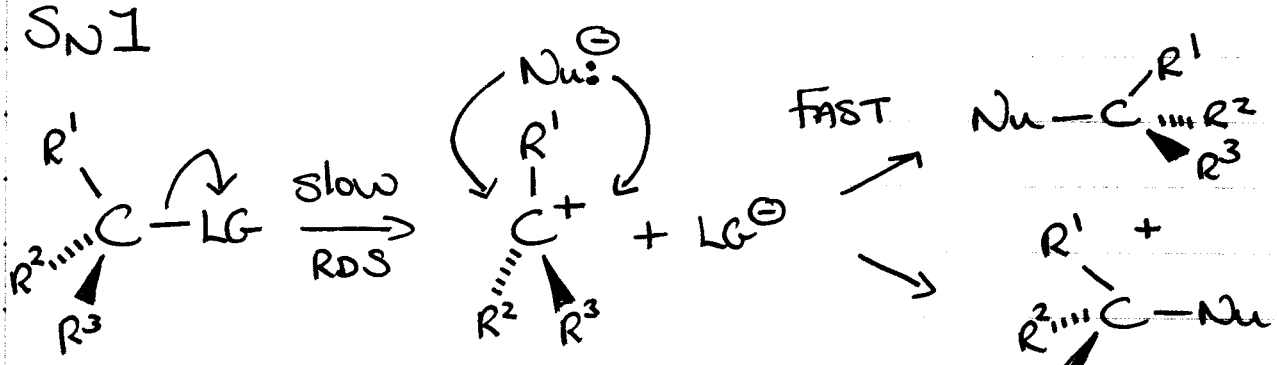
rate = k_b [Nu]

$k_a = k_2$[Nu]

$k_b = k_2$[E]

same value

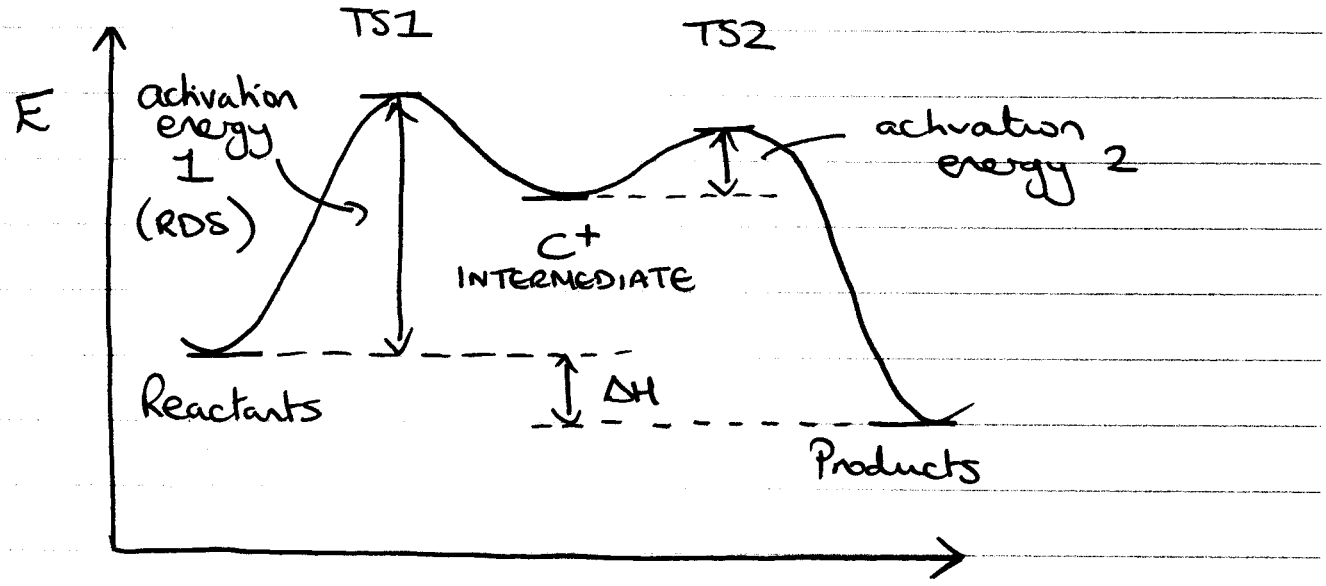
(ii) S_N1



- ANY STEREOCHEMICAL INFORMATION IN THE STARTING MATERIAL IS LOST

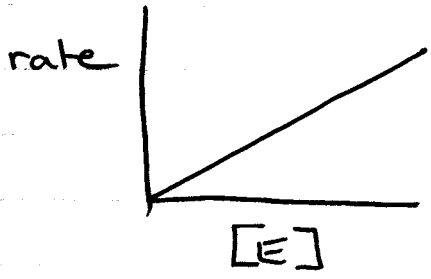
S_N1 – SUBSTITUTION, NUCLEOPHILIC, UNIMOLECULAR

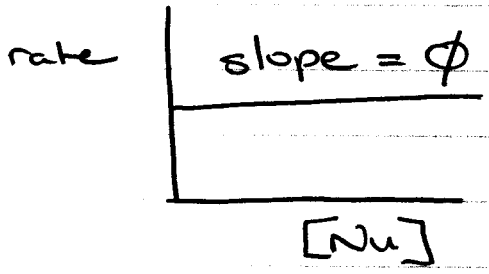
RATE ONLY DEPENDS ON [E]



$$\text{rate} = k_1[E]$$

↑ first order rate constant



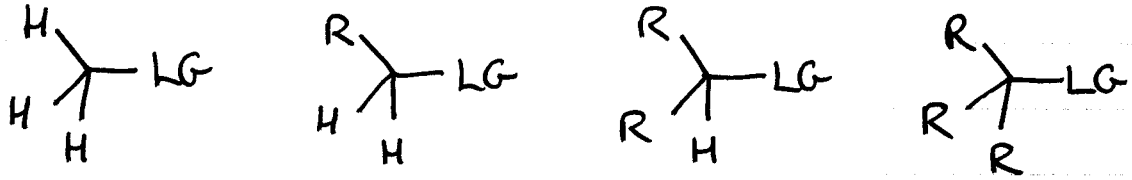


Rate determining step does not involve the NUCLEOPHILE, so adding more of it to the reaction DOES NOT affect the reaction rate.

Also, <u>reactivity</u> of the NUCLEOPHILE does not matter.

WHAT DECIDES S_N1 VS S_N2?

(3) ELECTROPHILE



methyl primary secondary tertiary

S_N2 Backside attack

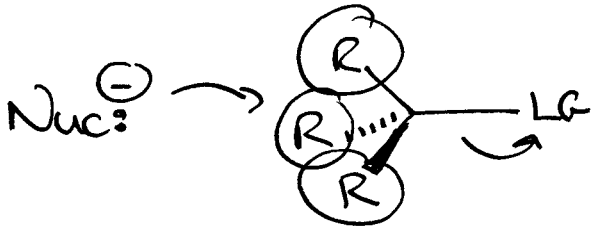
Filled orbital in Nucleophile

σ^* – empty antibonding orbital

Frontside attack?

ANTI BONDING INTERACTION Nu BONDING INTERACTION

So/



more R groups
⇒ STERIC CROWDING

Relative rates of S_N2 rxns

CH_3-LG	1
CH_3CH_2-LG	0.03
$(CH_3)_2CH-LG$	8×10^{-4}
$(CH_3)_3C-LG$	~0

RATE DECREASES

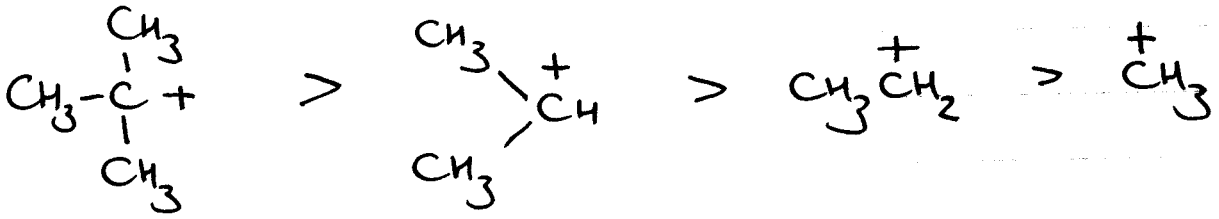
- Some 1° groups can also drastically alter reaction rate

2×10^{-7}

neo-pentyl

Consider S_N1 REACTIONS: opposite effect

C^+ STABILITY



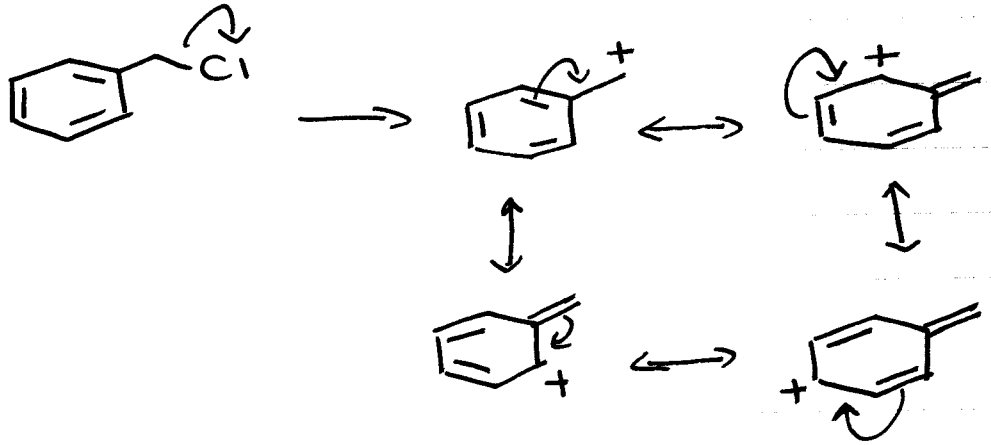
So, 1° and CH_3 electrophiles S_N2

3° electrophiles S_N1

2° C^+ can react either way, depending on other factors.

- Other types of C^+

RESONANCE STABILIZED
1° ALLYLIC



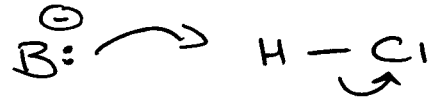
RESONANCE STABILIZED BENZYLIC C^+

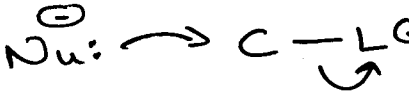
1° ALLYLIC / BENZYLIC electrophiles =>
SN1 or SN2 (depends on other factors)

STERICS favors SN2
ELECTRONICS favors SN1

2°/3° ALLYLIC / BENZYLIC electrophiles =>
ALMOST exclusively SN1

(4) THE NUCLEOPHILE

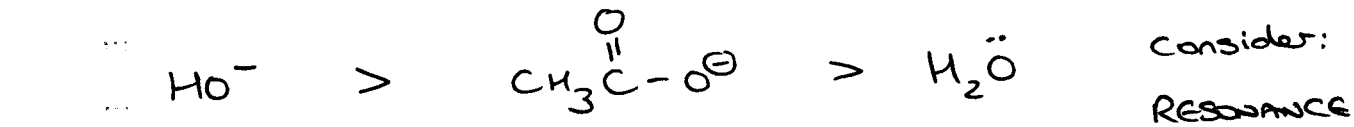
consider BASICITY 

NUCLEOPHILICITY is similar 
- AFFINITY FOR C atom
- KINETIC rather than THERMODYNAMIC EFFECT

IMPRECISE QUANTITY - for ANY GIVEN SPECIES, can vary depending on SOLVENT / ELECTROPHILE

GENERAL TRENDS

- SAME NUCLEOPHILIC ATOM (parallels BASICITY)



	HO^-	>	$CH_3C(=O)-O^-$	>	H_2O	consider: RESONANCE and CHARGE
pka of HX	16		5		2	

- NUCLEOPHILES in the SAME ROW (parallels BASICITY)

CH_3^- > NH_2^- > HO^- > F^- (Consider EN)

- NUCLEOPHILES in the SAME GROUP

In general, nucleophilicity INCREASES going down a group, i.e.,

$HS^\ominus$ > $HO^\ominus$ $\quad$ $I^\ominus$ > $Br^\ominus$ > $Cl^\ominus$ > $F^\ominus$

OPPOSITE TO BASICITY - Why?

- MANY FACTORS

(i) ENERGY LEVELS

Higher energy of lone pair electrons as you go down the table, better overlap with σ^*

(ii) POLARISABILITY

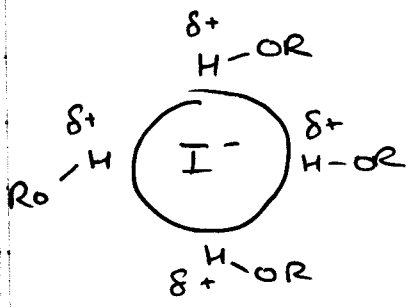
Larger atoms ⇒ more diffuse electron clouds, greater POLARISABILITY → BONDS can begin to form at greater INTERATOMIC DISTANCES.

SOLVENT HAS LARGEST EFFECT

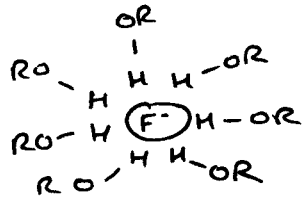
- POLAR PROTIC (H_2O, MeOH, EtOH)
- POLAR APROTIC (DMSO, DMF, MeCN, Acetone)

POLAR PROTIC SOLVENTS

$I^- > Br^- > Cl^- > F^-$



LOW CHARGE DENSITY
(weak solvent cage)



HIGH CHARGE DENSITY
(strong solvent cage)

HYDROGEN BONDING – noncovalent interaction

$$^{\delta-}X-H^{\delta+} \cdots\cdots Y^{\ominus}$$

So, smaller Nu = higher charge density
→ more solvated, less nucleophilic

BUT, IN POLAR APROTIC SOLVENTS

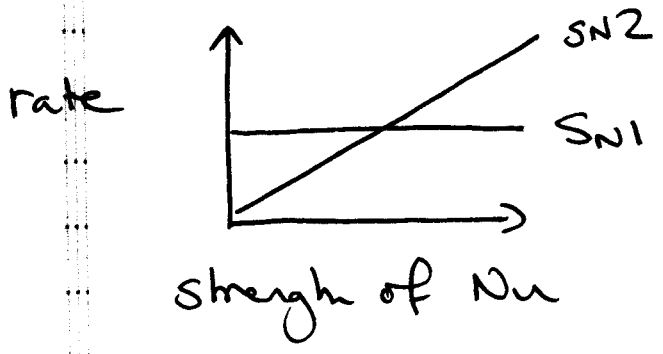
ANIONS WEAKLY SOLVATED, TREND REVERSED,
& CORRELATES W/ BASICITY

$$Nuc:^{\ominus} \rightarrow CH_3-I \longrightarrow Nuc-CH_3 + I^-$$

Nuc^-	pKa	MeOH (Time to complete reaction)	DMF	
I^-	−10	17 min	8.7 s	Overall message → POLAR APROTIC SOLVENTS GOOD
Br^-	−8	12 h	8.7 s	
Cl^-	−6	13 d	1.4 s	
F^-	3	> 2 yrs	< 1.2 s	

DMF / MeOH → equivalent polarities

S_N1 vs S_N2



S_N2 rate = $k_2[E][Nu]$

S_N1 rate = $k_1[E]$

Has no effect on S_N1, but stronger nucleophiles tend to favor S_N2 reactions

LEC (20) CHEM 30A Nov 17th

- NUCLEOPHILIC SUBSTITUTION
(1) NUCLEOPHILE
(2) LEAVING GROUP
(3) SOLVENT

MIDTERM (2) ROOM ASSIGNMENTS

READ 8.1 – 8.10
PROBLEMS 8.14 – 8.35

[THURSDAY – CARI'S OFFICE HOURS CANCELLED]

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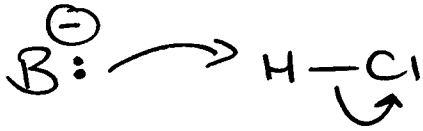
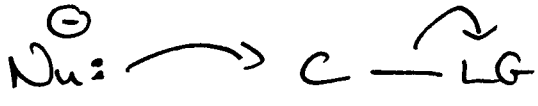
(1) THE NUCLEOPHILE

Consider BASICITY 

measure of how strong the affinity a base has for a proton

NUCLEOPHILICITY is similar

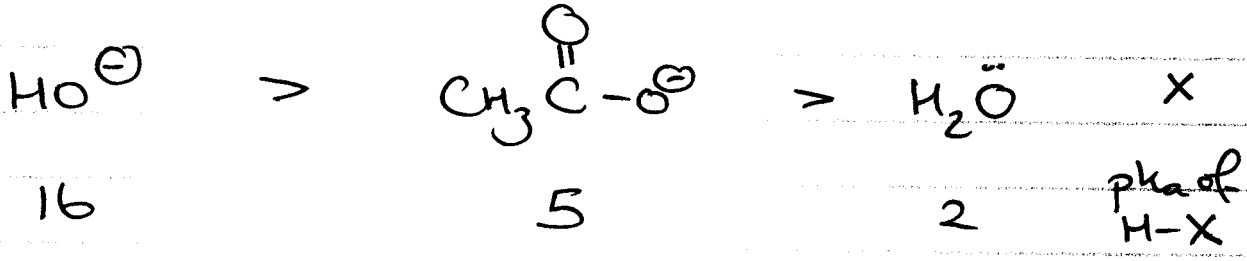


- affinity for a CARBON atom
- KINETIC rather than a THERMODYNAMIC effect

- IMPRECISE QUANTITY
for any given species, can vary depending on SOLVENT / ELECTROPHILE

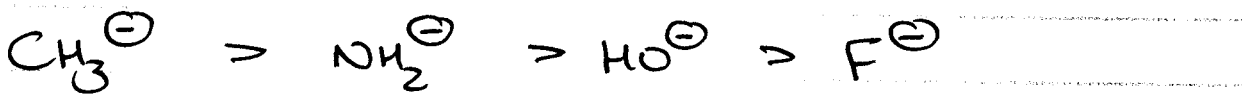
Some general trends:

(i) same nucleophilic atom
(parallels basicity)



need to consider RESONANCE / CHARGE

(ii) nucleophiles in the same row
(parallels basicity)



need to consider ELECTRONEGATIVITY

(iii) nucleophiles in the same group

in general NUCLEOPHILICITY increases going down a group

$HS^{\ominus} > HO^{\ominus}$

$I^{\ominus} > Br^{\ominus} > Cl^{\ominus} > F^{\ominus}$

opposite to basicity - WHY?

- MANY FACTORS

a) ENERGY LEVELS

As you go down the periodic table, lone pair electrons in valence shell are in higher energy orbitals → better overlap with σ^*

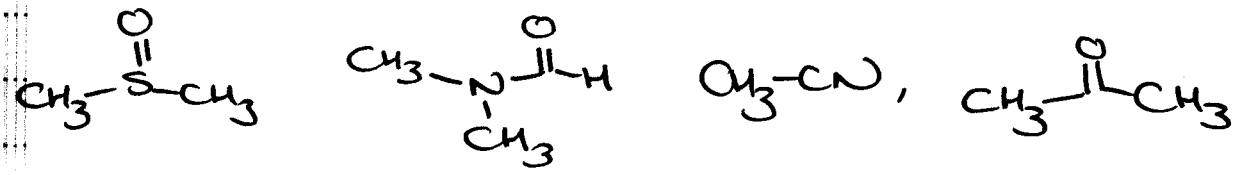
b) POLARISABILITY

Larger atoms → more diffuse electron clouds (greater POLARISABILITY) - bonds can begin to form at greater INTER-ATOMIC DISTANCES

c) SOLVENT (very dramatic effect)

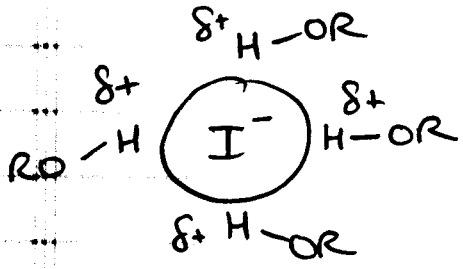
- POLAR PROTIC (H_2O, CH_3OH, CH_3CH_2OH)

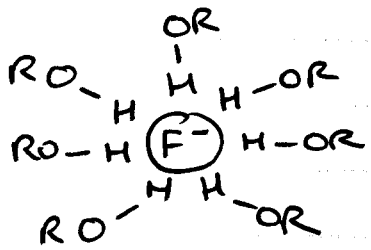
- POLAR APROTIC (DMSO, DMF, MeCN, Acetone)



- In POLAR PROTIC SOLVENTS

$$I^- > Br^- > Cl^- > F^-$$





LOW CHARGE DENSITY
- weak solvent cage

HIGH CHARGE DENSITY
- strong solvent cage

HYDROGEN BONDING - noncovalent interaction

$$X^{\delta-}—H^{\delta+}\cdots Y^{\ominus}$$

So, smaller nucleophile → more solvated
⇒ LESS NUCLEOPHILIC

BUT IN POLAR APROTIC SOLVENTS

- anions are only weakly solvated,

TREND REVERSED – correlates w/ BASICITY

Consider

$$Nu:^{\ominus} \rightarrow CH_3—I \longrightarrow Nu—CH_3 + I^{\ominus}$$

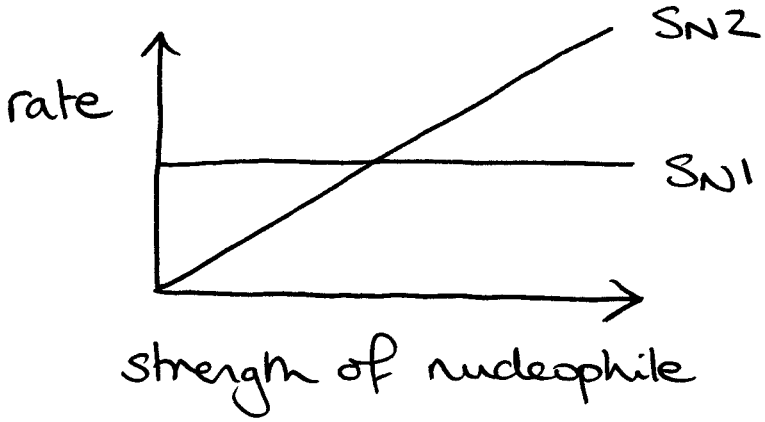
Nuc	pka	PROTIC MeOH (time to complete reaction)	APROTIC DMF
I^-	-10	17 min ↑	8.7s ↓
Br^-	-8	12h	8.7s
Cl^-	-6	13d	1.4s
F^-	3	>2yrs	<1.2s

DMF / MeOH ~ equal polarities

<u>OVERALL</u> Polar aprotic solvents are the best in S_N2 reactions

(more on solvent effects later)

S_N1 vs S_N2

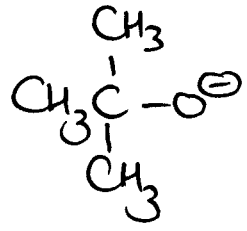


Nu strength has no effect on S_N1, but in S_N2, the stronger the Nu, the faster the rate, so STRONG NUCLEOPHILES favor S_N2 reactions

...d) Size

... Consider

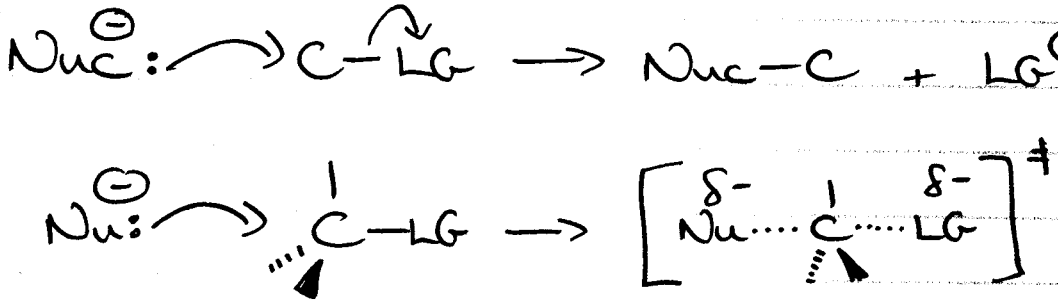
... $CH_3O^{\ominus}$
...methoxide
...pka 15.5



t-butoxide
pka ~18

MORE BASIC, but much less nucleophilic (STERICS)

② LEAVING GROUP



...(also in S_N1, form $LG^{\ominus}$ in RDS)

...BETTER CHARGE STABILIZATION ⟶ BETTER LEAVING GROUP

...-reduces energy of transition state, faster reaction

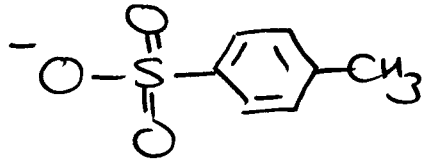
...So, more ACIDIC H-LG, more stable $LG^{\ominus}$

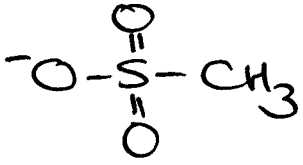
...GOOD LEAVING GROUPS / BAD LEAVING GROUPS

relative reactivity

$^{\ominus}NH_2$, $^{\ominus}OH$, $^{\ominus}OR$	$F^{\ominus}$	$Cl^{\ominus}$	$Br^{\ominus}$	$I^{\ominus}$
$<<1$	1	200	10,000	30,000

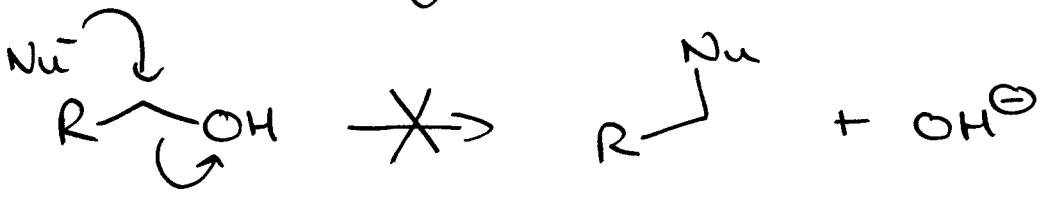
other good leaving groups

tosylate  ~60,000

mesylate 

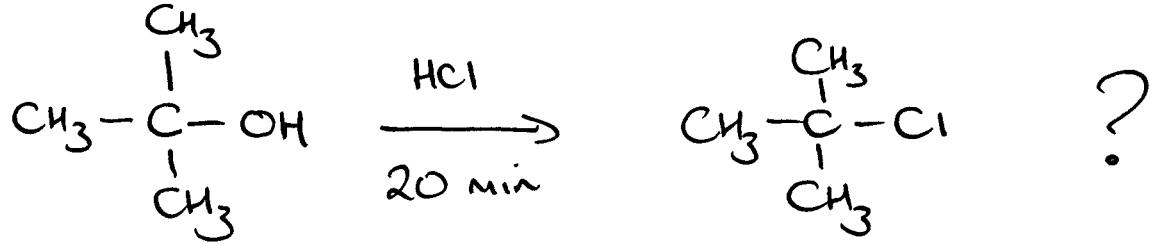
So, R-F, R-OH, R-OR', $R-NH_2$

- do not undergo S_N2 reactions



DOES NOT HAPPEN

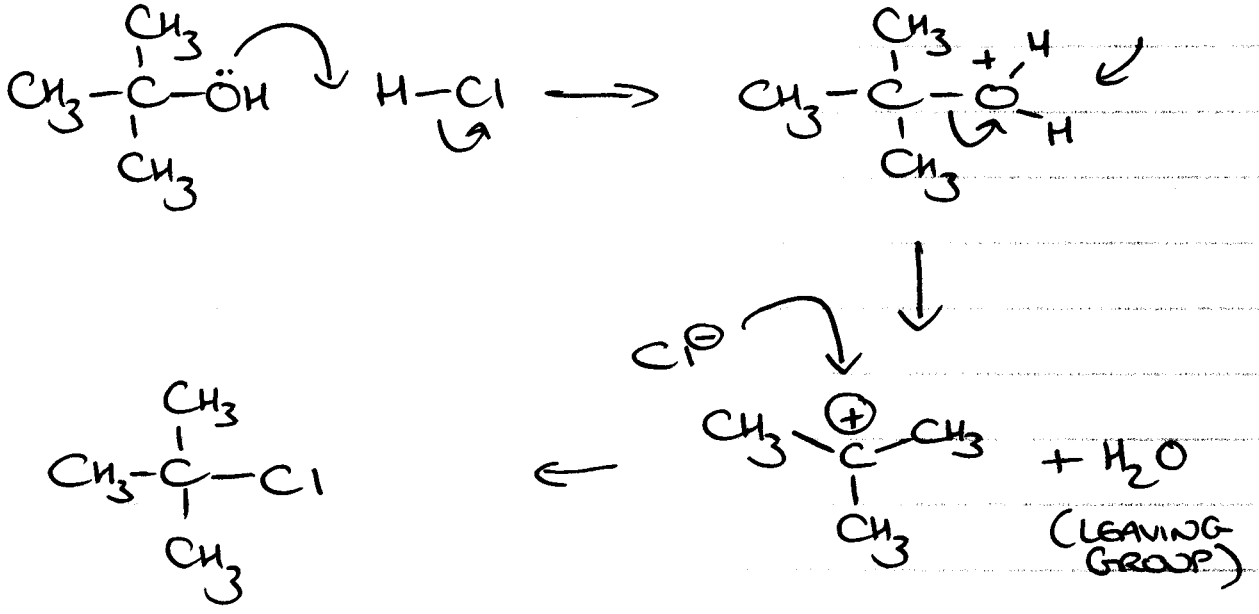
But



?

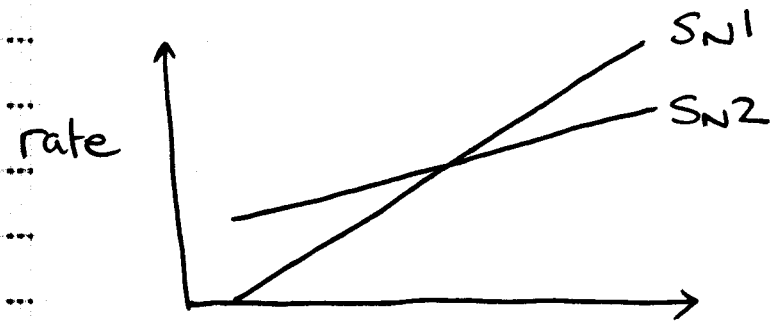
- converted OH into a better LG

pka H_3O^+ ~ -2



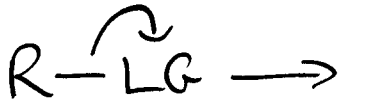
(SN1 mechanism)

SN1 vs SN2



BAD ⟶ LG ABILITY ⟶ V. GOOD

SN1 reaction is MUCH MORE SENSITIVE to the leaving group ability, as RDS involves



In S_N2 reaction → as long as

$LG^{\ominus}$ more stable than $Nu^{\ominus}$,

reaction can proceed

BUT deciding on LG ability alone, not easy to figure out S_N1 vs S_N2

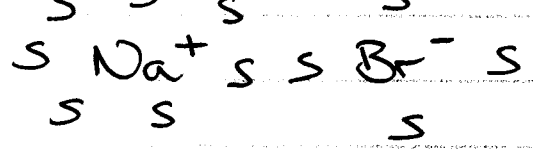
(3) SOLVENT

S_N2 reactions POLAR APROTIC solvents

↓

Solvate CATIONS well, but not ANIONS

e.g.

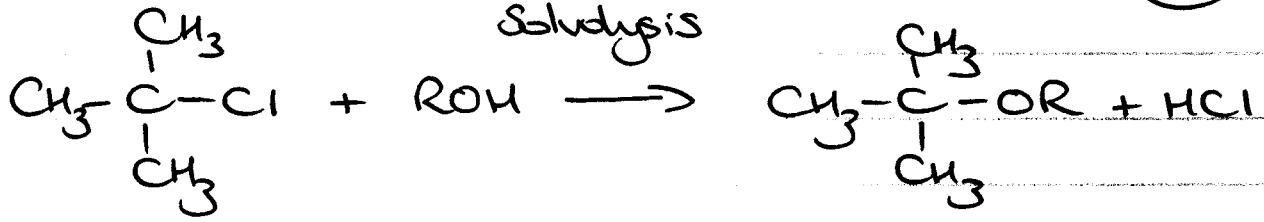
$NaBr \xrightarrow{\text{Solvent}}$ 

S_N1 reaction

$R-LG \longrightarrow R^{+} \quad LG^{\ominus}$

creation and separation of charge

⇒ More polar the solvent, the better



Water	/ Ethanol	Relative rate
100	0	100,000
80	20	14,000
40	60	100
0	100	1

So/

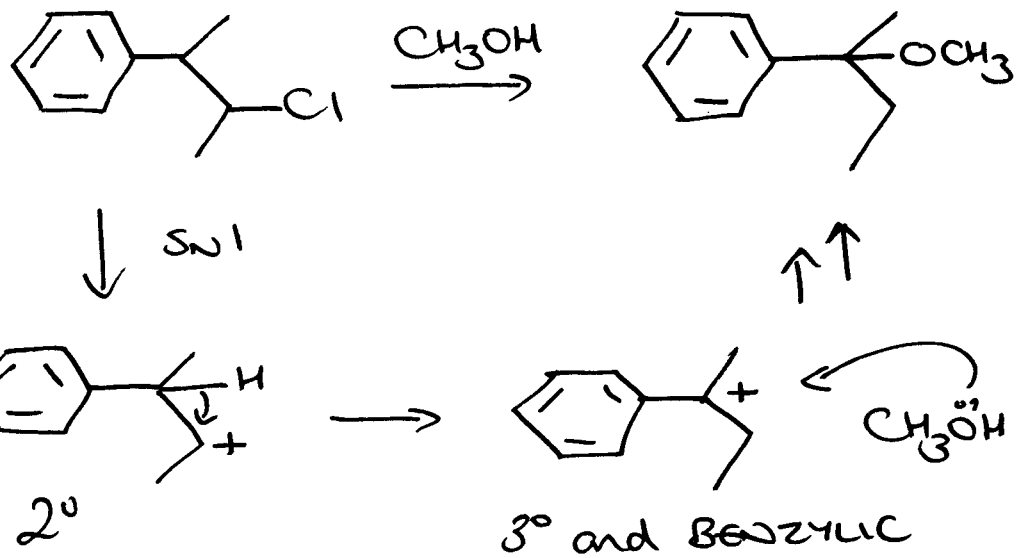
S_N2 reactions
DISFAVORED IN PROTIC SOLVENTS
(ground state energy lowered by SOLVATION)

S_N1 reactions
FAVORED IN PROTIC SOLVENTS
(transition state energy lowered by solvation)

Note about S_N1

- Goes through C^+, so be on the lookout for skeletal rearrangement

e.g.



SUMMARY

Electrophile	SN2	SN1
Me / 1°	✓	X
2°	FAVORED GOOD NUCLEOPHILES POLAR APROTIC SOLVENTS	FAVORED POOR NUCLEOPHILES POLAR PROTIC SOLVENTS
3°	X	✓

also helped by REALLY GOOD LEAVING GROUPS

- COMPLICATING FACTOR

=> COMPETING ELIMINATION REACTIONS

LEC (21) CHEM 30A Nov 19th

- NUCLEOPHILIC SUBSTITUTION

(1) LEAVING GROUP cont
(2) SOLVENT
(3) REARRANGEMENT
(4) SUMMARY
(5) NEIGHBORING GROUP PARTICIPATION
(6) PHASE-TRANSFER CATALYSIS
(7) ELIMINATION

MIDTERM (2) MONDAY

LAST NAME A-N (CSSϕ)
O-Z (BUNCHE 1209B)

PROBLEMS: 8.4, 8.5, 8.6

OFFICE HOURS
FRI 2-4 pm
SUN 3 pm

---

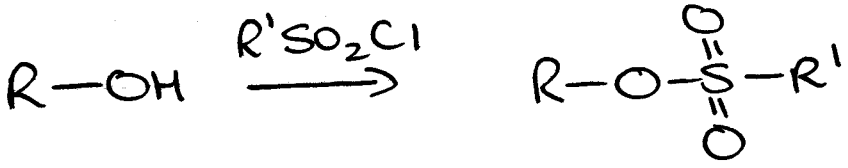
(1) LEAVING GROUPS

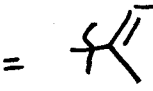
LG ABILITY →

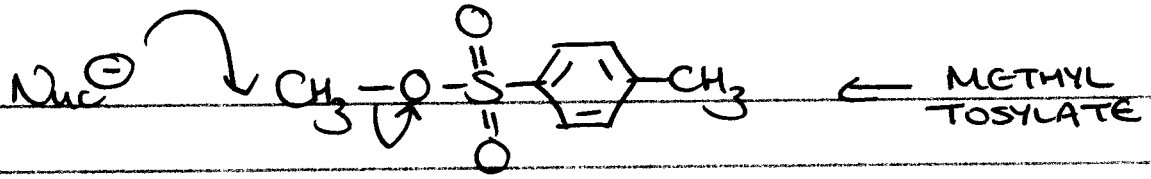
$(NH_2^{\ominus}, OH^{\ominus}, RO^{\ominus},)$ $F^{\ominus}$, $Cl^{\ominus}$, $Br^{\ominus}$, $I^{\ominus}$

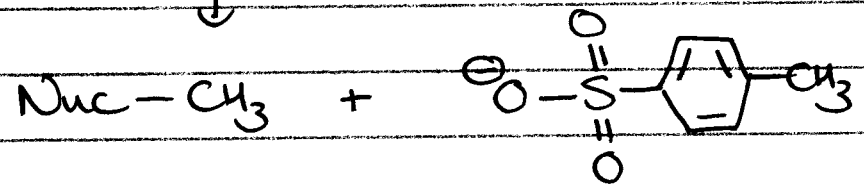
→ stability of anion
(lower pka of conjugate acid)

- Good leaving groups derived from alcohols



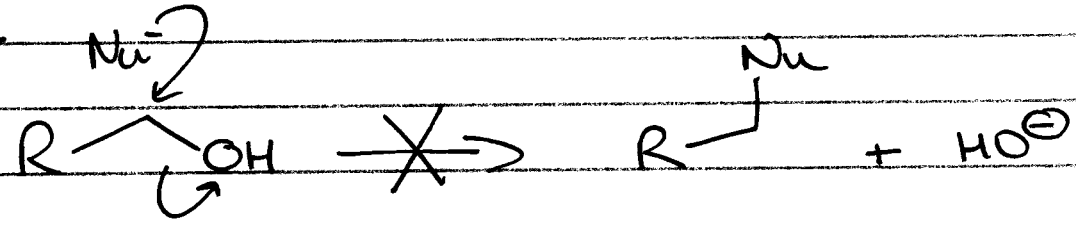
R' =  TOSYLATE R' = $-CH_3$ MESYLATE





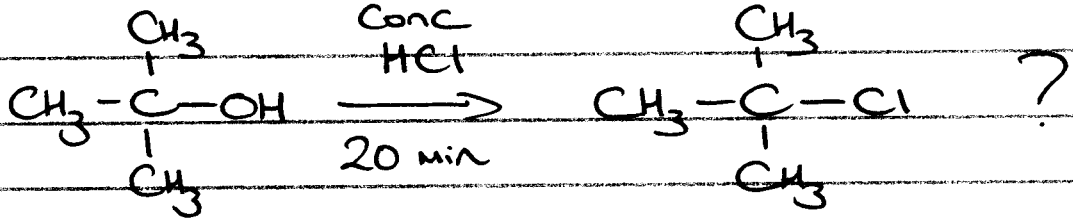
TOSYLATE/MESYLATE AS GOOD AS / BETTER IODIDE

So

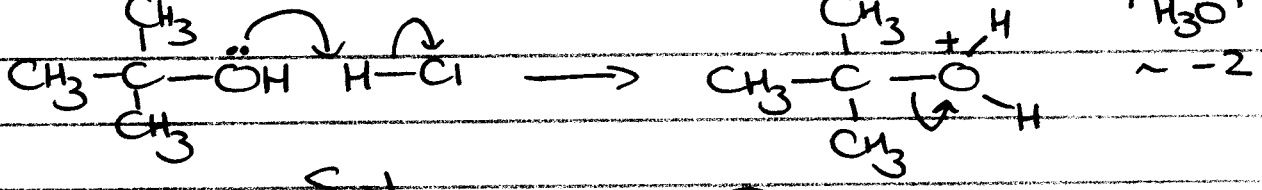


DOES NOT HAPPEN

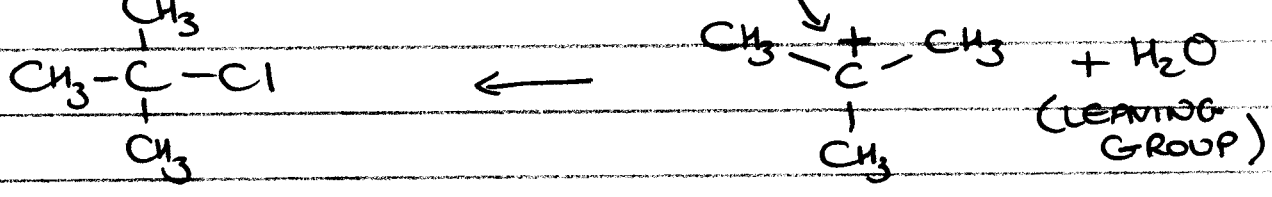
But



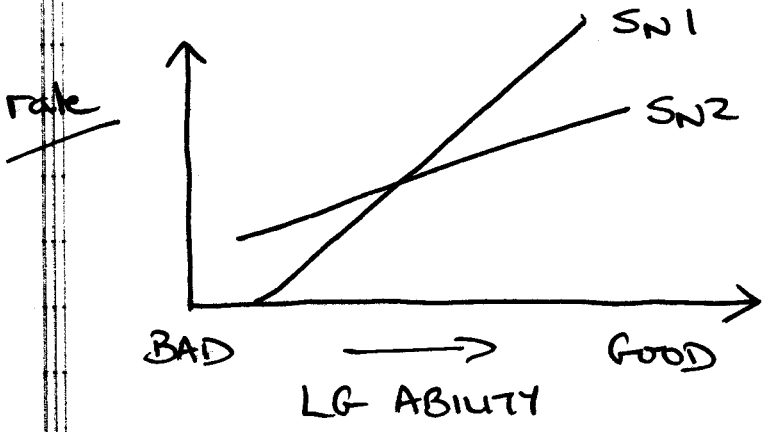
–OH is converted into a better LG



S_N1 MECHANISM



S_N1 vs S_N2



S_N1 mechanism MORE SENSITIVE to the leaving group ability →

RDS involves: $R-\overset{\curvearrowright}{LG} \longrightarrow R^+ + LG^\ominus$

+Whereas in S_N2 reaction:

as long as $LG^\ominus$ is more stable than $Nu^\ominus$, then the reaction can proceed.

BUT deciding on LG ability alone, not easy to figure out S_N1 vs S_N2

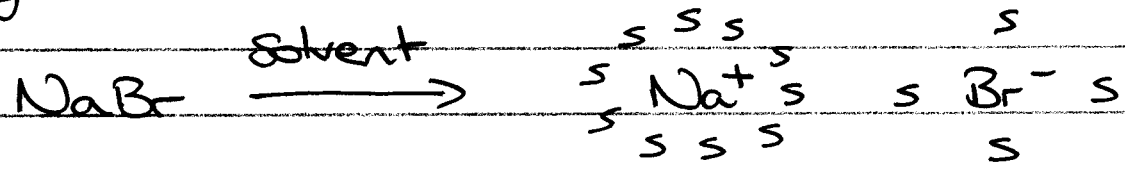
(2) SOLVENT

S_N2 REACTIONS ⇒ POLAR APROTIC SOLVENTS

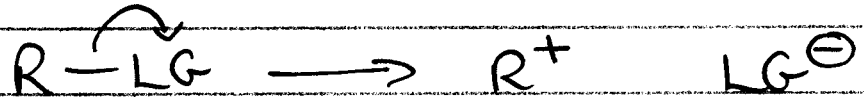
↓

Solvate CATIONS well, but not ANIONS

e.g.

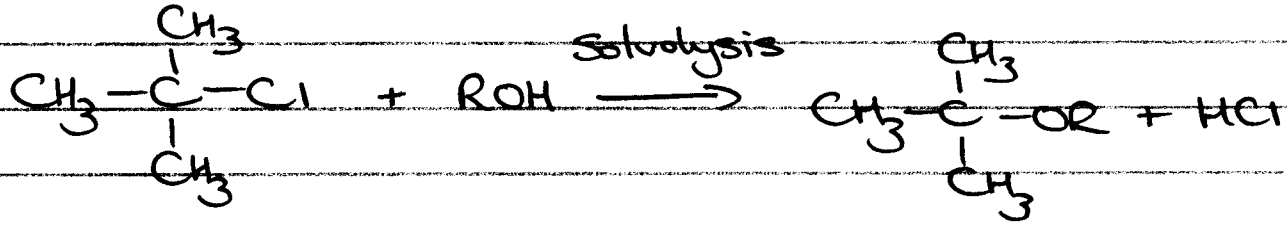


S_N1 reaction



creation and separation of charge

⇒ more polar the solvent the better



(ROH) Water/Ethanol		Relative Rate
100	0	100,000
80	20	14,000
40	60	100
0	100	1

So S_N2 REACTIONS

Disfavored in PROTIC SOLVENTS

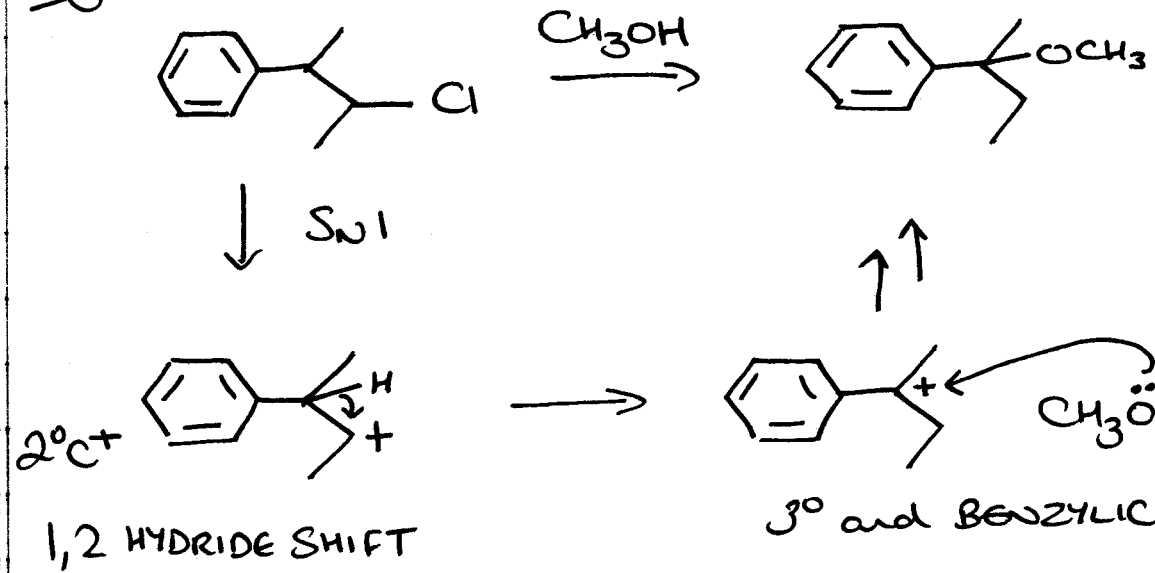
(ground state energy lowered by SOLVATION)

SN1 Reactions
Favored in POLAR PROTIC SOLVENTS
(transition state energy lowered by SOLVATION)

(3) REARRANGEMENT

SN1 reaction → goes through a CARBOCATION INTERMEDIATE, so rearrangement is a possibility.

e.g.



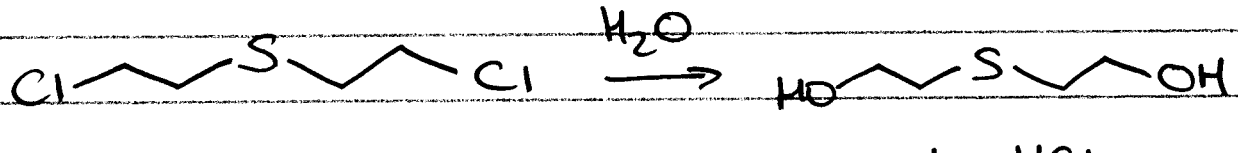
1,2 HYDRIDE SHIFT

3° and BENZYLIC C+

(4) SUMMARY

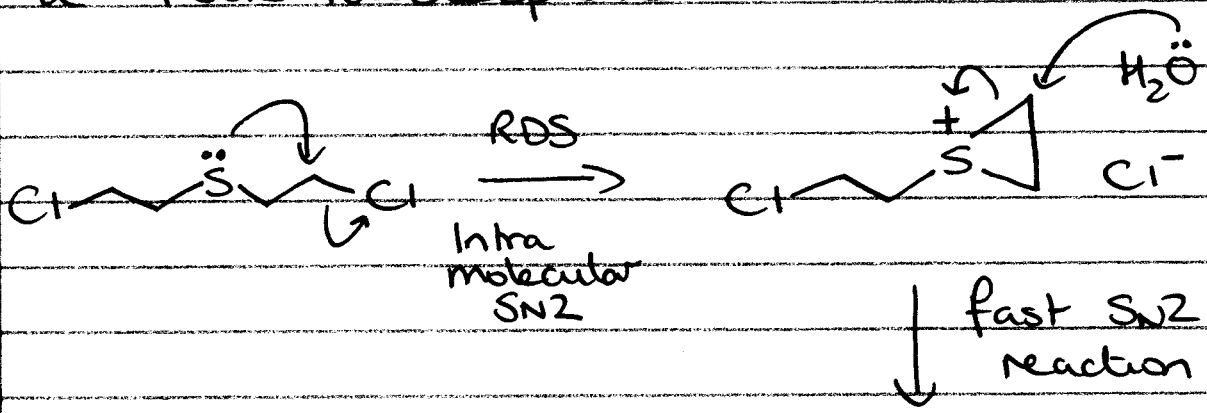
Electrophile	SN2	SN1
Me / 1°	✓	X
2°	GOOD NUCLEOPHILES POLAR APROTIC SOLVENTS	POOR NUCLEOPHILES POLAR PROTIC SOLVENTS (V. GOOD LEAVING GROUPS)
3°	X	✓

(5) NEIGHBORING GROUP PARTICIPATION

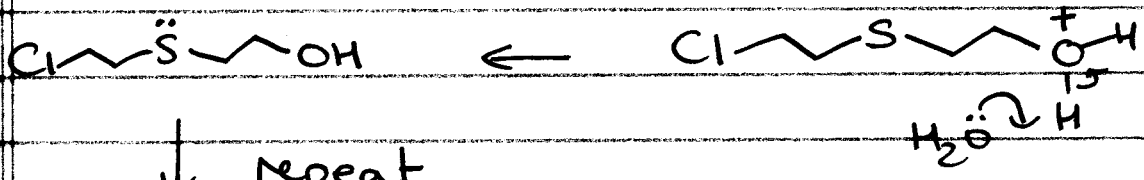


(mustard gas)

Very rapid reaction, even though H_2O is a POOR nucleophile



fast S_N2 reaction



repeat

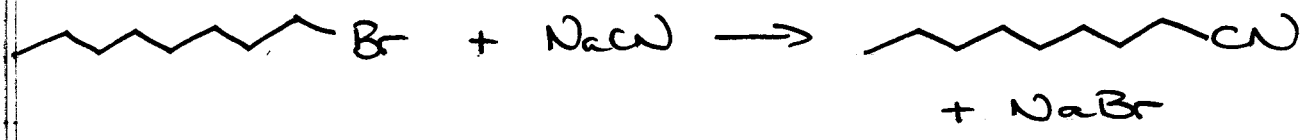
overall rate = $k[Cl\sim S\sim Cl]$

Independent of concentration of Nuc

TWO CONSECUTIVE S_N2 REACTIONS, with KINETICS of an S_N1 reaction

(6) PHASE TRANSFER CATALYSIS

consider:

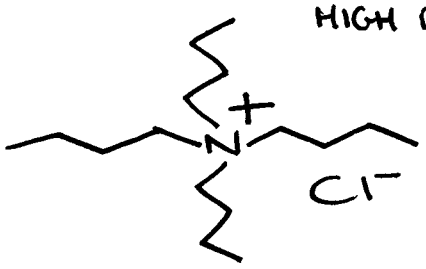


HYDROPHOBIC ORGANIC (non polar organics)

IONIC SALT (water)

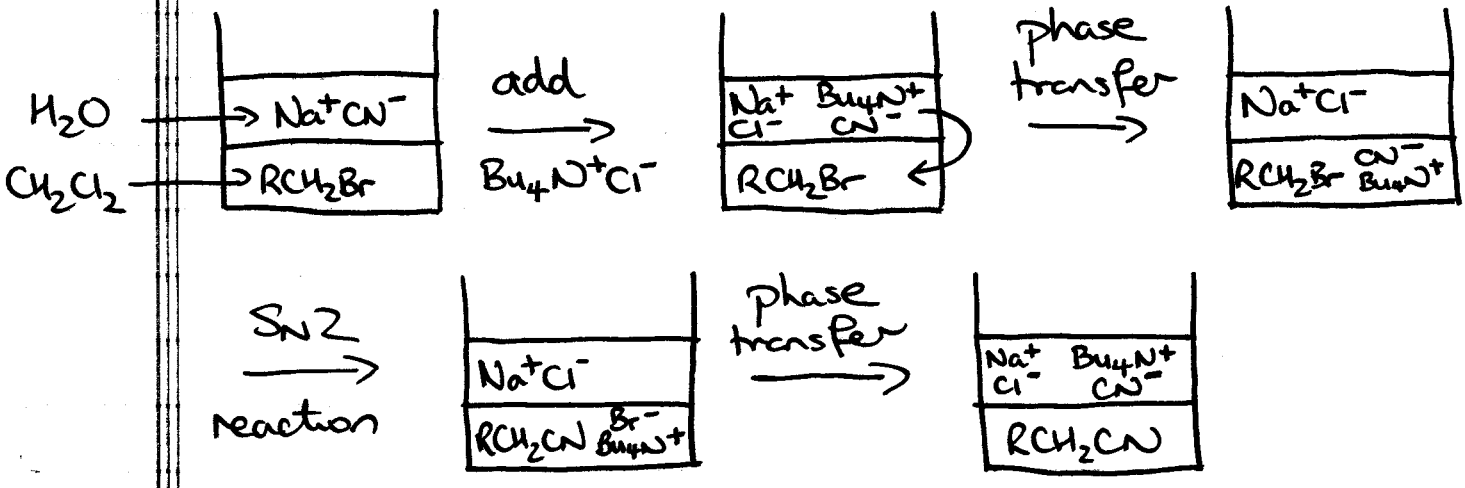
COULD USE
189 - DMSO, DMF - 153
(EXPENSIVE, WATER SOLUBLE (RECOVERY) HIGH BOILING

PHASE TRANSFER CATALYST



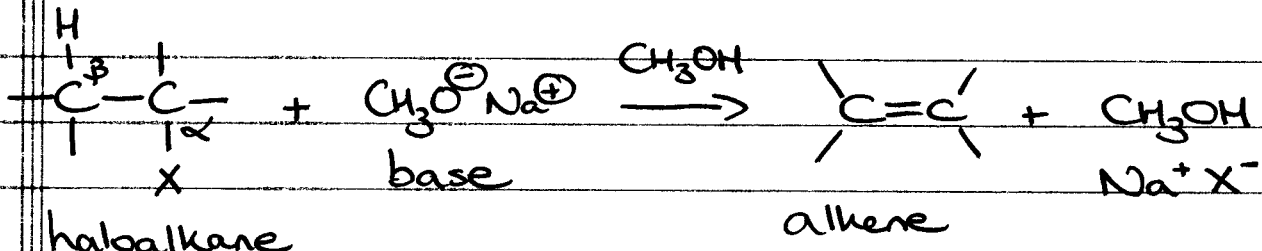
TETRABUTYL AMMONIUM CHLORIDE

TRANSPORTS THE ANION (NUCLEOPHILE) INTO THE ORGANIC PHASE



(7) β-ELIMINATION REACTIONS

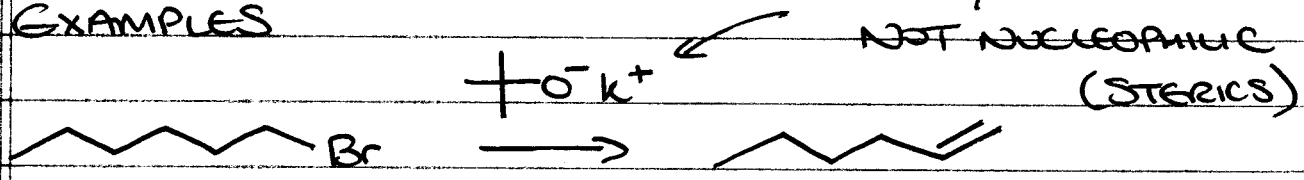
- one example DEHYDROHALOGENATION



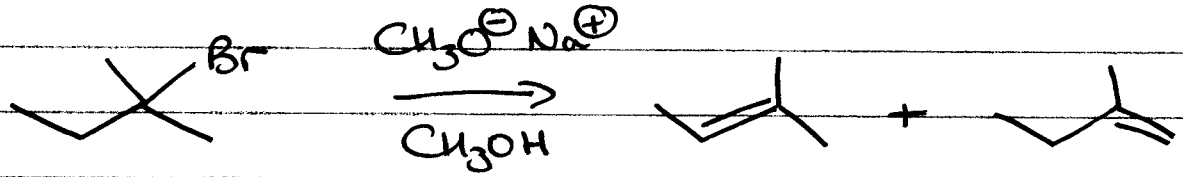
haloalkane — alkene

SUBSTITUTION
ELIMINATION
} COMPETING REACTIONS

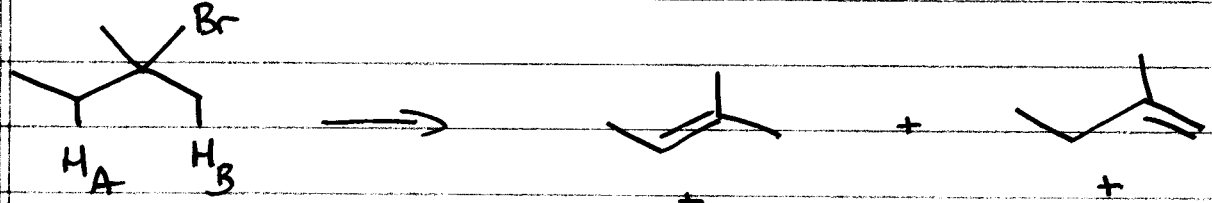
EXAMPLES



1 bromohexane — 1 hexene



MAJOR PRODUCT



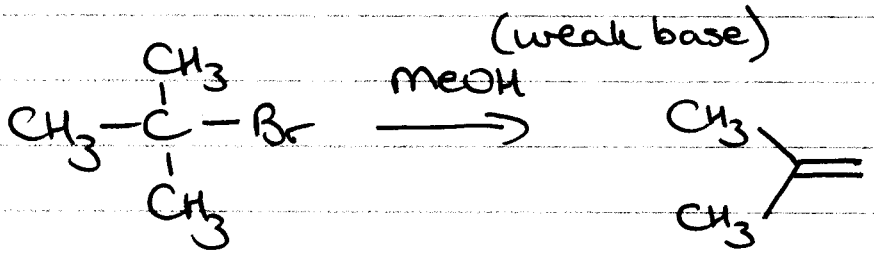
β PROTONS — H_ABr — H_BBr

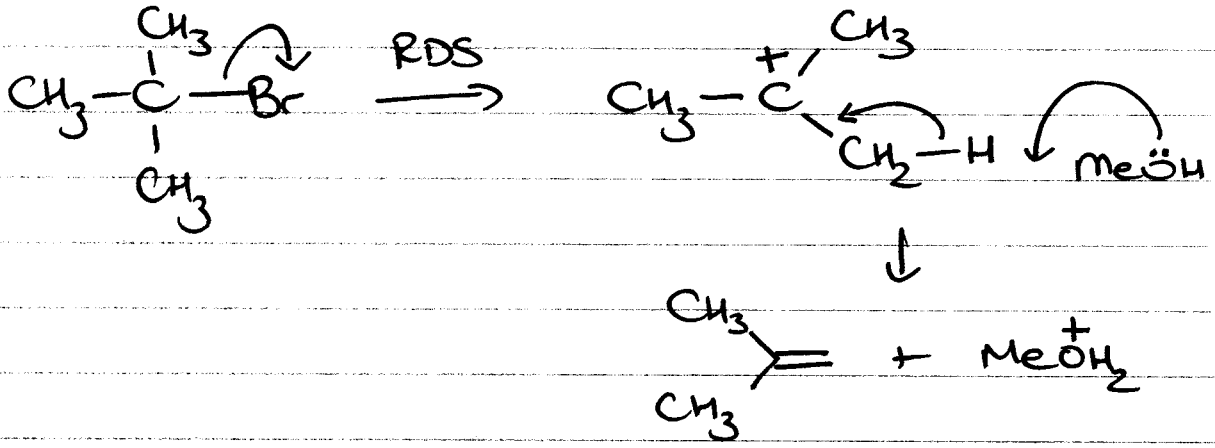
ZAITSEV'S RULE → major product is the MOST SUBSTITUTED alkene

Mechanisms for β-ELIMINATION

TWO LIMITING MECHANISMS

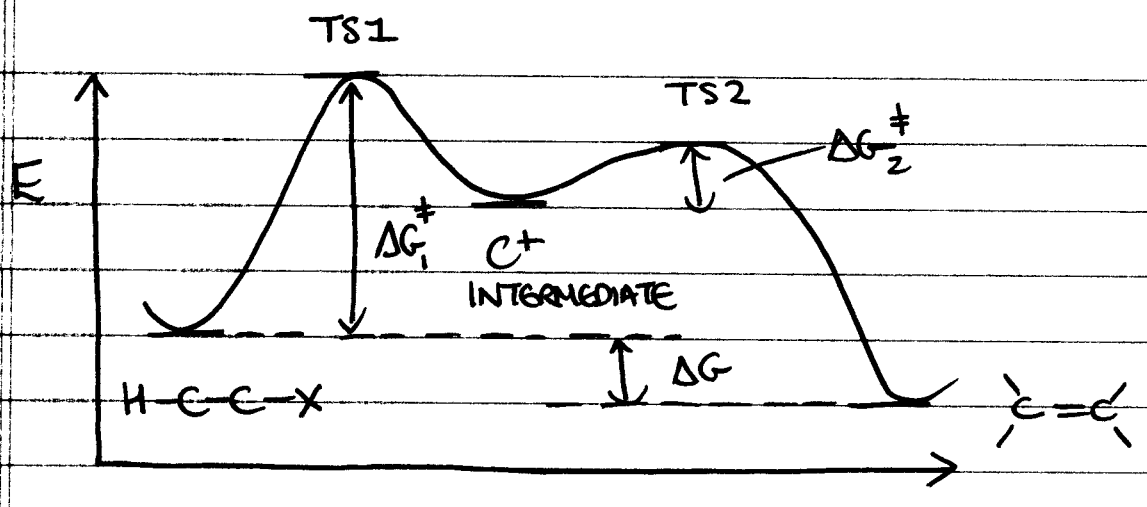
E1 (elimination unimolecular)



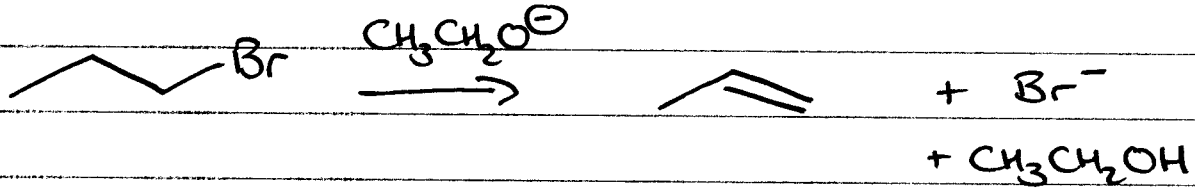


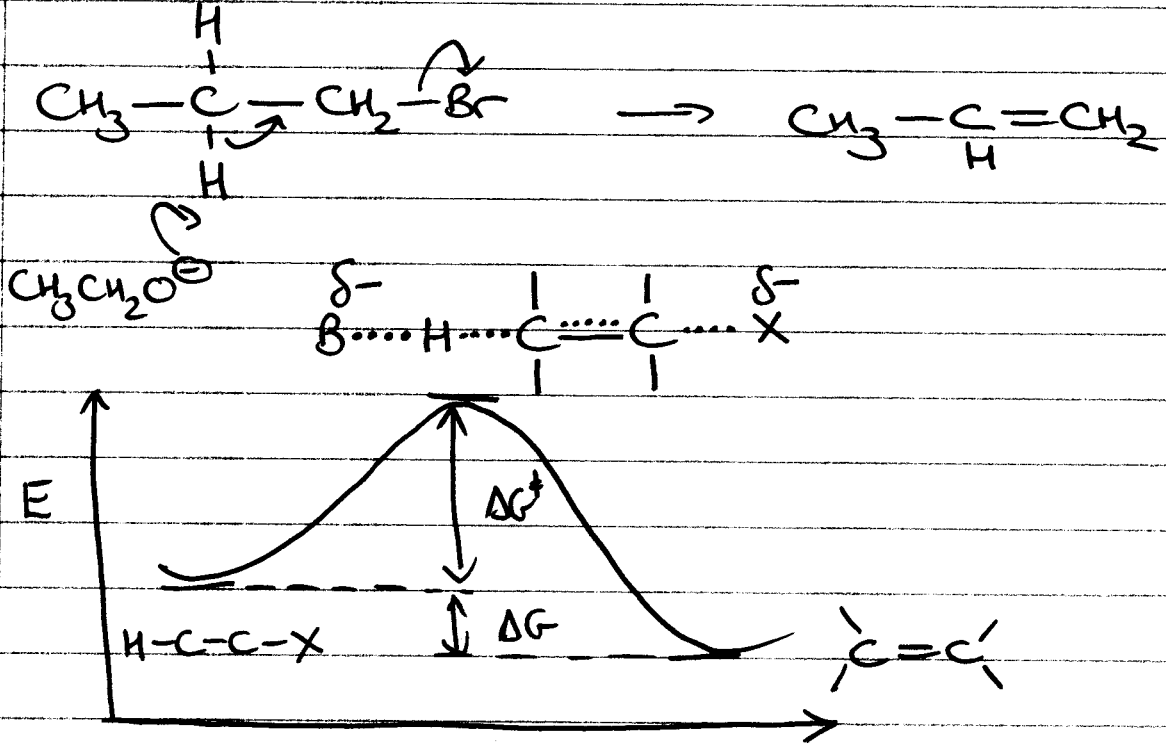
(competes with the SN1 reaction)

$$\text{rate} = k_1 \left[(CH_3)_3C-Br \right]$$



E2 (elimination bimolecular)





rate = k_2 [~Br] [Base]

LEC (22) CHEM 30A Nov 29th

ELIMINATION

READ: 8.8 - 8.11

PROBLEMS: 8.6 - 8.8, 8.36 - 8.45

(1) INTRODUCTION
(2) MECHANISMS
(3) STEREOCHEMISTRY
(4) E1/E2 Summary
(5) SUBSTITUTION VS ELIMINATION

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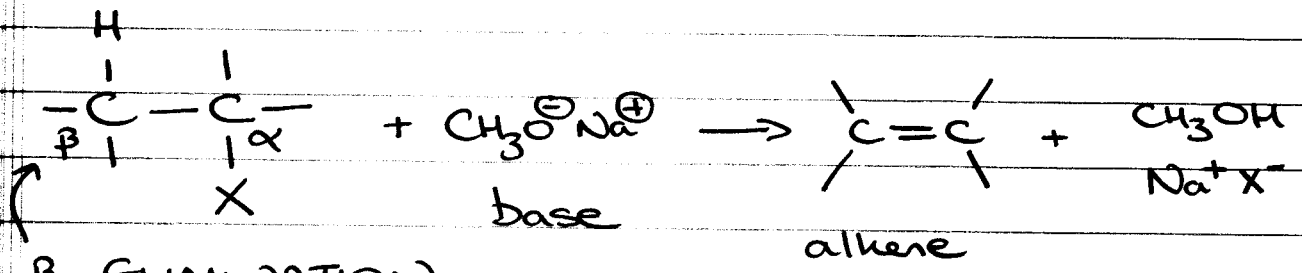
(1) INTRODUCTION

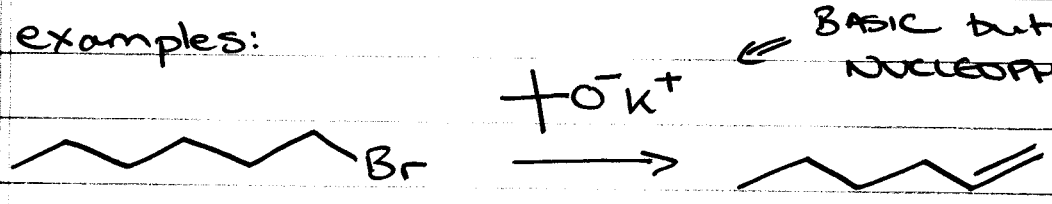
- one example is DEHYDROHALOGENATION



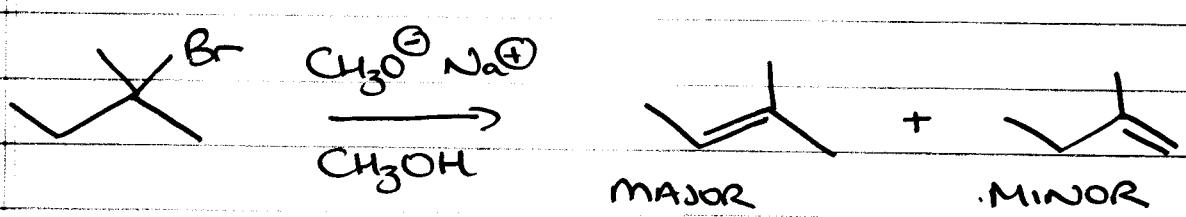
β-ELIMINATION

SUBSTITUTION/ELIMINATION => competing reactions

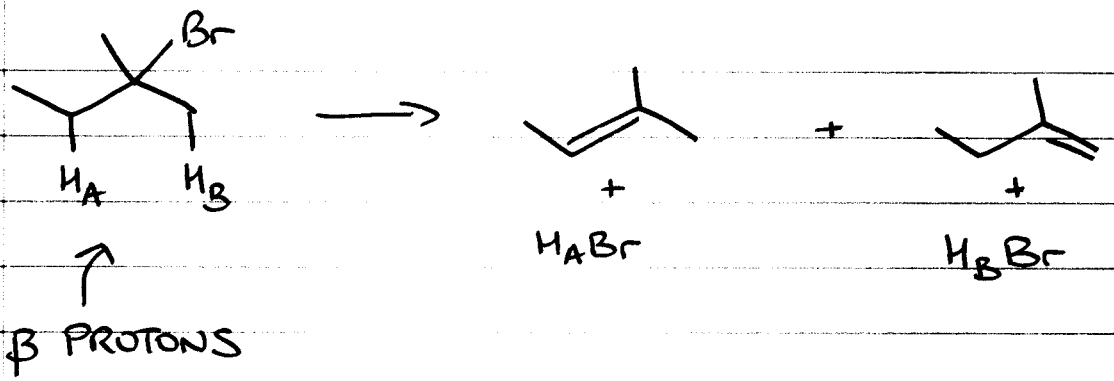
examples:



1bromohexane → 1-hexene



MAJOR MINOR



β PROTONS

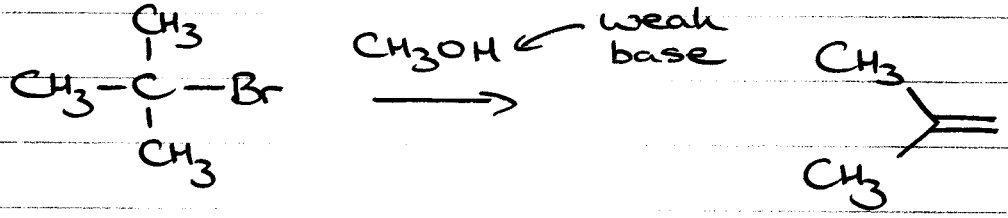
ZAITSEV'S RULE → major product is the MOST SUBSTITUTED ALKENE

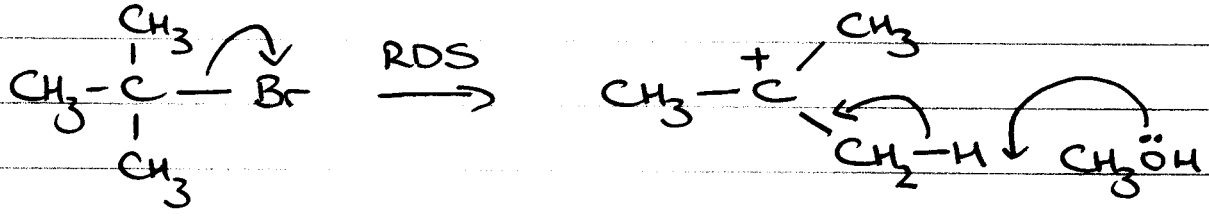
(There are EXCEPTIONS TO THIS RULE)

(2) MECHANISMS

(Just like substitution reactions ⇒ TWO LIMITING MECHANISMS)

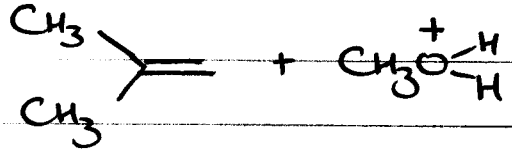
E1 (elimination unimolecular)

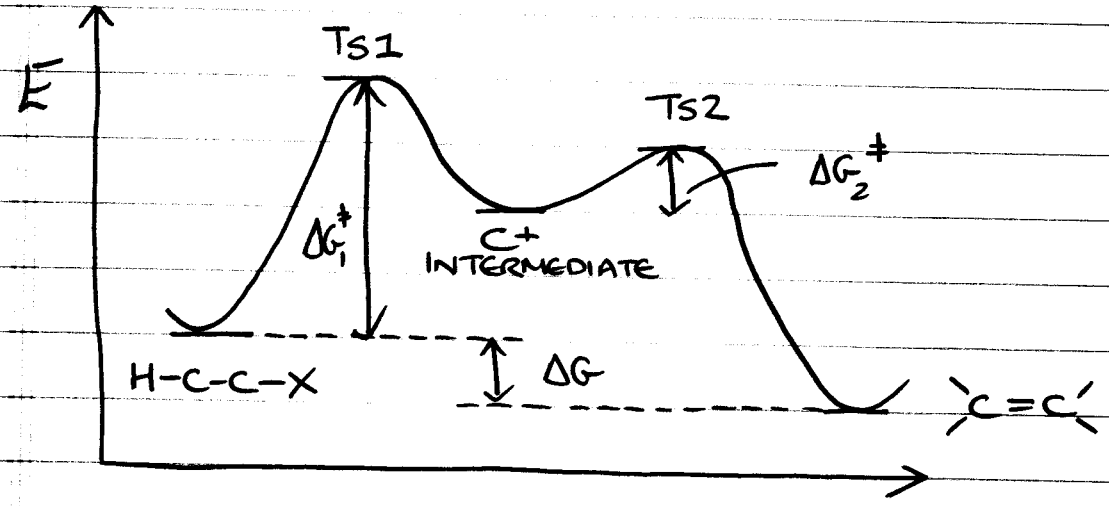




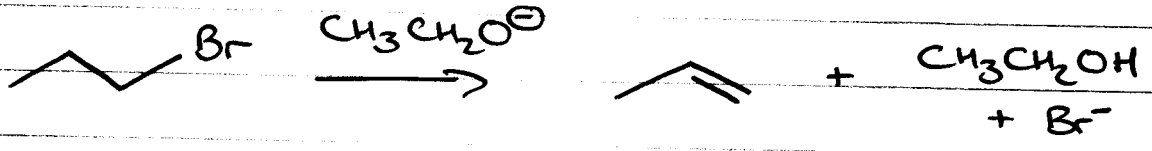
COMPETES WITH SN1 REACTION

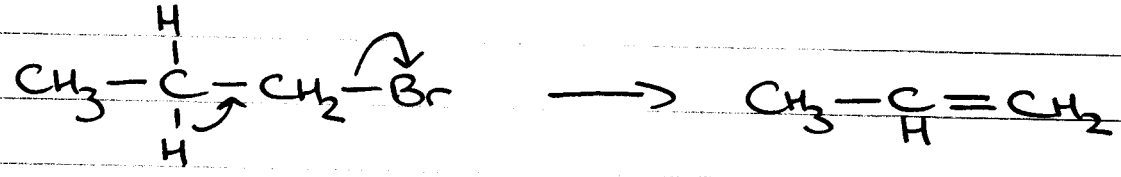
$$\text{rate} = k_1\left[(CH_3)_3C-Br\right]$$



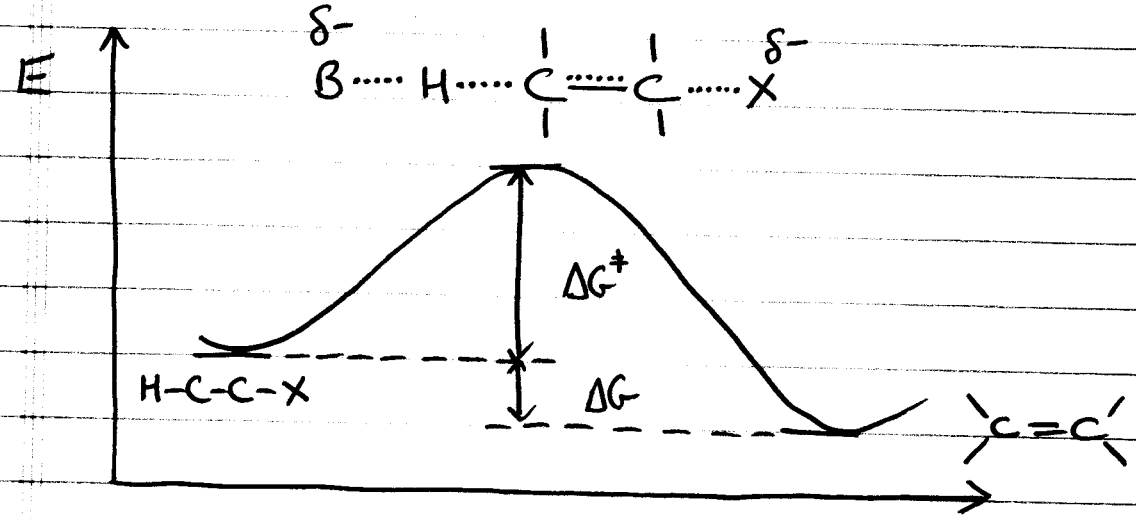


- E2 (elimination bimolecular)



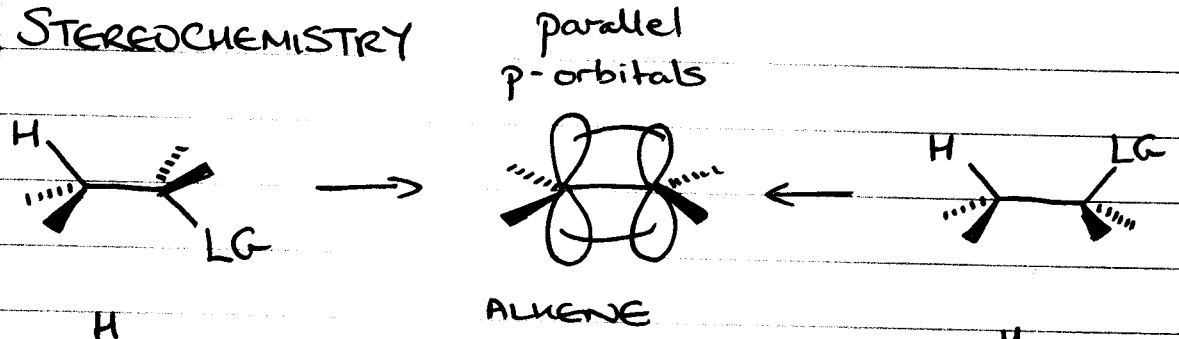


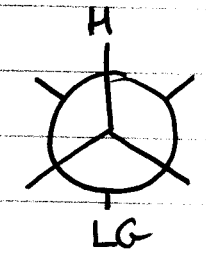
CONCERTED PROCESS



rate = k_2 [~Br] [Base]

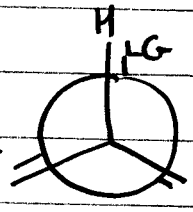
(3) STEREOCHEMISTRY





ANTI PERIPLANAR

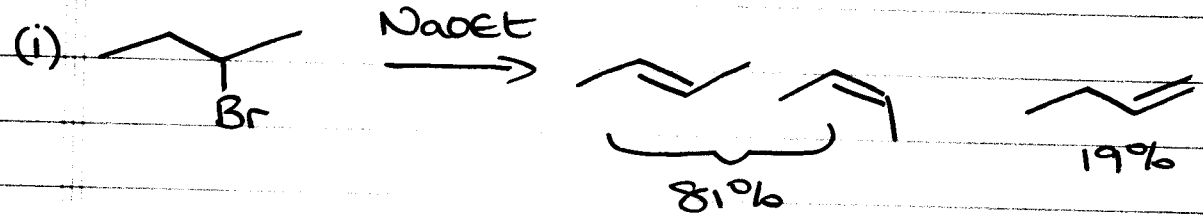
SYN PERIPLANAR

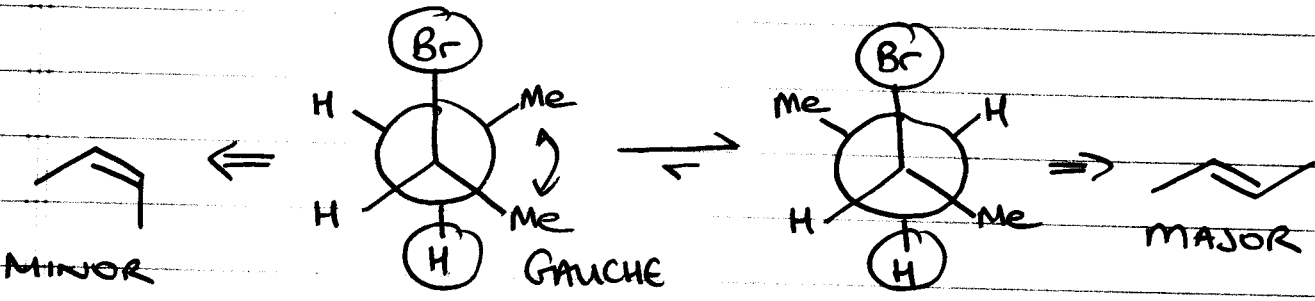


WITH A FEW EXCEPTIONS, AN ANTIPERIPLANAR GEOMETRY IS PREFERRED IN AN E2 REACTION

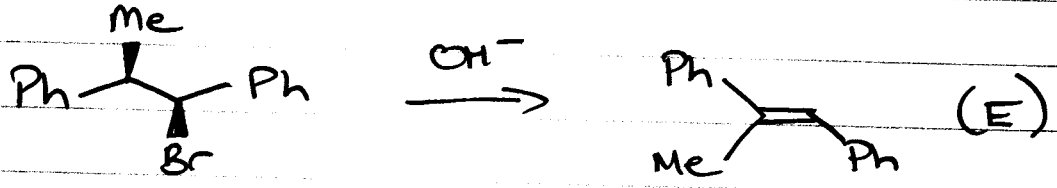
- examples

(i)

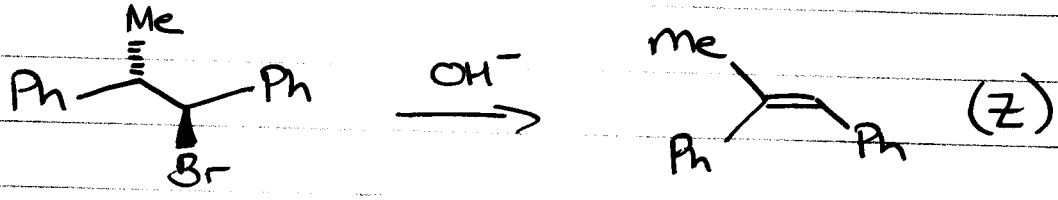




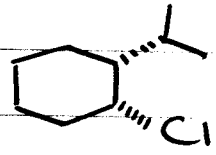
(ii)



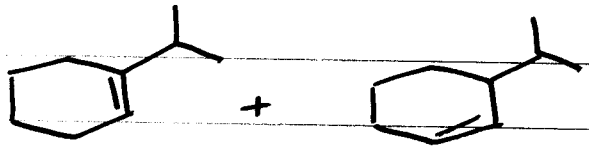
<u>BUT</u>



(iii)



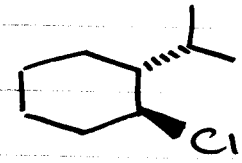
CH_3ONa → CH_3OH



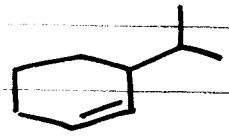
CIS

MAJOR

BUT



CH_3ONa → CH_3OH

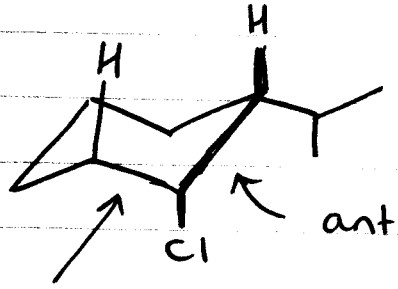


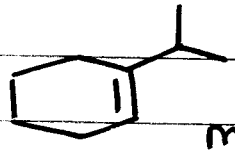
trans

ALSO: CIS reaction FASTER THAN TRANS.

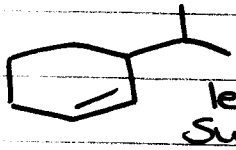
WHY?

- CIS



antiperiplanar → 

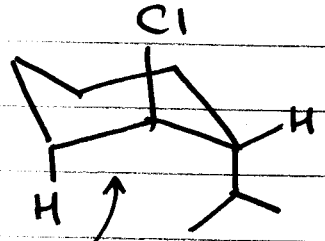
more substituted

also antiperiplanar → 

less substituted

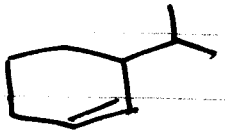
- trans

⇌



most stable chair (NO Hs ANTI-PERIPLANAR to Cl)

ONLY 1H IS ANTIPERIPLANAR

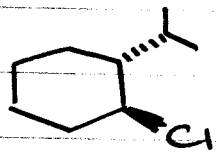
→ 

(reacts thru less stable chair)

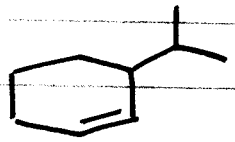
(4) E1|E2 Summary

ALKYL HALIDE	E1	E2
METHYL	ELIMINATION IMPOSSIBLE	
1° (RCH_2X)	DOES NOT HAPPEN (1° C+)	FAVORED ELIMINATION MODE
2° (R_2CHX)	(H_2O/ROH) WEAK BASES (ALLYLIC, BENZYLIC SUBSTRATES)	STRONG (RO^-) BASES (HO^-)
3° (R_3C-X)	WEAK BASES	STRONG BASES

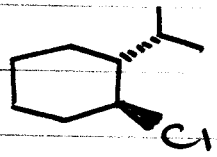
- reaction conditions



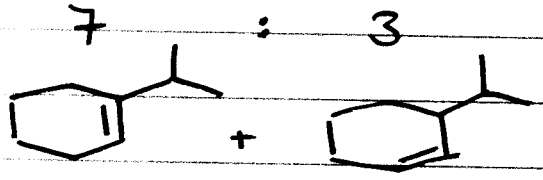
1.0 M NaOEt
Ethanol



E2 conditions

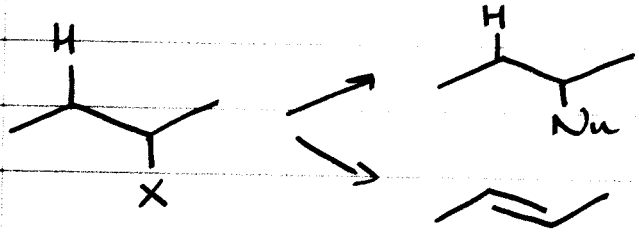


0.01 M NaOEt
80% EtOH
20% Water



E1 conditions

(5) SUBSTITUTION vs ELIMINATION



SUBSTITUTION

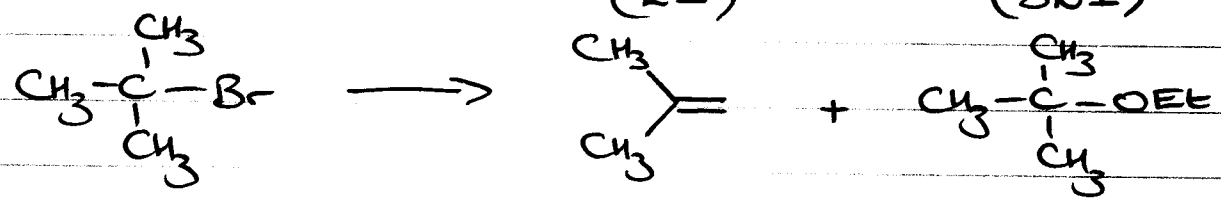
ELIMINATION

(i) S_N1 vs E1

- basicity of nucleophile

STRONG BASE ⇒ E1 WEAK BASE ⇒ SN1

e.g



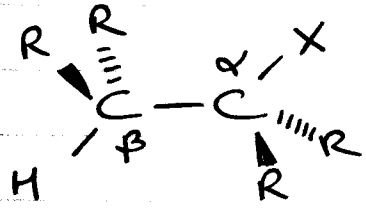
EtOH	20%	80%
EtONa/EtOH	90%*	10%

*actually E2!

Affinity for proton vs affinity for carbon

(ii) S_N2 vs E2

- structure of substrate

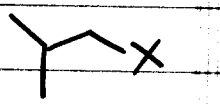
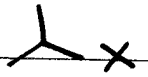
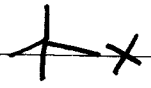


BRANCHING AT α AND/OR β SLOWS DOWN S_N2 reaction, has little effect on E2 reaction ⇒ ALSO INCREASES STABILITY OF ALKENE FORMED IN E2 reaction.

- attacking species

nucleophilicity ↑ greater SN2 : E2
basicity ↑ greater E2 : SN2

- SUMMARY

	Poor Nuc (H_2O, R-OH)	Weakly Basic Nuc (I^-, RS^-, $RCOO^-$)	(UNHINDERED) Strongly Basic Nuc (RO^-)	(HINDERED) Strongly Basic Nuc ($^tO^-$)
CH_3X	no reaction	SN2	SN2	SN2
	no reaction	SN2	SN2	E2
	no reaction	SN2	E2	E2
	SN1/E1 (slow)	SN2	E2	E2
	SN1/E1	SN1/E1	E2	E2

Again, 2° substrates BORDERLINE

attacking Nu → pka conjugate acid ≥ 11 (elimination)
→ pka conjugate acid < 11 (substitution)

Higher temperatures favor ELIMINATION reactions over SUBSTITUTION
($\Delta G = \Delta H - T\Delta S$)

LEC (23) CHEM 30A Dec 1ST

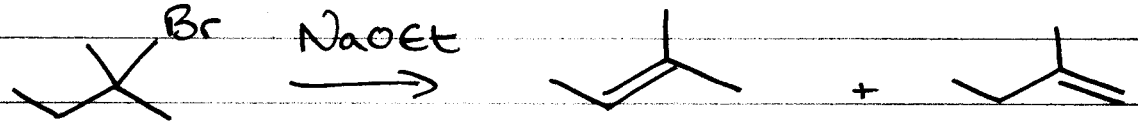
1. ZAITSEV / HOFMANN
2. SYN ELIMINATION
3. E1 / E2 SUMMARY
4. SUBSTITUTION vs ELIMINATION
5. SYNTHESIS

READ: Chapter 8

PROBLEMS: 8.42 – 8.50 (NOT 8.46 f, g, h)

---

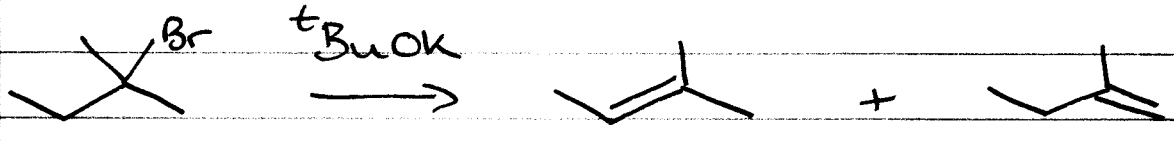
(1) ZAITSEV / HOFMANN



MAJOR 70% MINOR 30%

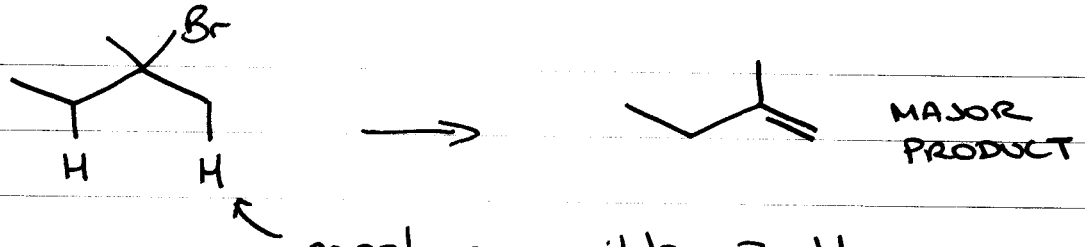
ZAITSEV → more substituted, more stable alkene

BULKIER BASES CAN GIVE OPPOSITE SELECTIVITY



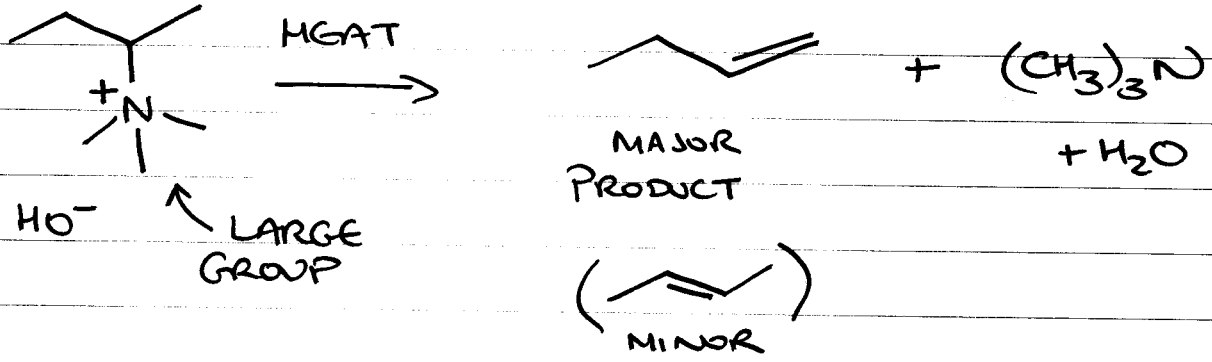
MINOR 30% MAJOR 70%

HOFMANN → least substituted alkene preferred

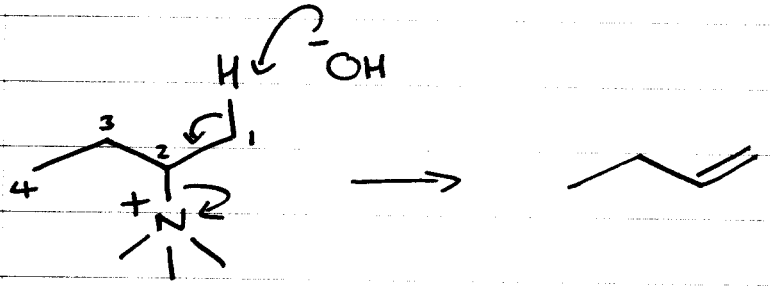


most accesible β-H

- Common reaction with quaternary ammonium salts

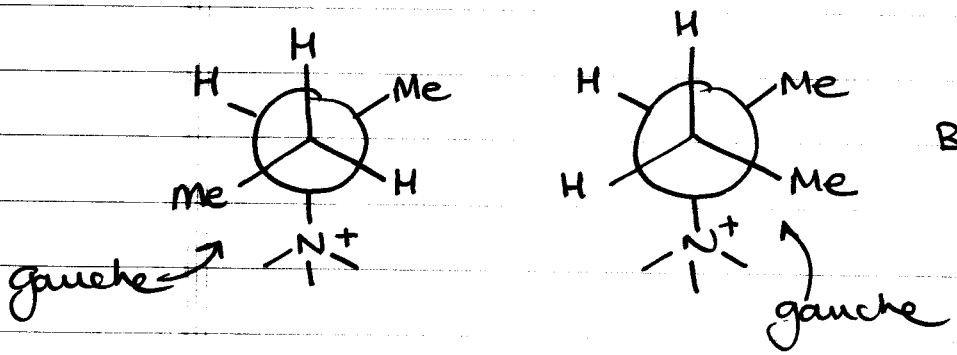


PROCEEDS w/ ANTISTEREOSPECIFICITY



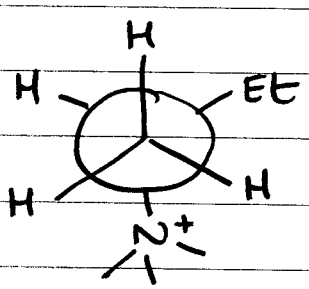
Consider NEWMAN PROJECTIONS

3 → 2 or 3 → 2



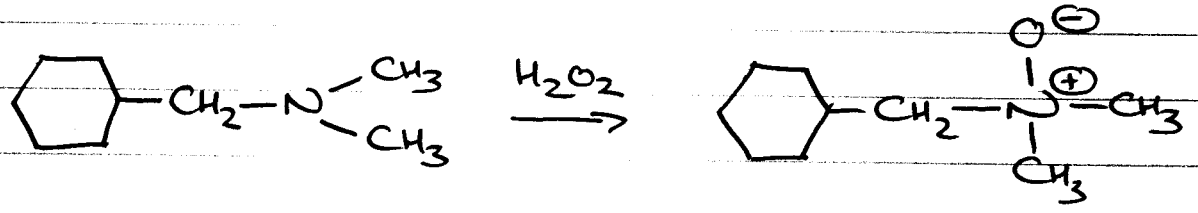
BUT

1 → 2



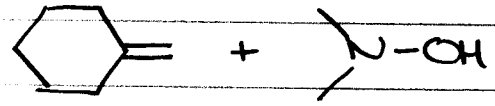
- also some electronic effects with AMMONIUM ION leaving groups

② SYN ELIMINATION
- cope elimination

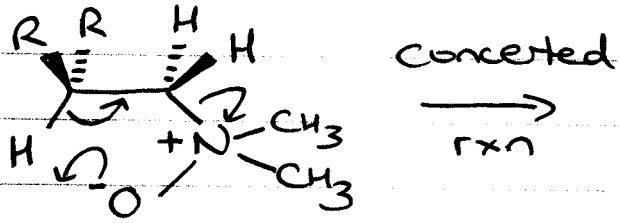


N-OXIDE

↓ HEAT



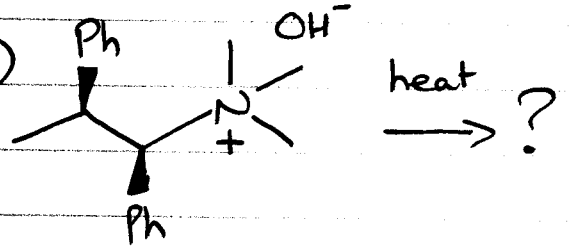
mechanism:



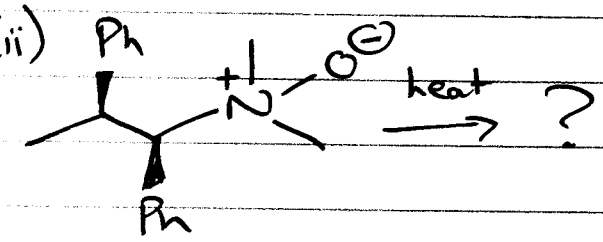
SYN

SO, FIGURE OUT THE PRODUCTS OF THESE RXNS

(i)



(ii)



(3) E1/E2 SUMMARY & (4) SUBSTITUTION VS ELIMINATION

See pages 6 thru 8 from LEC (22)

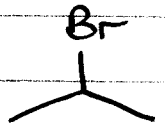
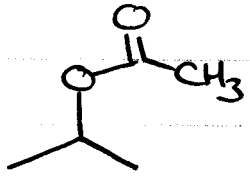
-examples

1°  $\xrightarrow[DMSO]{NaCN}$  S_N2

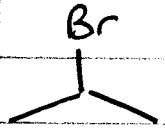
(CN^-, RS^-, NH_3, Br^-, I^-) good nucleophiles

 $\xrightarrow[{}^tBuOH]{+OK}$  E2

strong-hindered bases

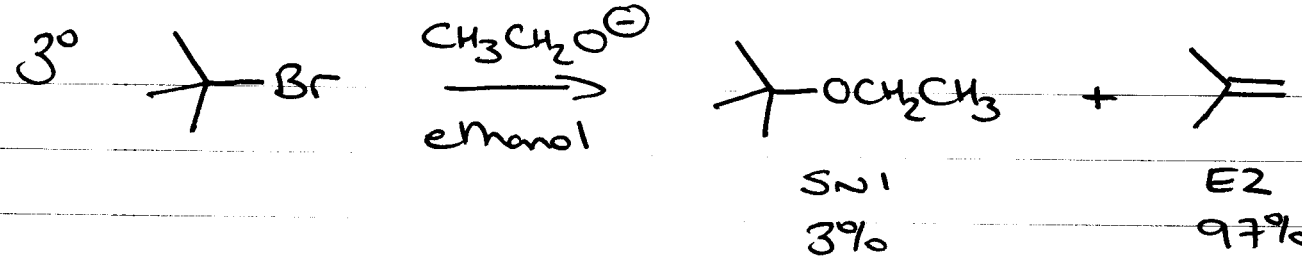
2°  $\xrightarrow[\text{(weak base)}]{CH_3\overset{O}{\overset{\|}{C}}-O^{\ominus}}$  + 

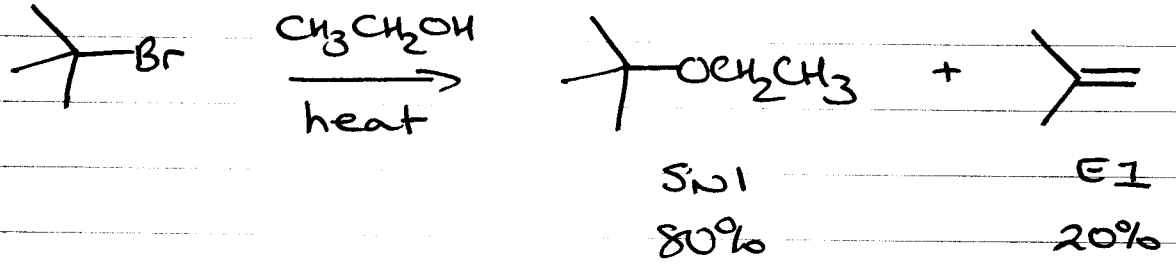
S_N2 100% E2 0%

 $\xrightarrow[\text{(strong base)}]{CH_3CH_2O^{\ominus}}$  + 

S_N2 20% E2 80%

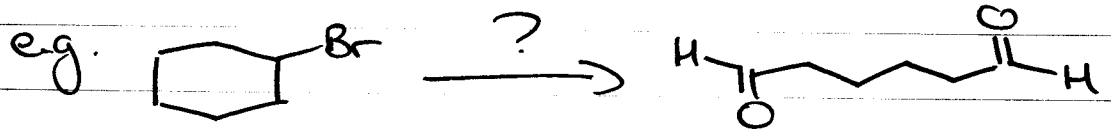
2° BENZYLIC/ALLYLIC SUBSTRATES CAN DO S_N1/E1 with weakly basic NUCLEOPHILES IN POLAR PROTIC SOLVENTS





(5) SYNTHESIS

- sequences of reactions

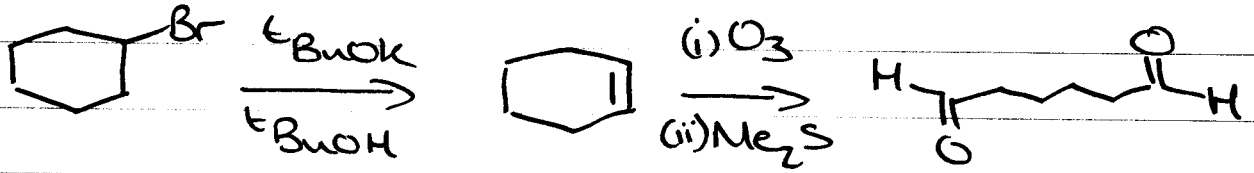


usually told if you need more than one step - and here you do.

RETROSYNTHESIS (work backwards)

Retrosynthesis arrows

So, forward synthesis:



LEC (24) CHEM 30A Dec 3rd

(1) S_N vs E
(2) SYNTHESIS
(3) HALOALKANES
(4) PREPARATION

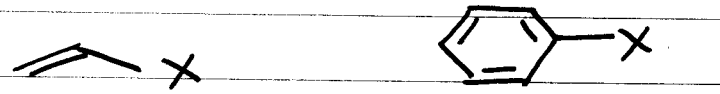
READ 7.1 – 7.6
PROBLEMS 7.1 – 7.3

---

(1) S_N vs E
(2) SYNTHESIS
} Pages 4 & 5 from Lec (23)

(3) HALOALKANES

halogens F, Cl, Br, I



alkyl halide vinylic halide aryl halide

- read through naming rules

POLARITY & BOILING POINT

- electronegativity
- bond length
- polarisability

	EN of X	C–X (pm)	DIPOLE MOMENT (μ)
CH_3F	4.0 ↑	139 ↓	1.85 D
CH_3Cl	3.0	178	1.87 D
CH_3Br	2.8	193	1.81 D
CH_3I	2.5	214	1.62 D
	N	N	

- boiling points increase

R–X	H <	F <	Cl <	Br <	I	
e.g CH_3CH_2–	-89	-37	13	38	72	°C

polarisability (DISPERSION FORCES)

BOND LENGTHS & STRENGTHS

Strength of bonds → BOND DISSOCIATION ENERGIES (BDE)

$$A\!-\!B \xrightarrow[\text{CLEAVAGE}]{\text{HOMOLYTIC}} A\cdot + B\cdot \quad \text{(RADICALS)}$$

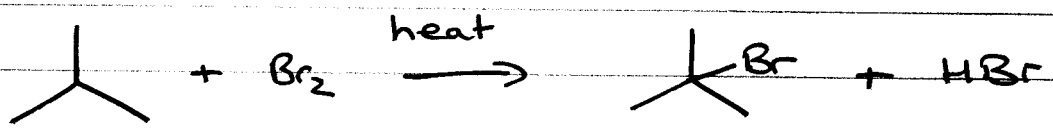
	LENGTH pm	BDE (Kcal/mol)
C–H	109	90–100
C–F	142	105
C–Cl	178	80
C–Br	193	65
C–I	214	50

(4) PREPARATION

ALKANE + X_2 $\xrightarrow[\text{or LIGHT}]{\text{HEAT}}$ HALOALKANE + HX

(Br_2 or Cl_2) SUBSTITUTION RXN

e.g.



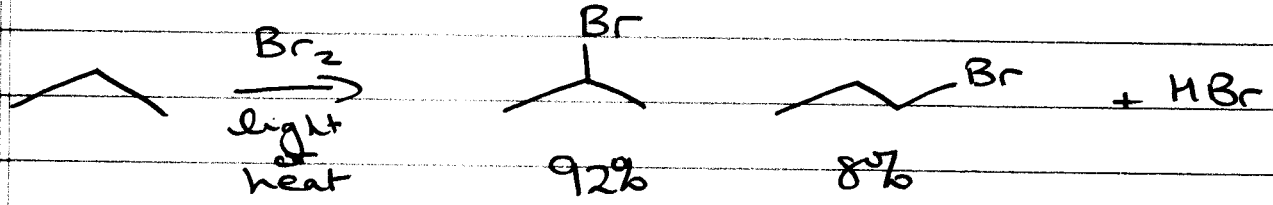
$CH_4 + Cl_2 \xrightarrow[rt]{\text{DARK}}$ NO REACTION

$CH_4 + Cl_2 \xrightarrow{\text{heat}} CH_3Cl + HCl$ $\quad \Delta H = -24$ kcal/mol

Reaction continues:

$CH_3Cl \xrightarrow[\text{heat}]{Cl_2} CH_2Cl_2 \xrightarrow[\text{heat}]{Cl_2} CHCl_3 \xrightarrow[\text{heat}]{Cl_2} CCl_4$

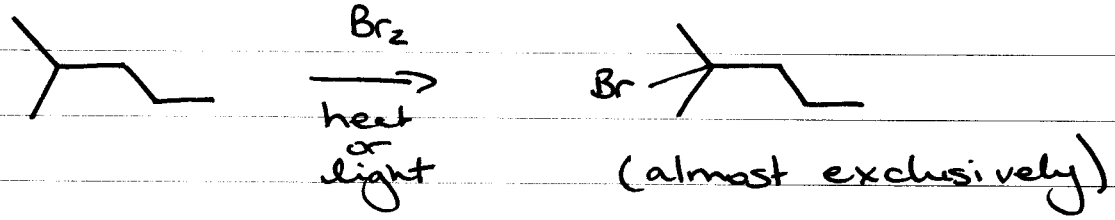
- REGIOSELECTIVITY



SUB OF 2° H FAVORED OVER 1°

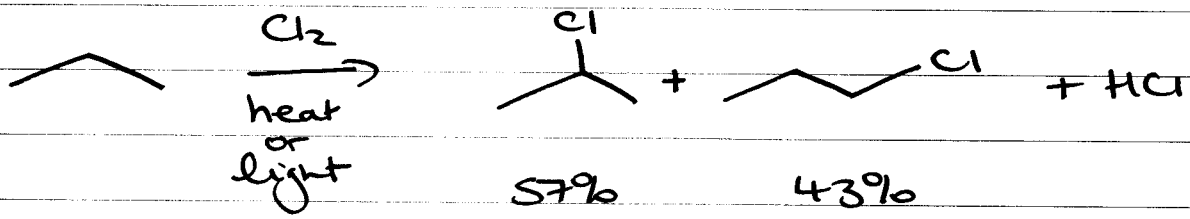
ALSO 3° FAVORED OVER 2°...

So/



(almost exclusively)

- Regioselectivity is not so pronounced for CHLORINATION

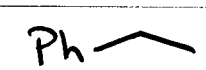
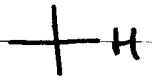
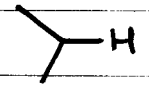


57% 43%

$3^\circ / 2^\circ / 1^\circ$ 1600 : 80 : 1 Br

5 : 4 : 1 Cl

ENERGETICS

C–H BOND		BDE (kcal/mol)
	(ALLYL)	86
	(BENZYL)	88
	(^{t}BUTYL)	93
	(^{i}PROPYL)	96
	(ETHYL)	100
CH_3–H	(METHYL)	105
	(VINYL)	106

RADICAL STABILITY ↑

So, for

	CH_4	+	Cl_2	$\longrightarrow$	CH_3Cl	+	H–Cl
BDE	105		59		−85		−103

164 + −188

= −24 kcal/mol

(EXOTHERMIC REACTION)

LEC (25) CHEM 30A Dec 6th

1. RADICAL MECHANISMS
2. HAMMOND POSTULATE
3. RADICAL STRUCTURE
4. RADICAL STABILITY
5. ALLYLIC HALOGENATION

WEDS
- QUIZ
- EVALS

FRIDAY
- WRAP UP

READ - Ch 7

PROBLEMS: 7.4, 7.5 - 7.27

FRIDAY 17th
FINAL

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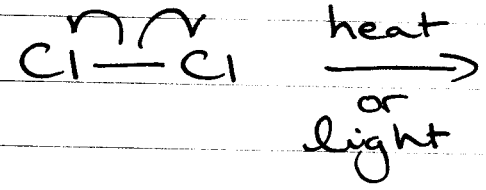
(1) RADICAL MECHANISMS

THREE STEPS: INITIATION / PROPAGATION / TERMINATION

$$CH_3CH_3 \xrightarrow{Cl_2} CH_3CH_2Cl + HCl$$

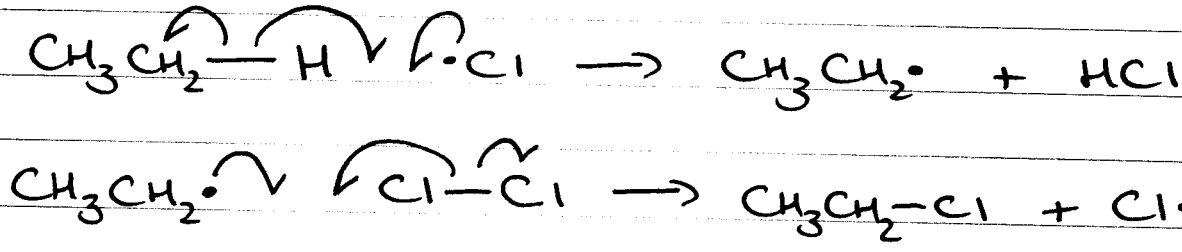
(i) CHAIN INITIATION



$Cl\!-\!Cl \xrightarrow[\text{or light}]{\text{heat}} Cl\cdot + Cl\cdot$

CREATES RADICALS

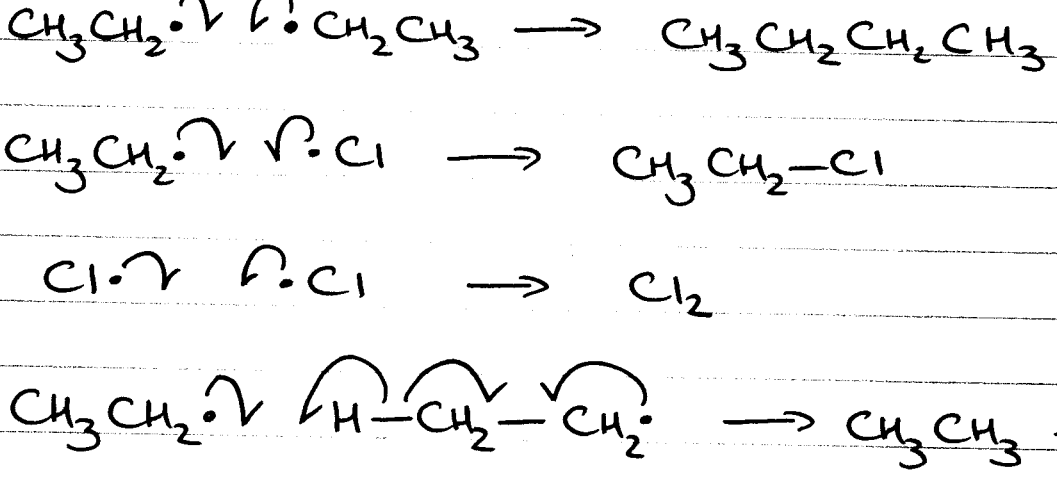
(ii) CHAIN PROPAGATION



$CH_3CH_2\cdot + Cl\!-\!Cl \longrightarrow CH_3CH_2\!-\!Cl + Cl\cdot$

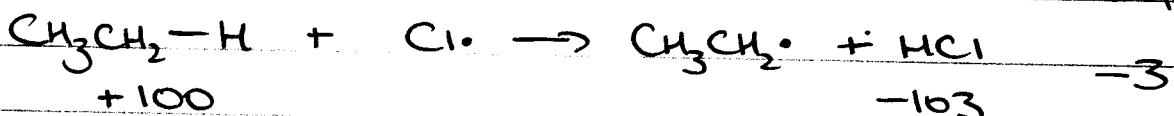
PROPAGATES RADICALS

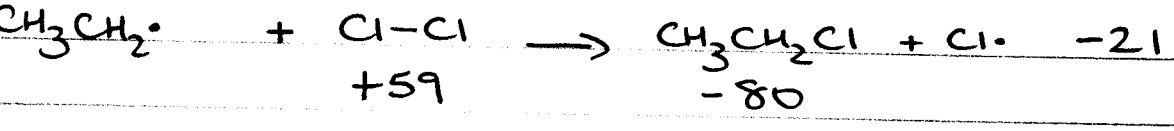
(iii) CHAIN TERMINATION



CONSUMES RADICALS

CHAIN PROPAGATION can happen many times before termination → number of cycles is called the CHAIN LENGTH



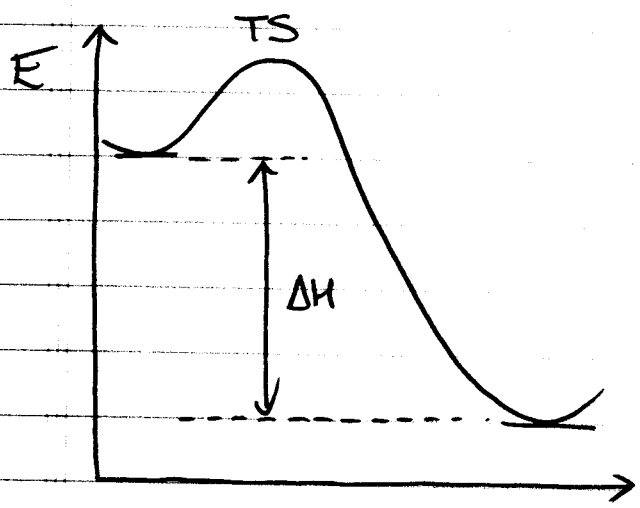


ADD TOGETHER

Gives reaction stoichiometry and heat of reaction (ΔH)

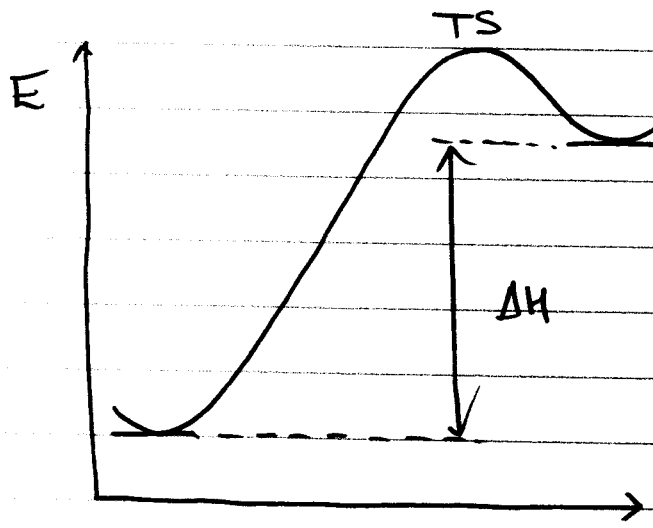
② HAMMOND POSTULATE

- A transition state will be most like the reactant, the intermediate, or the product, if it is close in energy to one of these structures



strongly exothermic reaction

TS looks like reactant

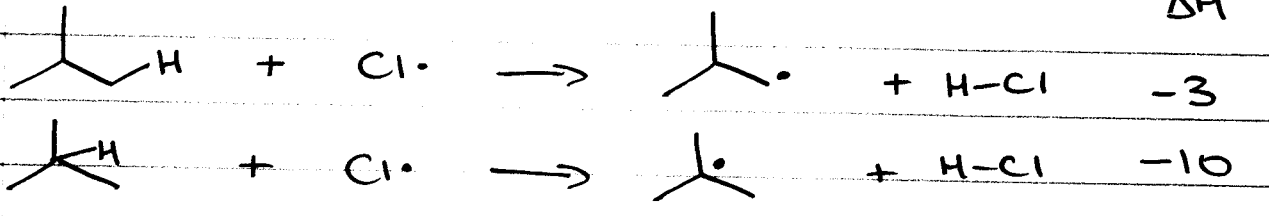


strongly endothermic reaction

TS looks like product

Consider: (ABSTRACTION of H is RDS)

CHLORINATION

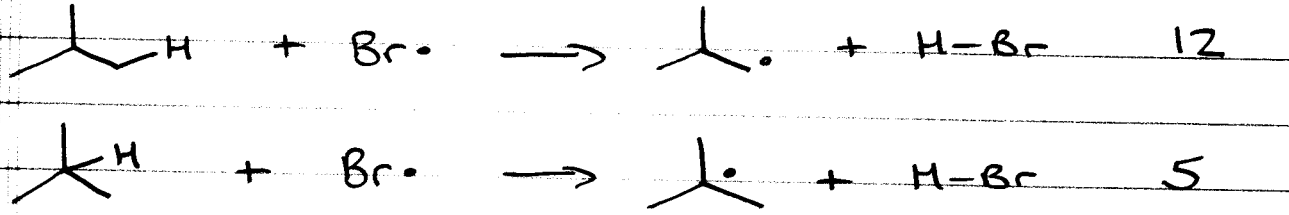


ΔH

-3

-10

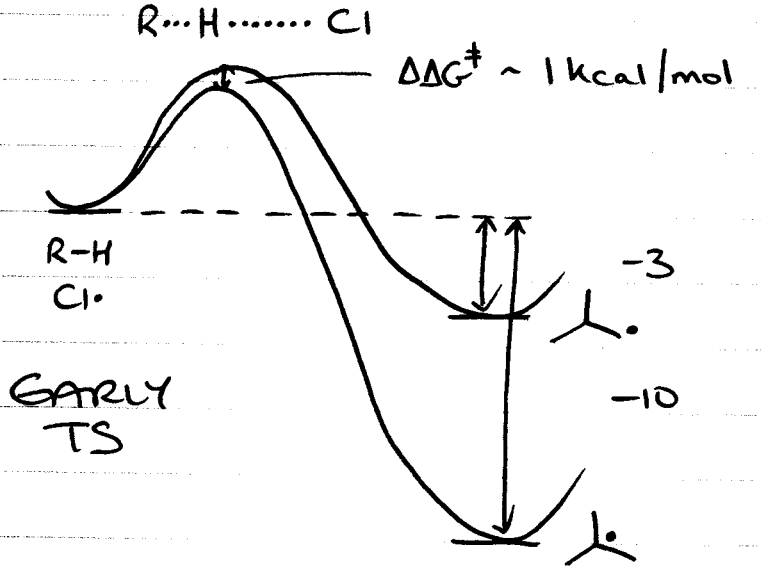
BROMINATION



12

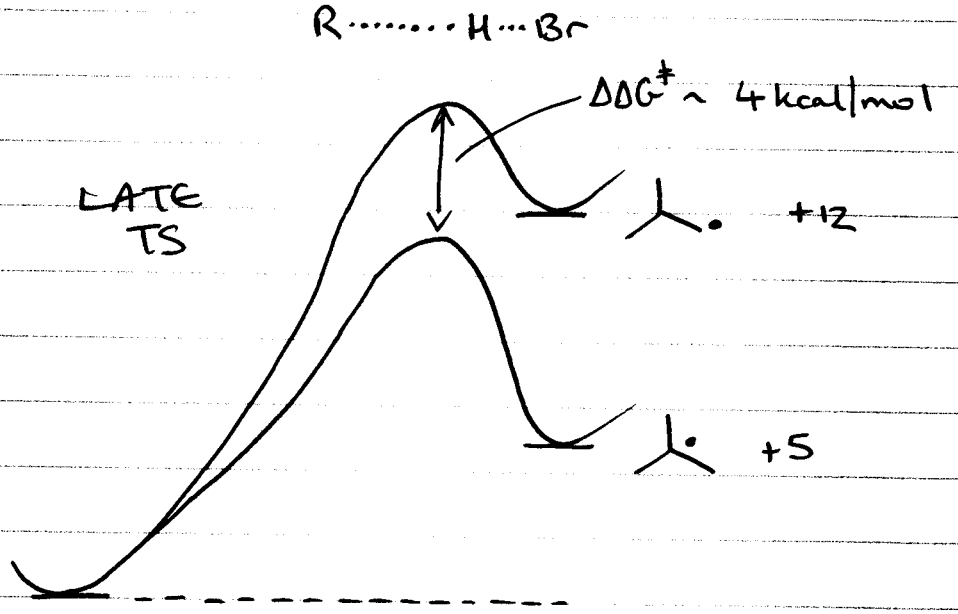
5

- CHLORINATION (exothermic)



VERY LITTLE ALKYL RADICAL CHARACTER IN TS

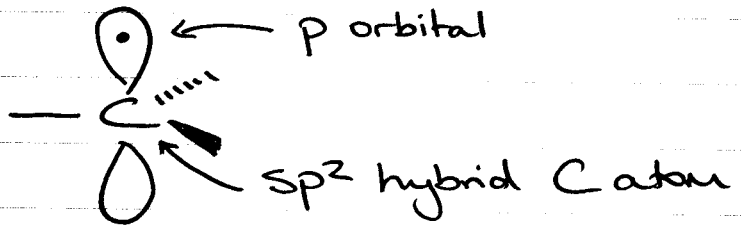
- BROMINATION (endothermic)



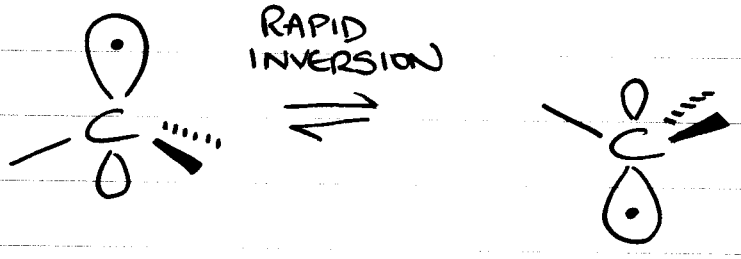
A LOT OF ALKYL RADICAL CHARACTER IN TS

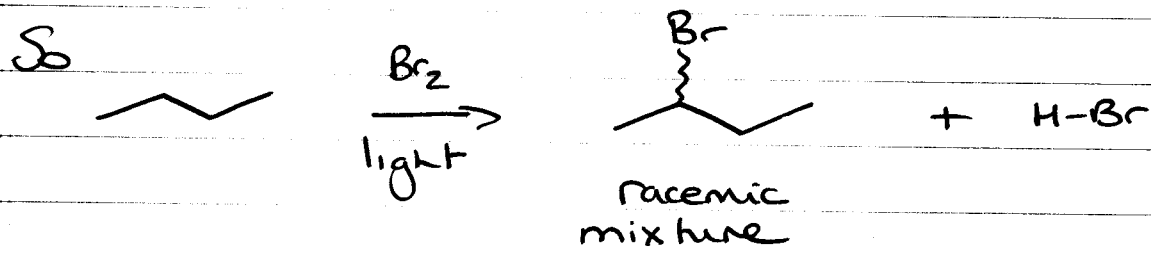
In BROMINATION, stability of radical is reflected more so in the TS than in CHLORINATION, explaining the MUCH GREATER REGIOSELECTIVITY for radical BROMINATION

③ RADICAL STRUCTURE

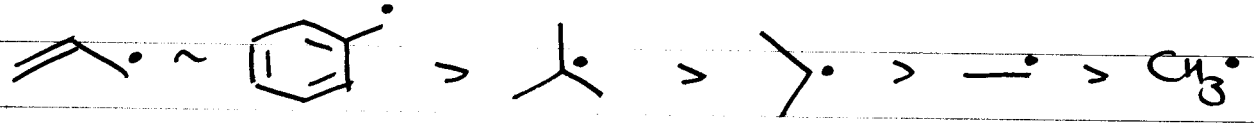


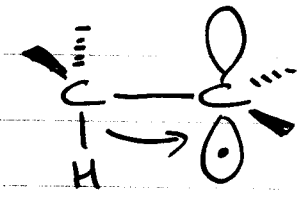
actually shallow pyramid





④ RADICAL STABILITY
(reflected in BDE values from last lecture)

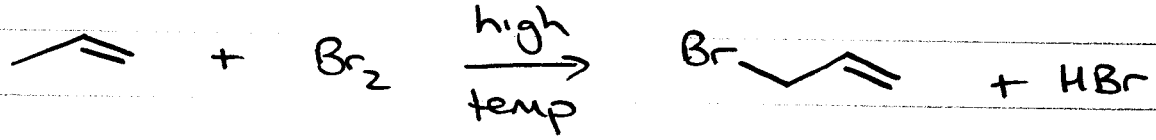




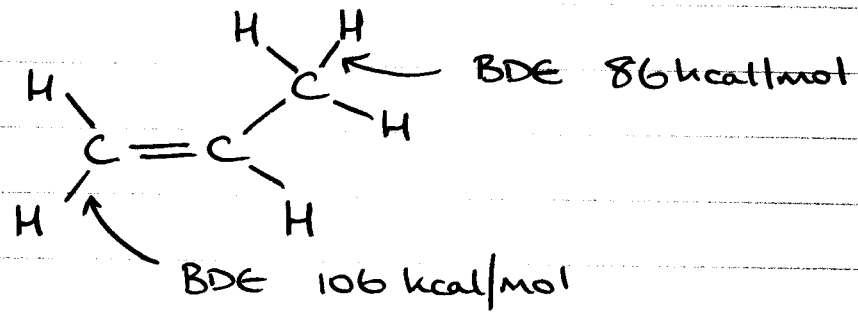
same effect as with carbocations

(5) ALLYLIC HALOGENATION

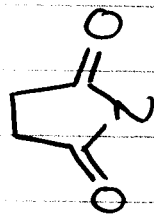
electrophilic addition



allylic substitution



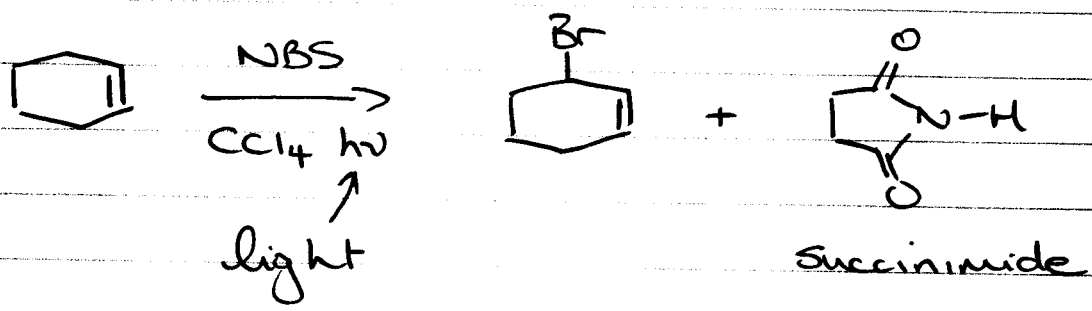
more convenient reagent



NBS

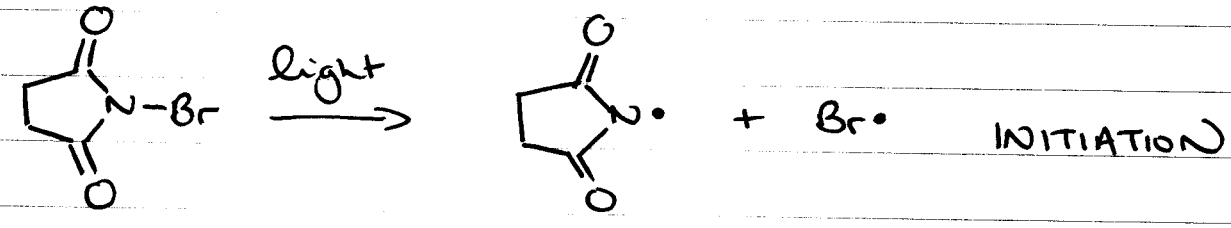
N-Bromosuccinimide

reaction can be done at room temperature

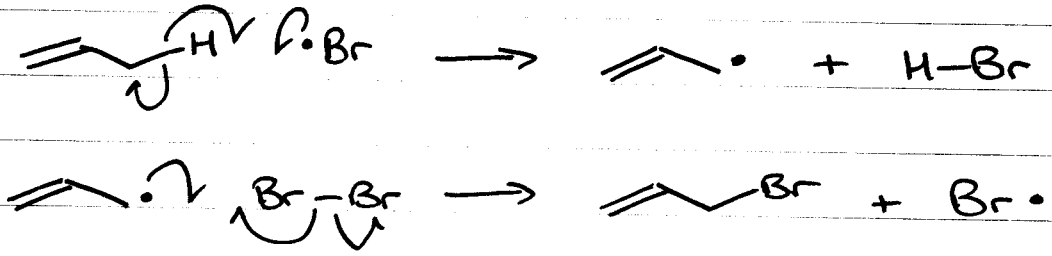


succinimide

mechanism



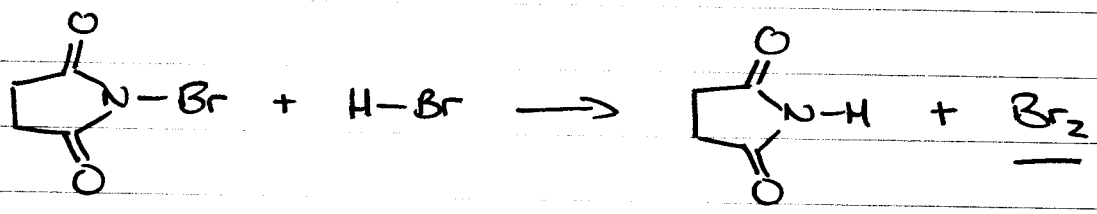
PROPAGATION



TERMINATION

- combination of 2 radical species

<u>BUT</u> where did Br_2 come from?



WHY DOES Br_2 not do electrophic addition?

- LOW CONC
- RADICAL REACTIONS are MUCH FASTER