LEC (1) CHEM 30A Jan 7th

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

HMK: READ CH1 sections 1–1.4
PROBLEMS 1.1–1.5, 1.19–1.22

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(1) Me

- Office 3077D YOUNG HALL

- cantrill@chem.ucla.edu

WEBSITE –

www.chem.ucla.edu/~cantrill/teaching.htm

↳ - Lecture notes
- Announcements
- Handouts
- Blank Exams + Keys

PREVIOUS QUARTER STUFF

- Questions OK in class ⇒ ENCOURAGE YOU TO COME TO CLASS

- ENGLISH ENGLISH
26th LETTER, 13th ELEMENT, FOOTBALL

MODEL KITS - May be useful

TAs

Mike and Rob

Discussion Sections begin MONDAY next week
↳ times/locations on WEBSITE

All office hours in Young HALL 3077F
- begin on MONDAY
↳ times/locations on WEBSITE

TEXTBOOK

Brown & Foote 3rd Edition
- HMK/Reading assignments

EXAMS

Times/locations in SYLLABUS

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

FINAL is COMPREHENSIVE

rules: see syllabus

→ PENCIL = NO REGRADE etc.

CHEATING

Don't even think about it...

SYLLABUS

IMPACTED CLASS

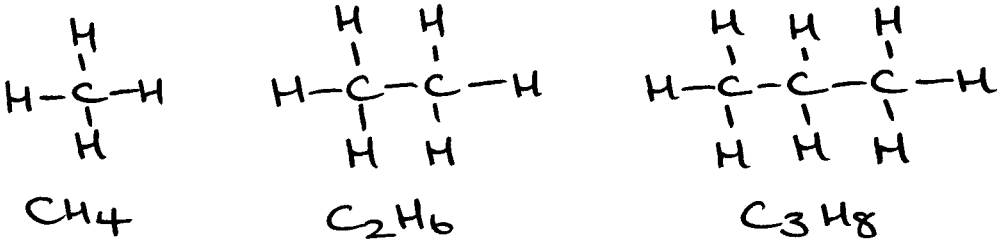
Tentative, and READ IT.

(2) WHAT? — ORGANIC CHEMISTRY

ORGANIC => CHEMISTRY OF COMPOUNDS FROM LIVING THINGS, AS OPPOSED TO INORGANIC COMPOUNDS.

→ STUDY OF COMPOUNDS CONTAINING CARBON

SIMPLEST COMPOUNDS CONTAIN CARBON AND HYDROGEN ONLY => HYDROCARBONS



CH_4 C_2H_6 C_3H_8

methane ethane propane

ALKANES

Hydrocarbons serve as a framework from which to dangle functional groups

– FUNCTIONAL GROUPS

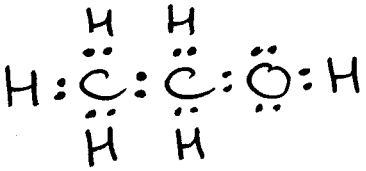
Specific combinations of atoms in precise arrangements –

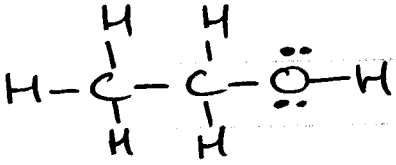
(i) DIVIDE ORGANIC COMPOUNDS INTO CLASSES
(ii) BASIS FOR NAMING
(iii) PREDICTABLE CHARACTERISTIC REACTIVITY

for example

ALCOHOLS e.g. CH_3CH_2OH ethanol

DRAWING MOLECULES

(i) 

(ii) 

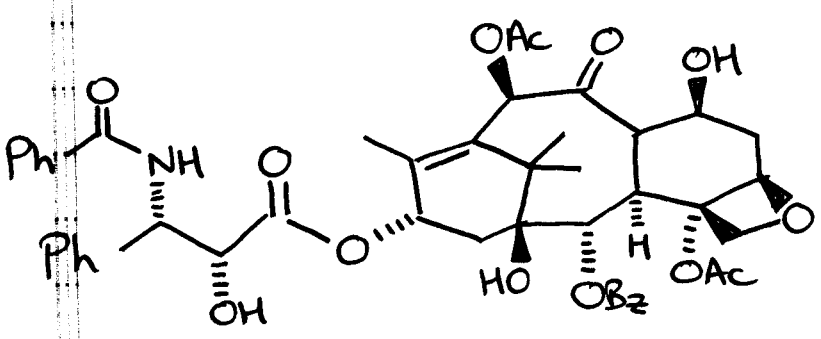
(iii) CH_3CH_2OH (iv) C_2H_5OH

(v) EtOH (vi) 

Line formula
(more on this later)

Atoms other than C, H => HETEROATOMS

e.g. O, N, S, P, F, Cl, Br, I



TAXOL

- FUNCTIONAL GROUPS
- STEREOCHEMISTRY
- COMMON ABBREVIATIONS
- LINE FORMULAE

- most promising anti-tumour 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

BUT six 100yr old trees → 1 patient
(kills trees)

SYNTHESIS (making molecules)

⇓

REACTIONS ($A + B \rightarrow C$)

⇓

MECHANISMS (how it all works)

⇓

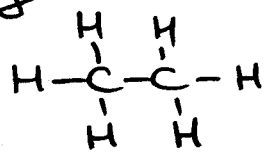
STRUCTURE & BONDING (electrons & orbitals)

THINGS YOU NEED TO KNOW

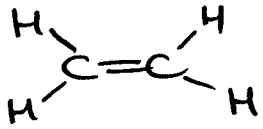
H forms 1 BOND
C forms 4 BONDS
(neutral species)

NOT AN ABSOLUTE RULE, BUT WORKS 99% of TIME

e.g.



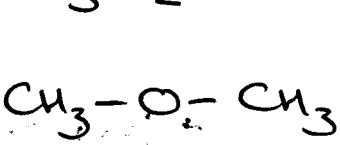
ethane
ALKANE



ethylene
ALKENE

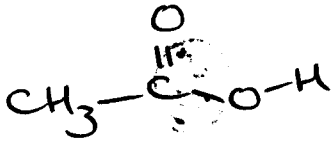
acetylene
ALKYNE

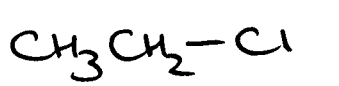
- O forms 2 BONDS
- Hal forms 1 BOND (F, Cl, Br, I)


alcohol

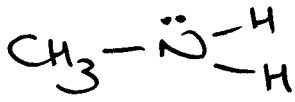

ether

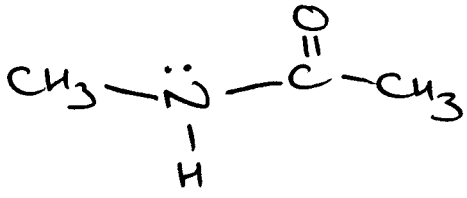
ketone


carboxylic acid


alkyl chloride

- N forms 3 BONDS


amine


amide.

- S, P ⇒ variable # of bonds.

LEC (2) CHEM 30A Jan 10th

1. CHEMICAL BONDING
2. LEWIS STRUCTURES
3. FORMAL CHARGE
4. SHAPES OF MOLECULES
5. DRAWING ORGANIC STRUCTURES

HMK Read 1.3–1.4
Problems 1.6–1.13, 1.23–1.47

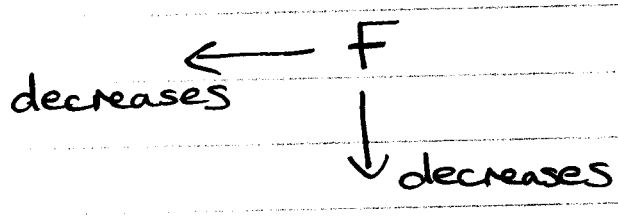
(1) CHEMICAL BONDING

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

1	2		3	4	5	6	7	8	# Valence electrons
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



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

ORGANIC CHEMISTRY – mainly concerned with COVALENT BONDS
⇓
EN Differences < 2

So, consider

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

O H (1.4) → $O^{\delta-}-H^{\delta+}$ 
3.5 2.1 polar covalent

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

EN difference < 0.5 ≅ NONPOLAR

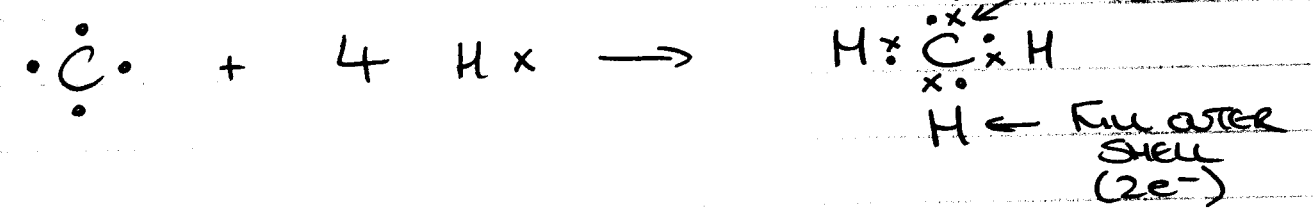
C–H
2.5 2.1

check out Table 1.5 on page 7, know values for common elements as well as trends

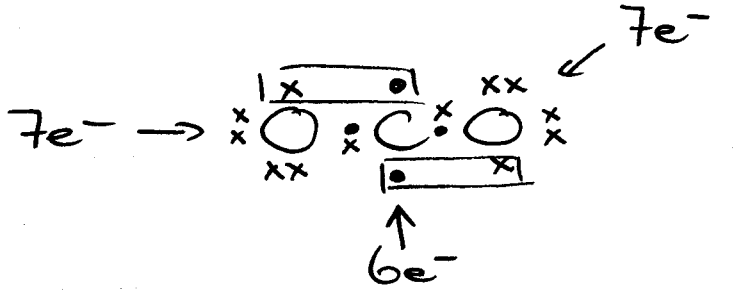
(2) LEWIS STRUCTURES

- # VALENCE electrons on each atom
- least EN element in center (not H)
- form single bonds
- fill octets (multiple bonds / charges)

a) CH_4 (methane)



b) CO_2 (carbon dioxide)



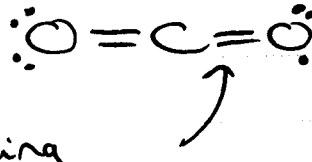
Single BONDS, but octets not full

SHARE MORE⁻ ELECTRONS

- redraw

ALL ATOMS have full octets

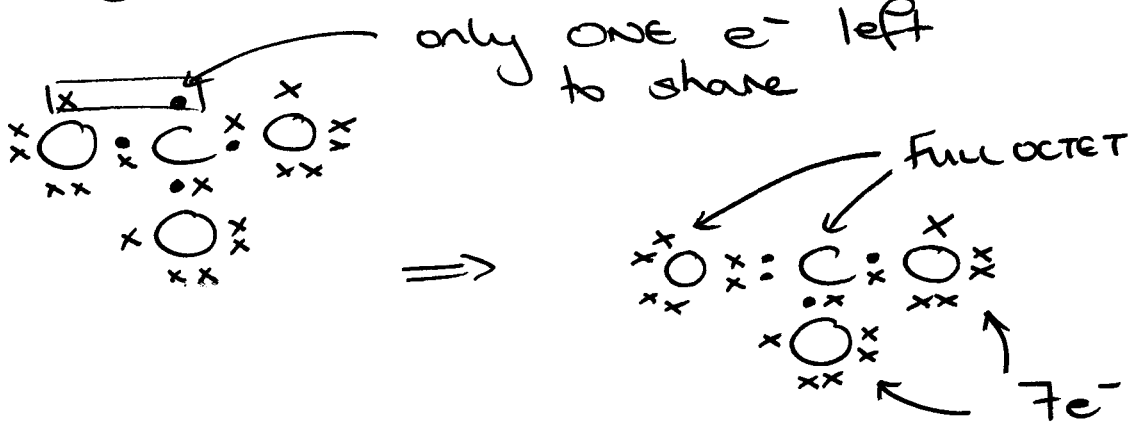
⇒



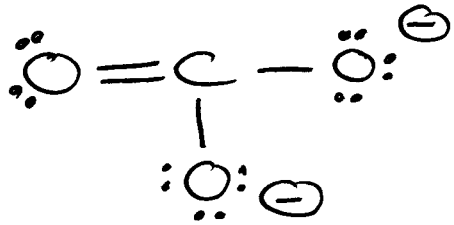
bonding pairs.

lone pair (nonbonded electron pair)

c) CO_3^{2-} (ANION)

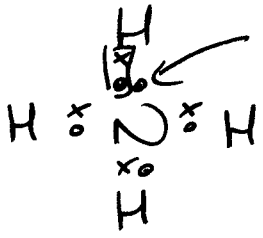


So, add in 2 electrons to fill octets. (DRAW THEM IN ABOVE)



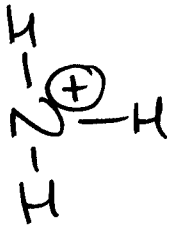
CO_3^{2-}

d) NH_4^+ (CATION)



– vidates octet rule

So, get rid of it! ⇒



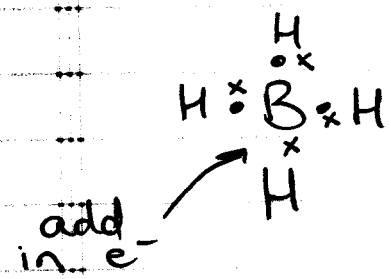
(3) FORMAL CHARGES

– Draw LEWIS structure

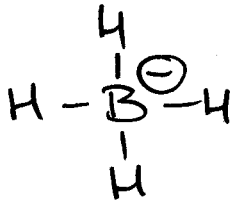
For each atom:

$$\text{FORMAL CHARGE} = \left(\begin{array}{c}\#\text{ VALENCE ELECTRONS IN ISOLATED NEUTRAL ATOM}\end{array}\right) - \left(\begin{array}{c}\#\text{ of NON BONDING ELECTRONS} \\ + \tfrac{1}{2}\#\text{ BONDING ELECTRONS}\end{array}\right)$$

a) $BH_4^{\ominus}$

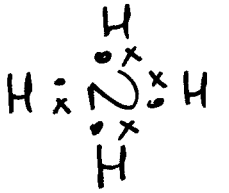


$\equiv$

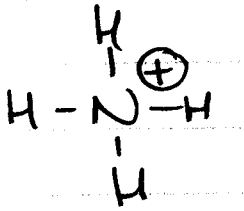


$(3 - 8/2) = \underline{\underline{-1}}$

b) NH_4^+

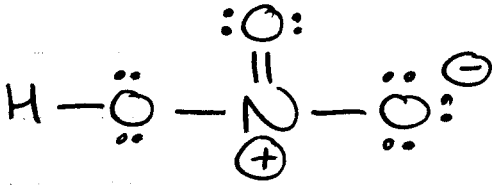


$\equiv$



$(5 - 8/4) = \underline{\underline{+1}}$

c) HNO_3 (nitric acid)

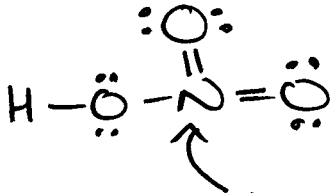


N $(5 - 8/2) = +1$

O $(6 - (6 + 2/2)) = -1$

other O's $(6 - (4 + 4/2)) = \phi$

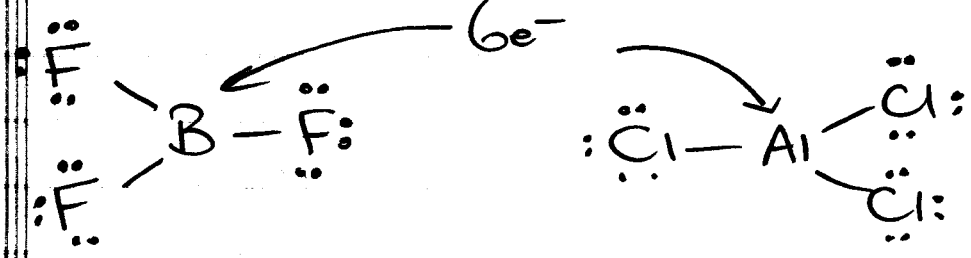
Note not



10e⁻ VIOLATES OCTET RULE

Note There are exceptions to the OCTET rule.

GROUP 3

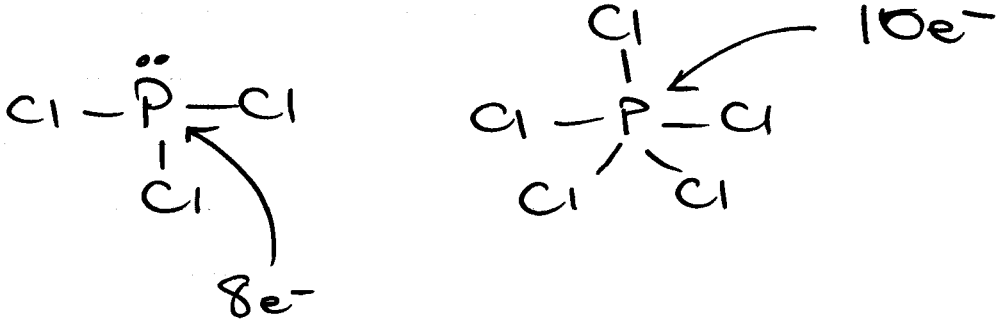


usually quite reactive species

3RD ROW ELEMENTS (P & S)

- d orbitals ⇒ EXPAND OCTET

eg. PCl_3 and PCl_5

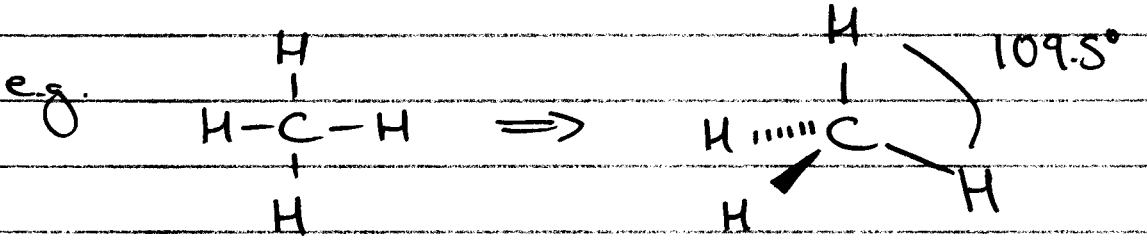


④ SHAPES of MOLECULES

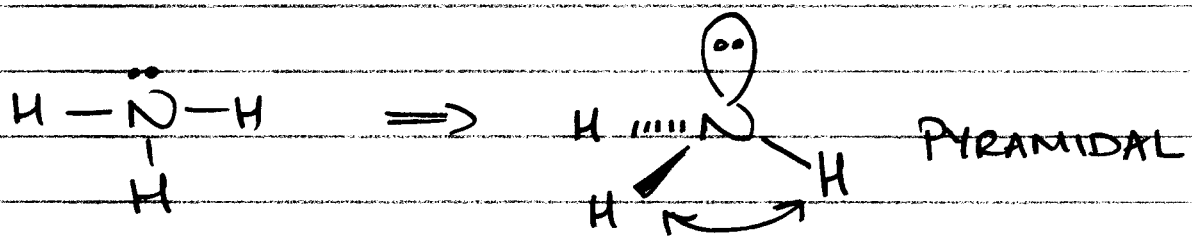
Valence Shell Electron Pair Repulsion Theory

VSEPR (Simplified model)

Geometry determined by valence shell electron pairs (BONDED & NON BONDED) arranging to minimize electrostatic repulsions

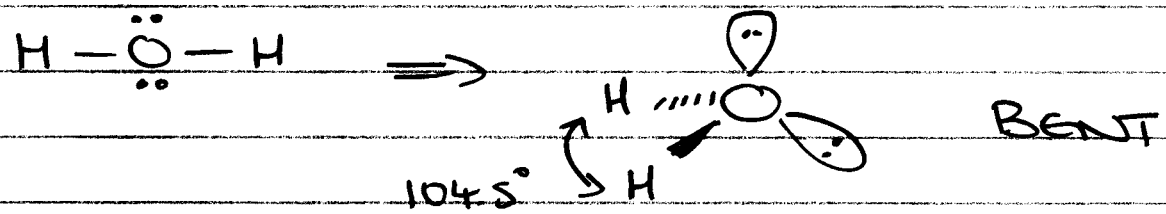
e.g. 

tetrahedral



PYRAMIDAL

(compressed)



BENT

(more compressed)

WHY?

lonepair/lone pair > lone pair/bonding pair

> bonding pair/bonding pair

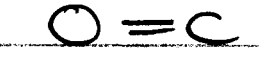
ALSO, $A \equiv B > A = B > A - B$

BASIC GEOMETRIES

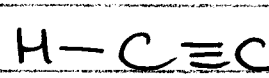
- for sake of geometry, treat multiple bonds as single bonds

- when considering the geometry of a given atom, add the number of other atoms bonded to it, to the number of lone pairs it has =>

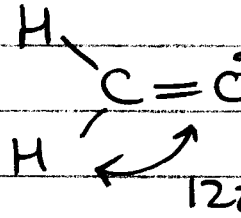
2 LINEAR
3 TRIGONAL PLANAR
4 TETRAHEDRAL
5 TRIGONAL BIPYRAMIDAL
6 OCTAHEDRAL



LINEAR

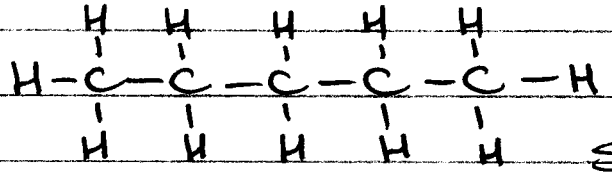


LINEAR



TRIGONAL PLANAR (BASICALLY)

(5) DRAWING ORGANIC STRUCTURES



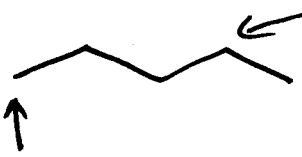
PENTANE STRUCTURAL FORMULA

- CONDENSED FORMULA

$CH_3CH_2CH_2CH_2CH_3$ or $CH_3(CH_2)_3CH_3$

- LINE FORMULA

- draw CHAINS as ZIGZAGS
- leave out any H attached to C
- draw nonbonded electrons (lone pairs)

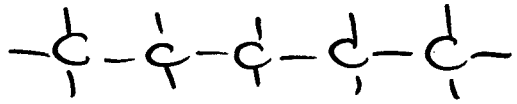


← This is a C atom with 2 Hs on it

↑ This is a C atom, it has 3 Hs on it

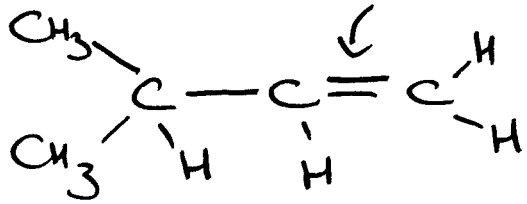
DO NOT WRITE

or

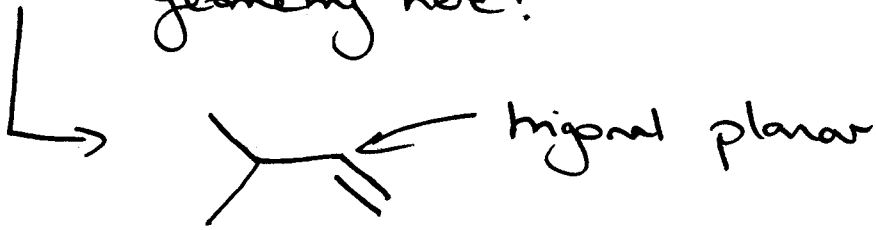


WRONG

b) $(CH_3)_2CHCHCH_2$ →



← what is the geometry here?



← trigonal planar

more examples next time.

LEC (3) CHEM 30A Jan 12th

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

HMK: Read rest of Ch 1
Problems 1.14–1.17, 1.48–1.54

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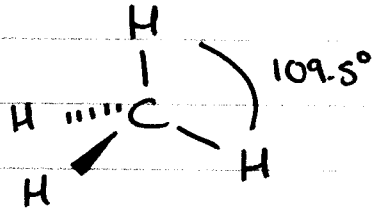
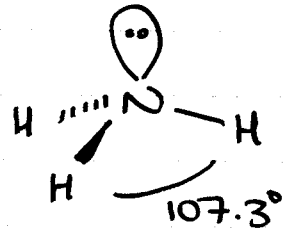
(1) SHAPES OF MOLECULES

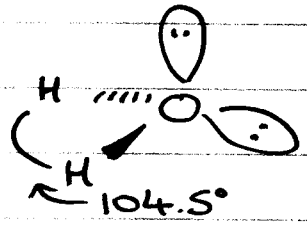
– PAIRS OF ELECTRONS IN VALENCE SHELL
(BONDED & NONBONDED – lone pairs)



TETRAHEDRAL



PYRAMIDAL



BENT

<u>BUT</u> GEOMETRY AROUND C, N, O is STILL DESCRIBED AS TETRAHEDRAL

REPULSION LP-LP > LP-BP > BP-BP

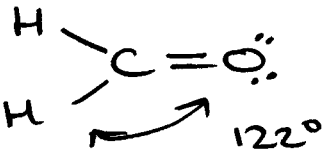
ADD # BP to LP
(or # atoms) to LP

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

ALSO:
TREAT MULTIPLE BONDS AS SINGLE BONDS

So, CO_2 $O=C=O$ LINEAR

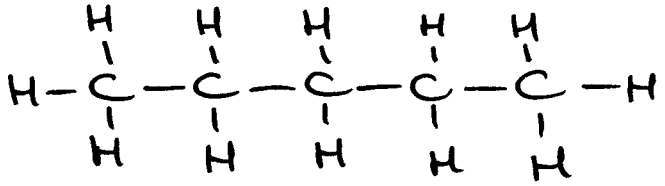
$H-C\equiv C-H$ LINEAR



TRIGONAL PLANAR

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

(2) DRAWING ORGANIC STRUCTURES



PENTANE
(structural formula)

- Condensed formula

$CH_3CH_2CH_2CH_2CH_3$ $CH_3(CH_2)_3CH_3$

- line formula

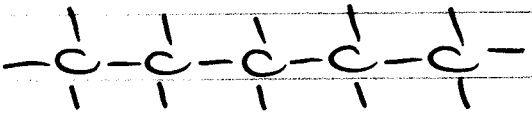
- draw chains as zigzags
- leave out H attached to C
- draw lone pairs

a) 

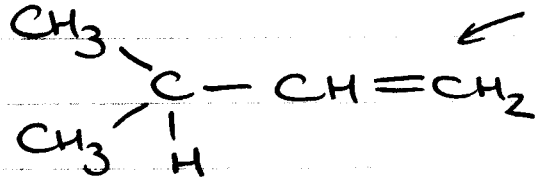
this is a C atom with 2 Hs on it

this is a C atom with 3 Hs on it

DO NOT WRITE

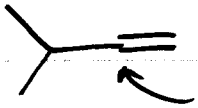
C-C-C-C-C or 

b) $(CH_3)_2CHCHCH_2$?

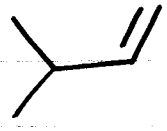


← what's missing?

maybe you would draw this:

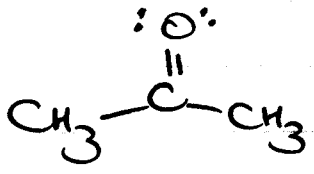
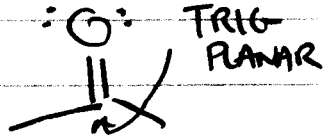


← geometry of C atom? => TRIGONAL PLANAR

So 

Try to be as true to molecular shape as possible.

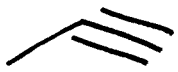
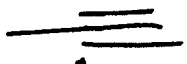
e.g.

c) $CH_3(CO)CH_3$ =>  => 

TRIG PLANAR

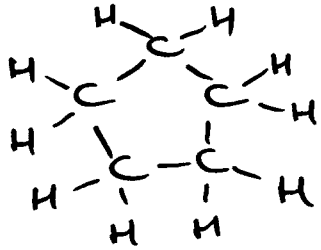
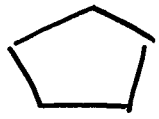
not 

d) $CH_3CCH \Rightarrow CH_3-C\equiv C-H$

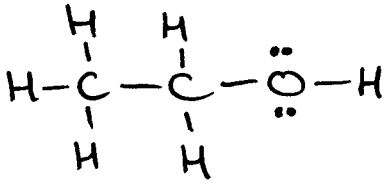
not  but 

↑ linear

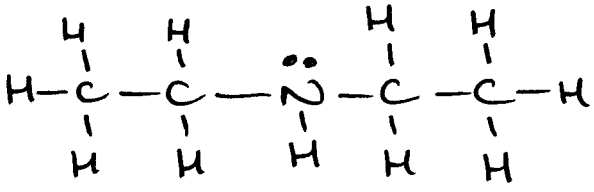
- RINGS

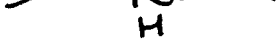
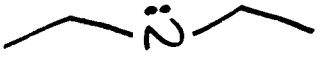
 ≡  ← each of these is a CH_2

- HETEROATOMS
(DRAW Hs on them)

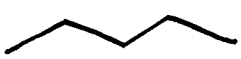


 not



 not 

- Example C_5H_{12}

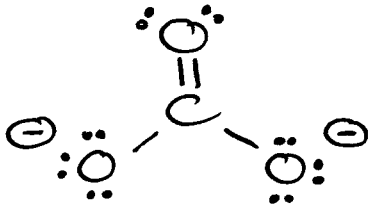
  

CONSTITUTIONAL ISOMERS

Same formula, different arrangements of atoms

③ RESONANCE

consider CO_3^{2-}

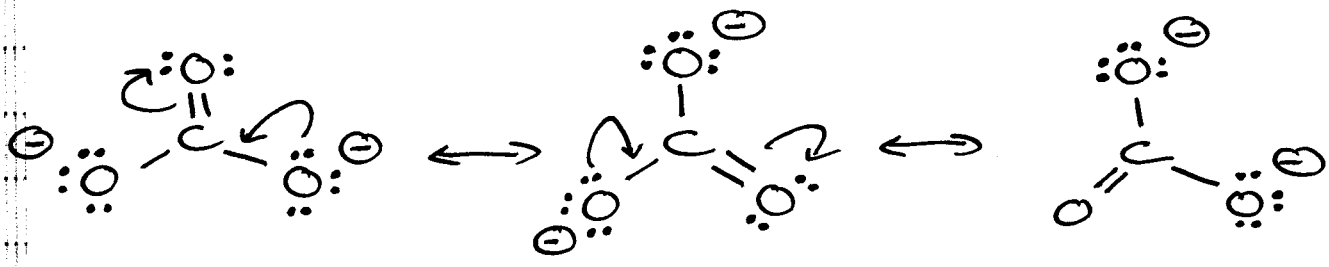


one C=O BOND
two C–O BONDS

C=O shorter/stronger bond than C–O

In CO_3^{2-}, however, all carbon/oxygen bonds are identical

WHY?



RESONANCE CONTRIBUTORS (ALL EQUIVALENT)

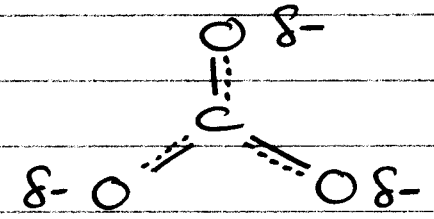
$\longleftrightarrow$ SEPARATES RESONANCE CONTRIBUTORS

ARROWS

 CURLY ARROW – movement of a pair of electrons

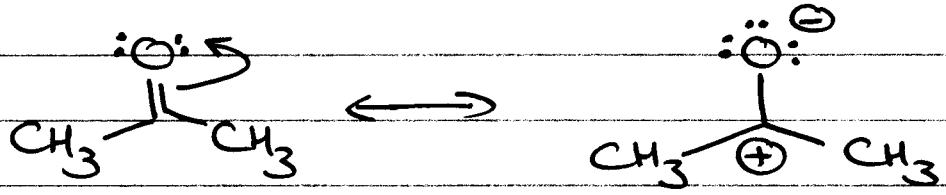
None of these contributors actually exist

actual structure is



RESONANCE HYBRID

Not all resonance contributors are necessarily equivalent, for example



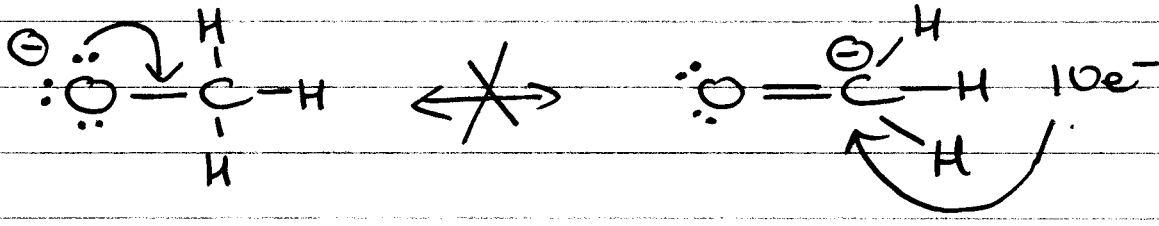
Which one of these is the most stable ?

– RULES FOR WRITING RESONANCE STRUCTURES

Do NOT

① BREAK ANY SINGLE BONDS

② VIOLATE THE OCTET RULE



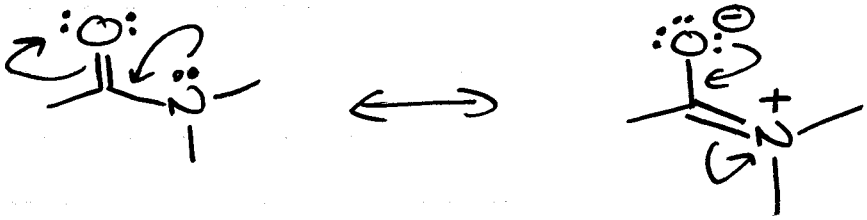
DRAWING RESONANCE STRUCTURES

Cannot break single bonds, SO we can only move electrons from double (or triple) bonds and lone pairs.

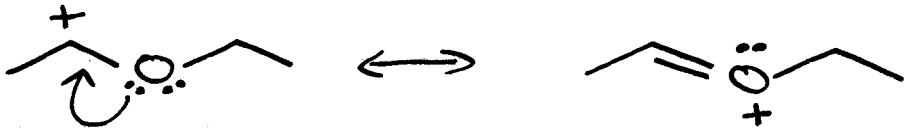
PATTERNS

(1) LONE PAIR NEXT TO π BOND (double or triple bond)

"next to" means one single bond away

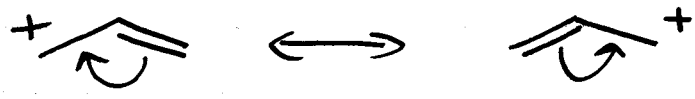


(2) LONE PAIR NEXT TO +ve CHARGE

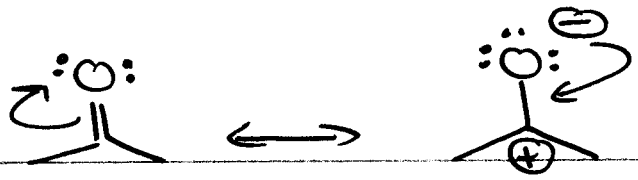


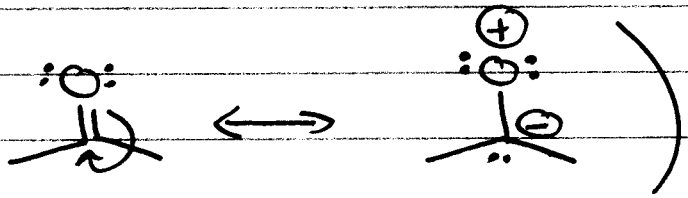
(3) π BOND NEXT TO +ve CHARGE

↷ double or triple bond

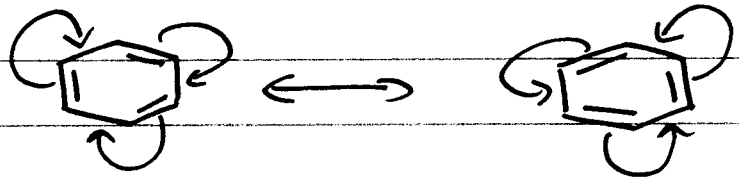


(4) π BOND BETWEEN TWO ATOMS WHERE ONE IS QUITE ELECTRONEGATIVE



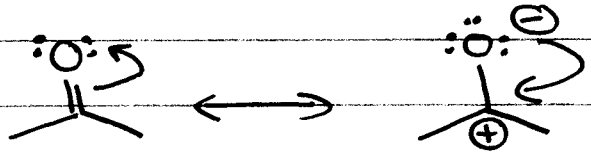
(NOT ) O is more EN than C

(5) ALTERNATING π BONDS IN A RING



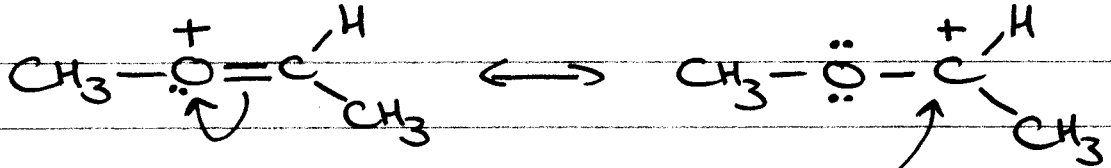
– RELATIVE IMPORTANCE OF CONTRIBUTING STRUCTURES

(1) MINIMIZE CHARGES



more significant

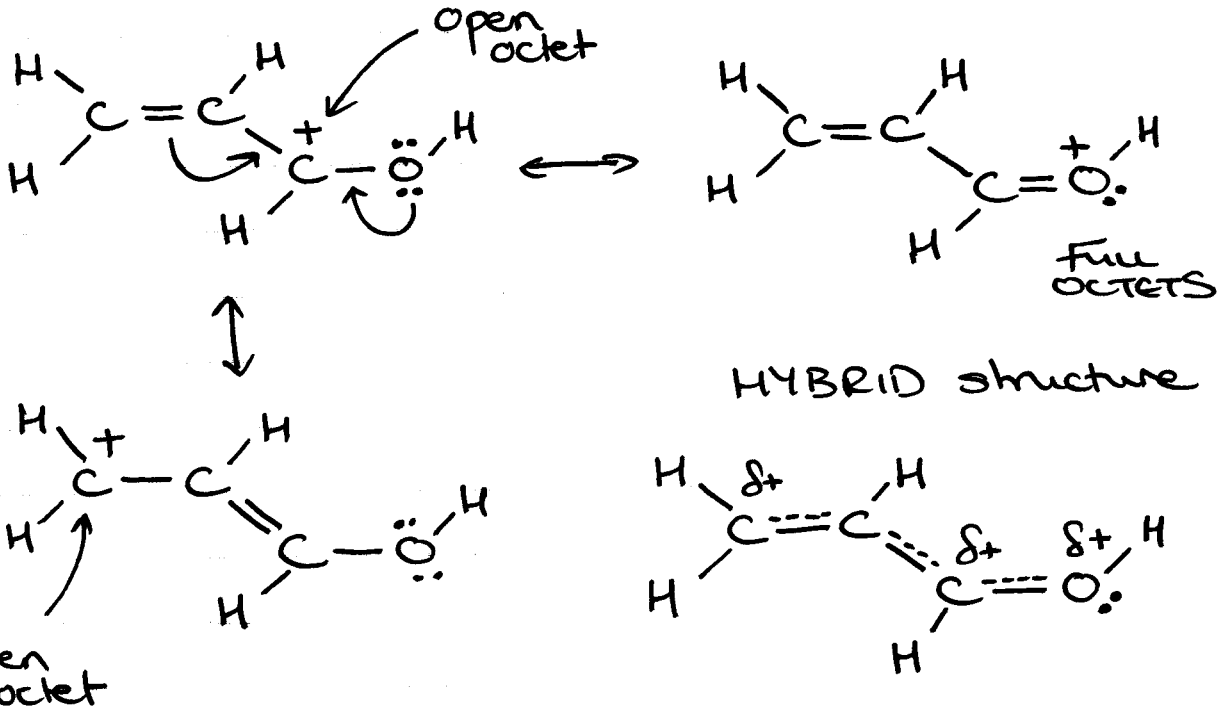
(2) MAXIMIZE OCTETS



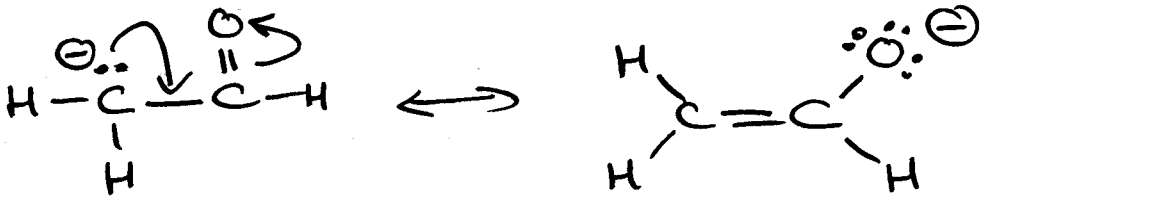
more significant

not a full octet

EXAMPLE



(3) NEGATIVE CHARGE ON MORE EN ELEMENT



next up: ATOMIC ORBITALS.

LEC (4) CHEM 30A Jan 14th

(1) RESONANCE
(2) ATOMIC ORBITALS
(3) MOLECULAR ORBITALS
(4) HYBRIDIZATION

HMK 1.18, 1.55–1.70
UCLA CLOSED ON MONDAY
QUIZ IN CLASS NEXT WEDS
OFFICE HOURS TUES 4pm

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(1) RESONANCE

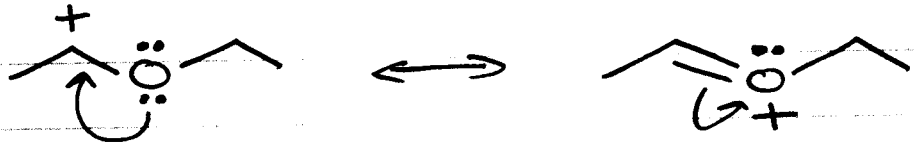
- drawing resonance structures

CANNOT BREAK SINGLE BONDS, SO WE can only move electrons from double (or triple) bonds and lone pairs

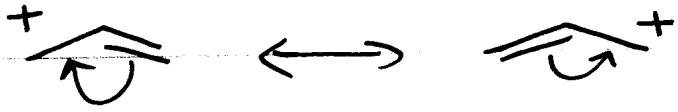
- PATTERNS

a) LONE PAIR NEXT TO π BOND ← DOUBLE/TRIPLE
('next to' means one single bond away)

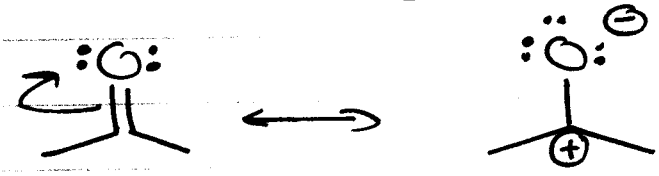
b) LONE PAIR next to +ve CHARGE



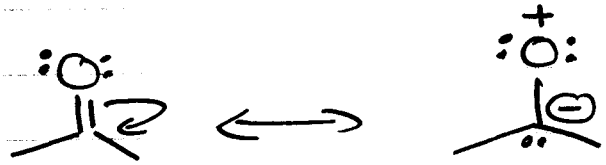
c) π BOND next to +ve CHARGE



d) π BOND between two ATOMS where one is very EN



NOT

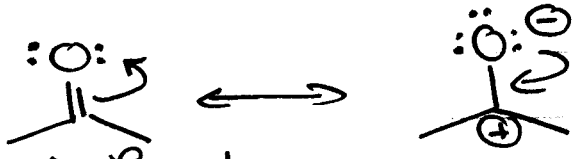


O is more EN than C

e) ALTERNATING π BONDS in a RING

– RELATIVE IMPORTANCE OF CONTRIBUTING STRUCTURES

① MINIMIZE CHARGES



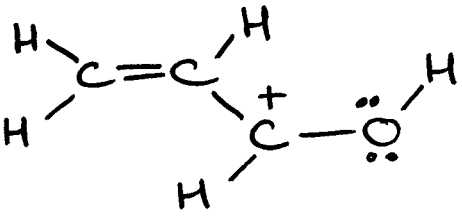
more significant

(2) MAXIMISE OCTETS

more significant

not a full octet

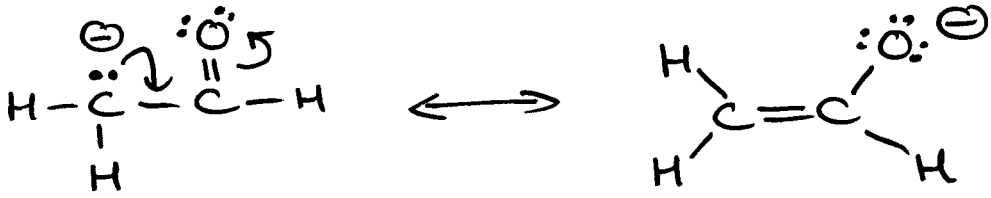
e.g.



DRAW OTHER TWO RESONANCE FORMS

- WHICH IS THE MOST SIGNIFICANT?
- WHAT IS THE STRUCTURE OF THE RESONANCE HYBRID

(3) NEGATIVE CHARGE ON MORE EN ELEMENT



more significant

(2) ATOMIC ORBITALS

Schrödinger equation

⇓

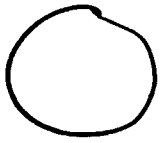
Probability distributions of electron density

⇓

Orbitals (shapes)

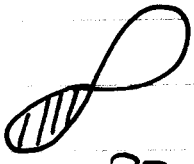
this class

s, p, d, f sharp, principal, diffuse, fundamental

1s  2s 

2p orbitals

different phases



(3) MOLECULAR ORBITALS

molecules => many atoms => many atomic orbitals

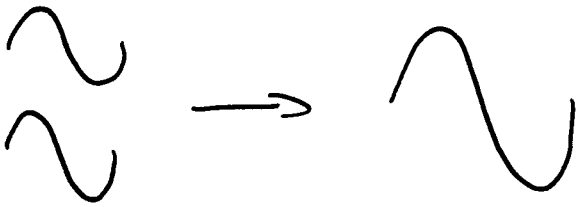
(LCAO – linear combination of atomic orbitals)

n AOs → n MOs

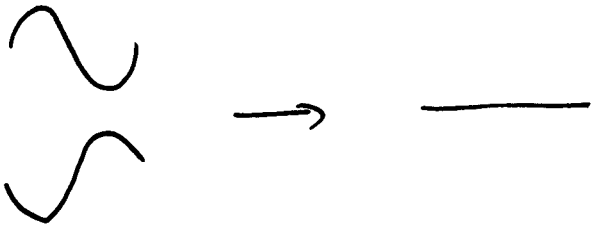
- same filling rules

AUFBAU PRINCIPLE (lowest energy first)
PAULI EXCLUSION PRINCIPLE (two e⁻, opp spin)
HUND'S RULE (don't pair until you have to)

Orbitals → wavefunctions
- combine like waves

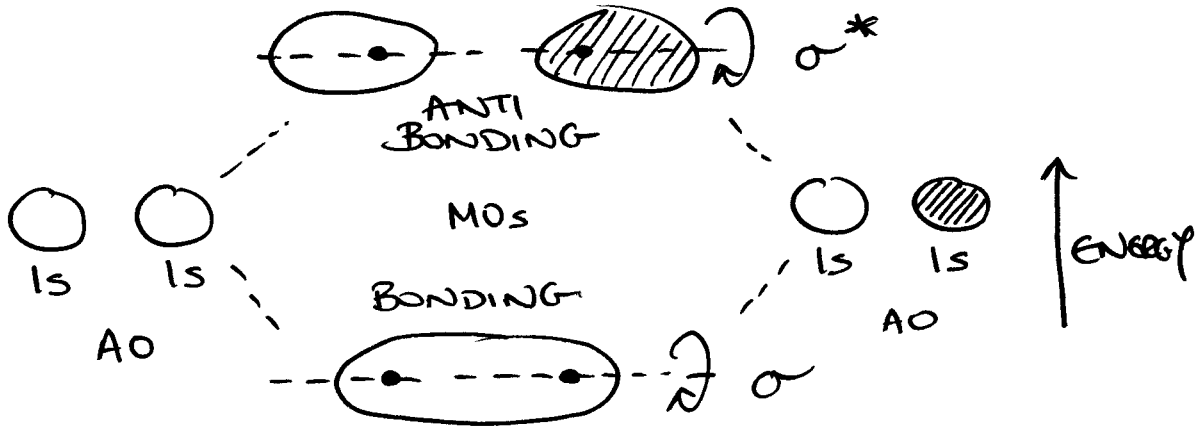


in phase (constructive)



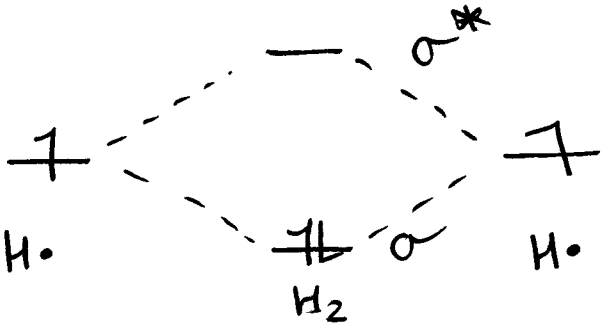
out of phase (destructive)

— s orbitals

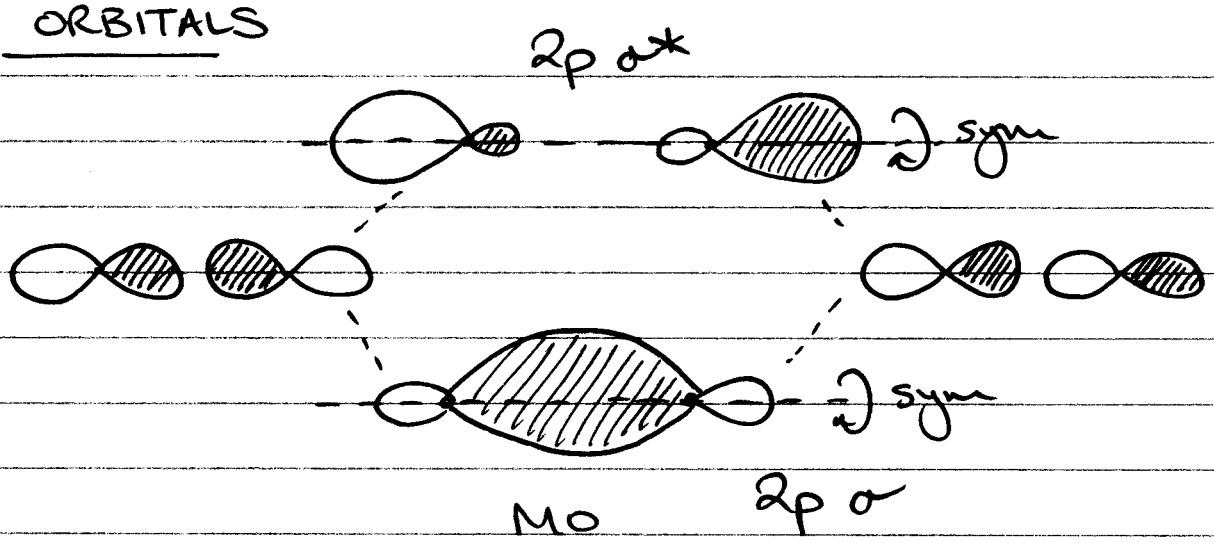


SYMMETRICAL ABOUT AXIS ⇒ σ

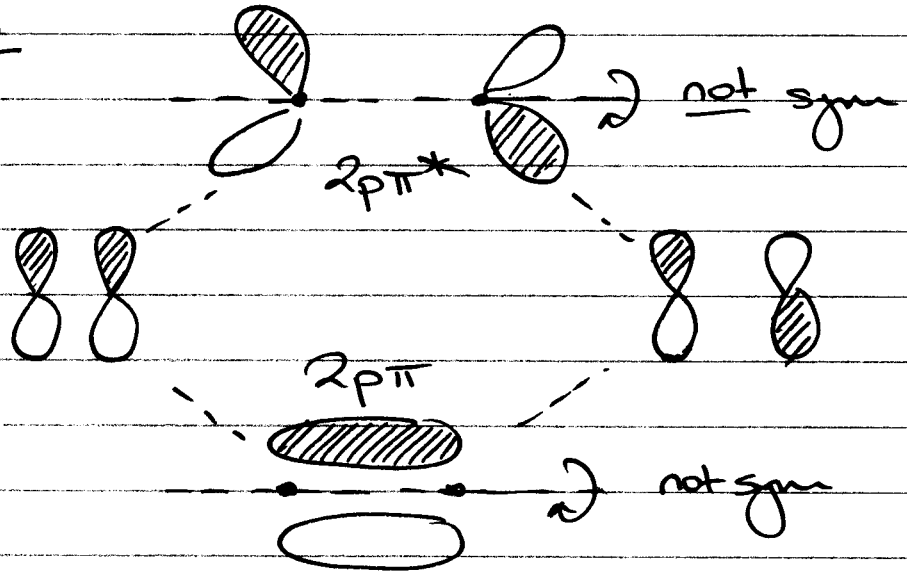
H_2



P ORBITALS



AND



σ BONDS stronger than π BONDS – MORE OVERLAP

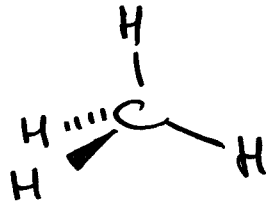
(4) HYBRIDISATION

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

$1s^2\ 2s^2\ 2p_x'\ 2p_y'\ 2p_z^{\phi}$

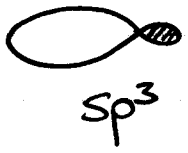
ONLY 2 UNPAIRED ELECTRONS

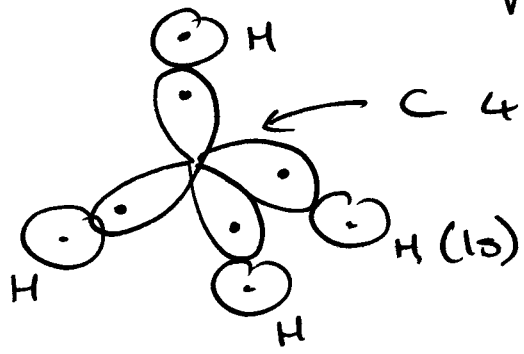
and p ORBITALS 90° apart

So, how do we explain 

HYBRID ORBITALS (PAULING)

$\underline{sp^3}$ 1 x 2s 3 x 2p ⇒ 4 sp^3 equivalent orbitals

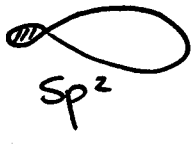


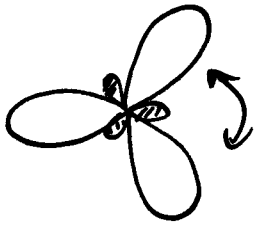


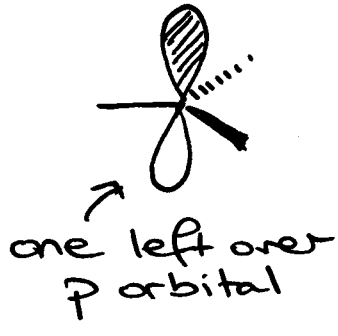
4 x 1s – 2sp^3 σ BONDS

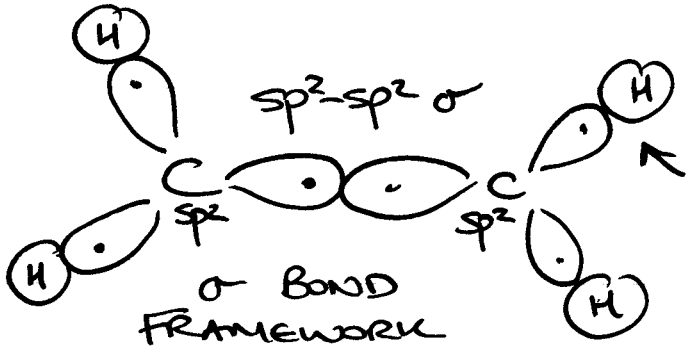
$\underline{sp^2}$ 1 x 2s and 2 x 2p

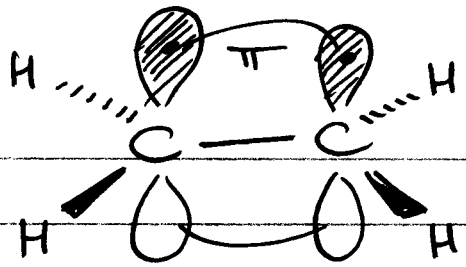
⇒ 3 x sp^2 orbitals



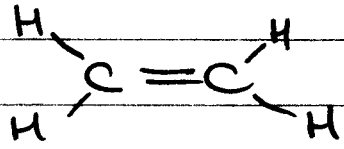




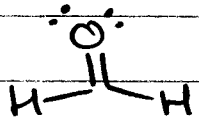


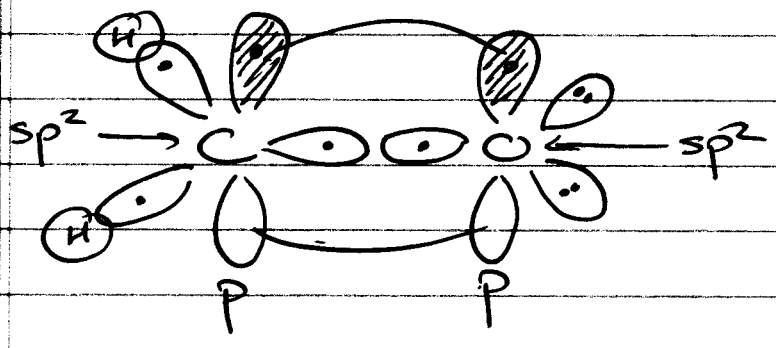


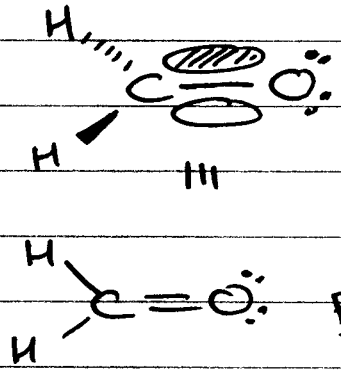
π BOND



FLAT

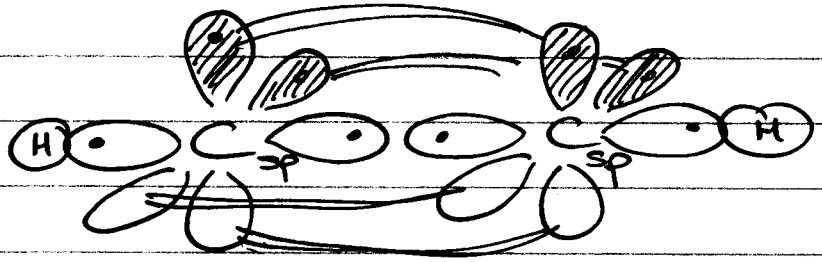






FLAT

sp 1 x 2s and 1 x 2p



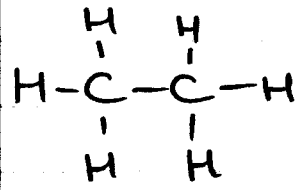
H–C≡C–H

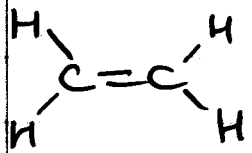
↑

1 x sp–sp σ

2 x 2p–2p π

CONSIDER





C–C
1.53 Å
88 kcal/mol

not ×2

C=C
1.34 Å
146 kcal/mol

not ×3

C≡C
1.21 Å
200 kcal/mol

C–H
sp^3 – 1s σ
1.11 Å
98 kcal/mol

C–H
sp^2 – 1s σ
1.10 Å
104 kcal/mol

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 of an atom

ADD # BONDED ATOMS TO # LONE PAIRS

4 → sp^3
3 → $3 \times sp^2 + 1 \times p$
2 → $2 \times sp + 2 \times p$

Lec (5) Chem 30 A Jan 19th

(1) HYBRIDIZATION

next time, Chapter 2

HMK: Read Ch 2
DO QUIZ AGAIN
Problems 2.1, 2.2, 2.8, 2.17-2.21, 2.24-2.26

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(1) HYBRIDIZATION

See last pages of Lecture (4)

next time, ALKANES.

Lec 6 CHEM 30A Jan 21st

ALKANES

1. STRUCTURE
2. ISOMERS
3. NOMENCLATURE
4. CONFORMATION
5. PROPERTIES
6. CONFORMATIONAL ANALYSIS

QUIZ LOW 0/30
MEAN 18/30
HIGH 35/30

HANDED BACK IN DISCUSSION

HMK
Read 2-2.6
Problems
2.1, 2.2, 2.8, 2.9, 2.17-2.21
2.24-2.28

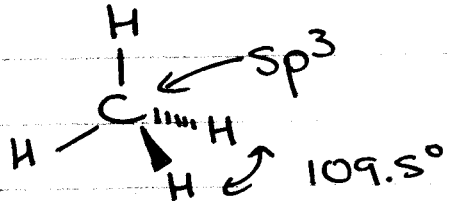
---

1. STRUCTURE

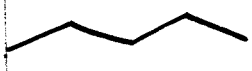
Alkanes → SATURATED HYDROCARBONS

- SATURATED → EACH C HAS MAX # H
- HYDROCARBONS → ONLY C & 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}

and so on... hex... hept... oct... non... dec...

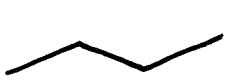
$CH_3(CH_2)_nCH_3$ UNBRANCHED

(2) ISOMERS

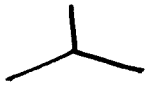
- same molecular formula, different attachment of atoms
  ⇒ CONSTITUTIONAL ISOMERS

CH_4, C_2H_6, C_3H_8 EACH HAS ONLY ONE ARRANGEMENT

HOW ABOUT C_4H_{10}



butane



2 methylpropane

Do C_6H_{14} for HMK (5 structures)

(3) NOMENCLATURE

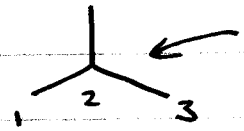
International Union of Pure and Applied Chemistry (IUPAC) ⇒ SYSTEMATIC NAMING

- STRAIGHT CHAINS (done)

- BRANCHED STRUCTURES

(i) IDENTIFY LONGEST CHAIN

(ii) EACH SUBSTITUENT GETS A NAME AND A NUMBER

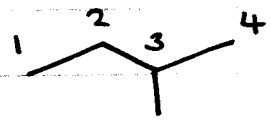


← 2-METHYL-PROPANE

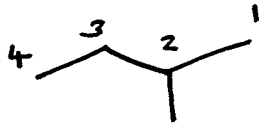
ALKYL GROUPS

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

(iii) MINIMIZE SUBSTITUENT NUMBER

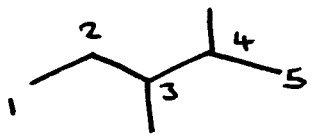


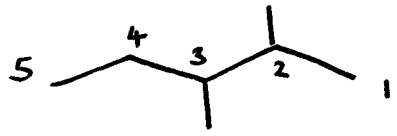
3-METHYLBUTANE ✗



2-METHYLBUTANE ✓

(iv) SAME SUBSTITUENT MORE THAN ONCE

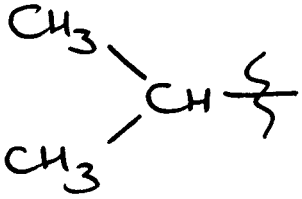




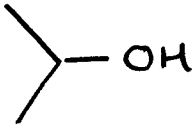
2,3 – DIMETHYL PENTANE

After this, it gets SILLY!

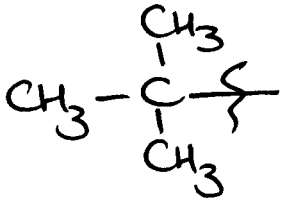
COMMON NAMES



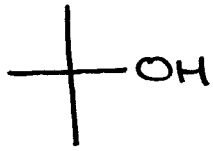
isopropyl



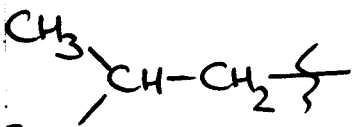
isopropyl alcohol



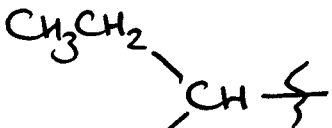
tert-butyl



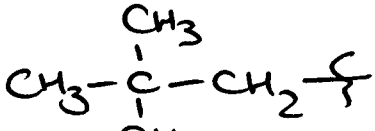
t-butyl alcohol



isobutyl



sec-butyl

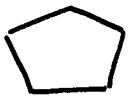


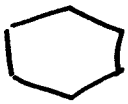
neo-pentyl

CYCLOALKANES

CYCLOPROPANE C_3H_8

 CYCLOBUTANE C_4H_8

 CYCLOPENTANE C_5H_{10}

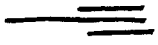
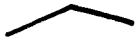
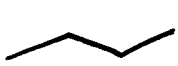
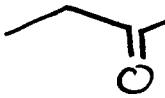
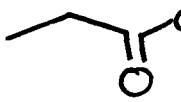
 CYCLOHEXANE C_6H_{12}

BICYCLOALKANES — FORGET IT!

General rules:

PREFIX – INFIX – SUFFIX

PROP	AN	E	
3Cs	Single Bonds	Hydrocarbons	

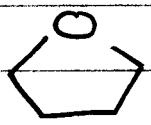
INFIX	–EN–	 PROPENE
	–YN–	 PROPYNE
SUFFIX	–E	 PROPANE
	–OL	 PROPANOL
	–AL	 PROPANAL
	–ONE	 PROPANONE
	–OIC ACID	 PROPANOIC ACID
	(–AMINE)*	 PROPYL AMINE

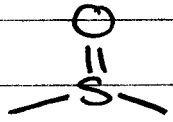
Common Structures / Names / Acronyms

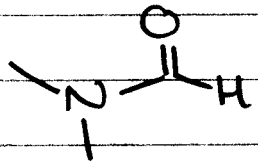
- Keep a notebook

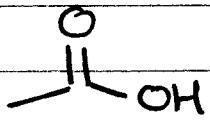
 acetone

 pyridine

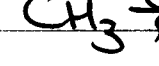
 tetrahydrofuran (THF)

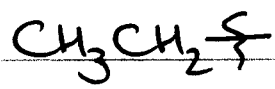
 dimethyl sulfoxide (DMSO)

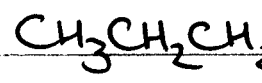
 dimethyl formamide (DMF)

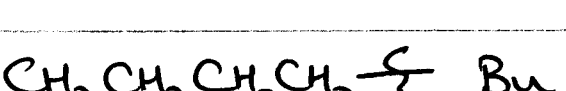
 acetic acid (AcOH)

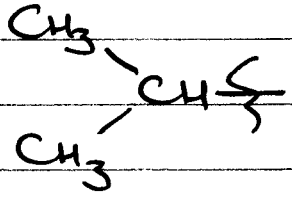
- other common abbreviations

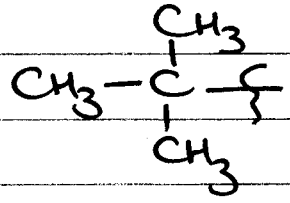
 Me

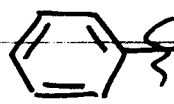
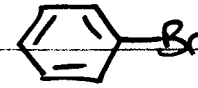
 Et

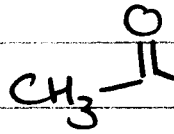
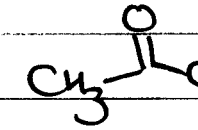
 Pr

 Bu

 ^{i}Pr

 ^{t}Bu

 Ph (PHENYL) e.g.  = PhBr

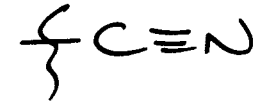
 Ac (ACETYL) e.g.  = AcCl

R GROUPS – stuff dangling off the area of interest in a molecule

e.g. R–Cl, R–OH, R–CO_2H

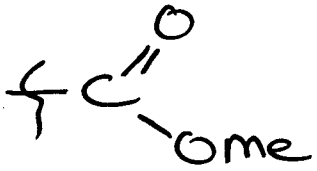
a chloride an alcohol a carboxylic acid

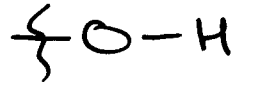
FUNCTIONAL GROUPS



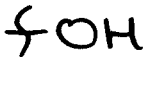
$\sim C\equiv N$

$\sim CN$



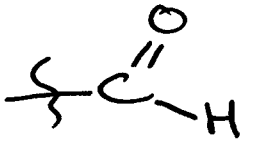


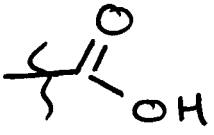
$\sim O-H$



$\sim OH$

$\sim NO_2$



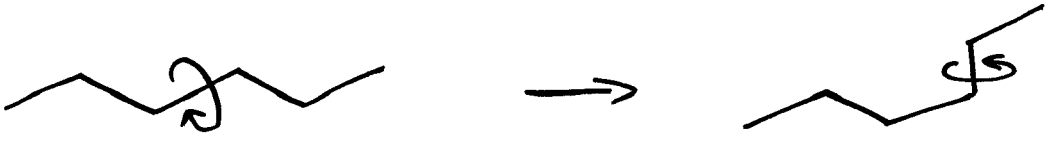


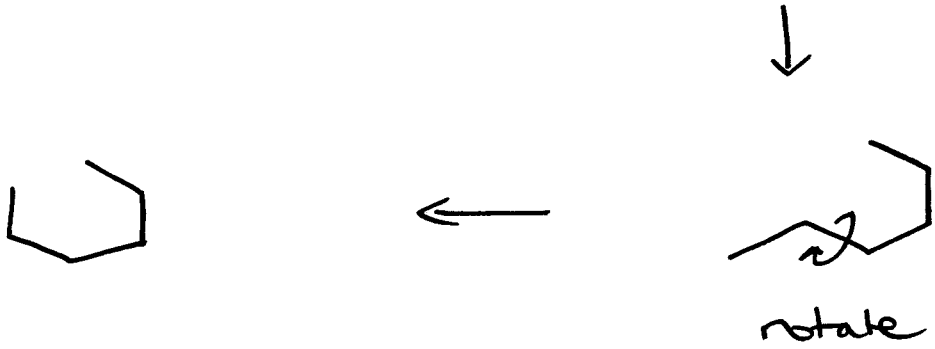
$\sim CO_2H$

$\sim CHO$

(6) CONFORMATIONAL ANALYSIS

– consider HEXANE



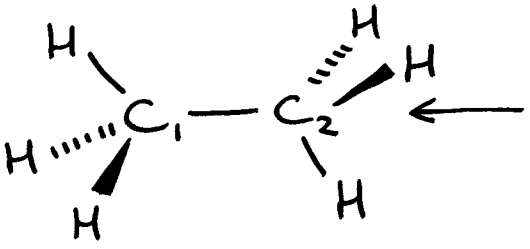


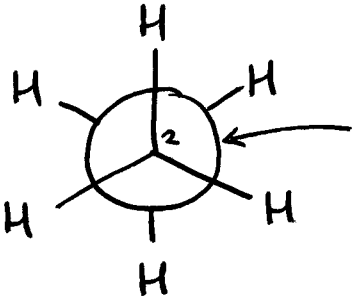
THESE ARE ALL THE SAME MOLECULE

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

At room temperature, all single bonds are constantly rotating

consider C_2H_6





LOOK DOWN C–C BOND

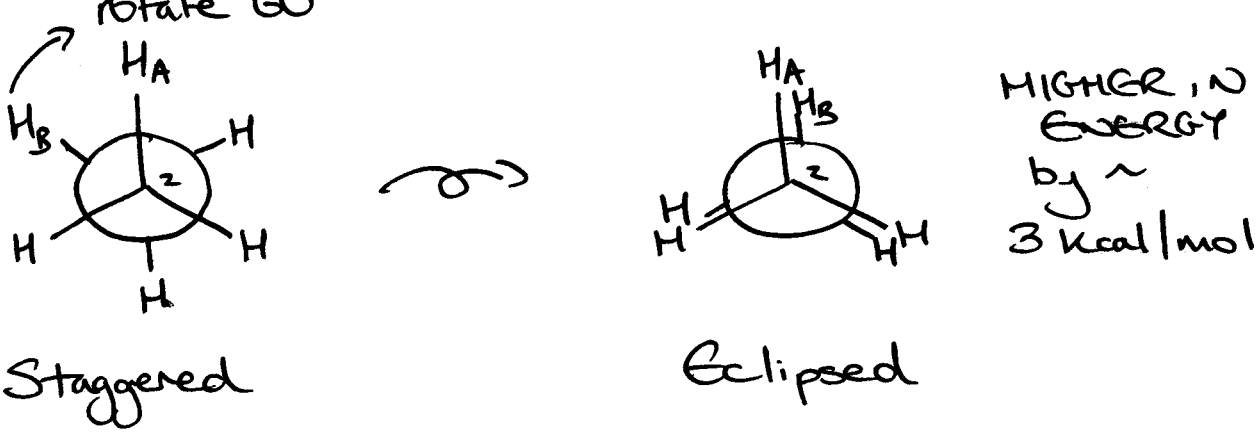
NEWMAN PROJECTION

- TWO METHYL GROUPS CAN ROTATE wrt ONE ANOTHER (0-360°)

  ⇒ INFINITE NUMBER OF CONFORMATIONS

- At RT, rate of rotation is ~10000000000 s^{-1}

However, rotation is not completely UNHINDERED



angle between 2 intersecting PLANES

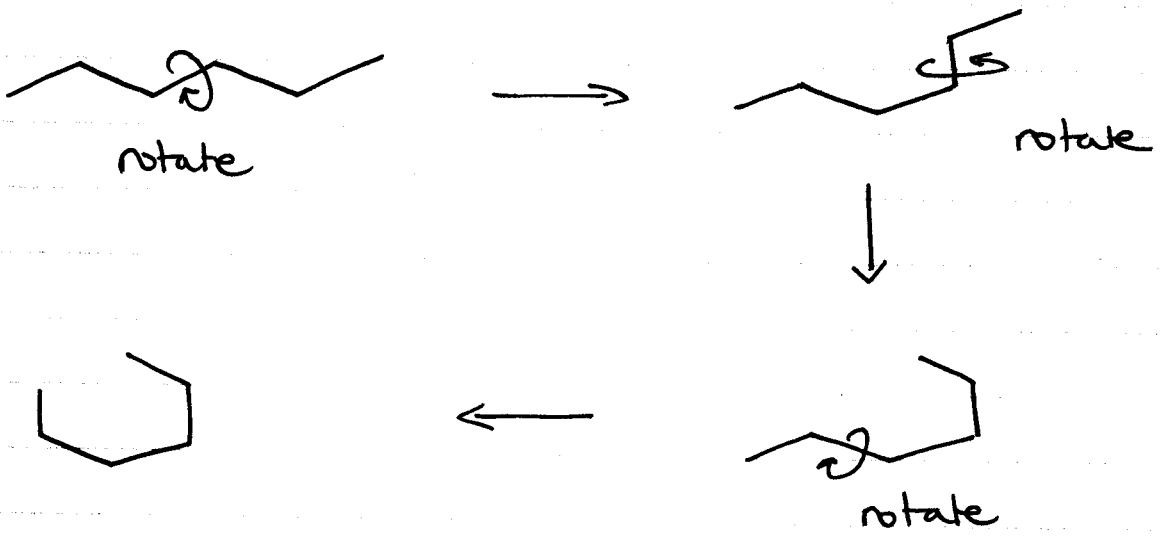
$H_A C_2 C_1$ & $H_B C_1 C_2$

Lec (7) CHEM 30A Jan 24th

- CONFORMATIONAL ANALYSIS
- CYCLOALKANES

HMK: Same problems assigned last time
Read the rest of Chapter 2

CONFORMATIONAL ANALYSIS
- consider HEXANE

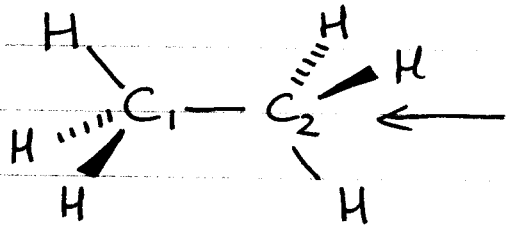


THESE ARE ALL THE SAME COMPOUND

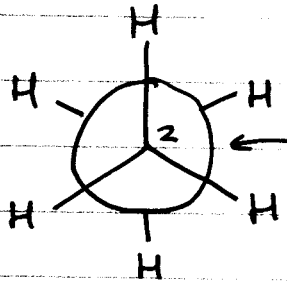
Different arrangements of atoms that result from ONLY single bond rotations are called CONFORMATIONS

At room temperature, all single bonds are constantly rotating —

Consider ETHANE (C_2H_6)



← look from here



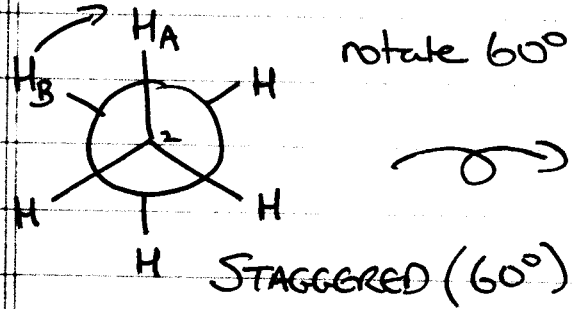
← C_1 is at the back

LOOKING DOWN THE C–C BOND: NEWMAN PROJECTION

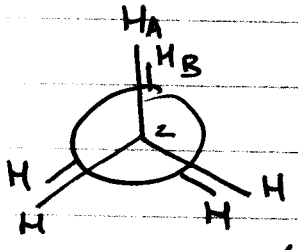
THE TWO METHYL GROUPS ROTATE wrt ONE ANOTHER (0 → 360°)

— INFINITE NUMBER OF CONFORMATIONS

At rt, rate of rotation is ~ 10 BILLION s^{-1}
but rotation is not completely UNHINDERED



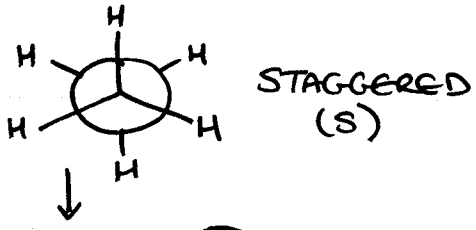
STAGGERED (60°)



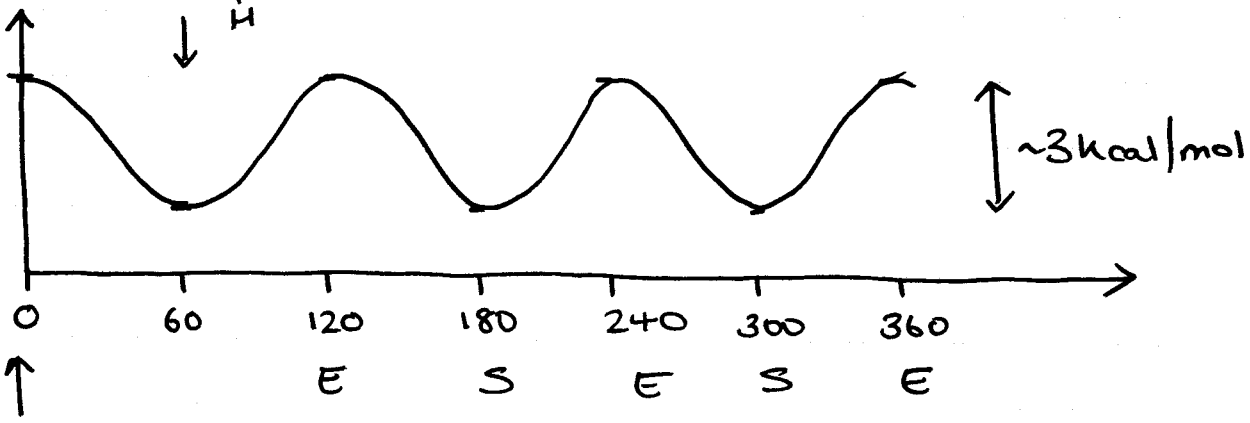
ECLIPSED (0°)

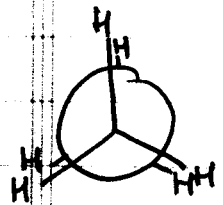
HIGHER IN ENERGY BY ~ 3 kcal mol^{-1}

DIHEDRAL ANGLE (θ) – angle between 2 intersecting planes $H_A C_2 C_1$ & $H_B C_1 C_2$



STAGGERED (S)



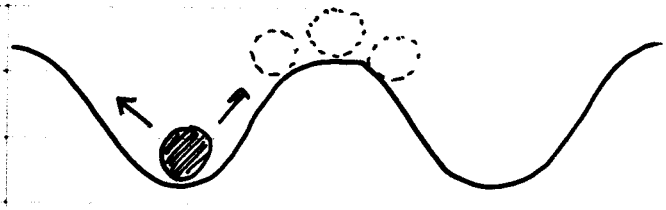


ECLIPSED (E)

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.

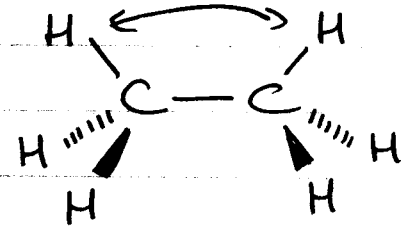
EQUILIBRIUM



with enough energy it will go over the barrier, but it won't spend a lot of time there.

WHY IS THERE A BARRIER?

(i) STERIC INTERACTION?

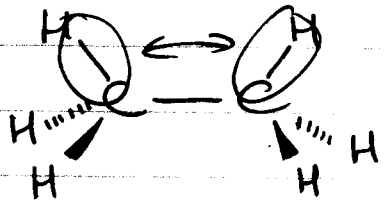


BUT H ATOMS are VERY SMALL

STERICS ACCOUNT FOR ~10% of BARRIER

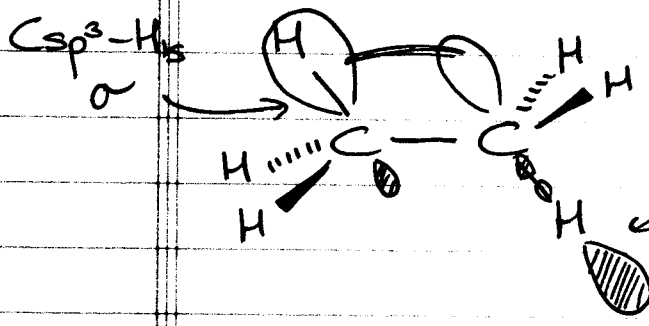
(ii) ELECTRON PAIR REPULSION

TORSIONAL STRAIN



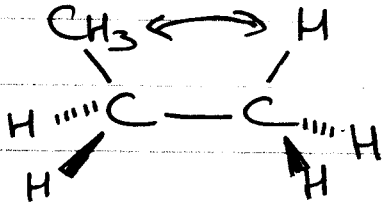
BIGGEST FACTOR

(iii) ATTRACTIVE INTERACTIONS

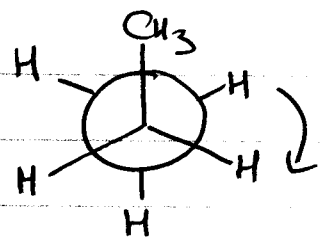


EMPTY ANTIBONDING ORBITAL

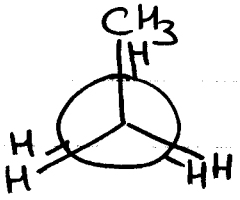
— CONFORMATIONS OF PROPANE?



Bigger repulsive interaction than C–H / C–H



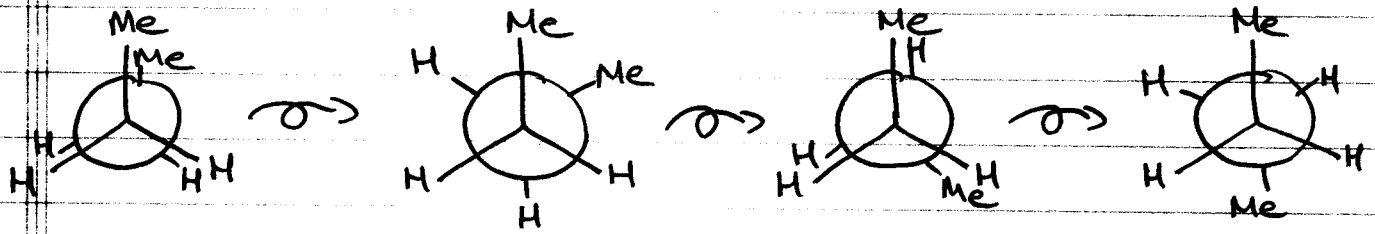
STAGGERED



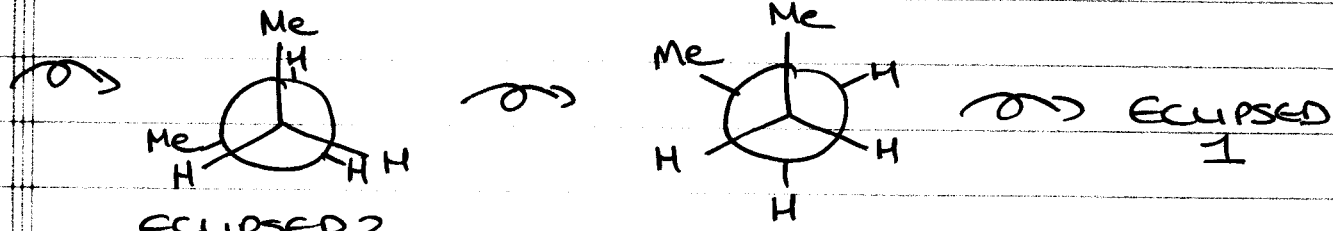
ECLIPSED

Same profile as ETHANE, but HIGHER BARRIER 3.4 kcal/mol

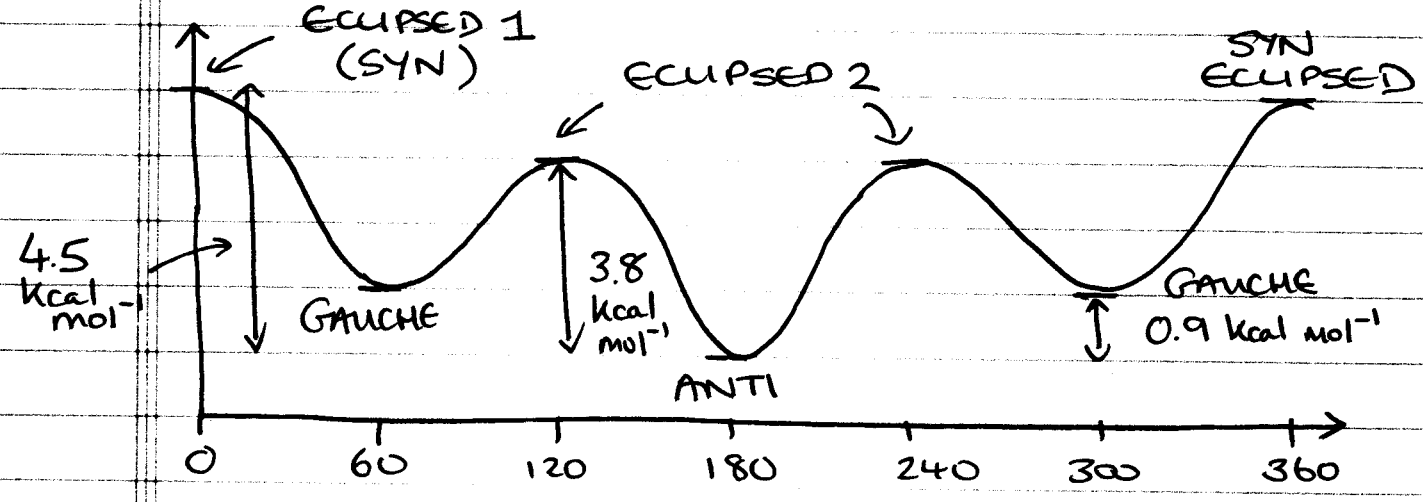
CONFORMATIONS OF BUTANE



ECLIPSED 1 — STAGGERED 1 (GAUCHE) — ECLIPSED 2 — STAGGERED 2 (ANTI)



ECLIPSED 2 (mirror image of other one) — STAGGERED 1 (GAUCHE) (mirror image of other one) — ECLIPSED 1

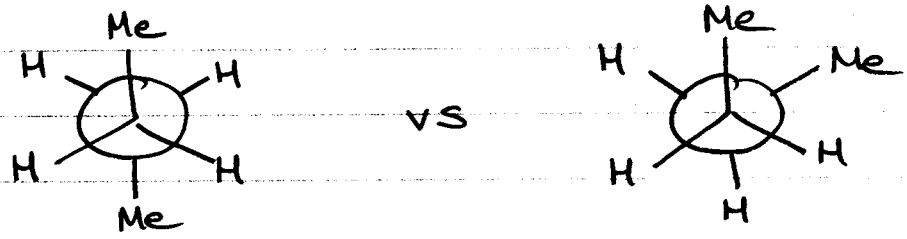


Each eclipsed conformer is a MAXIMA

Each staggered conformer is a MINIMA

BUT different MINIMA/MAXIMA energies

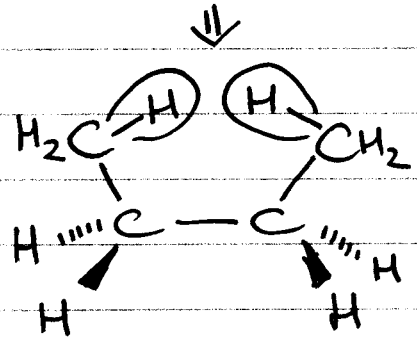
- consider



ANTI (180°) vs GAUCHE (60°)

Neither is ECLIPSED, but ANTI is more stable GAUCHE - difference in energy is due to STERIC STRAIN

STERIC STRAIN → forcing atoms closer together than atomic radii allow

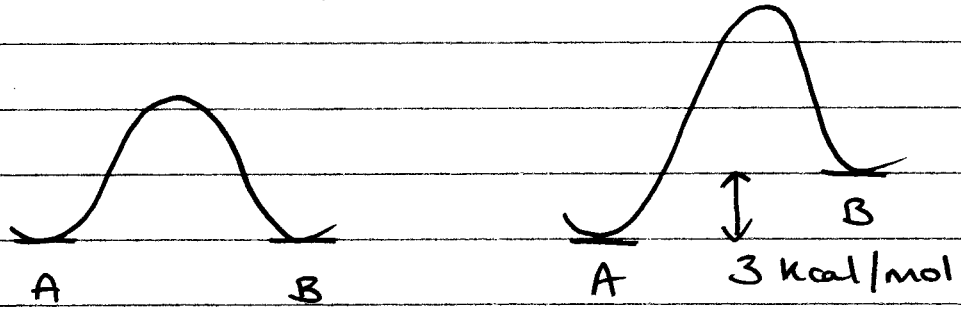


At room temperature, BUTANE is rapidly equilibrating between conformers

~80:20 anti : gauche.

Note: very small differences in energy barriers result in very different ratios of conformational isomers

At room temperature:



K ← equilibrium constant

$A \rightleftharpoons B$

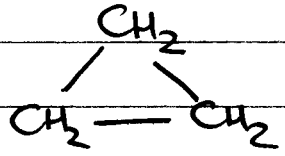
↑ equilibrium arrows

$$K = \frac{[B]}{[A]}$$

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

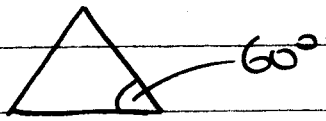
↑ difference in free energy

CYCLOALKANES



cyclopropane

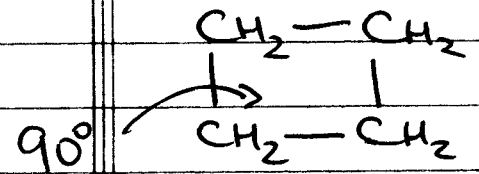
Ring strain of ~28 kcal/mol



TETRAHEDRAL angle is 109.5°

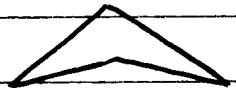
Angle strain is mainly responsible

Also eclipsed C–H bonds (cannot be any other way) ⇒ TORSIONAL STRAIN



cyclobutane

If planar, all C–Hs are eclipsed, so RING PUCKERS to reduce TORSIONAL STRAIN

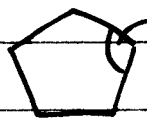


C–C angle ~ 88°

So, ANGLE STRAIN actually increases

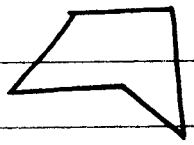
Ring strain is ~ 26 kcal/mol

IN FACT, ALL CYCLOALKANES LARGER THAN CYCLOPROPANE ADOPT NONPLANAR CONFORMATIONS



cyclopentane

PLANAR ⇒ 108°, v. close to 109.5° (TETRAHEDRAL)
very little angle strain, but all C–H bonds would be eclipsed — so/



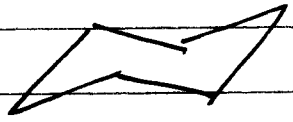
ENVELOPE CONFORMATION
(five equivalent ones – equilibrium)

ring strain is ~ 7 kcal/mol

120° cyclohexane

ANGLE STRAIN & TORSIONAL STRAIN

BUT CYCLOHEXANE is almost STRAIN free

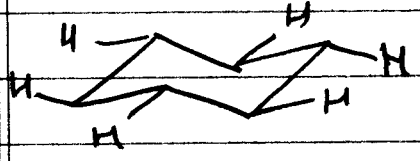


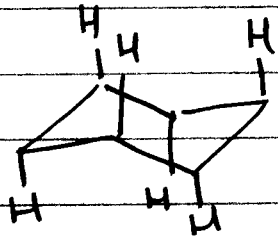
CHAIR CONFORMATION

C–C–C angles ~109.5° NO ANGLE STRAIN

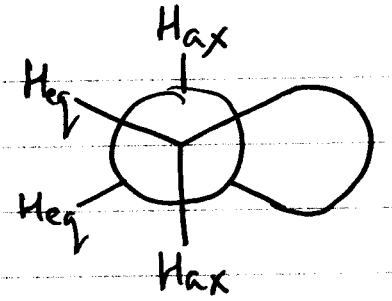
Hs on adjacent Cs are STAGGERED
⇒ NO TORSIONAL STRAIN

EQUATORIAL





AXIAL



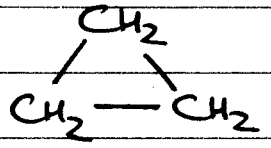
NEWMAN PROJECTION down ANY C–C axis.

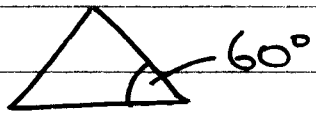
LEC (8) CHEM 30A Jan 26th

CYCLOALKANES

Problems: 2.10 - 2.15, 2.31 - 2.45
Reading: Review Ch2

CYCLOPROPANE



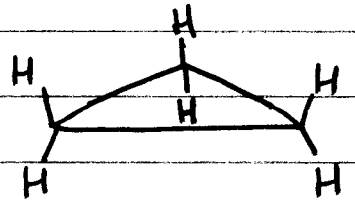


60° very different to 109.5° (TETRAHEDRAL ANGLE)

⇒ ANGLE STRAIN

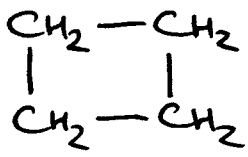
Total ring strain ~ 28 kcal/mol

- most of this is angle strain, but all C-H bonds are eclipsed ⇒ TORSIONAL STRAIN

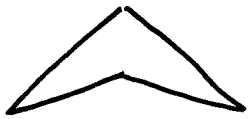


ALL ECLIPSED

CYCLOBUTANE



If PLANAR, all C–Hs would be eclipsed, so ring puckers to avoid TORSIONAL STRAIN



C–C–C angles ~88°
(so, worse than 90° => more ANGLE STRAIN)

Total ring strain is ~26 kcal/mol

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

CYCLOPENTANE

If it were planar,
108° ≈ 109.5°
there would be little angle strain

<u>BUT</u> ALL C–H BONDS WOULD BE ECLIPSED
=> TORSIONAL STRAIN

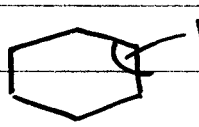
ENVELOPE CONFORMATION (105° ANGLES)

=> REDUCES TORSIONAL STRAIN

4Cs in plane 1 out (EQUILIBRIUM)

Total ring strain ~ 7 Kcal/mol^{-1}

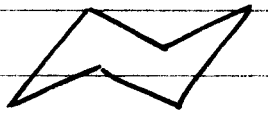
+ CYCLOHEXANE



PLANAR STRUCTURE

=> Angle & torsional strain

BUT cyclohexane is virtually strain free

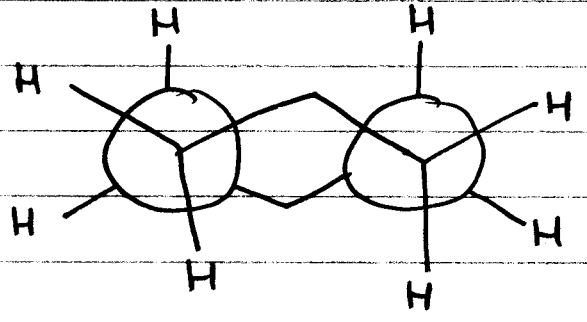


CHAIR CONFORMATION

C–C–C ANGLES 109.5°

no angle STRAIN

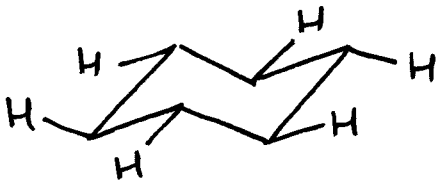
ALSO NO TORSIONAL STRAIN, Hs ON ADJACENT CARBON ATOMS STAGGERED



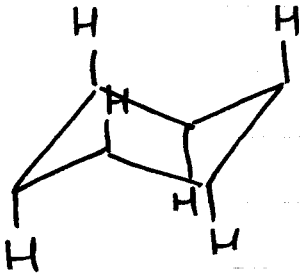
NEWMAN PROJECTION

– ALSO NO STERIC STRAIN

Two Different orientations for C–H BONDS

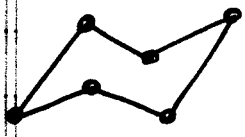


EQUATORIAL

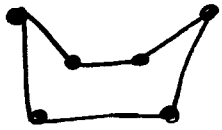


AXIAL

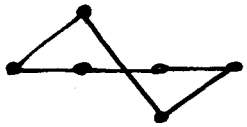
other cyclohexane conformations



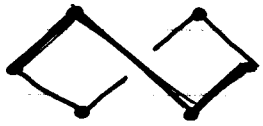
CHAIR



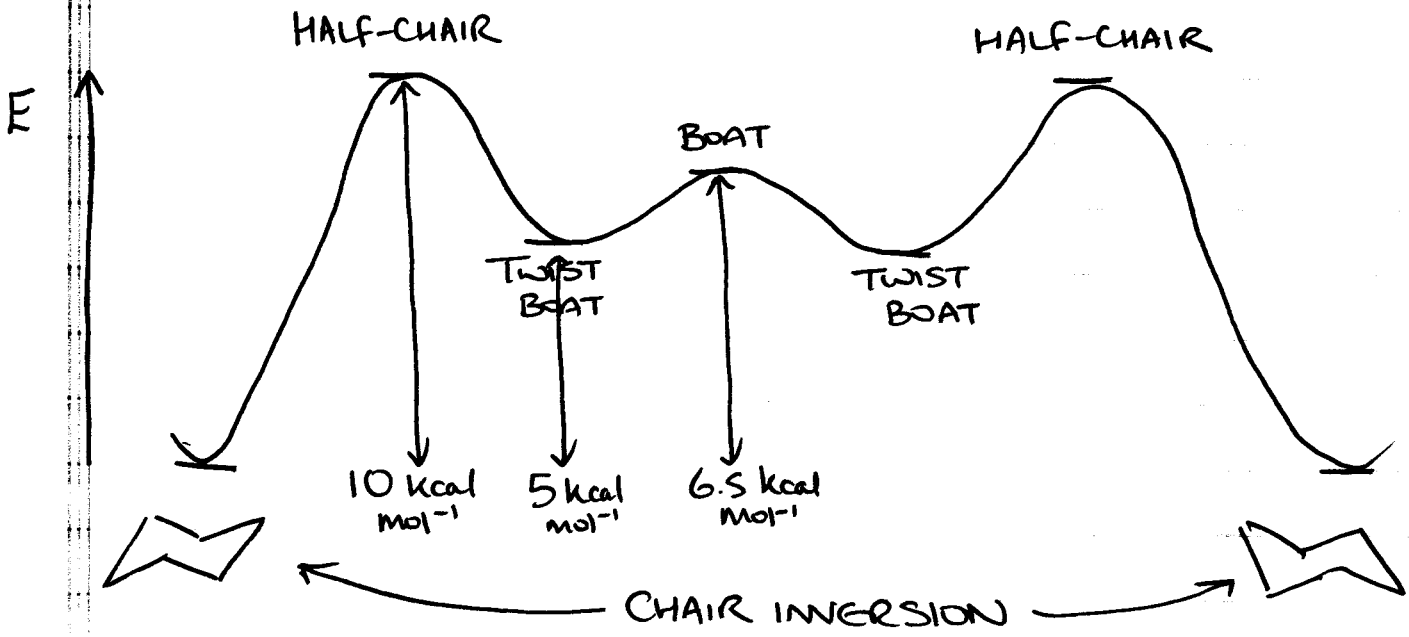
BOAT



HALF-CHAIR

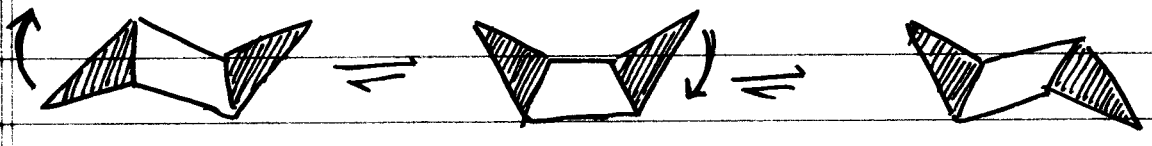


TWIST BOAT

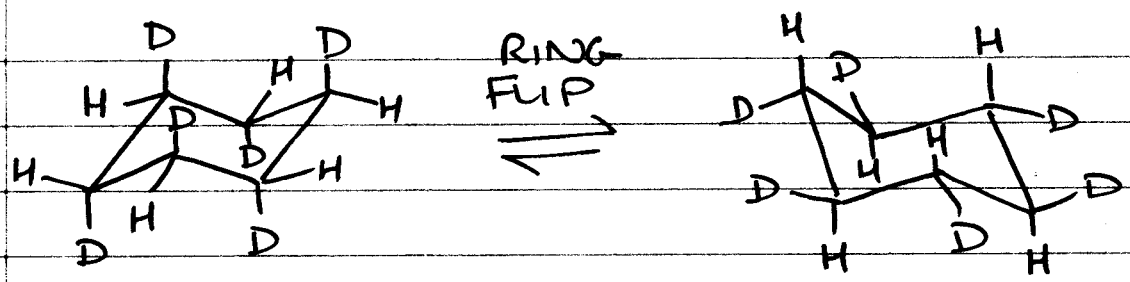


At RT, CHAIR > 99.99% of EQUILIBRIUM MIXTURE

RING-RING FLIP



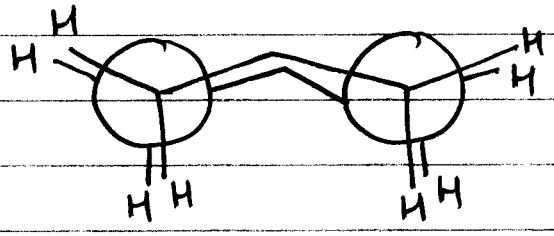
SWITCHES AXIAL & EQUATORIAL POSITIONS



D AXIAL
H EQUATORIAL

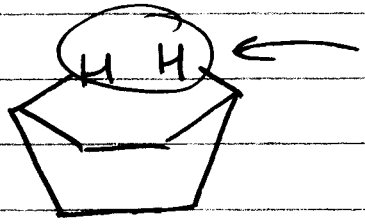
D EQUATORIAL
H AXIAL

BOAT CONFORMATION



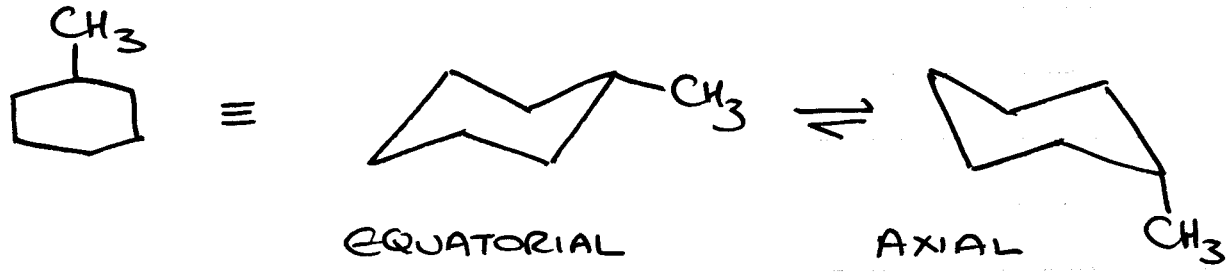
← ECLIPSED C–Hs

also



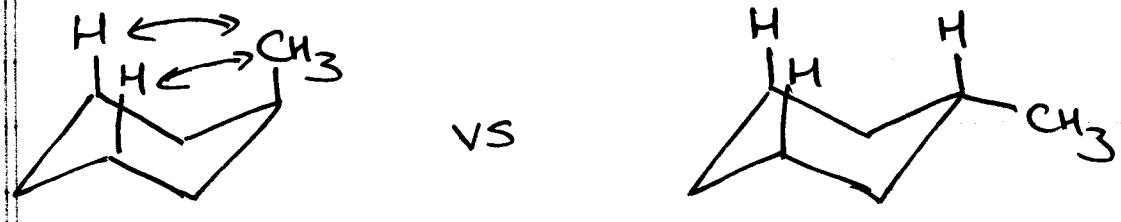
← NONBONDED (STERIC) INTERACTIONS

Consider METHYL CYCLOHEXANE



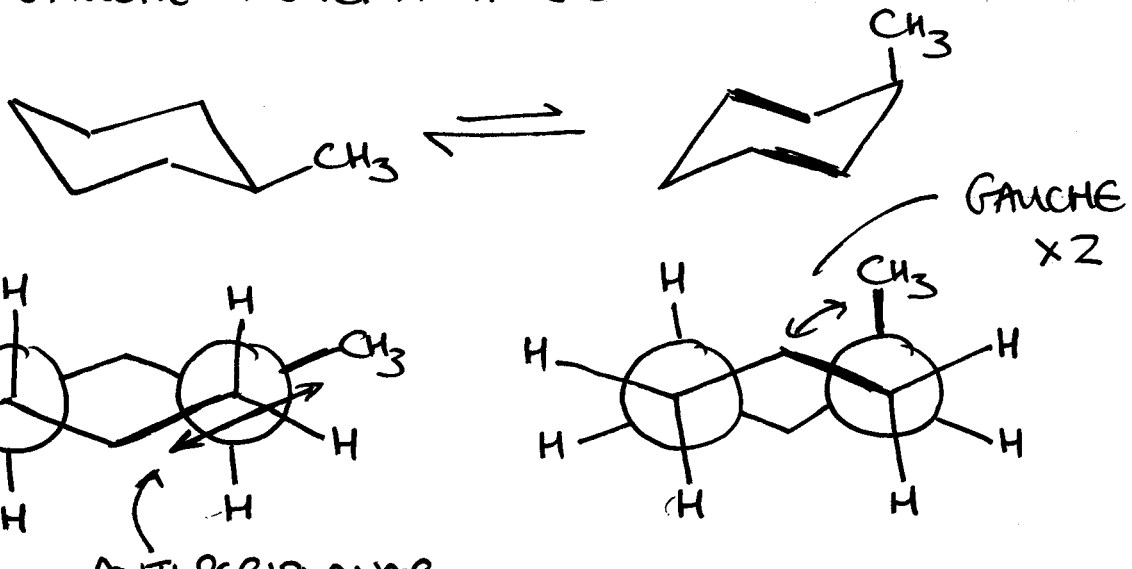
Which is more STABLE?

(i) 1,3 – DIAXIAL INTERACTIONS

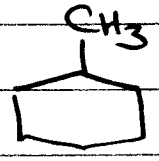


NON BONDED INTERACTIONS (STERIC)

(ii) GAUCHE INTGRACTIONS



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

For  equatorial is more stable by ~ 1.74 kcal/mol

A VALUES → measure of preference for the equatorial position

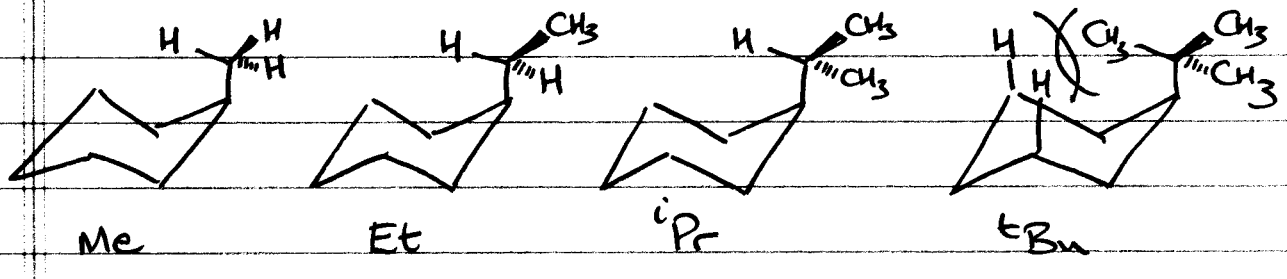
A = $-\Delta G$ change for axial → equatorial

So, A values are usually +ve

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

NOTE small changes for Me, Et, ^iPr

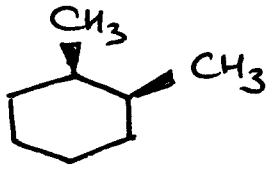
1,3 DIAXIAL



^tBu => LOCKING GROUP →

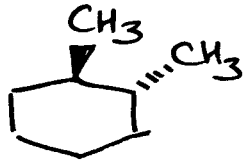
OVERWHELMING PREFERENCE FOR EQUATORIAL POSITION

DISUBSTITUTED CYCLOHEXANES



same side <u>cis</u>

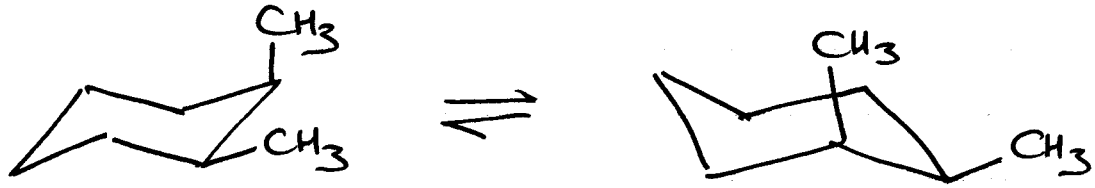
cis-1,2-dimethylcyclohexane



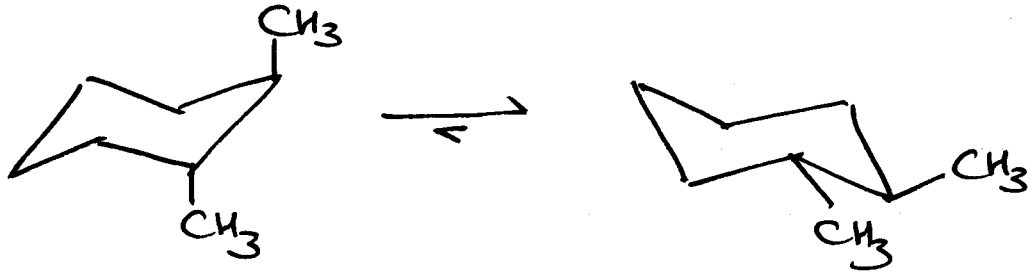
opposite sides <u>trans</u>

trans-1,2-dimethylcyclohexane

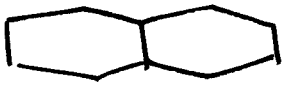
cis



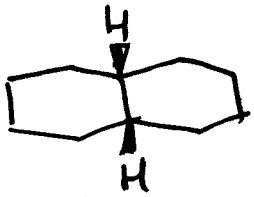
trans

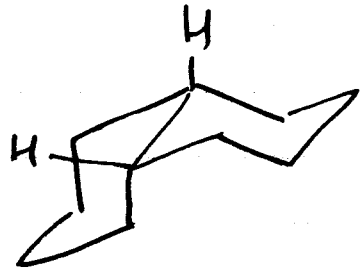


DECALIN

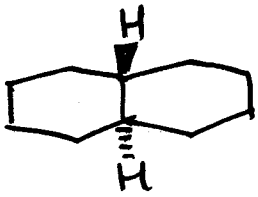


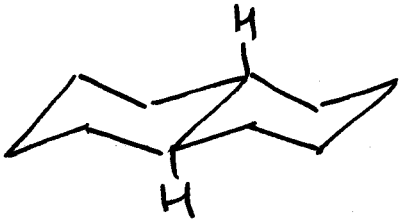
cis decalin





trans decalin





LEC (9) CHEM 30A Jan 28th

(1) CYCLOALKANES cont
(2) PROPERTIES OF ALKANES
(3) REACTIONS / SOURCES / IMPORTANCE

CHAPTER 3
(4) STEREOCHEMISTRY
(5) CHIRALITY

HMK: Reading 2.9 - 3.4
Problems 2.16, 2.46-2.61, 3.1-3.5, 3.10-3.23

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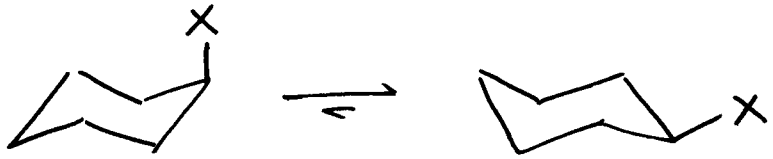
(1) CYCLOALKANES

A values = $-\Delta G$ for:



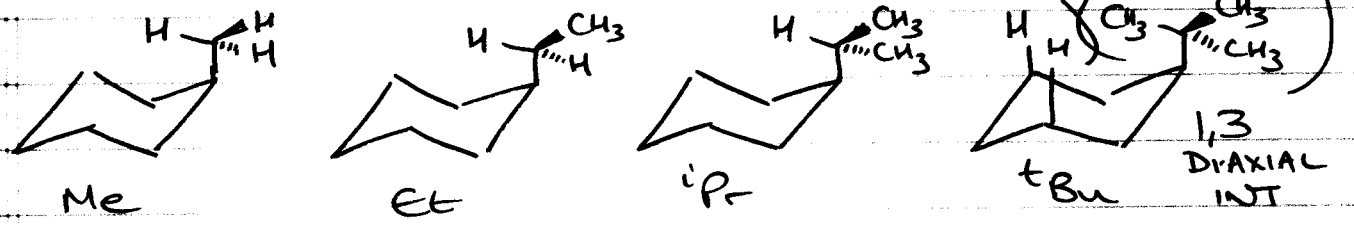
axial ⇌ equatorial

So, values are +ve

Larger the value, the stronger the preference for the EQUATORIAL position

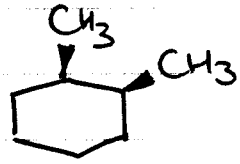
$-CH_3$	$-CH_2CH_3$	$-CH(CH_3)_2$	$-C(CH_3)_3$
1.74	1.75	2.15	>5

Note: small changes for Me, Et, ^{i}Pr → WHY?

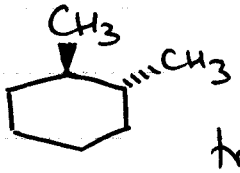


^{t}Bu ⇒ LOCKING GROUP
OVERWHELMING PREFERENCE
FOR THE EQUATORIAL POSITION

— DISUBSTITUTED CYCLOHEXANES

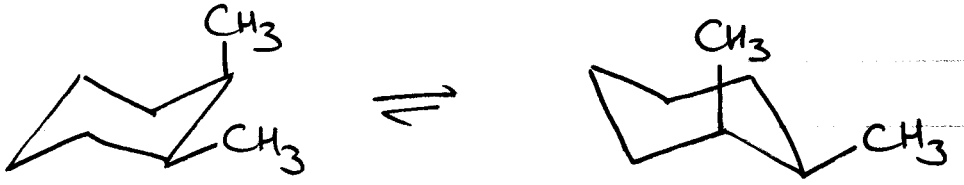


same side cis
cis-1,2-dimethylcyclohexane

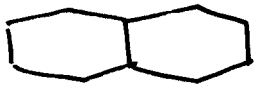


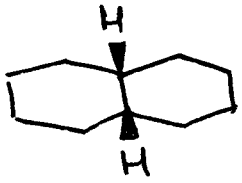
opposite side trans
trans-1,2-dimethylcyclohexane

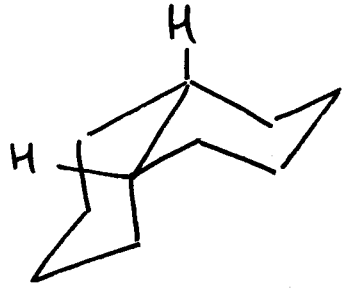
cis

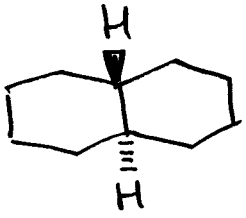


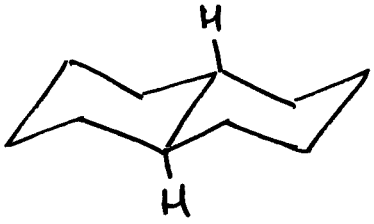
trans

— DECALIN 

cis Decalin 



trans Decalin 



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(2) PROPERTIES OF ALKANES

as MW increases, mp & bp increase

Intermolecular Interactions

- Ionic interactions
- Hydrogen Bonding
- Dipole – dipole
- Dipole - induced dipole
- Induced Dipole - Induced Dipole

↓ Decreasing Strength

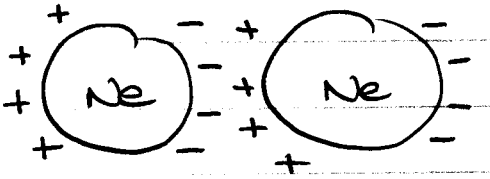
↳ DISPERSION FORCES / LONDON FORCES ↘

low MW nonpolar substances can be liquefied

He 4K Ne 27K

Bigger e^- clouds, stronger forces

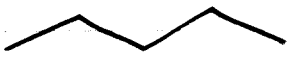
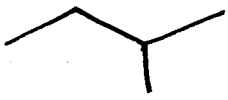
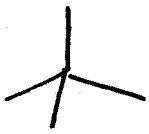
transient polarization →



Symmetrical electron density distribution

temporary electrostatic attraction

- consider

	bp
	36°C
	28°C
	10°C

Constitutional isomers

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

(3) Reactions / Sources / Importance

↳ Read sections 2.9 / 2.10 and look over associated questions

(4) STEREOCHEMISTRY

ISOMERS → different compounds with the same molecular formula

CONSTITUTIONAL ISOMERS ⇓ Different connectivity

e.g. CH_3-O-CH_3

CH_3CH_2-OH

or

STEREOISOMERS (configurational isomers) ⇓ Same connectivity, different geometry

STEREOISOMERS → ENANTIOMERS (non-superimposable mirror images)

↓

DIASTEREOISOMERS (non-superimposable non-mirror images) → CONFIGURATIONAL DIASTEREOISOMERS

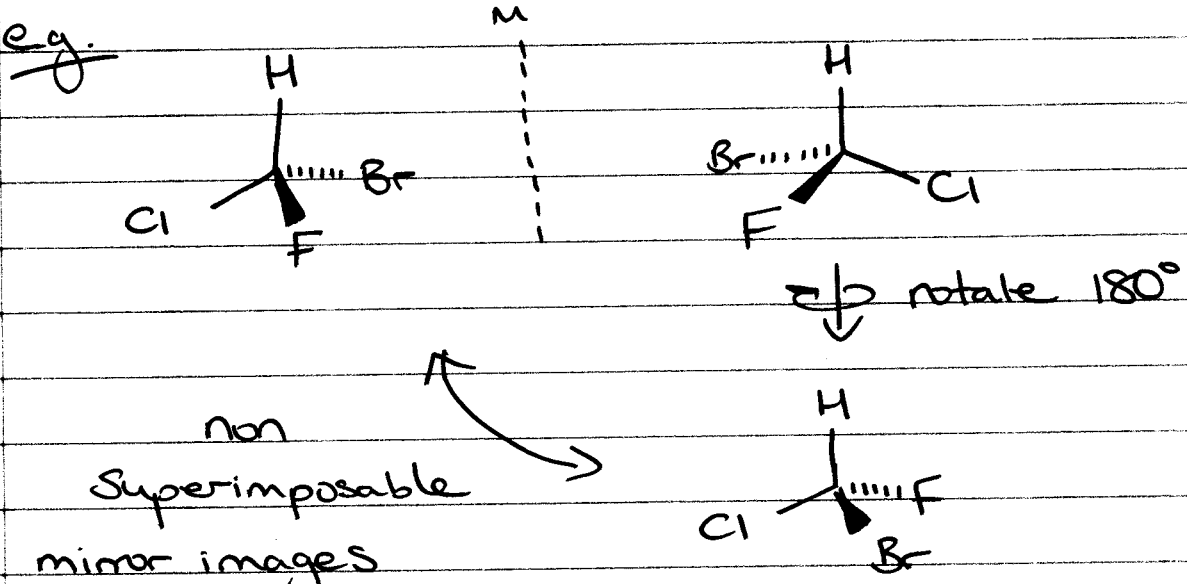
→ CIS/TRANS DIASTEREOISOMERS

(5) CHIRALITY

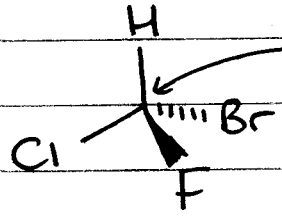
An object (molecule) that is NOT superimposable on its mirror image is said to be <u>CHIRAL</u>

from Greek cheir meaning hand

e.g.



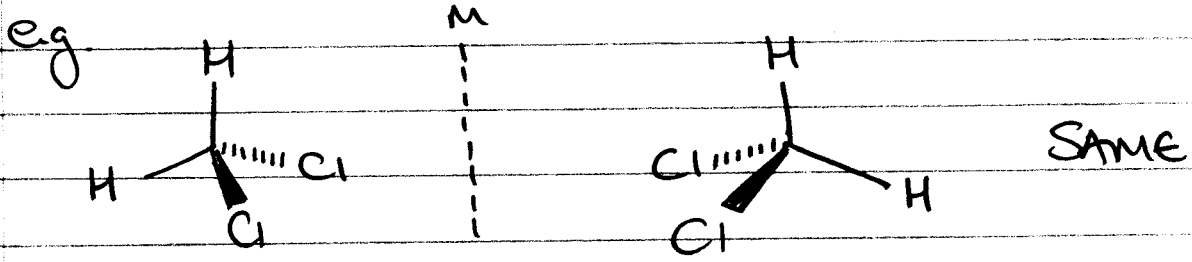
So, each of these molecules is CHIRAL and they are ENANTIOMERS



called a CHIRAL or STEREOGENIC CENTER

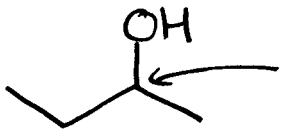
If an OBJECT (or molecule) is not CHIRAL, it is referred to as ACHIRAL

e.g.

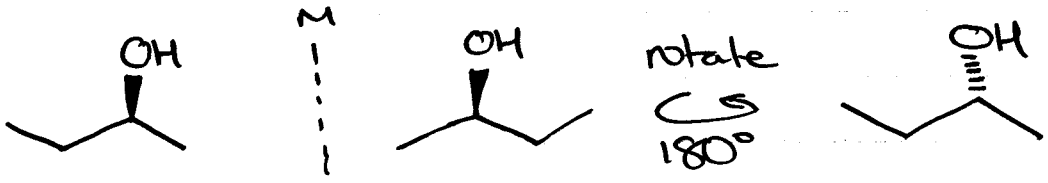


SAME

One of the most common causes of chirality in organic molecules is a TETRAHEDRAL atom (usually C) bonded to FOUR DIFFERENT GROUPS

e.g. 

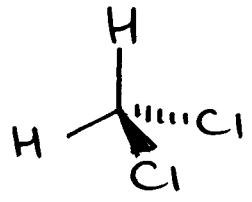
ENANTIOMERS come in pairs



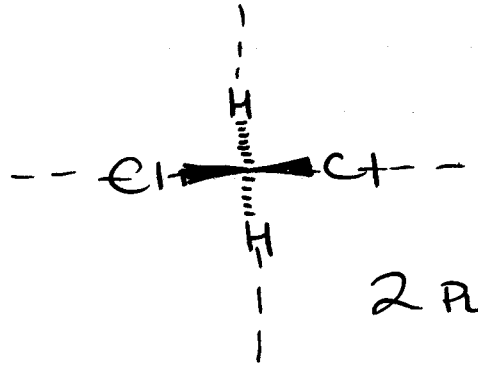
IDENTIFYING CHIRAL OBJECTS

If a molecule can be drawn with
(i) a PLANE of symmetry or
(ii) an INVERSION center

$\Rightarrow$ IT IS ACHIRAL

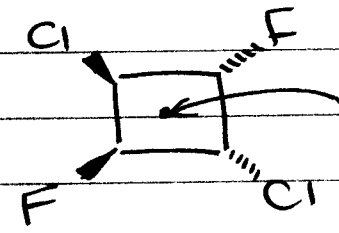
eg. (i) 

ACHIRAL



2 PLANES!

- YOU WILL SEE THIS MORE THAN:

(ii) 

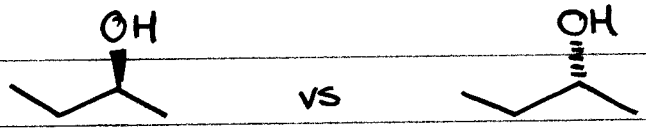
center of inversion

NO PLANE

ACHIRAL

centre of inversion ⟹ identical groups lie equidistant of a point, on opposite sides of that point.

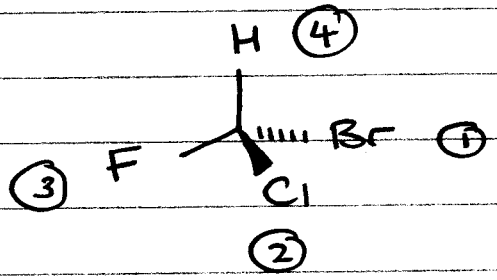
— DISTINGUISHING ENANTIOMERS



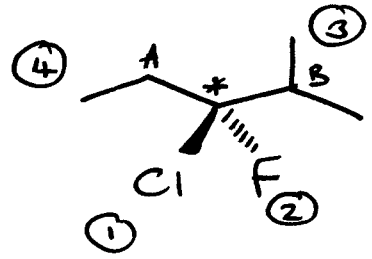
R, S designation

① Assigning Priority

(i) ATOMIC WEIGHT of atoms attached to the stereocenter

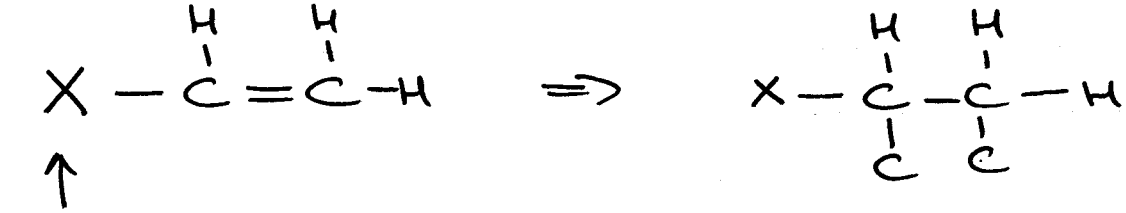


(ii) Keep going until the first point of difference

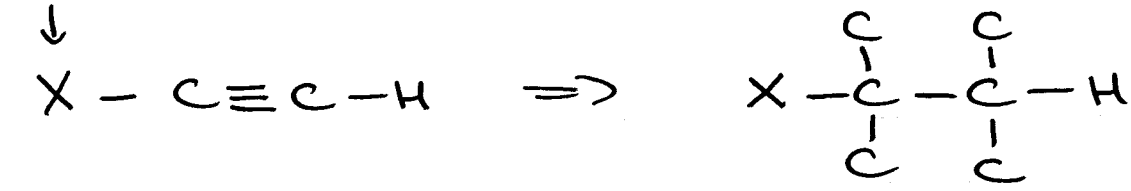


C_A attached to C, H, H (4)
C_B attached to C, C, H (3)

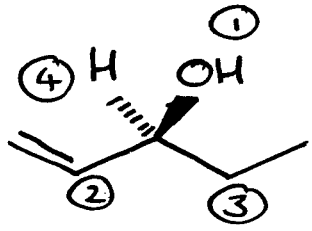
(iii) MULTIPLE BONDED ATOMS count as the equivalent number of singly bonded atoms



Chiral center



So



Use 1, 2, 3, 4 to set R or S

LEC (10) CHEM 30A Jan 31st

(1) CHIRAL CENTERS
(2) R/S DESIGNATION
(3) FISCHER PROJECTIONS
(4) CIS/TRANS DIASTEREOISOMERS

HMK Read Ch3
Problems 3.1 – 3.5, 3.10 – 3.23
+ Stereochem PROBLEM SET

MIDTERM => WEDNESDAY

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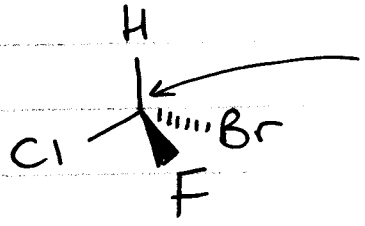
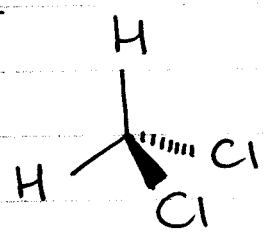
(1) CHIRAL CENTERS



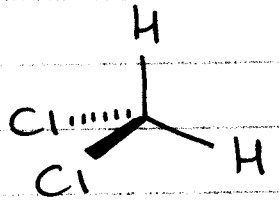
CHIRAL or STEREOGENIC center

IF AN OBJECT (molecule) is not CHIRAL, it is ACHIRAL

e.g.



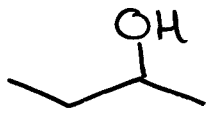
m



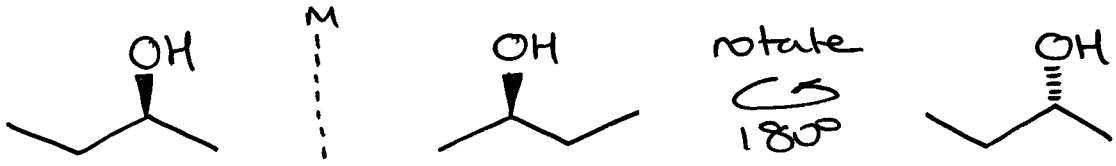
THESE MOLECULES ARE THE SAME

One of the most common causes of chirality in organic molecules is a TETRAHEDRAL atom (usually C) bonded to FOUR DIFFERENT GROUPS.

* This does not define "CHIRAL"

e.g. 

ENANTIOMERS come in PAIRS



IDENTIFYING CHIRAL OBJECTS

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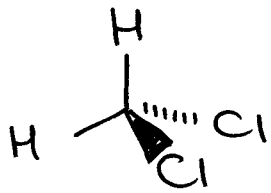
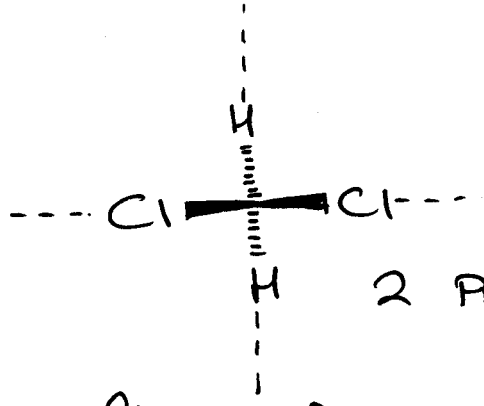
(ii) an INVERSION CENTER

$\Longrightarrow$ IT IS ACHIRAL

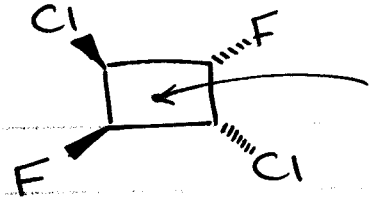
e.g. (i) 

ACHIRAL



2 PLANES

You will see this more often than:

(ii) 

center of INVERSION (no plane)

ACHIRAL

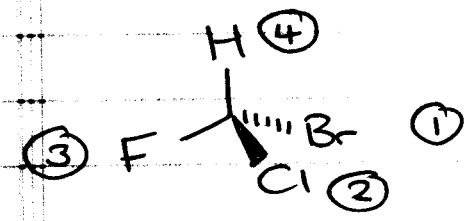
centre of inversion ⇒ identical groups lie equidistant of a point on opposite sides of that point.

– DISTINGUISHING ENANTIOMERS

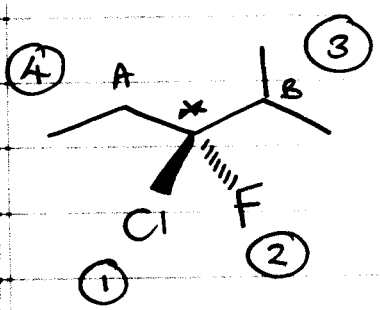
R,S designation

– assigning priority

(i) ATOMIC WEIGHT of atoms on stereocenter



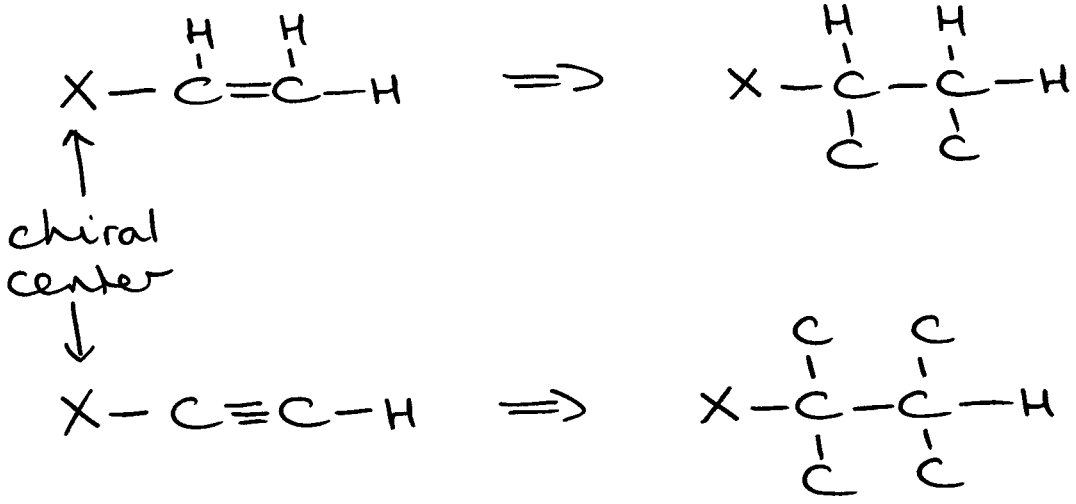
(ii) FIRST POINT of DIFFERENCE



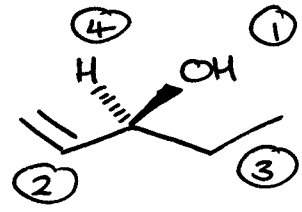
C_A attached to C, H, H (4)

C_B attached to C, C, H (3)

(iii) MULTIPLE BONDED ATOMS – count as the equivalent number of singly bonded atoms



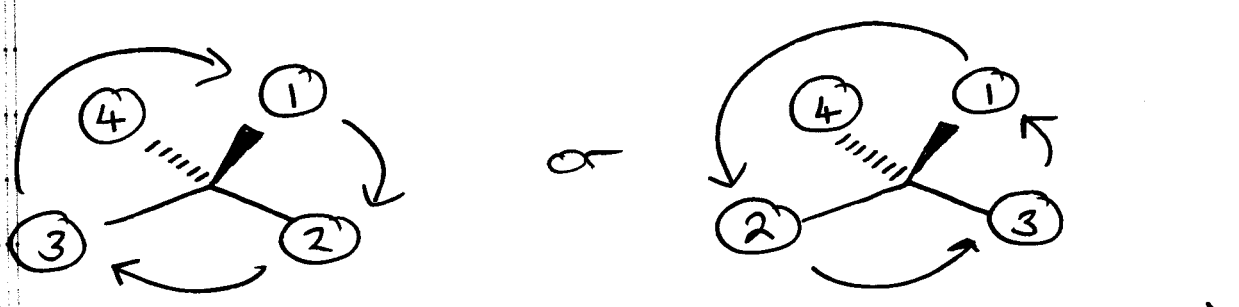
So consider:



use 1, 2, 3, 4 to set R or S

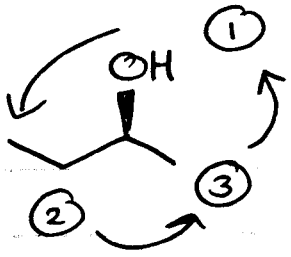
Rotate molecule to put lowest priority group in the back ⇒

TWO POSSIBLE ORIENTATIONS

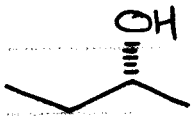


CLOCKWISE (R) COUNTERCLOCKWISE (S)

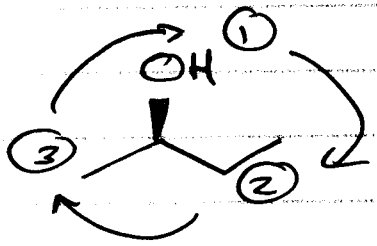
So/



(S)-2-BUTANOL



rotate ↻ 180°



Small group is not in the back

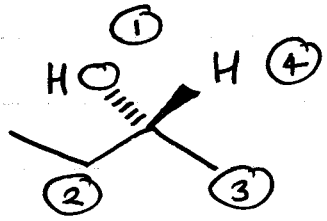
(R)-2-BUTANOL

or if you have trouble rotating molecules

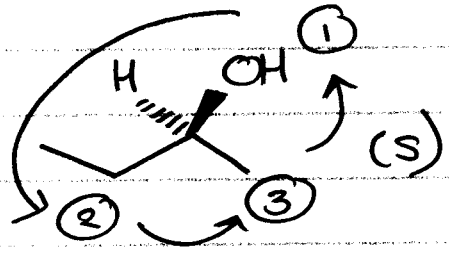
TRICK...

- 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

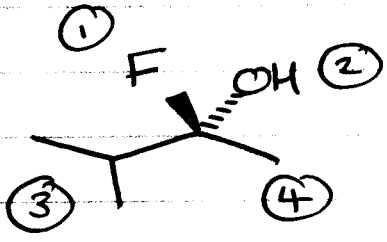
e.g



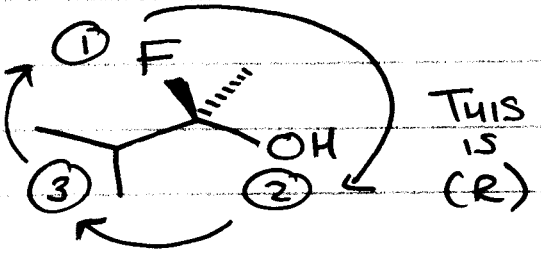
switch ① / ④



↑ SO THIS MUST BE (R)



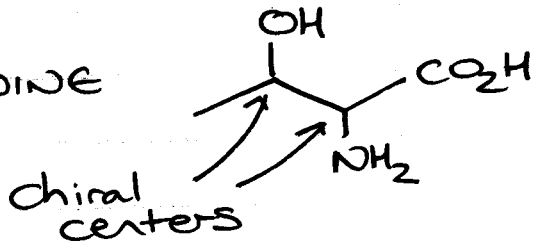
switch ② / ④

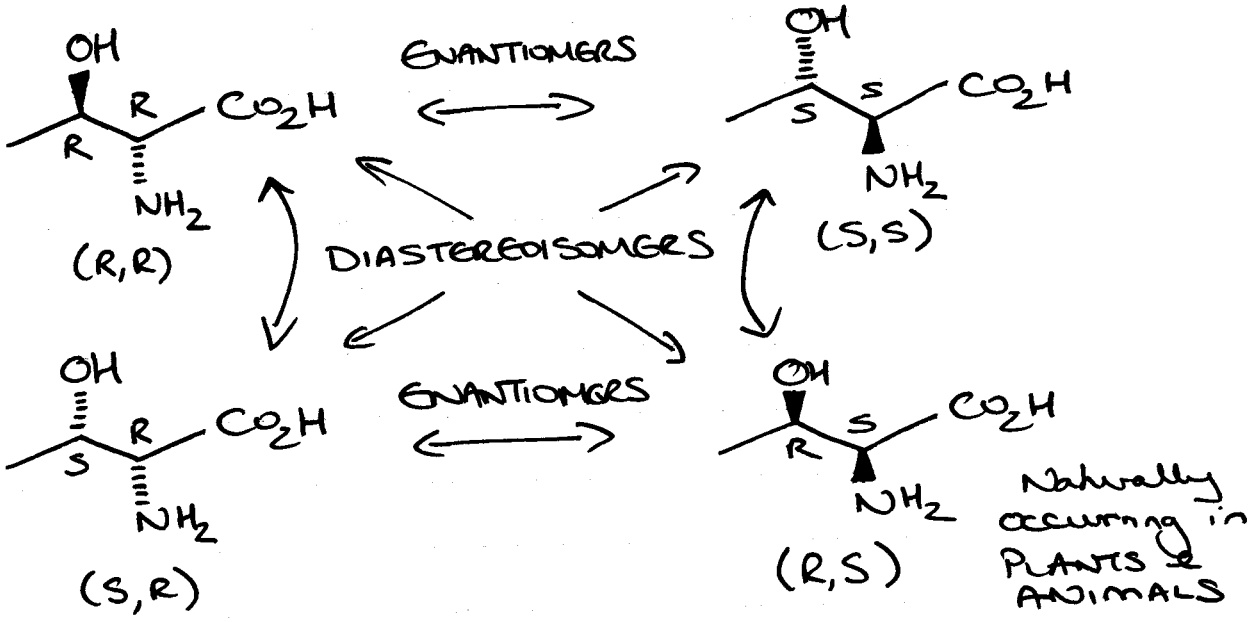


SO, THIS ONE IS (S)

COMPOUNDS W/ MORE THAN ONE STEREOCENTER

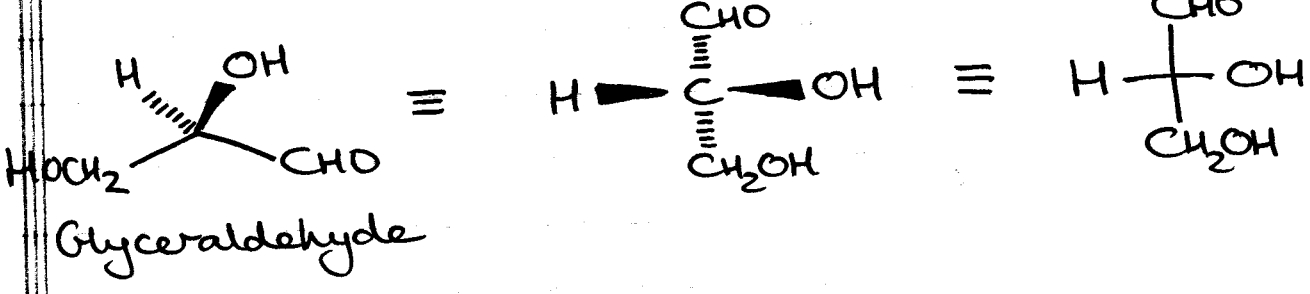
Amino acid THREONINE





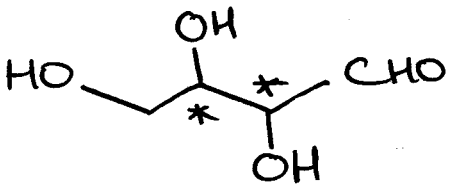
DIASTEREOISOMERS — NON MIRROR IMAGE STEREOISOMERS

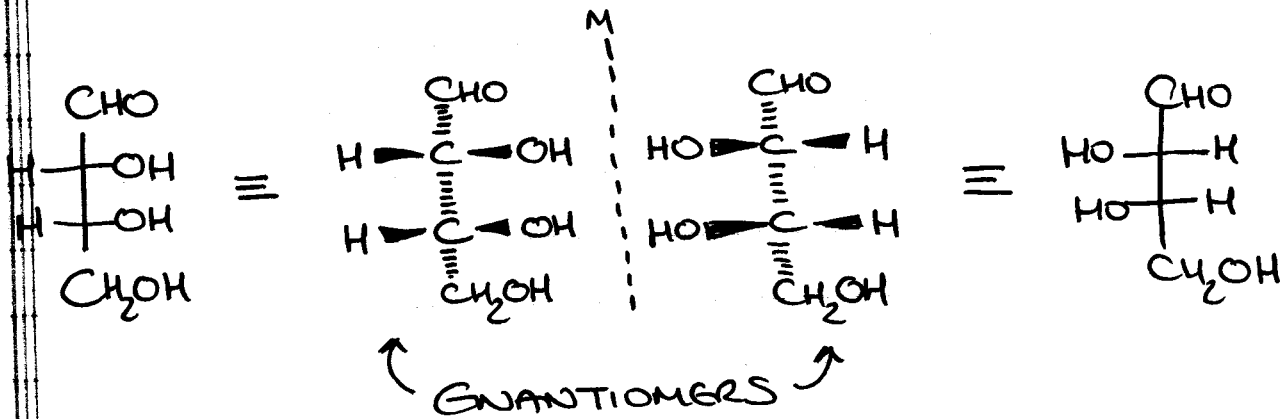
FISCHER PROJECTIONS



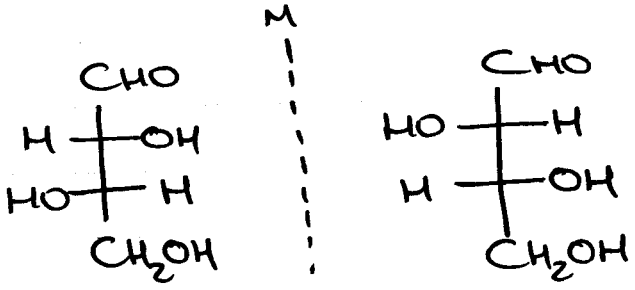
Useful for compounds with many continuous stereocenters

2,3,4-trihydroxybutanal

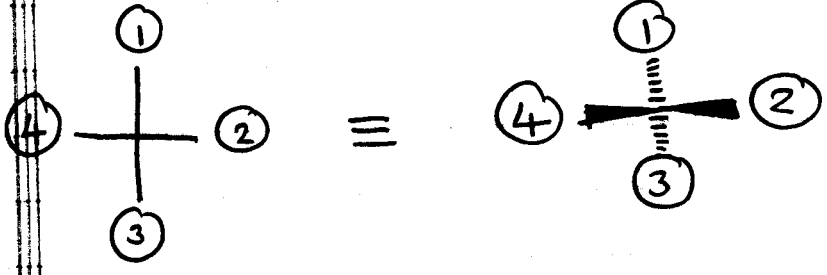




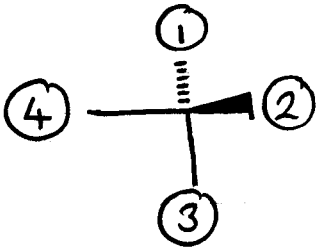
ANOTHER PAIR OF ENANTIOMERS



Determining R/S in Fischer Projections



Switch one wedge & one dash for STRAIGHT LINES



⇐ assign R/S

(THIS ONE IS (S))

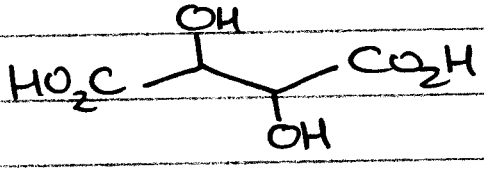
Go back and determine R/S for 2,3,4 trihydroxybutanal

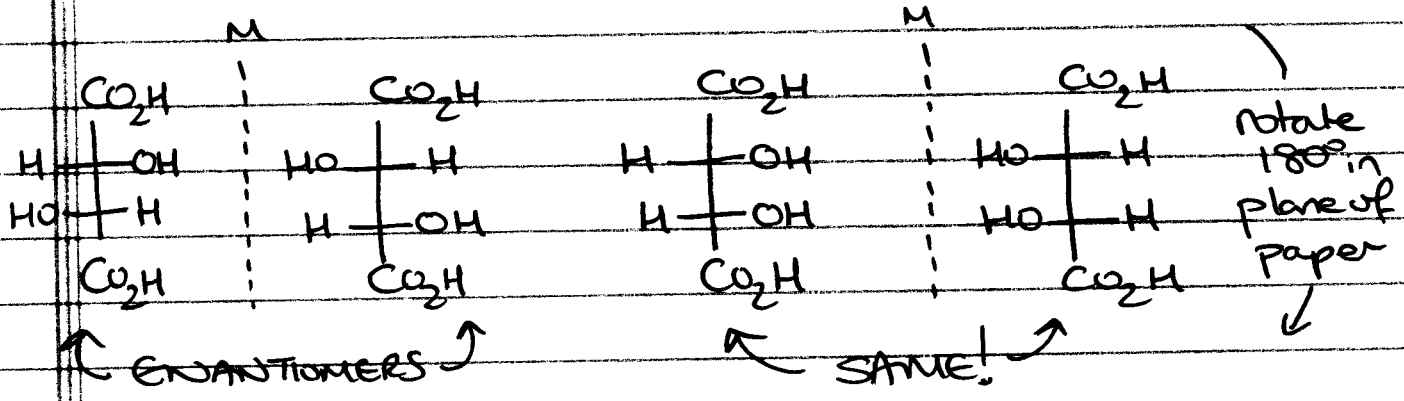
- A molecule with $\leq n$ chiral centers can have a maximum number of stereoisomers $= 2^n$

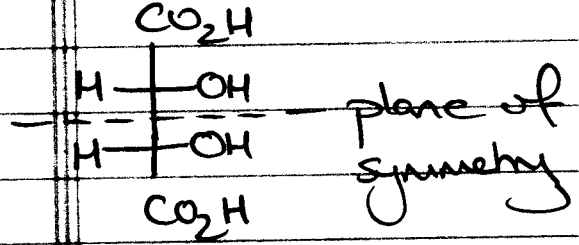
e.g. 2,3,4 trihydroxybutanal has 2 stereocenters

$2^2 = 4$ stereoisomers

CONSIDER TARTARIC ACID







COMPOUND w/ STEREOISOMERS but is ACHIRAL

$\Rightarrow$ MESO

- ENANTIOMERS ✓
- DIASTEREOISOMERS
  - CONFIGURATIONAL ✓
  - CIS/TRANS
    - RINGS e ALKENES

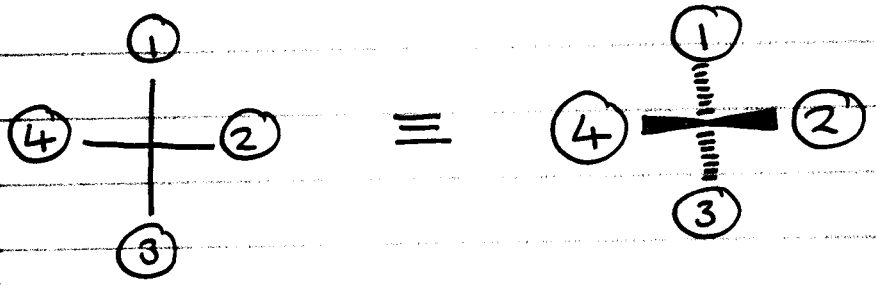
LEC 11 CHEM 30A Feb 4th

1. FISCHER PROJECTIONS
2. CIS/TRANS DIASTEREOISOMERS
3. CONSEQUENCES OF CHIRALITY
4. ACIDS & BASES – INTRO

Read Ch 4
Problems 3.6-3.9, 3.24-3.36

MIDTERM
LOW 9, HIGH 95
MEAN = 67

1. Determining R/S in Fischer Projections



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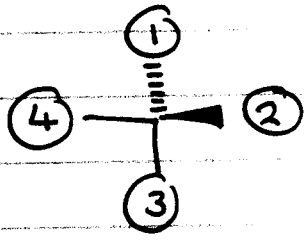


⇐ assign R/S
(THIS ONE IS (S))

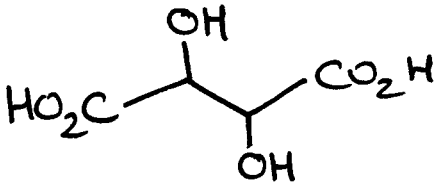
Go back and determine R/S for 2,3,4 trihydroxybutanal

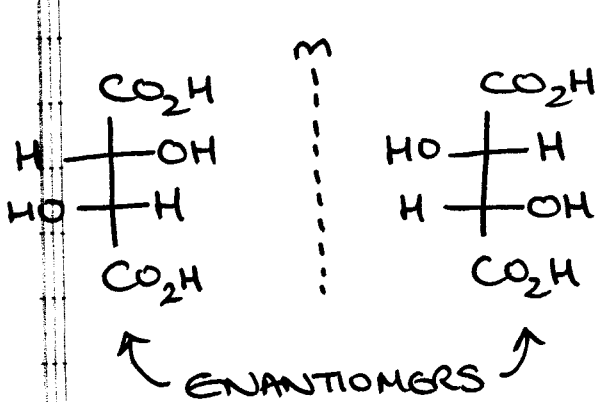
– a molecule with n chiral centers can have a maximum of stereoisomers = 2^n

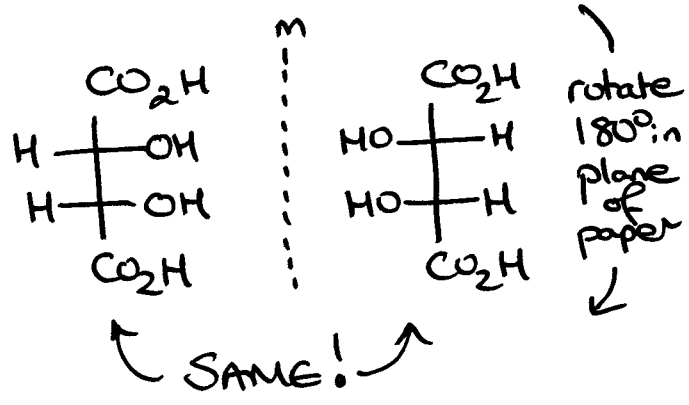
e.g. 2,3,4 trihydroxybutanal has 2 stereocenters

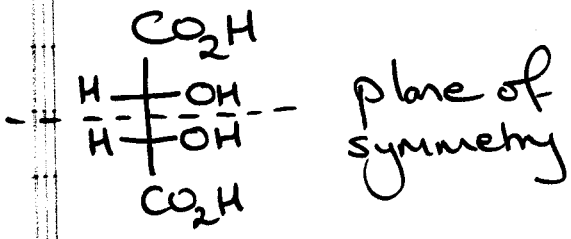
$2^2 = 4$

CONSIDER TARTARIC ACID









Compound w/stereoisomers but is ACHIRAL
$\Rightarrow$ MESO

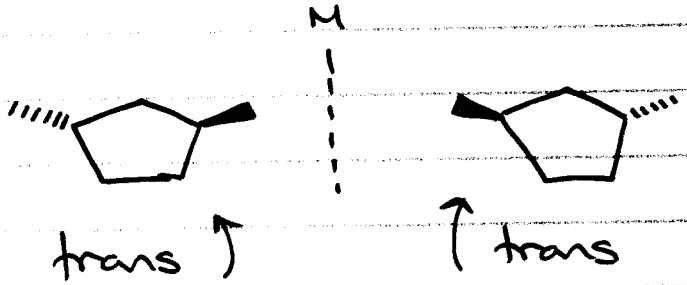
ENANTIOMERS ✓

DIASTEREOISOMERS → CONFIGURATIONAL ✓

DIASTEREOISOMERS → CIS/TRANS → RINGS, ALKENES

RINGS

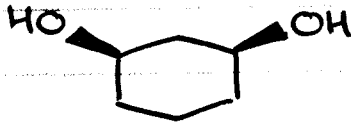
cis
(meso)



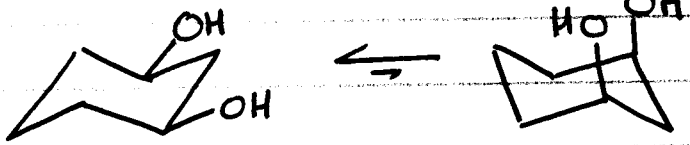
ENANTIOMERS

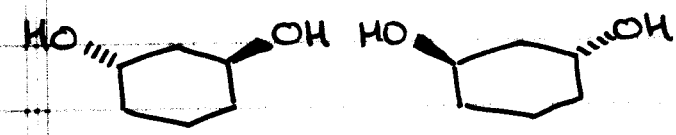
consider CYCLOHEXANES

1,3



cis
(meso)



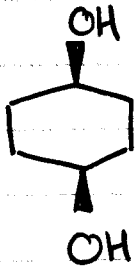


trans
ENANTIOMERS

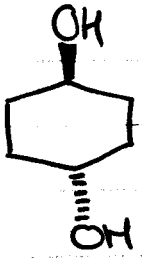
DRAW CHAIR FOR EACH, AND DO A RING FLIP FOR EACH ENANTIOMER

(IN EACH CASE, CHAIRS ARE IDENTICAL)

1,4



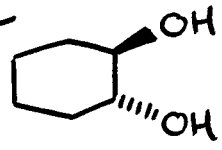
cis



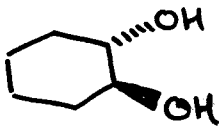
trans

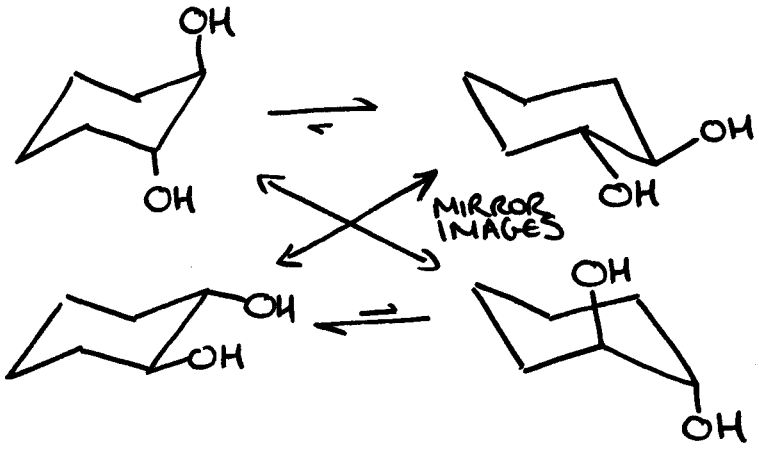
BOTH ACHIRAL

1,2

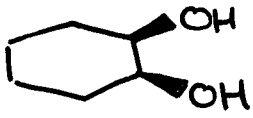


trans

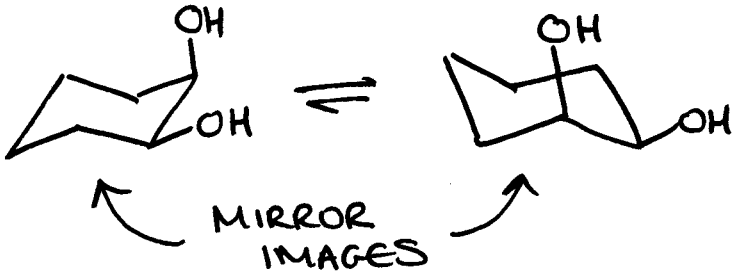




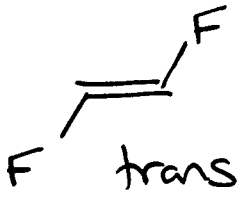
cis



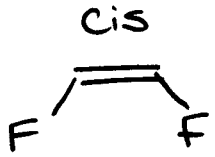
meso



ALKENES

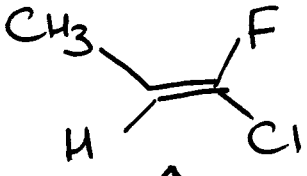


trans



cis

DIASTEREOISOMERS

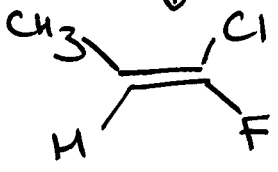


cis / trans? (E)

↑

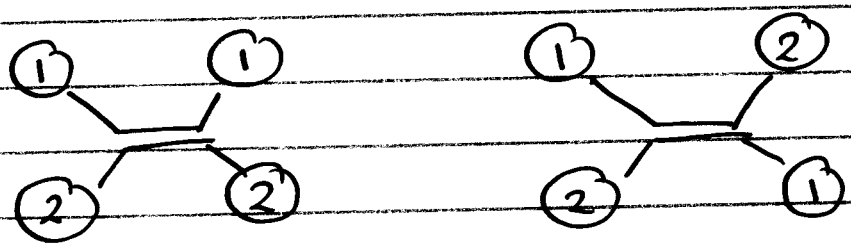
DIASTEREOISOMERS

↓



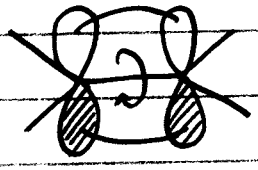
? (Z)

Use same priority rules as for R/S on each C of the 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) CONSEQUENCES OF CHIRALITY

Properties of stereoisomers

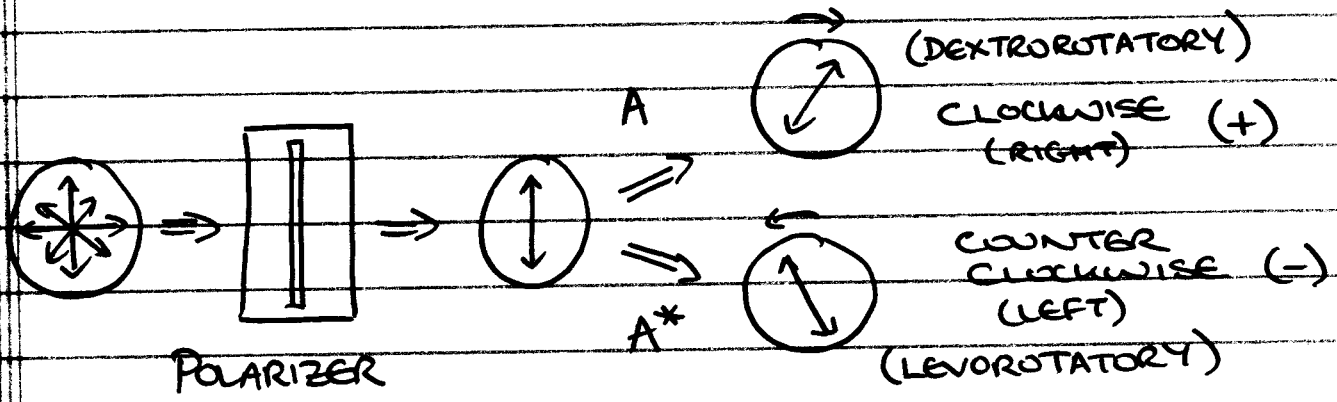
ENANTIOMERS — Identical PHYSICAL & CHEMICAL PROPERTIES (in an ACHIRAL environment)

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

DIASTEREOISOMERS — different....

OPTICAL ACTIVITY

– rotation of plane polarized light



Specific Rotation $[\alpha]_{\lambda}^{T} = \dfrac{\text{Obs rotation}(^\circ)}{\text{Length(dm)} \times \text{conc (g/mL)}}$

T = temperature

λ = wavelength of light

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

NO RELATIONSHIP b/w R/S and +/–

ENANTIOMERIC EXCESS (ee)

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

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

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

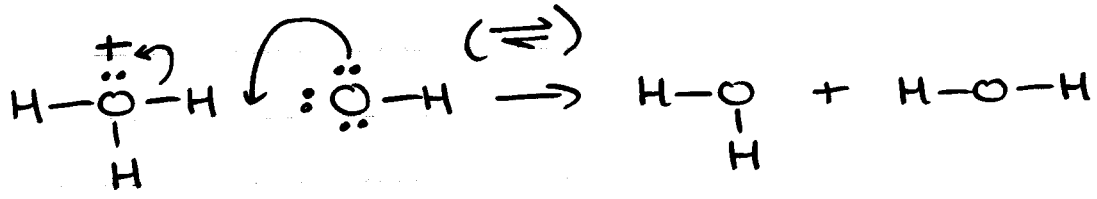
the ee = 90 − 10 = 80%

Read Sections 3.8 and 3.9
↳ chirality in the natural world
(DNA, PROTEINS, ENZYMES, DRUGS)

Chapter (4) ACIDS/BASES

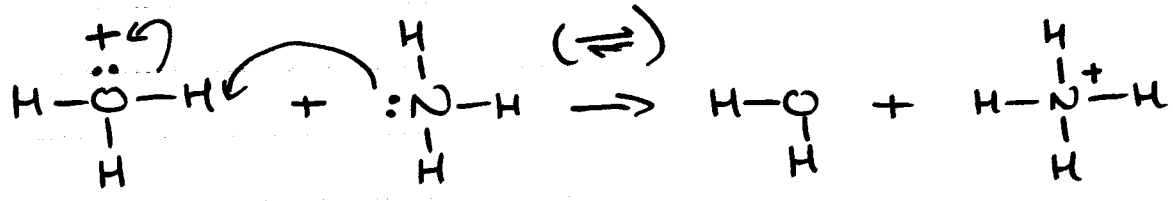
BRONSTED LOWRY ⇒ ACID H^+ DONOR
BASE H^+ ACCEPTOR

e.g.



ACID (H^+ DONOR) hydronium ion

BASE (H^+ ACCEPTOR) hydroxide ion



ACID BASE CONJUGATE BASE CONJUGATE ACID

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 pka values

$pK_a = -\log_{10} K_a$

$pK_a (CH_3CO_2H) = 4.76$

LARGER pka VALUE → WEAKER ACID

STRONG ACID ≡ WEAK CONJUGATE BASE / WEAK ACID ≡ STRONG CONJUGATE BASE

scan to table page 147

LEC (12) CHEM 30A Feb 7th

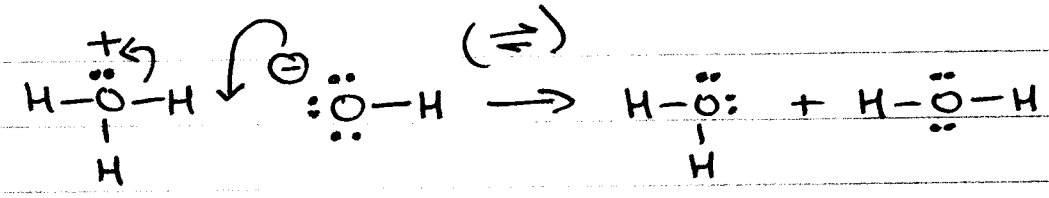
ACIDS & BASES

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

READ Ch4, PROBLEMS 4.1 → 4.45

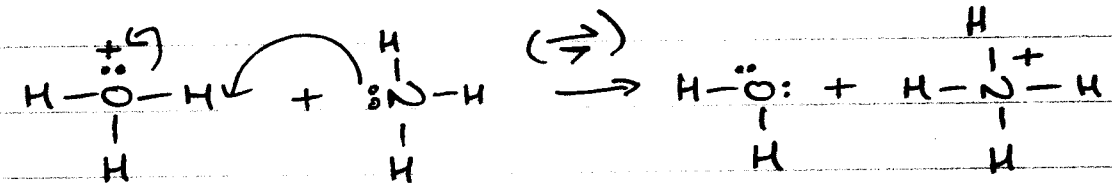
(1) BRONSTED LOWRY ⇒ ACID H^+ DONOR
BASE H^+ ACCEPTOR

e.g.



ACID
H^+ DONOR
hydronium ion

BASE
H^+ ACCEPTOR
hydroxide ion



ACID BASE CONJUGATE BASE CONJUGATE ACID

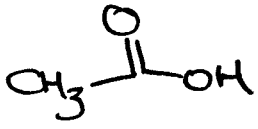
(2) ACID/BASE EQUILIBRIA

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 

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

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

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

$$pK_a (CH_3CO_2H) = 4.76$$

LARGER pK_a VALUE → WEAKER ACID

STRONG ACID = WEAK CONJUGATE BASE
WEAK ACID = STRONG CONJUGATE BASE

Scan through table on page 141

- POSITION OF ACID BASE EQUILIBRIA

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

Competition between B^- and A^- for $H^{\oplus}$

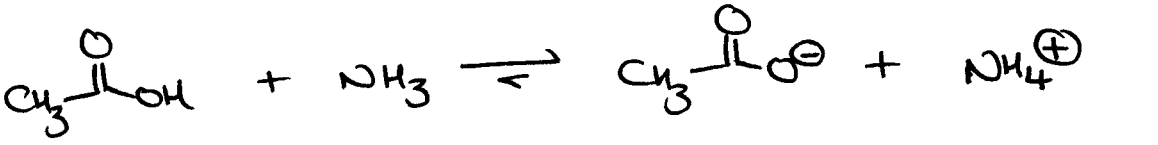
$$K_{eq} = \frac{[A^-][HB]}{[HA][B^-]}$$

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

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

$$K_{eq} = \frac{K_{HA} \text{ (ACID)}}{K_{HB} \text{ (CONJUGATE BASE)}}$$

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



ACID BASE CONJUGATE BASE CONJUGATE ACID

pka 4.76 pka 9.24

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

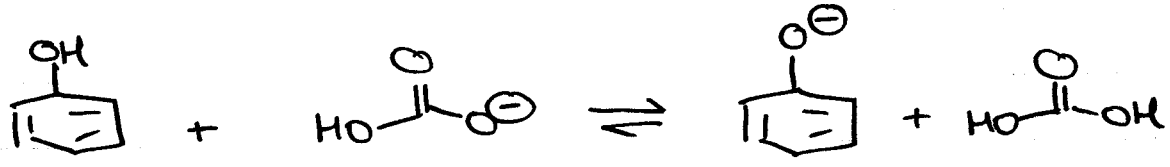
$K_{eq} = 10^{-pK_{eq}}$

$= 3 \times 10^4$

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

If stronger acid on left $K_{eq} > 1$
If stronger acid on right $K_{eq} < 1$

For example



pka ~10 pka ~ 6.4

STRONGER ACID

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

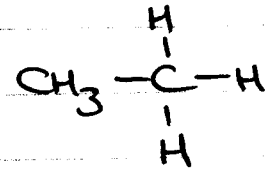
(3) STRUCTURE AND ACIDITY

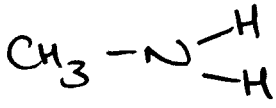
$HA \rightleftharpoons H^+ + A^-$ all about A^-

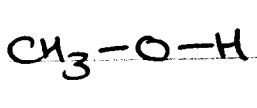
The more stable A^-, the more acidic HA is

a) ELECTRONEGATIVITY

consider:

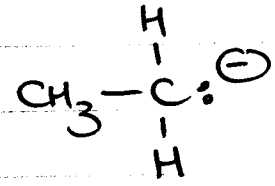


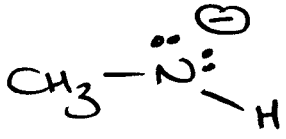


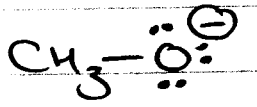


pka	51	38	16

⟶ INCREASING ACIDITY







conjugate bases

⟵ INCREASING BASICITY

C	N	O
2.5	3.0	3.5

Larger EN, electrons held more strongly, A^- more stable

This trend holds across any given row of the periodic table

b) ATOM SIZE

consider:

CH_3-S-H vs CH_3-O-H

pka 7 16

$CH_3-S^{\ominus}$ $CH_3O^{\ominus}$

↑

more stable

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

So, for HALOGEN ACIDS

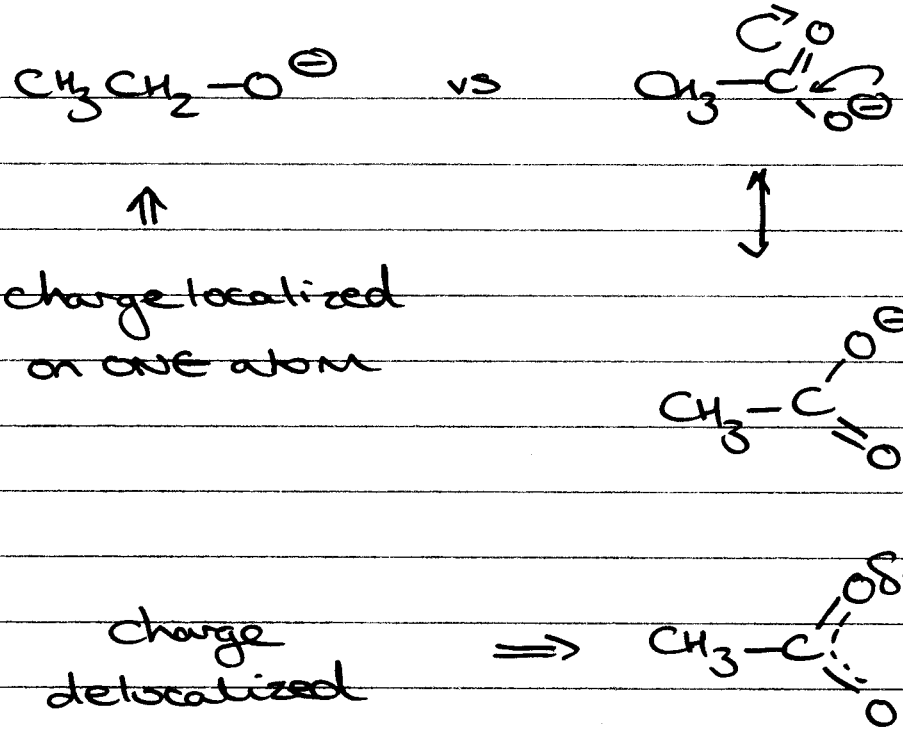
$HI > HBr > HCl > HF$

c) RESONANCE

consider:

CH_3CH_2-O-H vs $CH_3-C(=O)-OH$

pka 16 5



DELOCALIZATION ≡ STABILITY

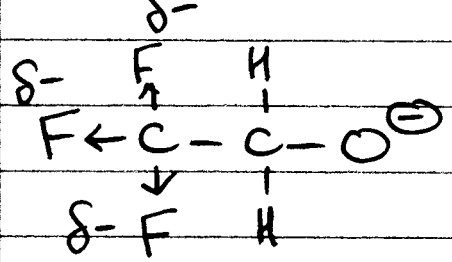
(hot potato analogy)

d) INDUCTIVE EFFECT

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

pka 15.9 12.4

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

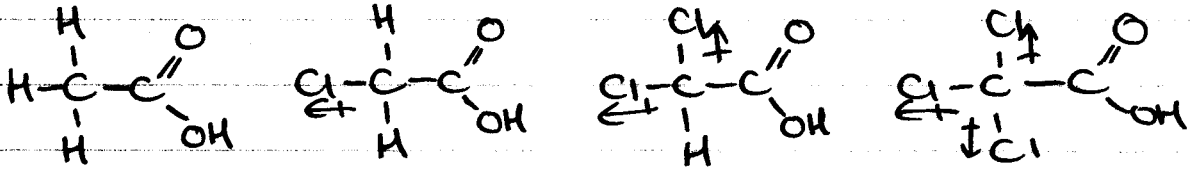


THROUGH BOND EFFECT

falls off rapidly w/ distance

	CF_3CH_2OH	$CF_3CH_2CH_2OH$	$CF_3CH_2CH_2CH_2OH$
pka	12.4	14.6	15.4

Same effect on carboxylic acids



4.75	2.85	1.48	0.64

e) HYBRIDIZATION

CH_3CH_2-H (sp^3) pka 51

↓ MORE ACIDIC

$CH_2=CH-H$ (sp^2) 44

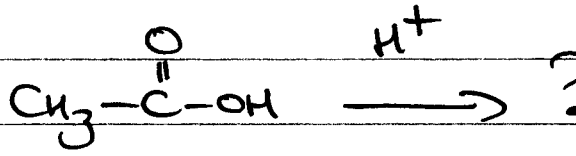
↓

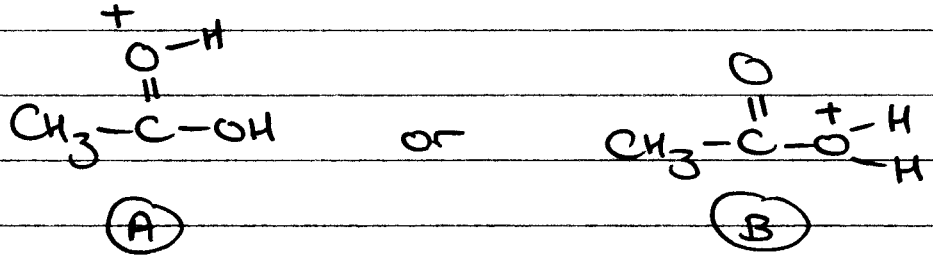
$H-C\equiv C-H$ (sp) 25

S character of orbitals 25% → 33% → 50%

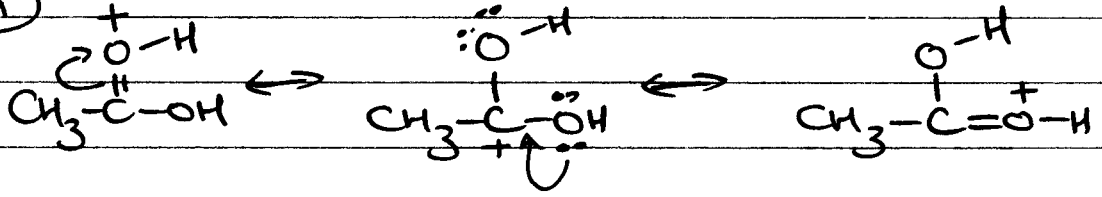
electrons held closer to the nucleus
- more stable anion
- more acidic

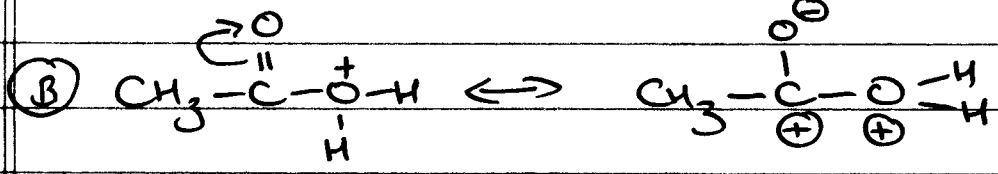
(4) ORGANIC STRUCTURES

(i) 

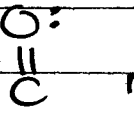
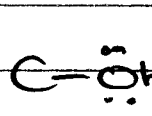


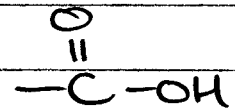
consider resonance

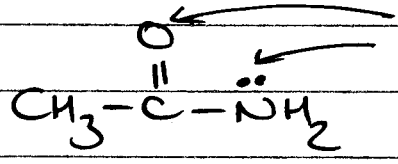
(A) 

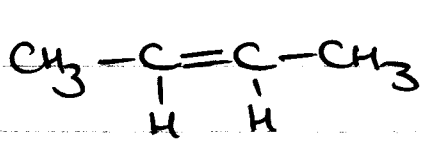
(B) 

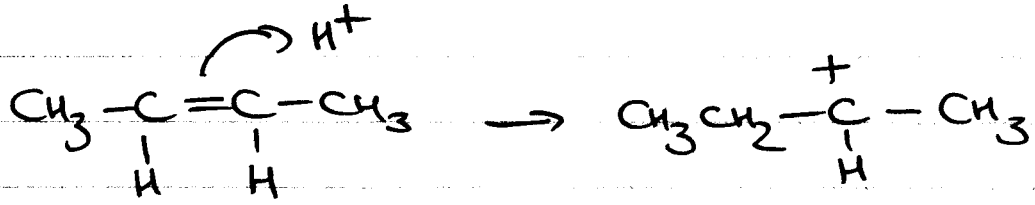
not a good resonance form

So  more basic than 

in 

HMK  which is more basic

(ii)  + H^+ → ?

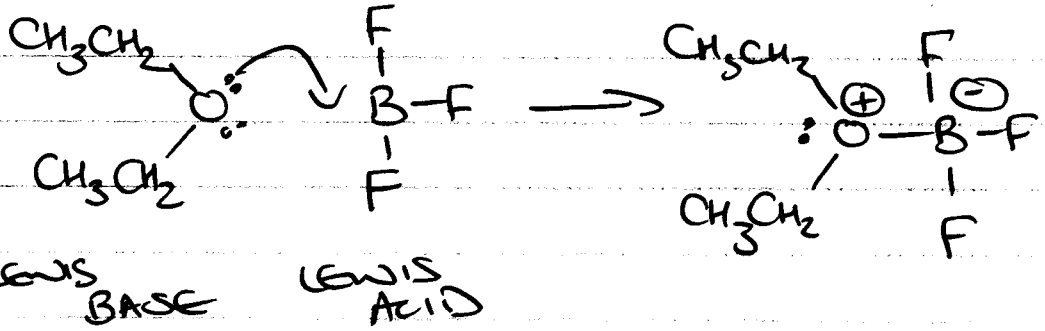


(see a lot more of these soon)

(5) LEWIS ACIDS / BASES

about e^- pairs, not H^+

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

e.g. 

LEC (13) CHEM 30A Feb 9th

— acids and bases
(1) STRUCTURE & ACIDITY
(2) PROTONATING ORGANIC STRUCTURES
(3) LEWIS ACIDS / BASES
— organic reactions
(4) TYPES
(5) MECHANISMS
(6) ENERGY DIAGRAMS (next lecture)

Finish problems 4.1 → 4.45
+ acid/base problem set on WEB

Read Ch5, (Alkene intro) Problems 5.2, 5.6-5.10, 5.13-5.19
6.1 - 6.3 6.1, 6.2

---

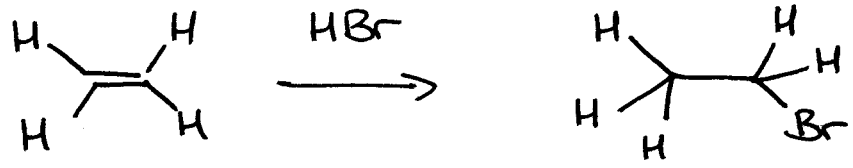
(1) STRUCTURE & ACIDITY
a) Electronegativity (of atom w/ -ve charge)
b) Size (of atom w/ -ve charge)

c) RESONANCE... continue
Page 6 - 10 of Lec (12)

— ORGANIC REACTIONS
(4) TYPES

a) ADDITION (A + B → C)

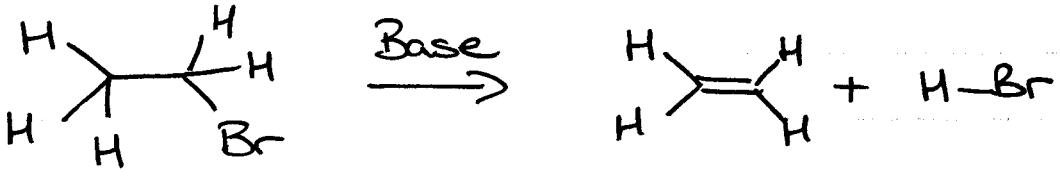
e.g.



alkene alkyl halide

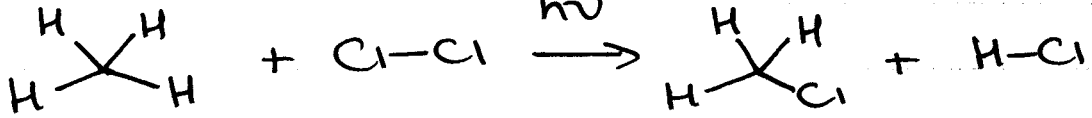
b) ELIMINATION (A ⟶ B + C)

e.g.



c) SUBSTITUTION (A–B + C–D ⟶ A–C + B–D)

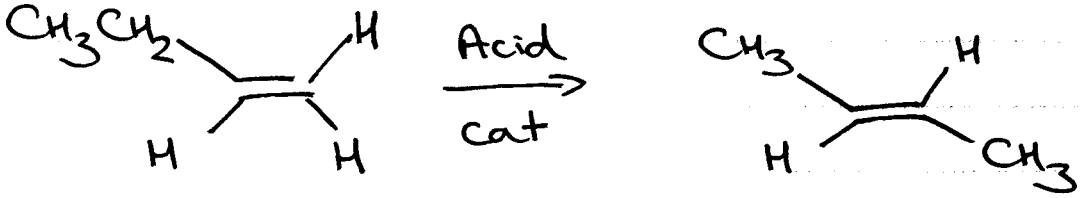
e.g.



alkane alkyl halide

d) REARRANGEMENT (A ⟶ B)

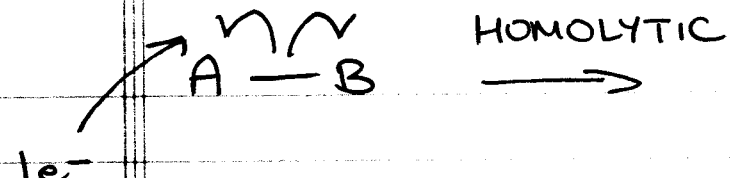
e.g.



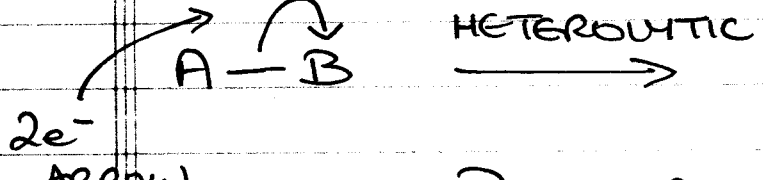
(5) MECHANISMS

BOND MAKING / BOND BREAKING

- BOND BREAKING

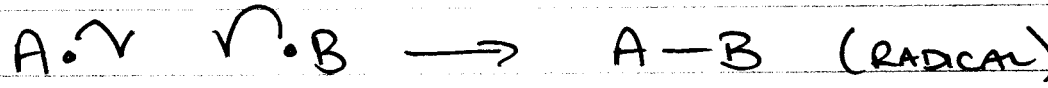


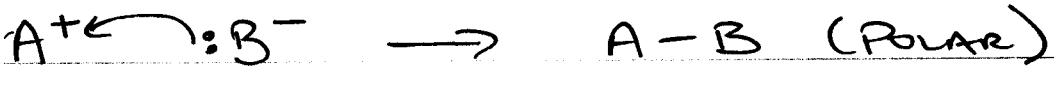
RADICAL REACTIONS → a radical is a neutral chemical species that contains a single unpaired electron



POLAR REACTIONS

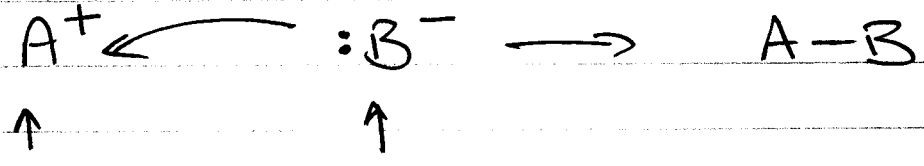
- BOND MAKING





- POLAR REACTIONS
(radical reactions at end of course)

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

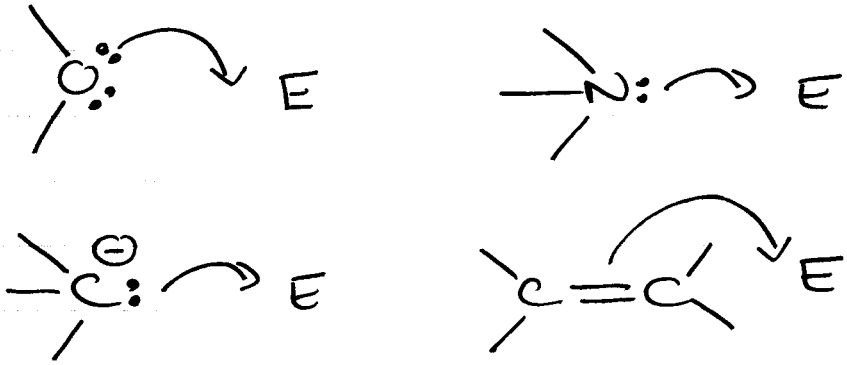


Nucleophiles : have an e^- rich atom and are NEUTRAL or −VELY charged

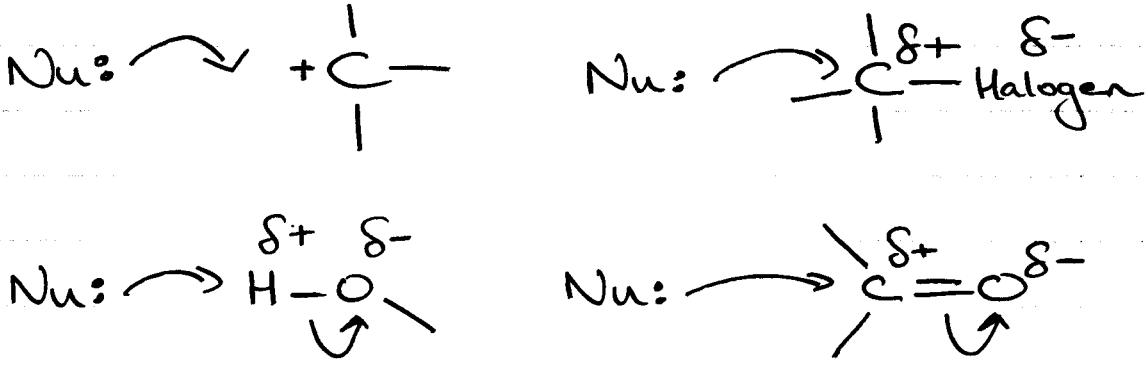
Electrophiles : have an e^- poor atom and are NEUTRAL or +VELY charged

Patterns

Electrons flow <u>from</u> nucleophiles

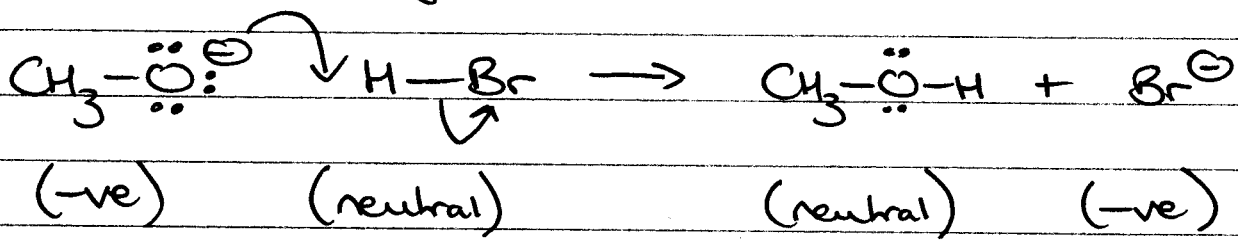


Electrons flow <u>to</u> electrophiles

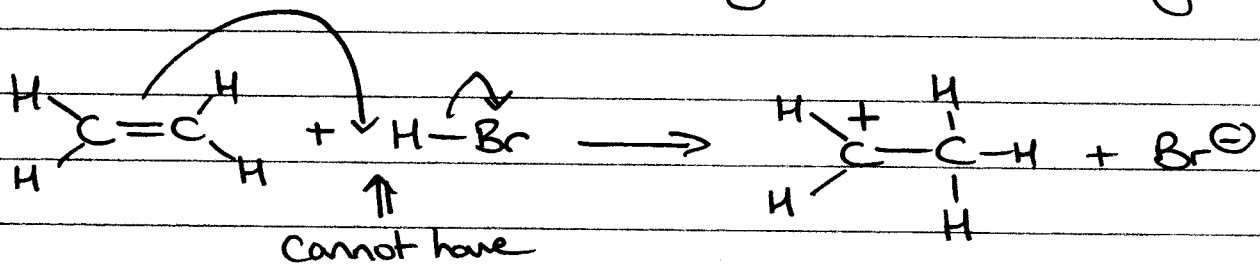


RULES

- conserve charge



- octet rule must be obeyed (if necessary)



Cannot have 2 BONDS TO H, so H–Br bond breaks

note that overall charge is conserved.

LEC (14) CHEM 30A Feb 11th

(1) ELECTROPHILES / NUCLEOPHILES
(2) ENERGY DIAGRAMS
(3) KINETICS VS THERMODYNAMICS

HMK: READ 6 – 6.5

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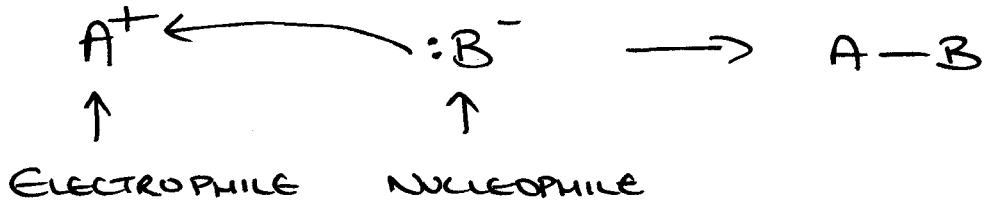
(1) ELECTROPHILES / NUCLEOPHILES



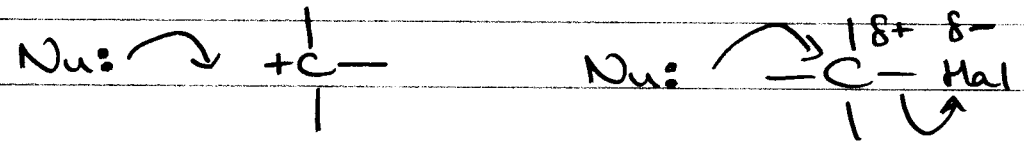
Nucleophiles : have an e^- rich atom and are NEUTRAL or –VELY charged

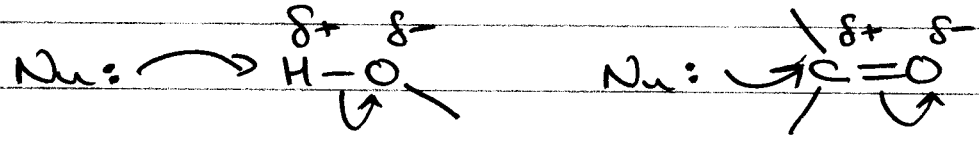
Electrophiles : have an e^- poor atom and are NEUTRAL or +VELY charged.

PATTERNS

Electrons flow FROM nucleophiles

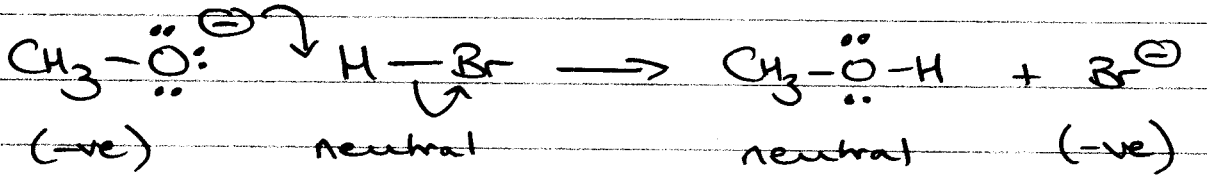
Electrons flow to electrophiles



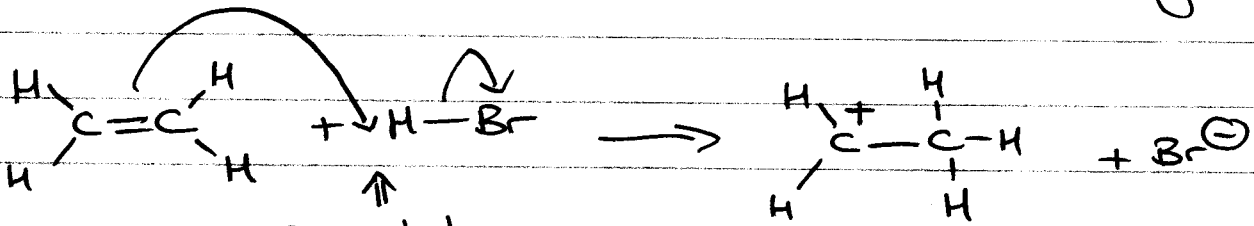


Rules

- conserve charge



- octet rule must be obeyed (if necessary)



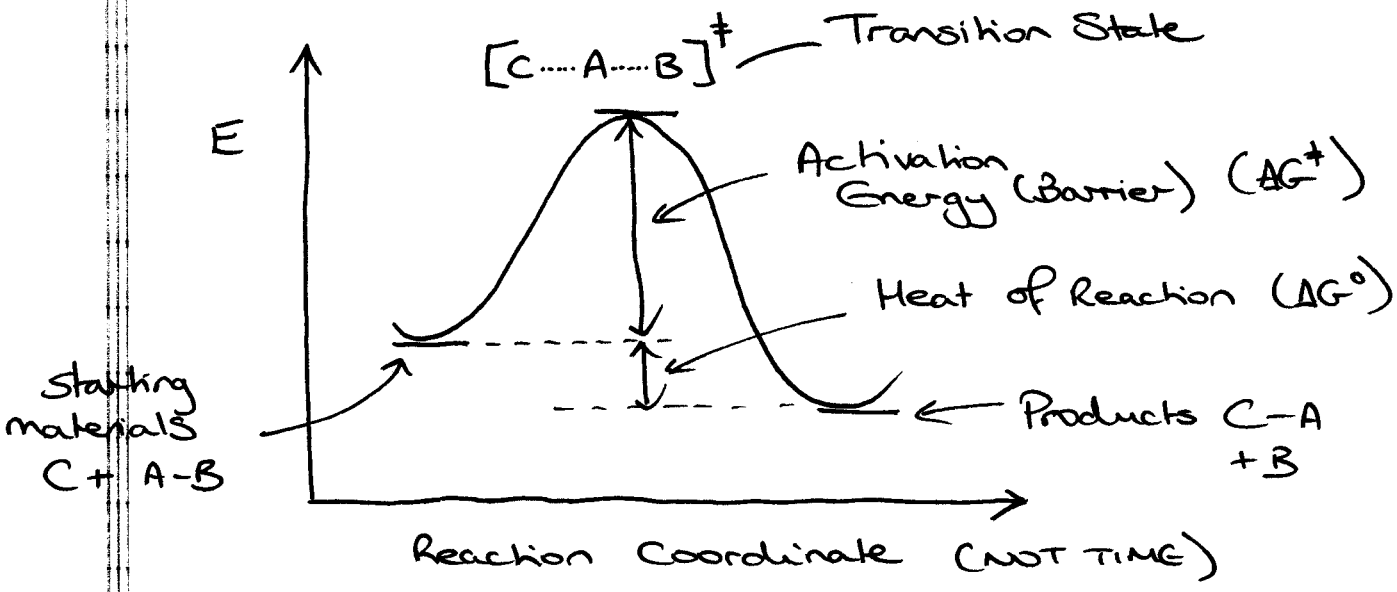
cannot have 2 BONDS to H, so H-Br bond breaks

note that overall charge is conserved

(2) 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

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$

ΔH°: change in enthalpy (CAN BE MEASURED DIRECTLY)

$T\Delta S^\circ$: change in ENTROPY (more significant at higher T)

ΔH° −ve EXOTHERMIC Rxn

ΔH° +ve ENDOTHERMIC Rxn

- TRANSITION STATE

Energy maximum on reaction co-ordinate

⇒ definite geometry and arrangement of atoms but CANNOT BE ISOLATED, STRUCTURE CANNOT BE DETERMINED EXPERIMENTALLY

(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

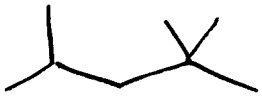
$k = Ae^{(-E_A/RT)}$

↑ ← pre-exponential factor

rate constant of reaction

(3) KINETICS vs THERMODYNAMICS

↓	↓
How fast will it happen	Will it happen

e.g.  + O_2 ⇌ $8CO_2 + 9H_2O$

isooctane

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

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

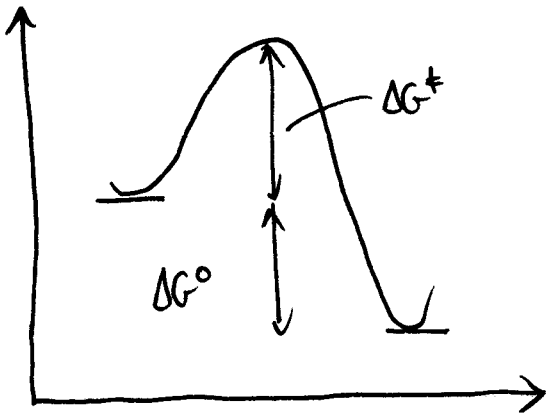
(only 10^{86} atoms in the observable universe!)

<u>But</u> isooctane is <u>stable</u>

(you put it in your car)

Energy is required to start the reaction

⇒ ACTIVATION ENERGY (spark plug!)



So, isooctane + oxygen

THERMODYNAMICALLY UNSTABLE,

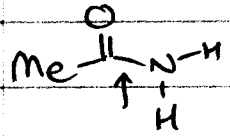
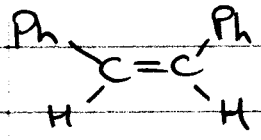
BUT

KINETICALLY STABLE!

However → apply a burst of energy to a mixture of H_2O and CO_2, they will not reconvert to octane and oxygen

ENERGY BARRIERS and RATE

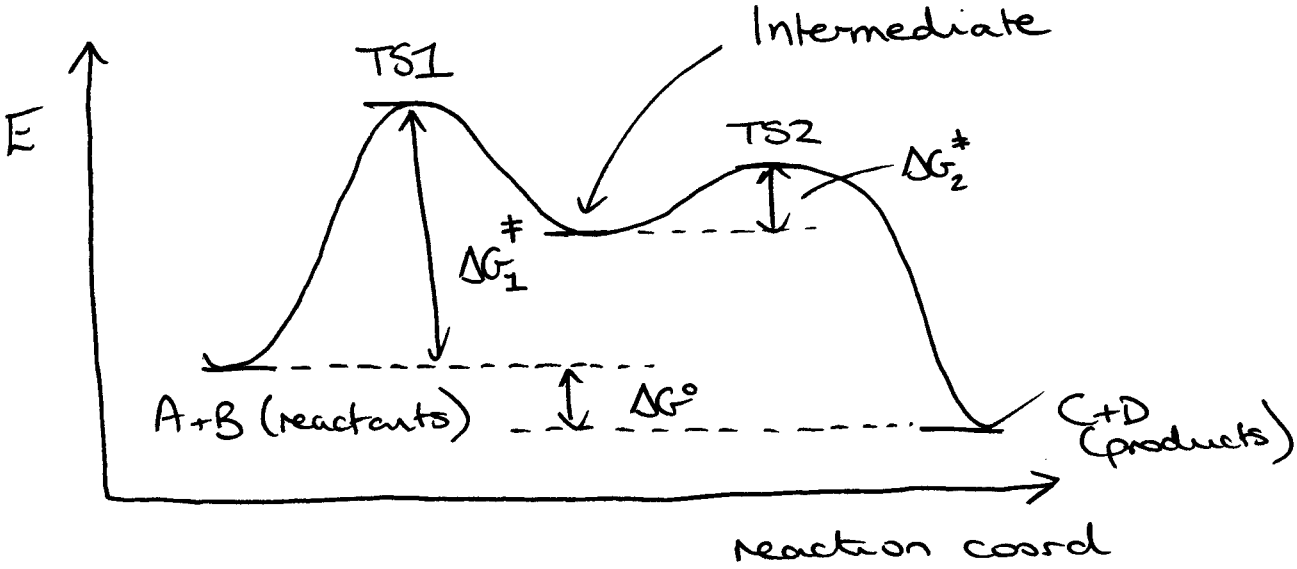
(consider BOND ROTATIONS → same principles apply to reactions)

	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 ps
	17	3	0.2 s
	45	2×10^{-9}	$\sim10^{11}$ years

(AGE of the EARTH $\sim 4.6 \times 10^9$ years)

BACK TO ENERGY PROFILES

⇒ TWO STEP REACTION



Reaction Intermediate

=> localized energy minimum between two transition states

(sometimes possible to isolate)

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

LEC (15) CHEM 30A Feb 14th

1. ENERGY PROFILES
2. ADDITION TO ALKENES
3. CARBOCATIONS ⟸ (i) ADDITION of H_2O (ii) REARRANGEMENT
4. ADDITION OF Br_2 / Cl_2

HMK: Read 6-6.5 Prob 6.3-6.8, 6.14-6.16
Quiz on WEDNESDAY

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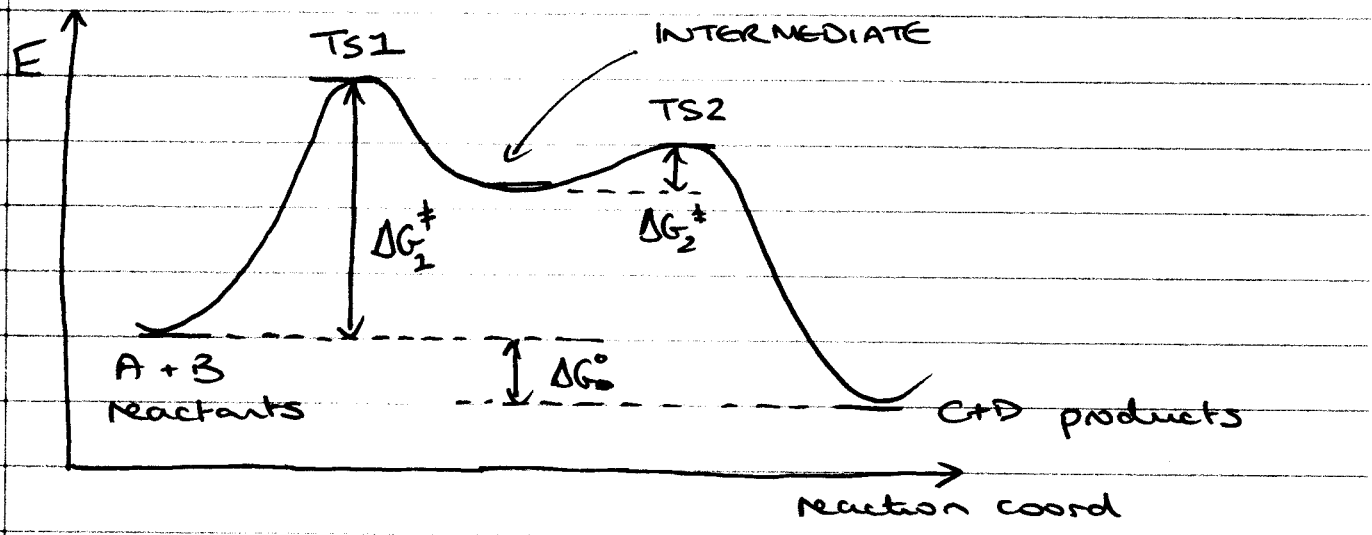
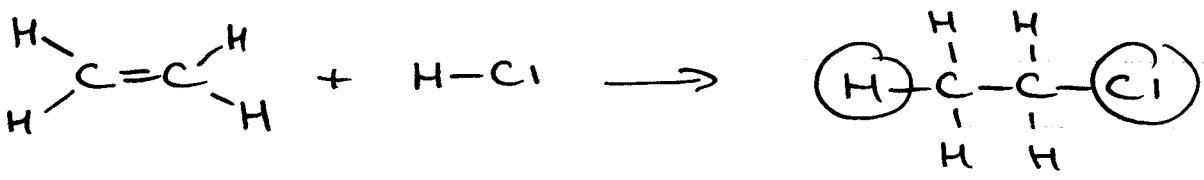
(1) ENERGY PROFILES



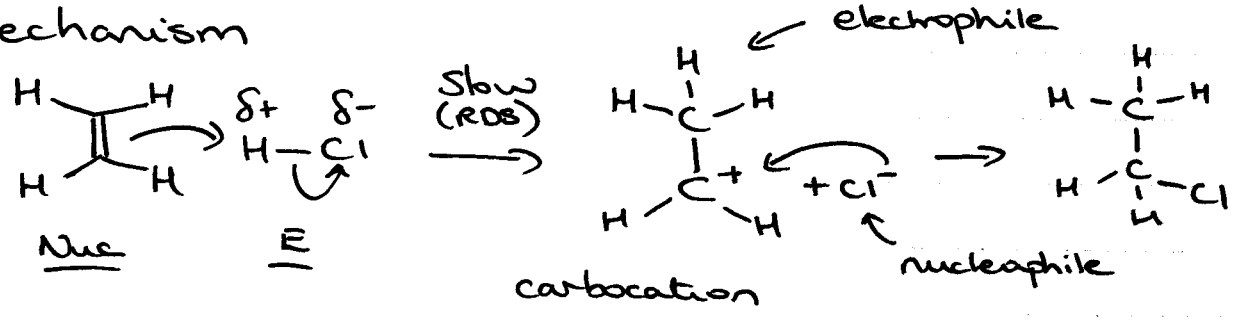
REACTION INTERMEDIATE ⇒ localized energy minimum between two TRANSITION states (sometimes possible to isolate)

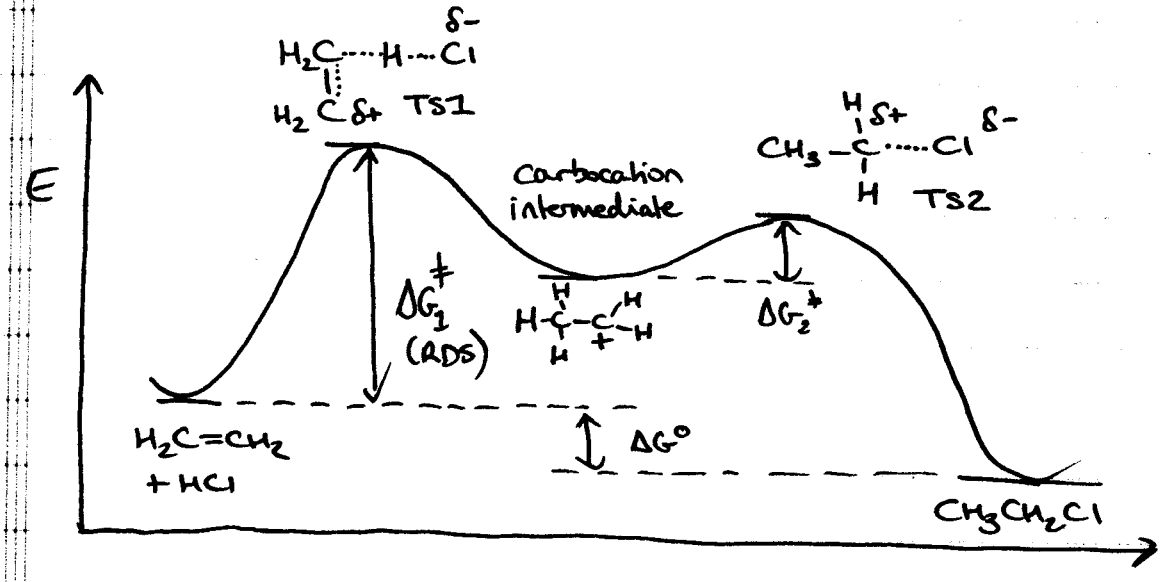
SLOWEST STEP in a multistep process (one w/highest barrier) is called the RATE DETERMINING STEP (RDS)

(2) ELECTROPHILIC ADDITION TO ALKENES

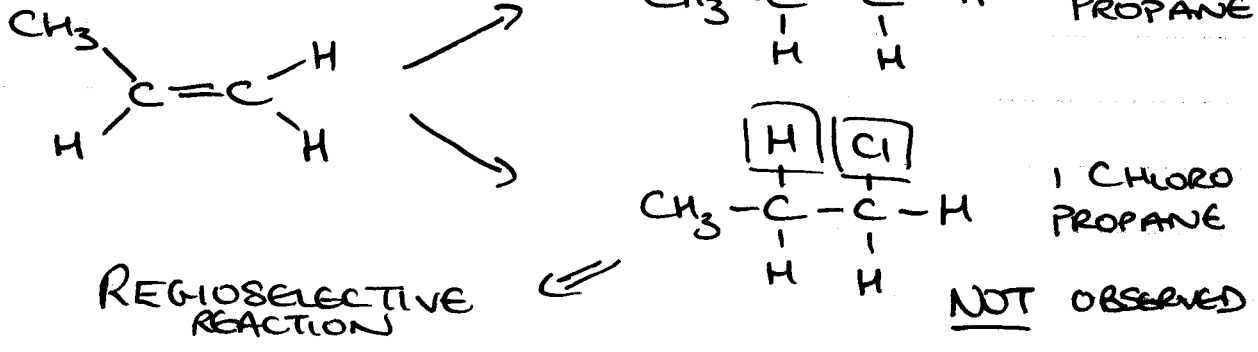


mechanism





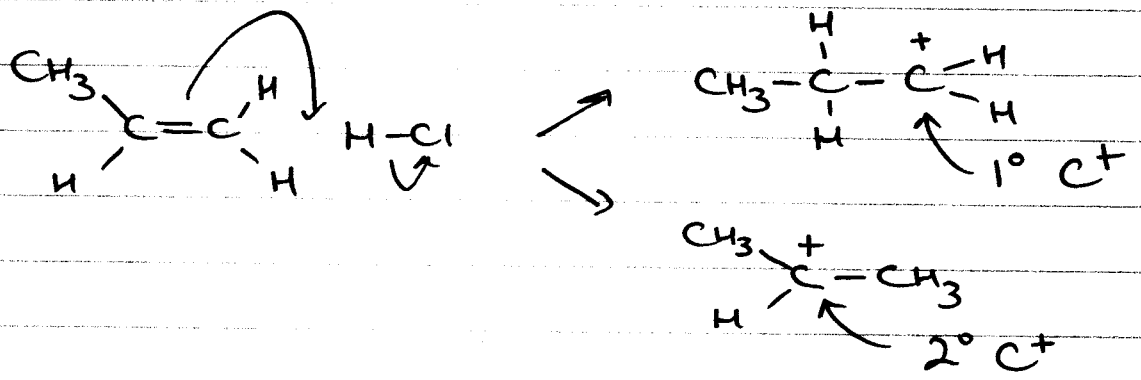
NOW CONSIDER:



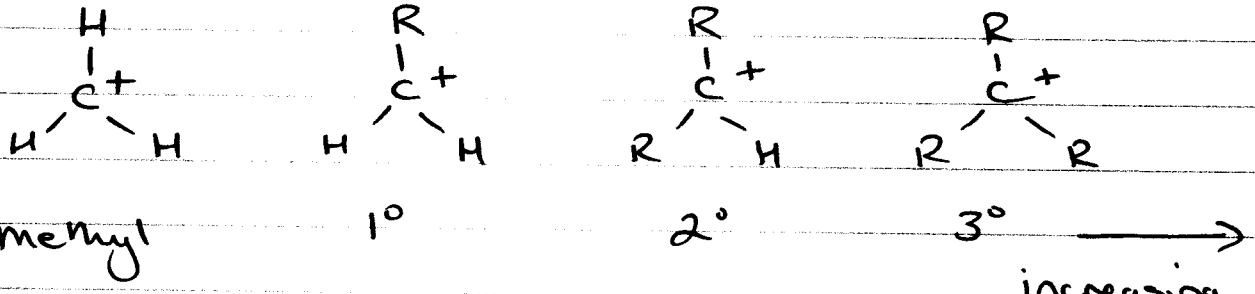
MARKOVNIKOV'S RULE:

Addition of H–X to an ALKENE, H adds to the double bonded C atom with greatest number of H atoms.

WHY? ⇒ CARBOCATIONS (3)

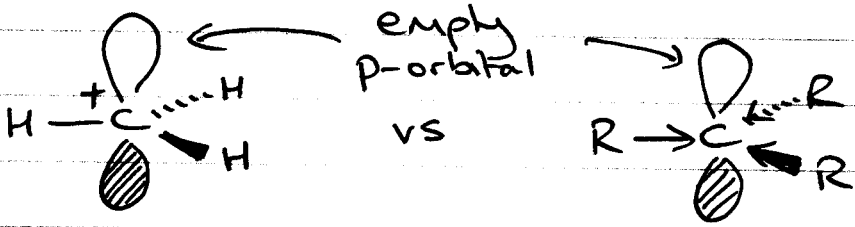


STABILITY (R = ALKYL)



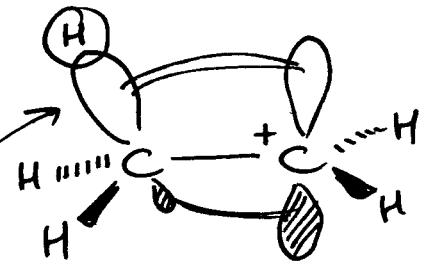
TWO FACTORS: (i) INDUCTIVE EFFECT
(ii) HYPERCONJUGATION

(i)



ALKYL GROUPS ARE INDUCTIVELY DONATING

(ii)



filled sp^3–1s σ orbital

← empty p orbital

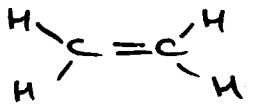
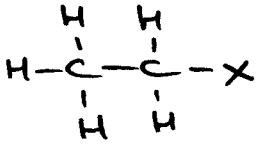
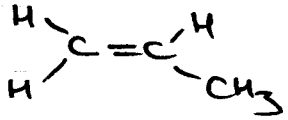
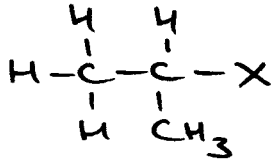
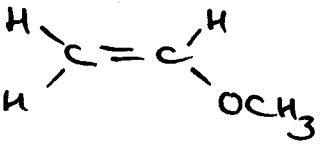
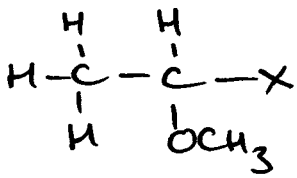
DELOCALIZATION of an adjacent σ BONDS electrons into the empty p-orbital

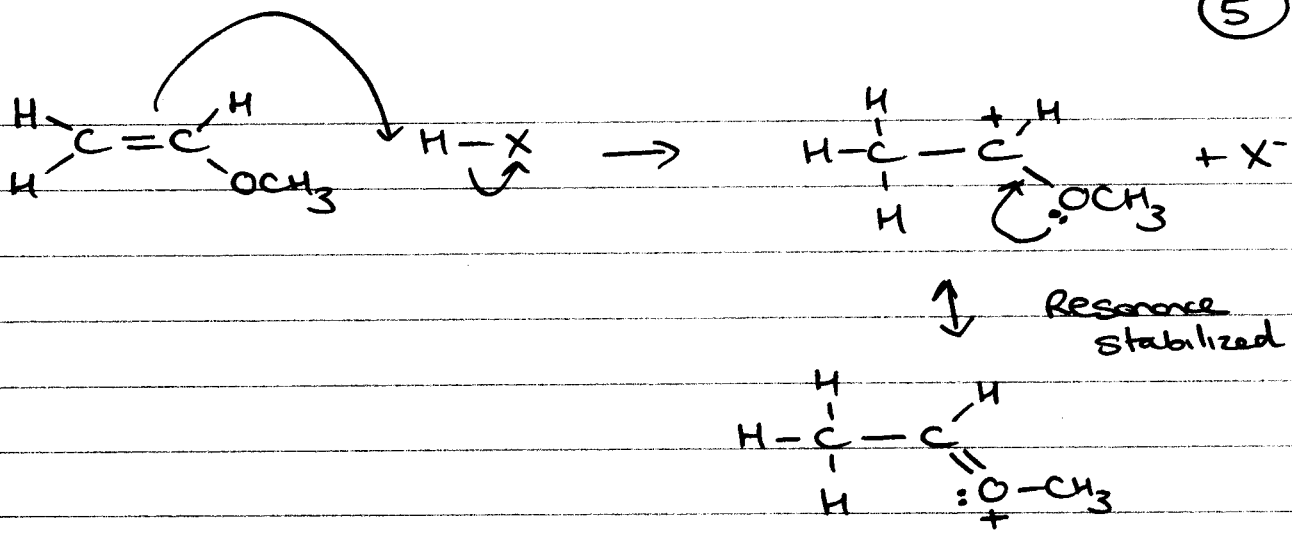
⇒ HYPERCONJUGATION

the more C–H bonds, the more significant the stabilization, so $Me^+ < 1° < 2° < 3°$

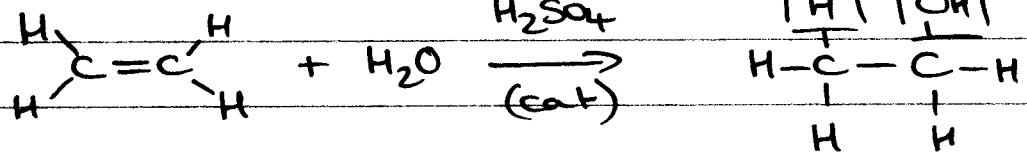
.... AND OTHER FACTORS.... (RESONANCE)

Consider:

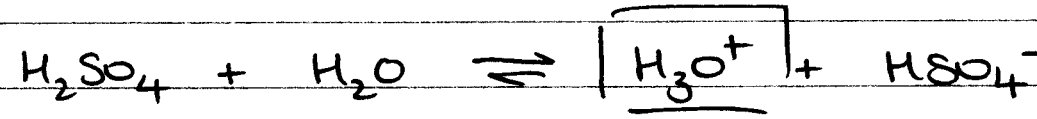
		relative rate
		1
		2×10^6
		5×10^{14}

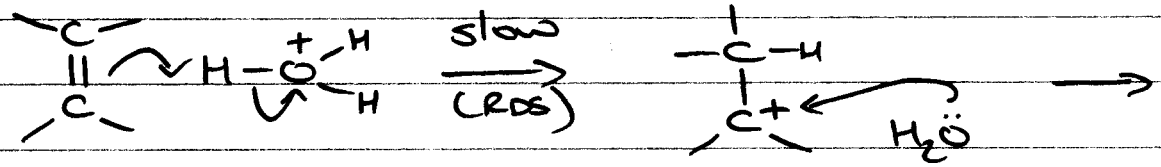


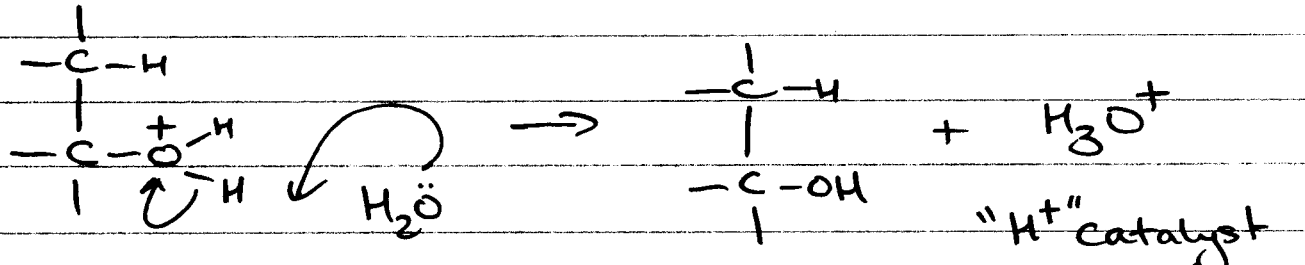
(i) ADDITION of H_2O (acid catalyzed hydration)



H_2O cannot protonate a C=C bond, like H-Cl or H-Br, but:



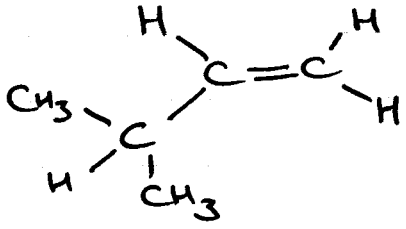


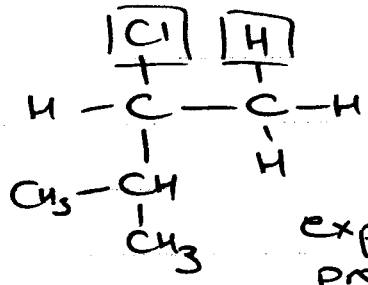


"H⁺" catalyst regenerated.

mechanism involves a carbocation, so proceeds with MARKOVNIKOV regioselectivity

(ii) – CARBOCATION REARRANGEMENT

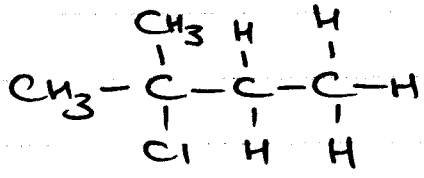




2 CHLORO – 3 METHYL BUTANE

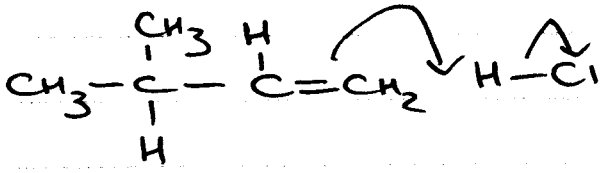
expected product ~40%

– other 60% ?

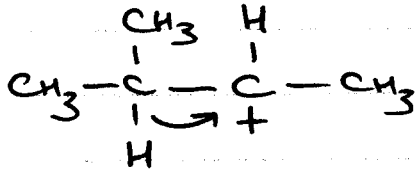


2 CHLORO – 2 – METHYL BUTANE

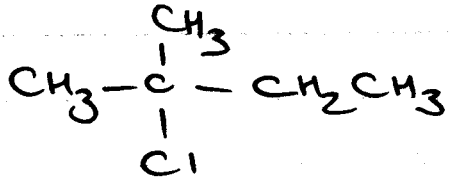
WHY?

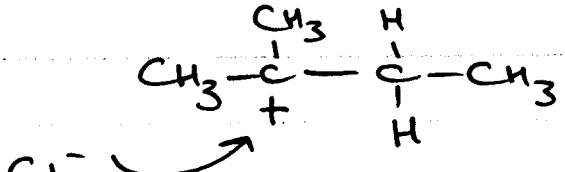


2° C+



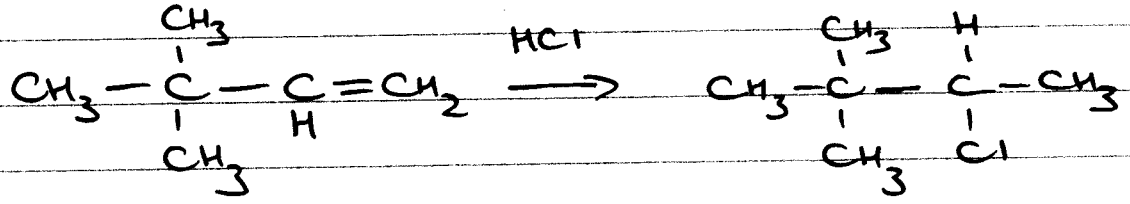
1,2 hydride shift (H–)





3° C+ (more stable)

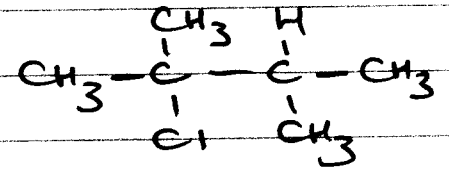
Rearrangement can happen wherever you have a CARBOCATION, so also happens in ACID cat hydration



Minor (20%)

SHOW WHY THIS HAPPENS ⟹

(NOT A H^- SHIFT, BUT A 1,2 METHYL SHIFT)



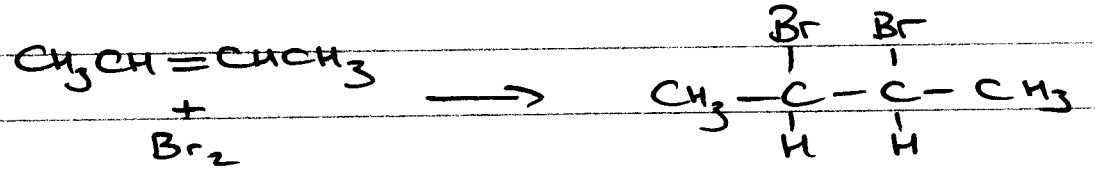
Major (80%)

2° CARBOCATIONS ↻ 3° CARBOCATIONS

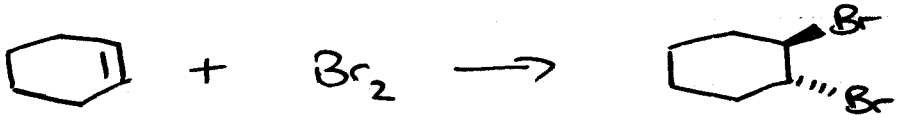
(v. rarely rearrange in reverse direction)

Don't really need to worry about 1° C^+ as in reality they do not form during reactions in solution as they are so unstable.

(4) ADDITION of Br_2/Cl_2

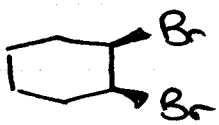


Note



trans 1,2-dibromo cyclohexane

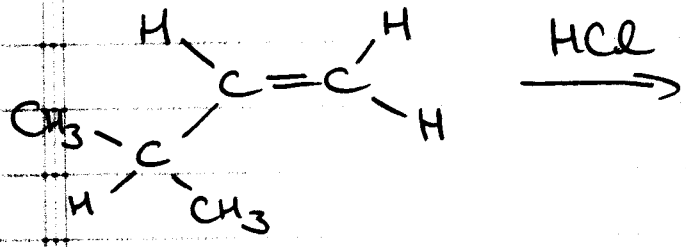
STEREOSPECIFIC REACTION

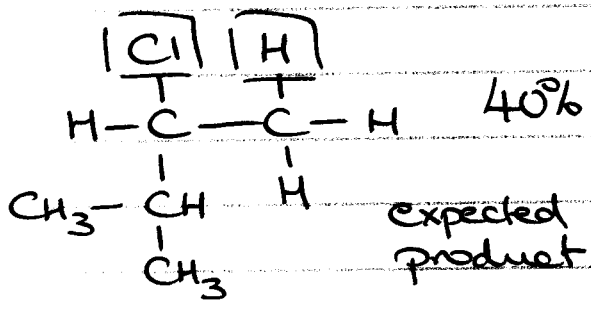
DO NOT FORM ANY  — WHY?

LEC (16) CHEM 30A Feb 16th

1. CARBOCATION REARRANGEMENT
2. ADDITION of Br_2 / Cl_2
3. ADDITION of HOCl / HOBr
4. OXYMERCURATION

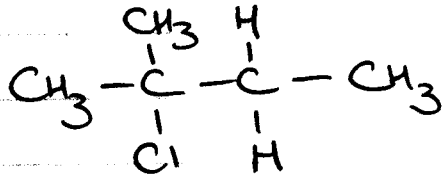
(1) C^+ REARRANGEMENT





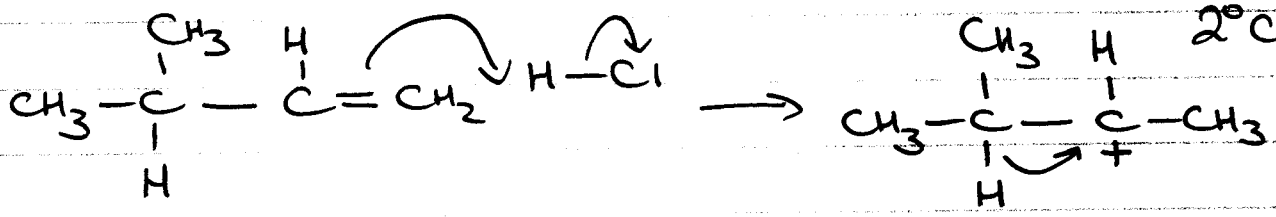
2CHLORO-3-METHYLBUTANE

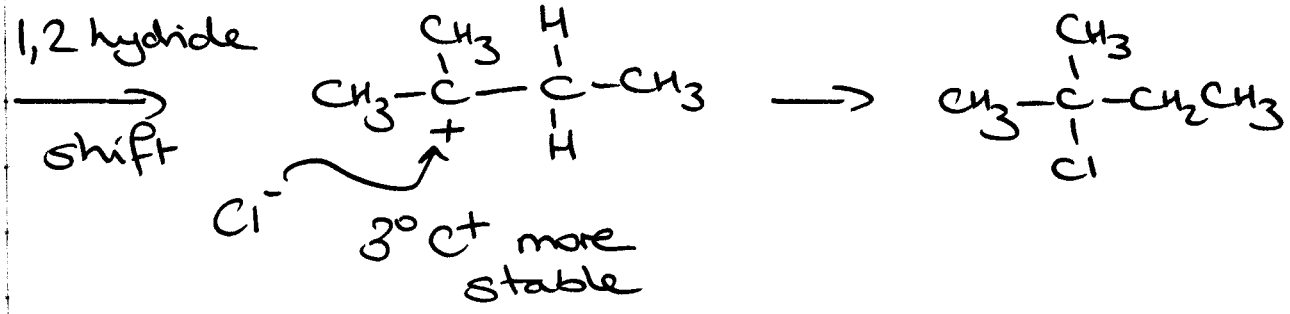
— other 60%



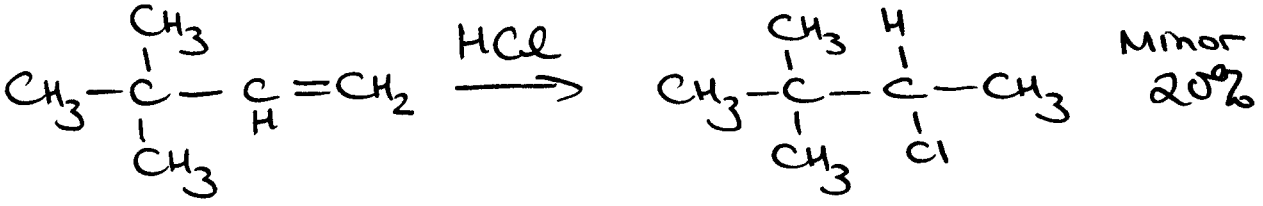
2 CHLORO-2-METHYL BUTANE

WHY? — MECHANISM

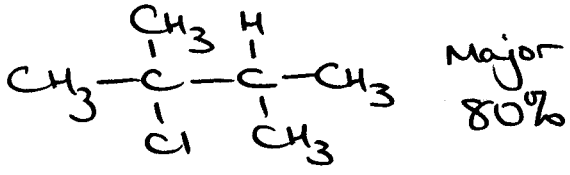




Rearrangement is possible anytime you form a CARBOCATION, so can also happen w/ ACID catalyzed hydration



1,2 METHYL SHIFT, not 1,2 hydride shift

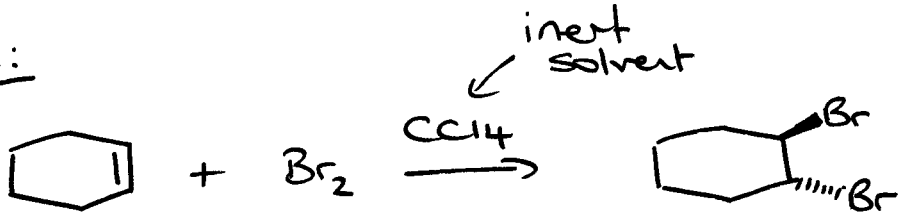


2° C+ ⟷ 3° C+
(rarely go in the reverse direction)

Don't worry about 1° C+ as in reality they do not form during reactions in solution as they are so unstable

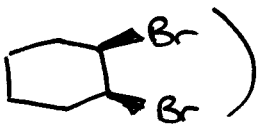
(2) ADDITION of Br_2/Cl_2

ote:



trans 1,2 dibromocyclohexane

STEREOSPECIFIC reaction

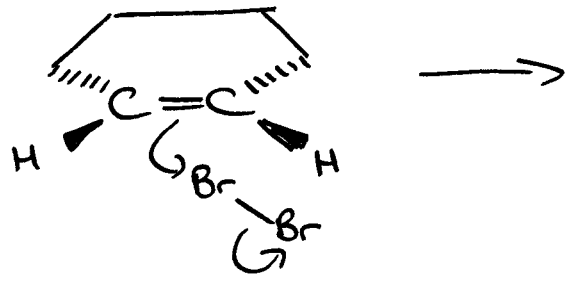
CIS ISOMER  IS NOT formed

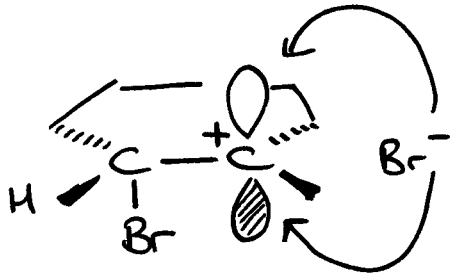
NOTE:

STEREOSPECIFIC exclusion (REGIO)
STEREOSELECTIVE preference

- consider mechanism

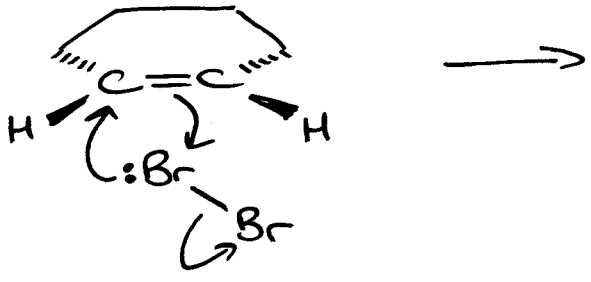
IF

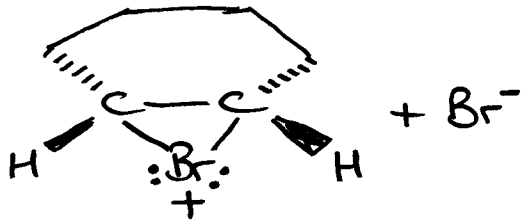




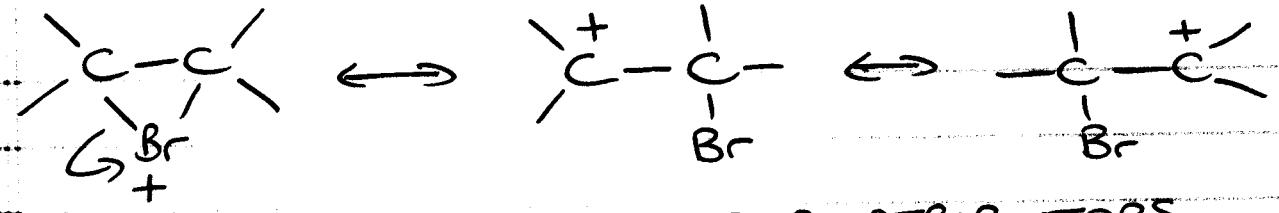
could give cis or trans

mechanism is:

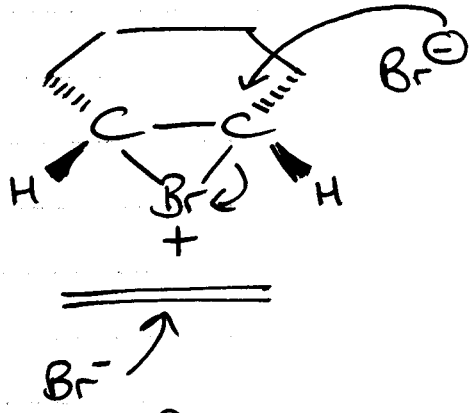




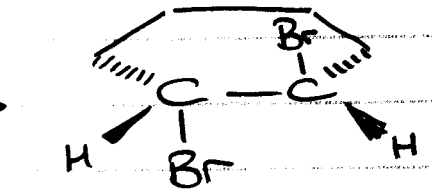
CYCLIC BROMONIUM ION



MINOR CONTRIBUTORS

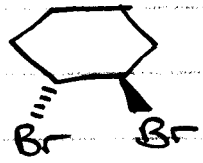


Bottom face attacked is BLOCKED



attack occurs from TOP FACE

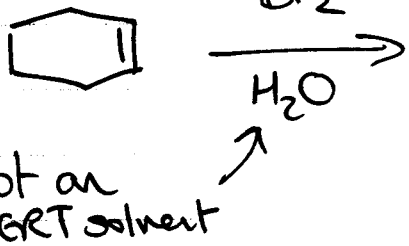
⟹ ANTI-STEREOSPECIFICITY



TRANS

IF OTHER C ATOM ATTACKED, OTHER ENANTIOMER FORMED

(3) ADDITION of HOCl/HOBr

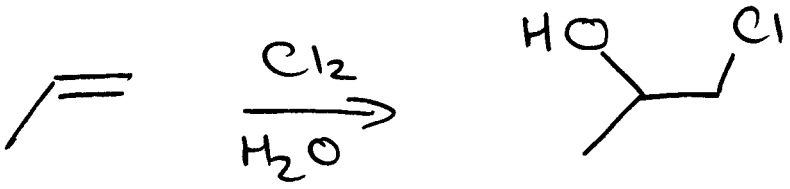


not an INERT solvent

MALOHYDRIN (BROMOHYDRIN)

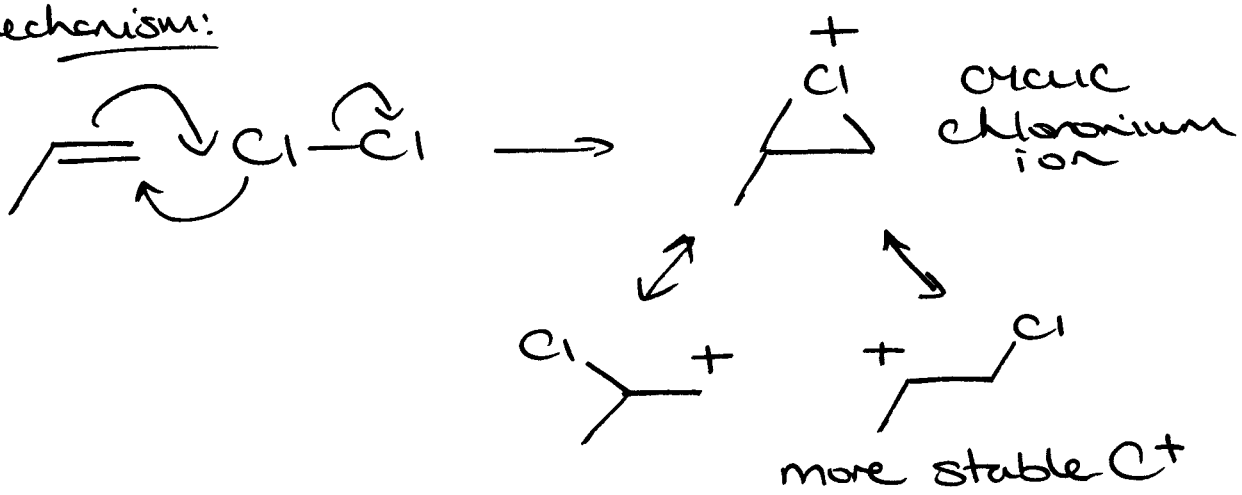
ANTI-STEREO SPECIFIC

– also REGIOSPECIFIC

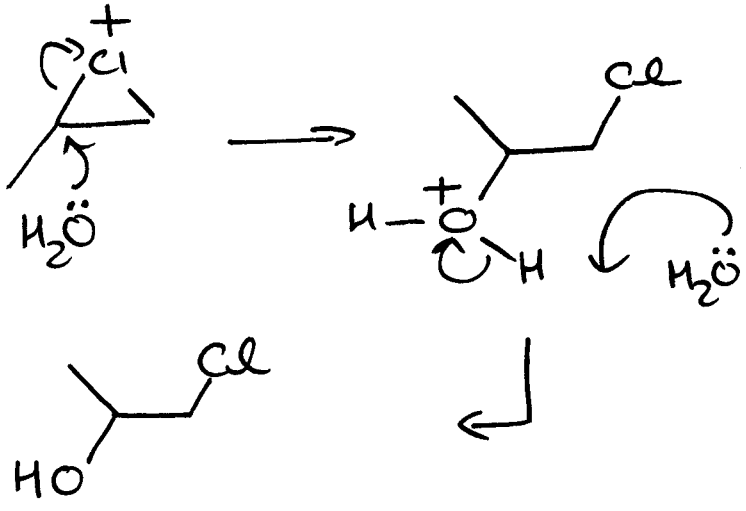


- OH adds to more substituted C ATOM of the alkene.

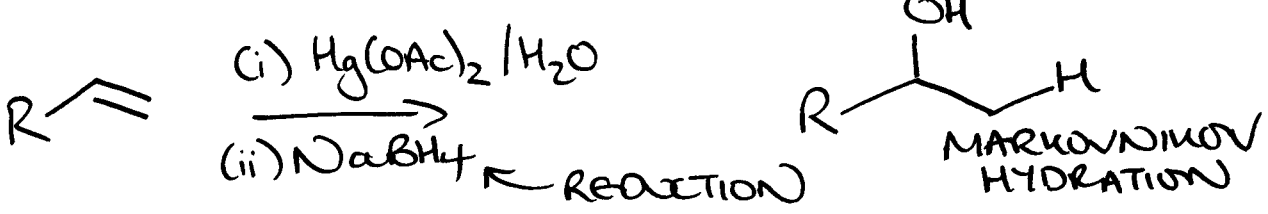
Mechanism:



OPENS VIA MORE STABLE C+



(4) OXYMERCURATION



LEC (17) CHEM 30A Feb 18th

1. ADDITION of HOCl/HOBr
2. OXYMERCURATION
3. HYDROBORATION
4. OXIDATION

QUIZ — Low 3, Mean 16, High 29

READ Ch 6, PROBLEMS 6.9-6.11, 6.13, 6.17-6.42

MECHANISM SHEETS ON WEB

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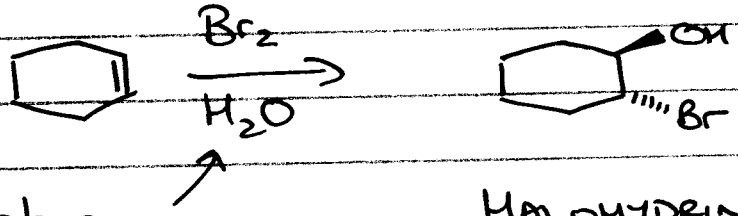
(1) ADDITION of HOCl/HOBr

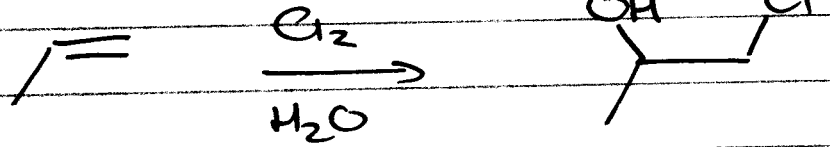


ANTI-STEREO SPECIFIC

not an INERT solvent

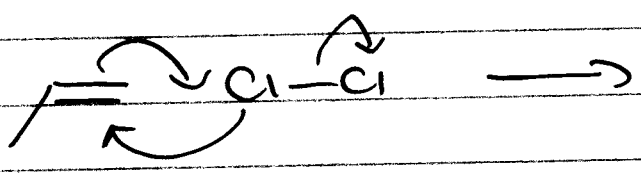
HALOHYDRIN (Bromohydrin)

- also regiospecific

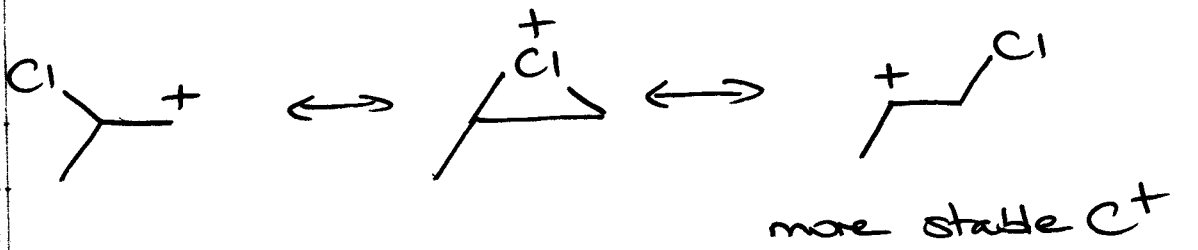


—OH adds to more SUB C atom of ALKENE

mechanism:

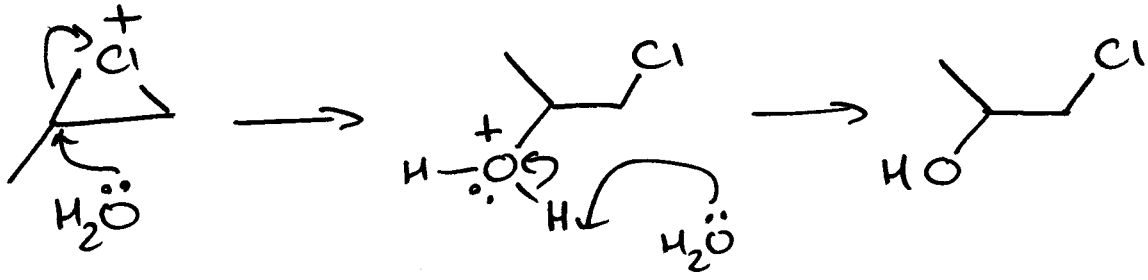


CYCLIC CHLORONIUM ION

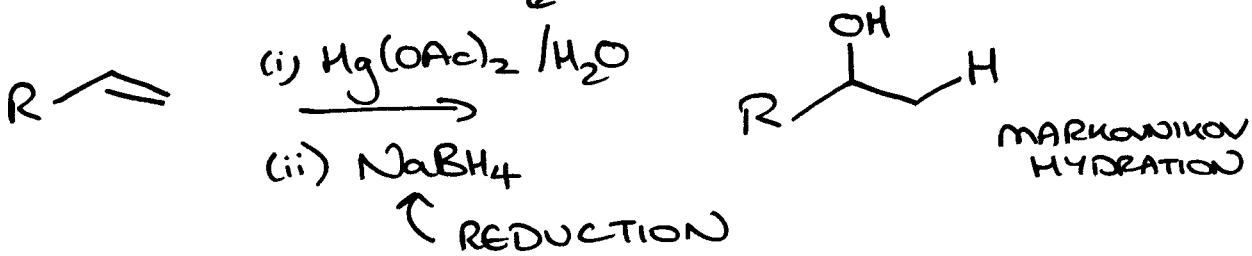


more stable C^+

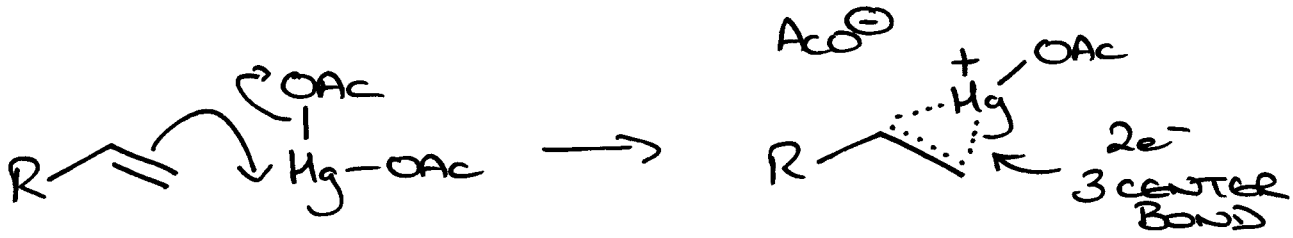
OPENS via more stable C^+, hence



(2) OXYMERCURATION

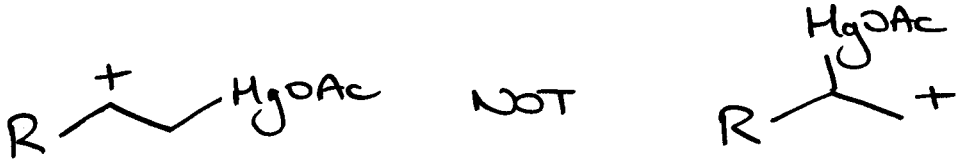


mechanism

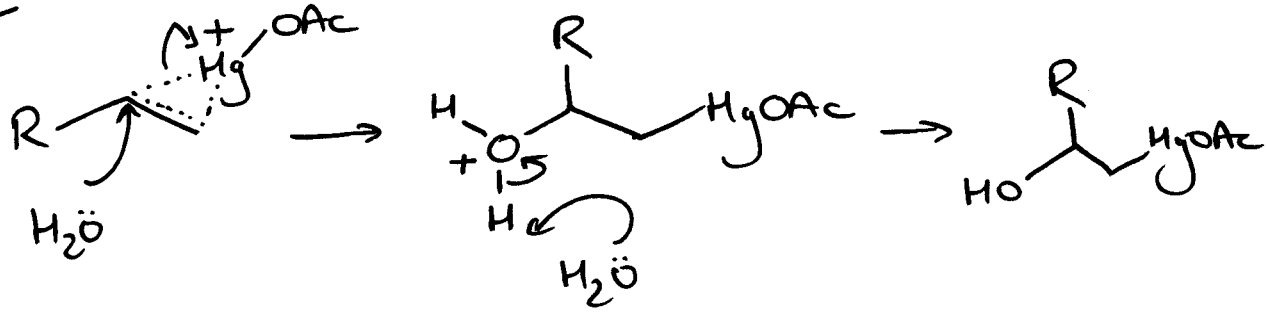


CYCLIC MERCURINIUM ION

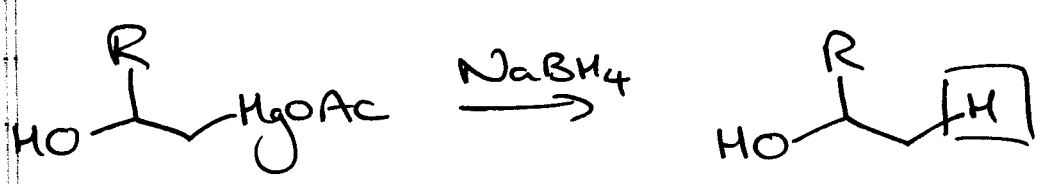
opens via most stable C^+



So



Organomercury cmpd reduced w/ $NaBH_4$

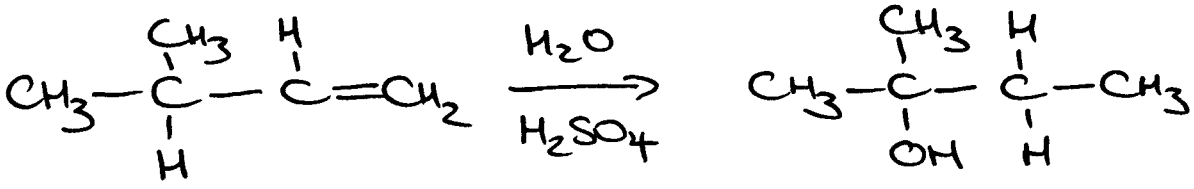


replaces "HgOAc" for "H"

DON'T NEED TO KNOW MECHANISM FOR THIS

WHY IS THIS USEFUL?

consider:

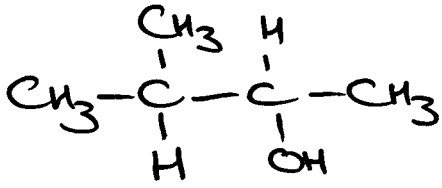


(ACID CAT HYDRATION)

REARRANGED PRODUCT (via C^+)

(i) $Hg(OAc)_2 / H_2O$

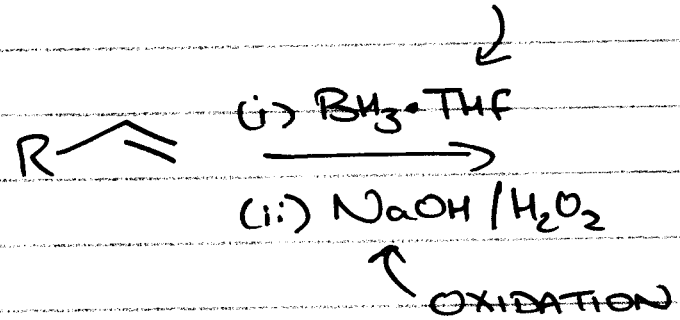
(ii) $NaBH_4$

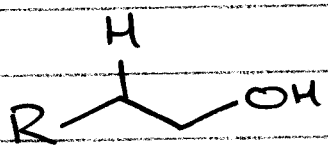


MARKOVNIKOV PRODUCT (NO REARRANGEMENT, no C^+)

So, REGIOSPECIFIC w/ ANTISTEREOSPECIFICITY
(Similar to addition of HCl (HBr)

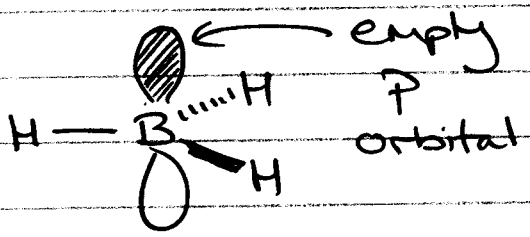
(3) HYDROBORATION





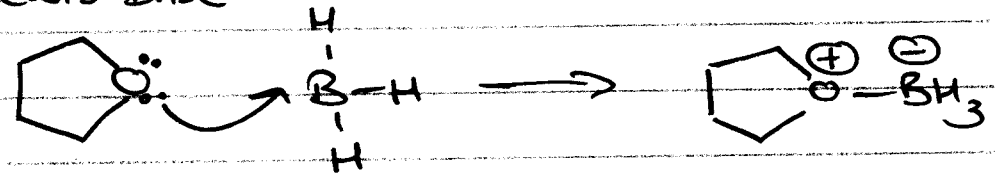
ANTI-MARKOVNIKOV HYDRATION

BORANE (BH_3)



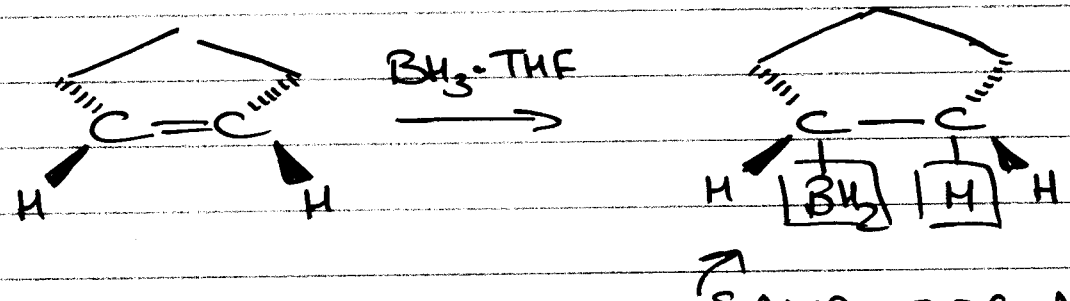
(actually exist as B_2H_6 – structure?)

LEWIS BASE

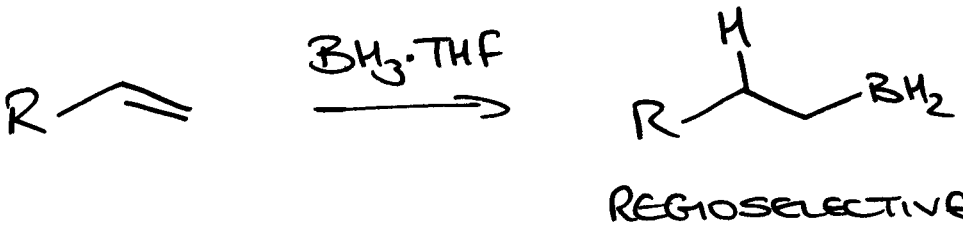


THF — LEWIS ACID — BH_3·THF

– SYN STEREOSPECIFIC



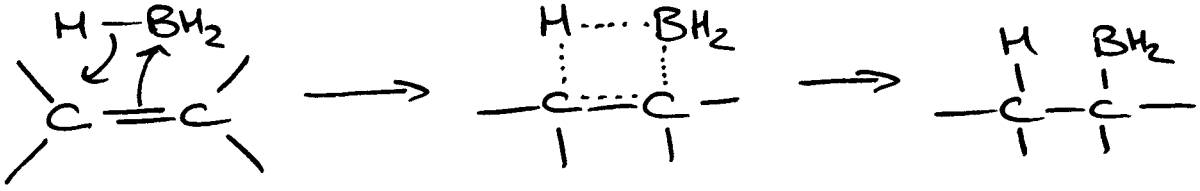
SAME SIDE ADDITION



REGIOSELECTIVE

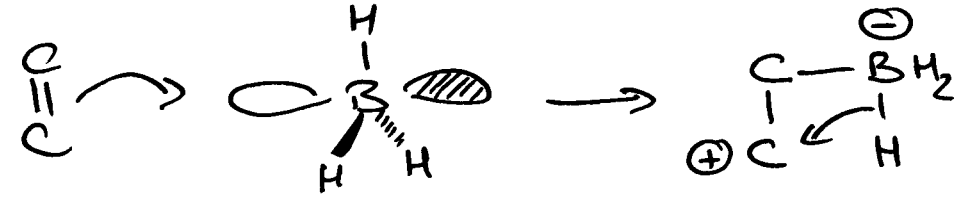
BORON ADDS TO LESS SUBSTITUTED C ATOM

Mechanism:



DOES NOT GO THROUGH A C^+

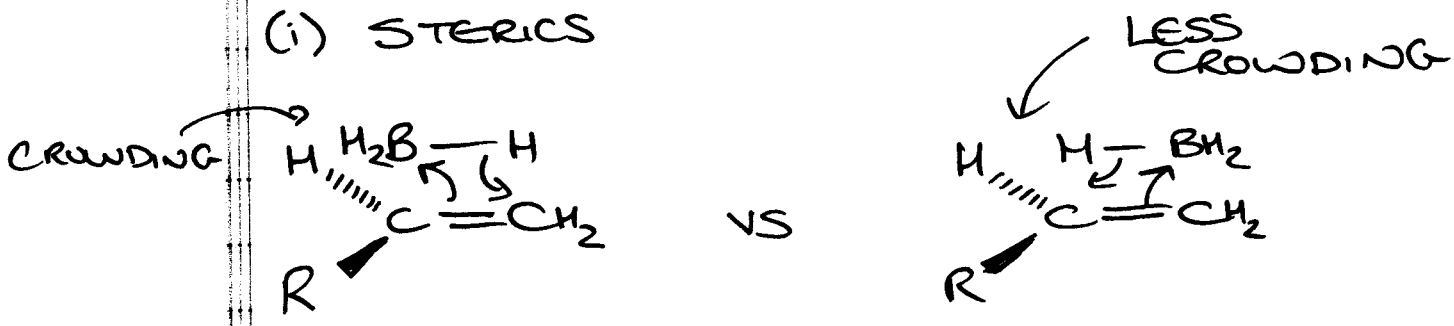
i.e.



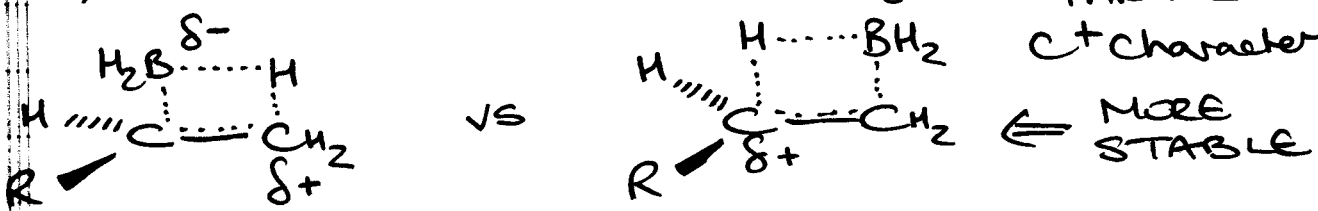
⇒ NO REARRANGEMENTS

WHY REGIOSELECTIVE?

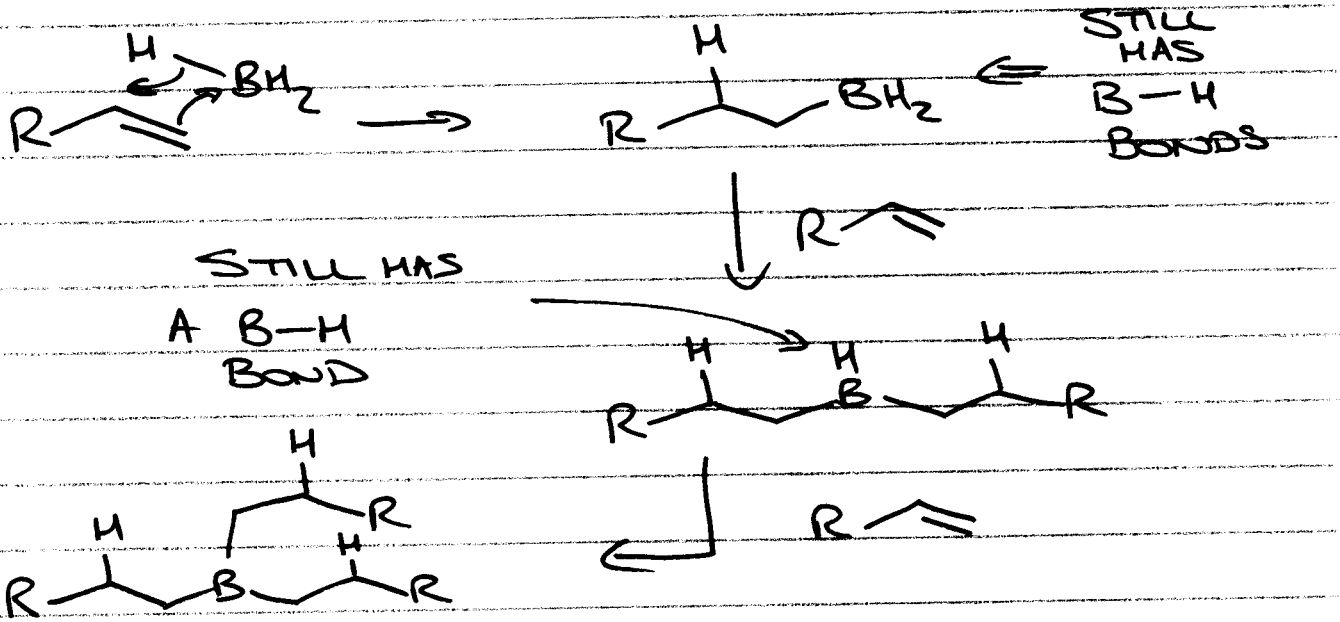
(i) STERICS



(ii) ELECTRONICS



Full mechanism



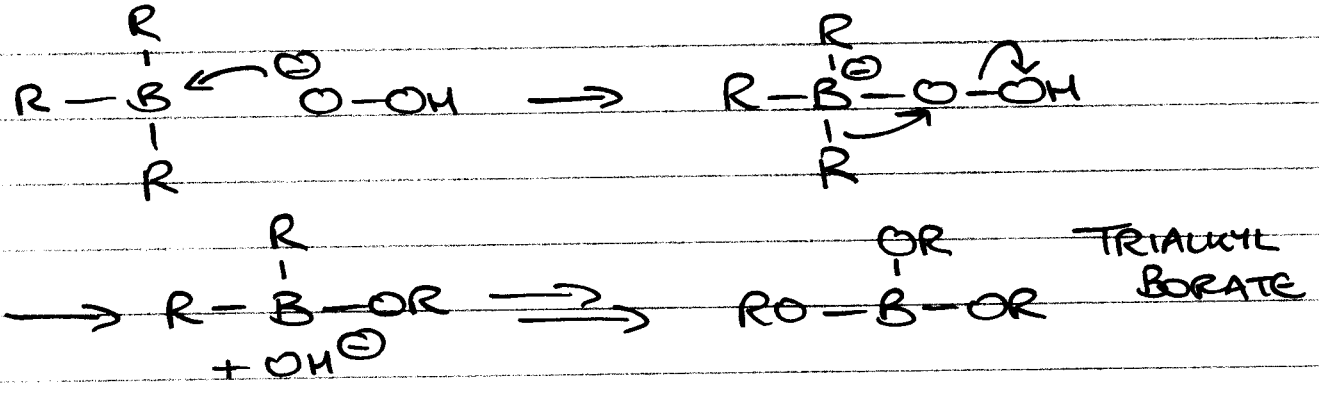
TRIALKYLBORANE

SECOND STEP

$$R-B(R)-R \xrightarrow[H_2O_2]{NaOH} 3\,R-OH + Na_3BO_3$$

$$NaOH + H-O-O-H \rightleftharpoons H-O-O^{\ominus} + H_2O$$

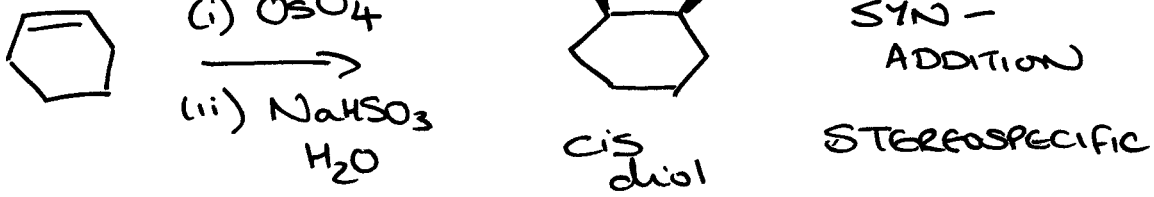
hydroperoxide ion

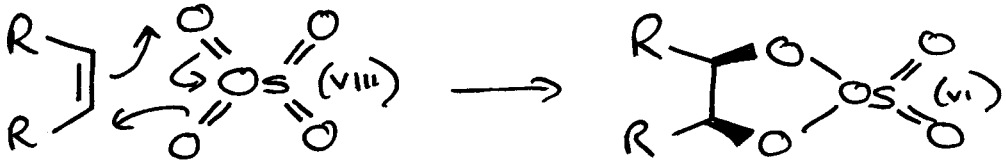


$NaOH/H_2O$ ⇒ 3 × R–OH + Na_2BO_3

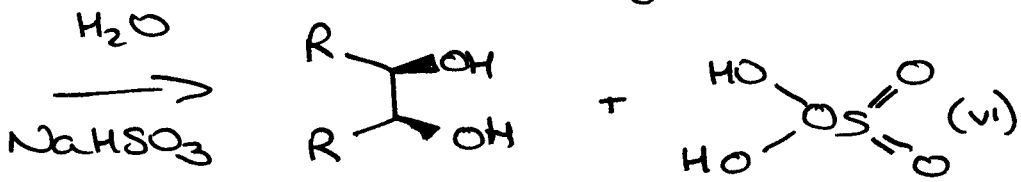
(4) OXIDATION

(i) OSO_4 osmium tetroxide



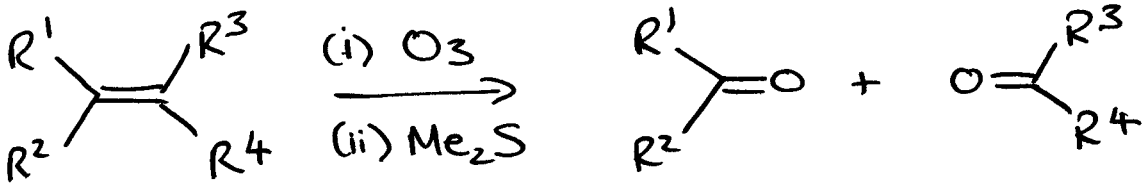


Cyclic osmate ester

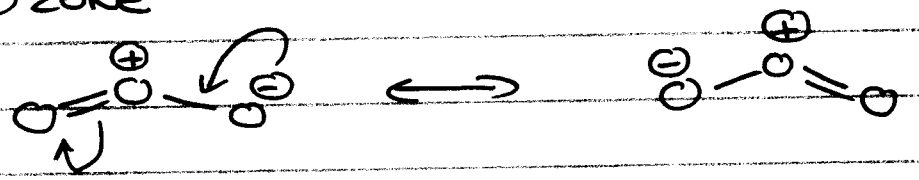


OS REDUCED (VIII → VI), ALKENE OXIDIZED

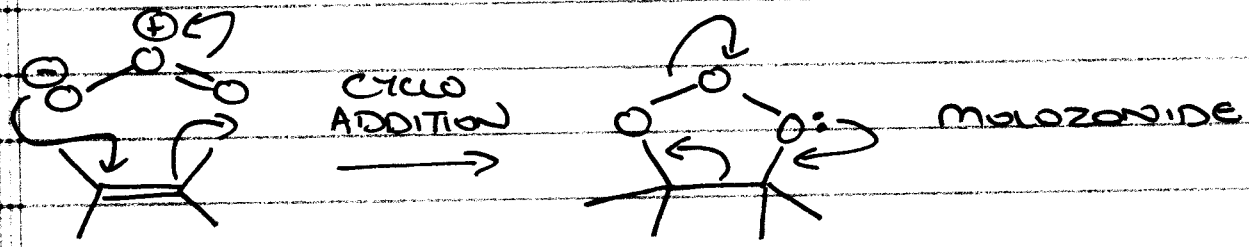
(ii) OZONOLYSIS

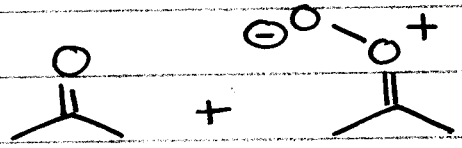


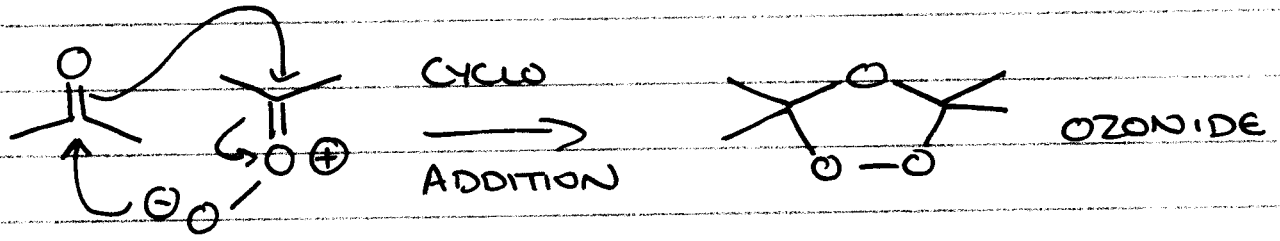
OZONE



mechanism:







LEC (18) CHEM 30A Feb 23rd

1. OXIDATION
2. REDUCTION
3. STEREOCHEM AGAIN
4. ALKYNES

READ 6.5–6.7, 10.9
PROBLEMS 6.39–6.49, 10.5

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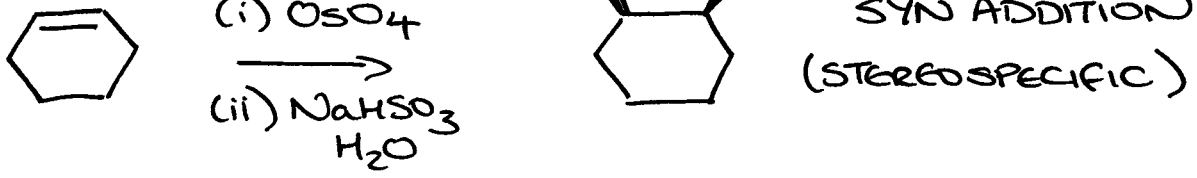
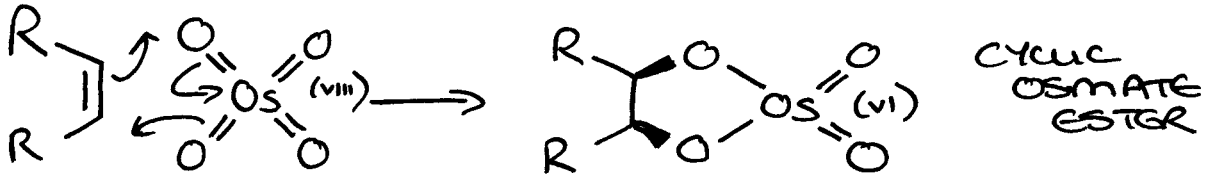
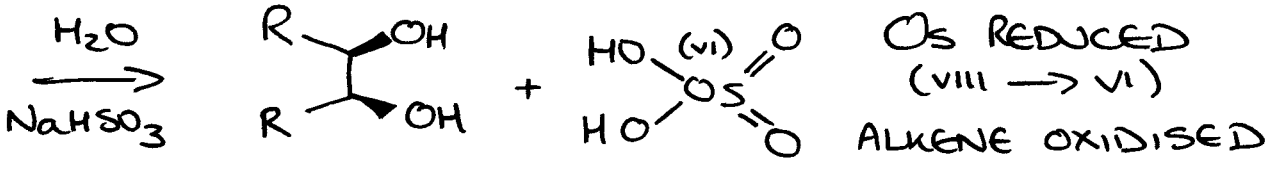
(1) OXIDATION

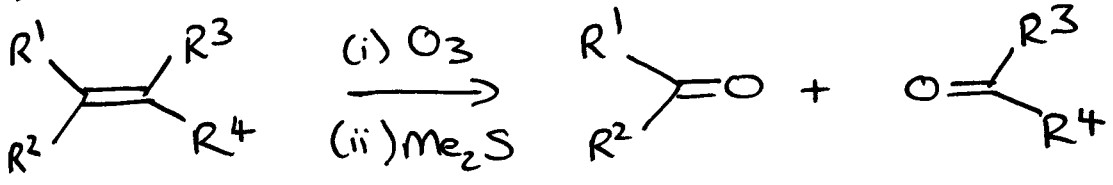
(i) OsO_4 osmium tetroxide





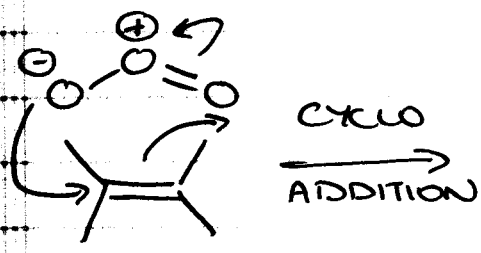


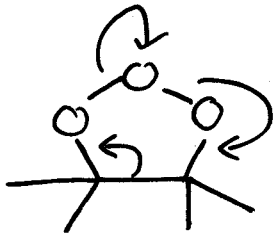
(ii) OZONOLYSIS



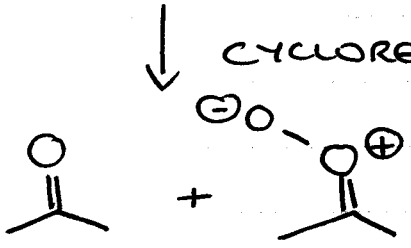
ozone

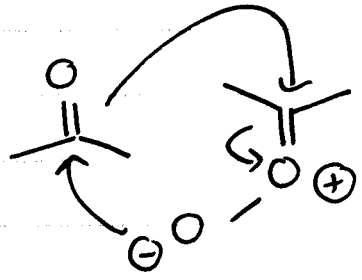
mechanism

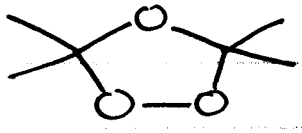




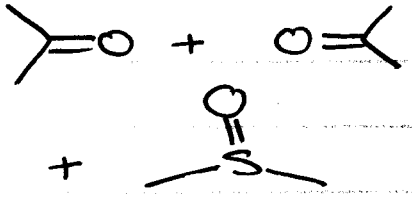
MOLOZONIDE



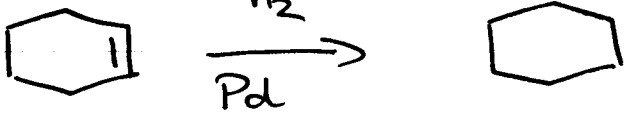




OZONIDE



② REDUCTION

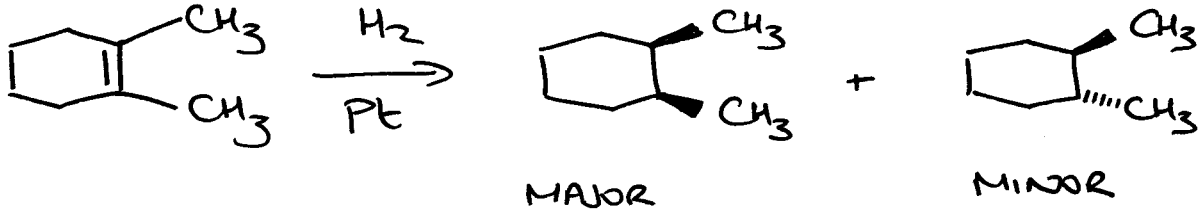


METAL CATALYST
(finely divided on an inert support → charcoal)

Transition metal catalyst Pt, Pd, Ru, Ni

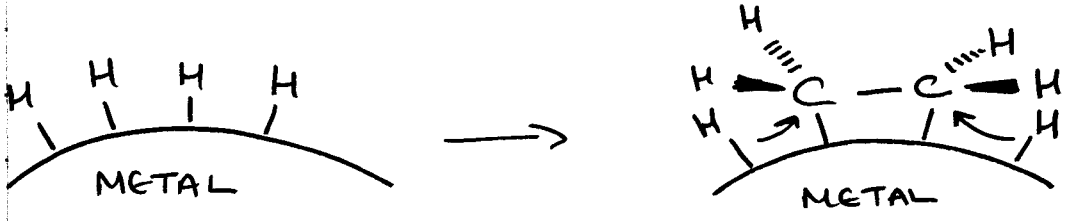
- Catalytic REACTION / HYDROGENATION

- Stereoselective



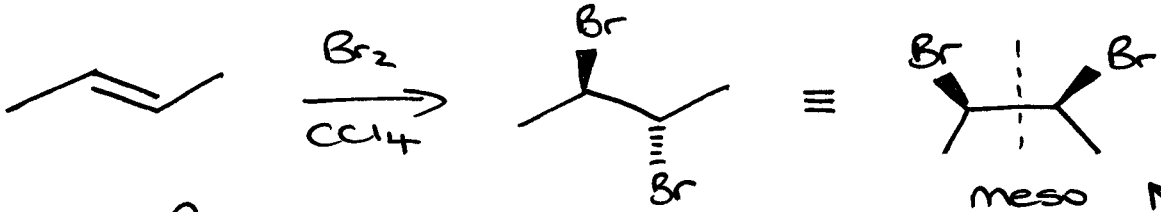
MAJOR MINOR

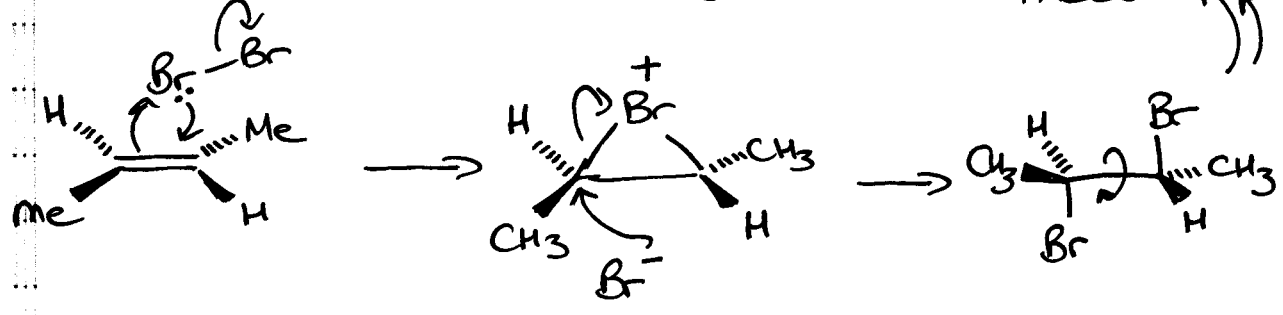
mechanism

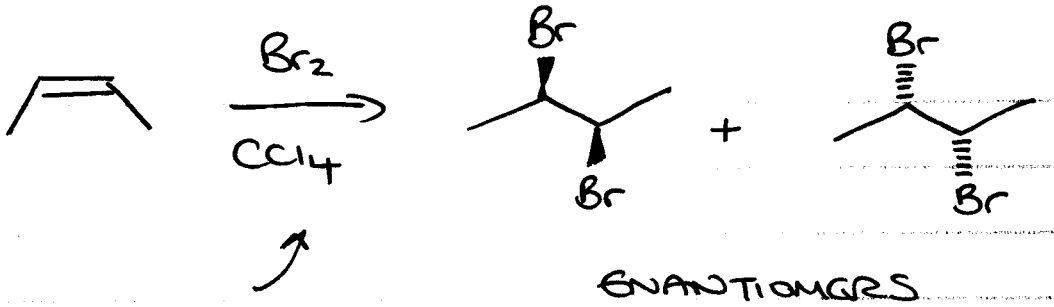


MINOR PRODUCTS RESULT FROM ISOMERIZATION OF THE ALKENE ON THE METAL CATALYST

(3) STEREOCHEMISTRY AGAIN

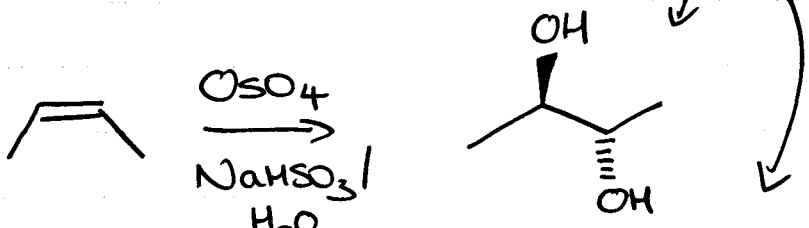


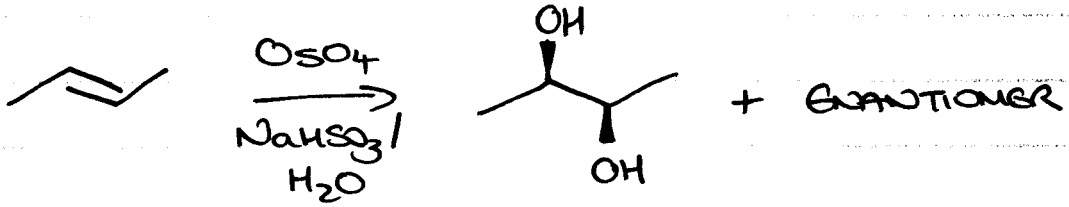




ENANTIOMERS

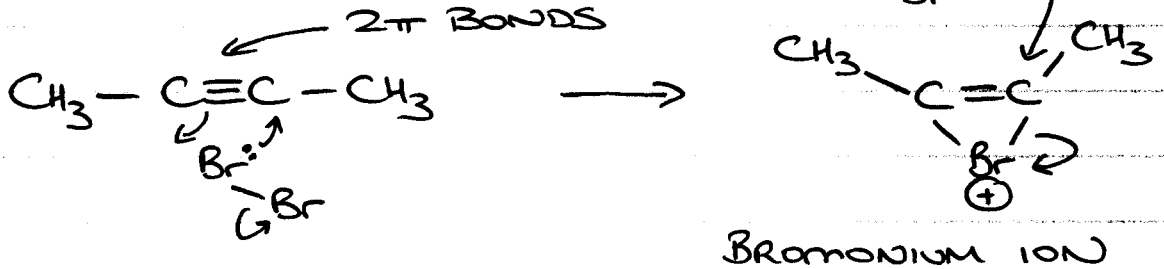
- WORK THRU MECHANISM





(4) ADDITION TO ALKYNES

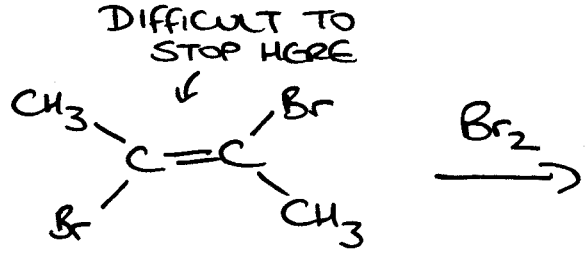
(i) X_2 (Br_2/Cl_2)



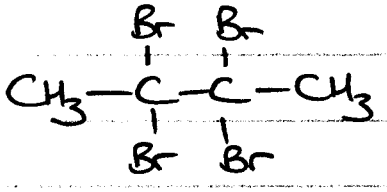
BROMONIUM ION

ANTI-

STEREO SPECIFICITY



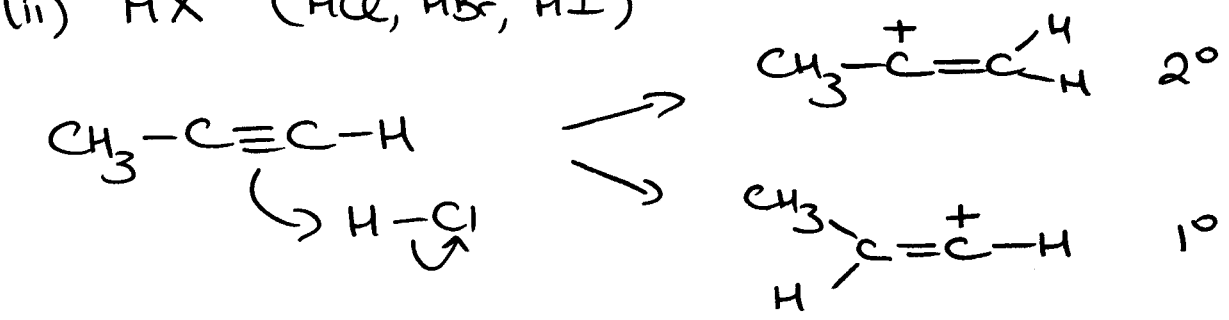
Br_2



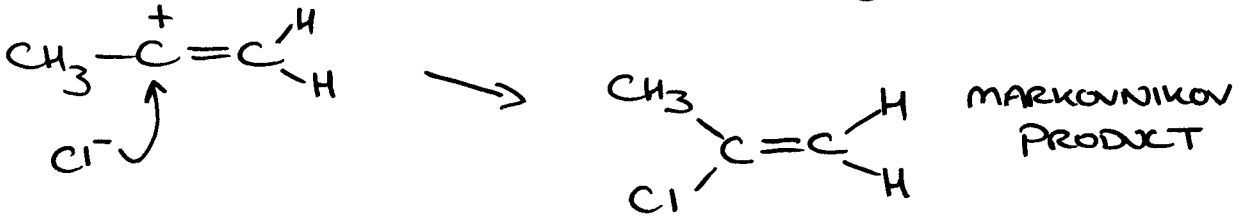
trans-dibromide

tetrabromoalkane

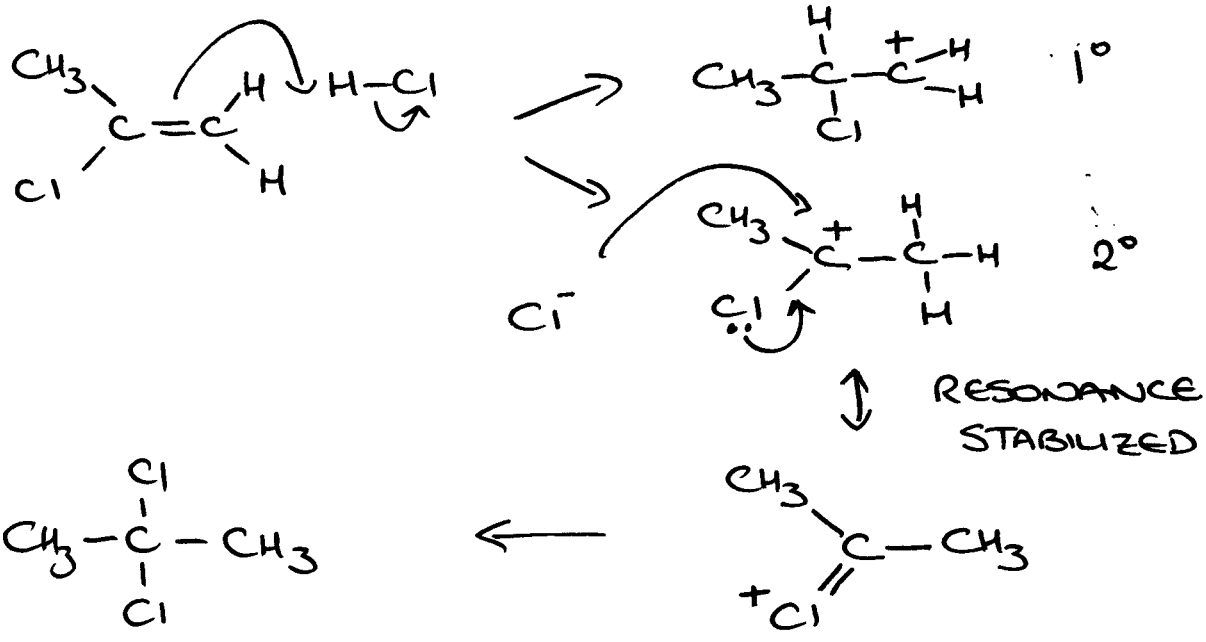
(ii) HX (HCl, HBr, HI)



VINYL CARBOCATIONS
(not very stable)



ALKENE PRODUCT COMPETES WITH ALKYNE FOR H-Cl IN THE REACTION (ALKENES MORE REACTIVE)



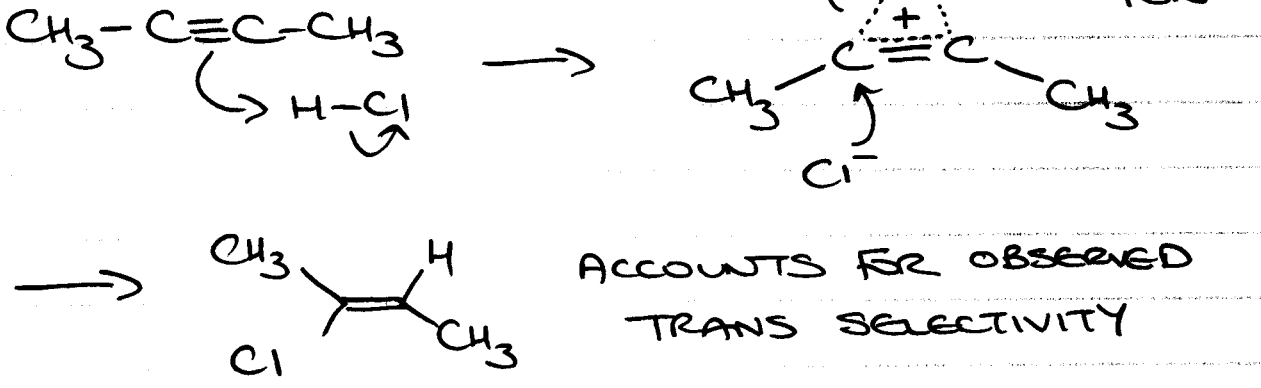
mechanisms actually more complicated, but these are good models.

VINYLIC C^+ QUITE UNSTABLE

2° VINYLIC $C^+ \simeq 1^\circ C^+$

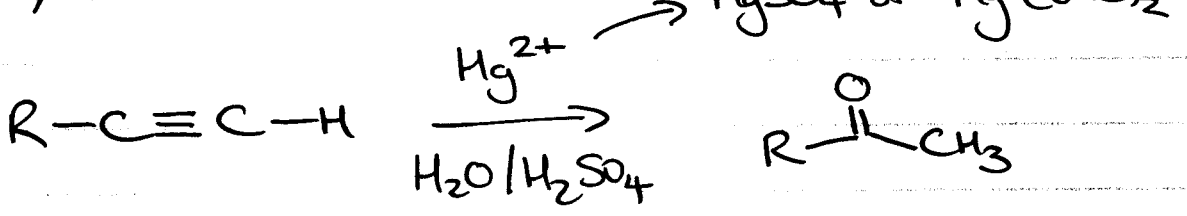
and $1^\circ C^+$ not usually a viable reaction intermediate.

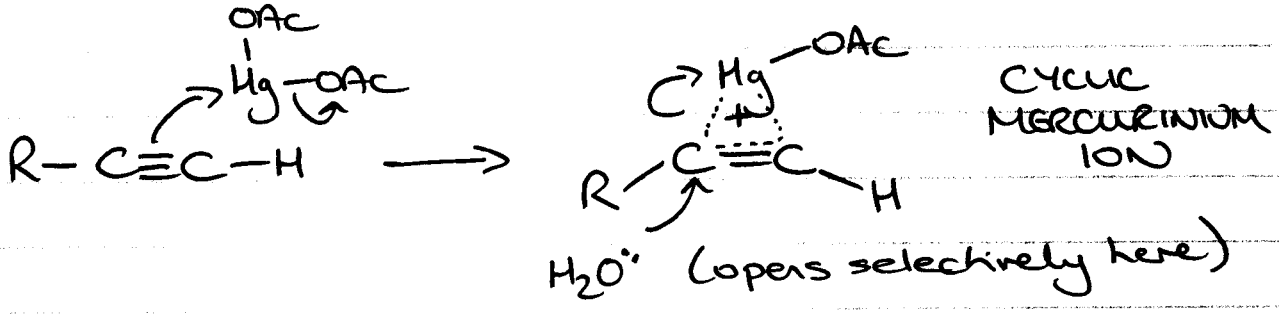
PROPOSED INTERMEDIATE

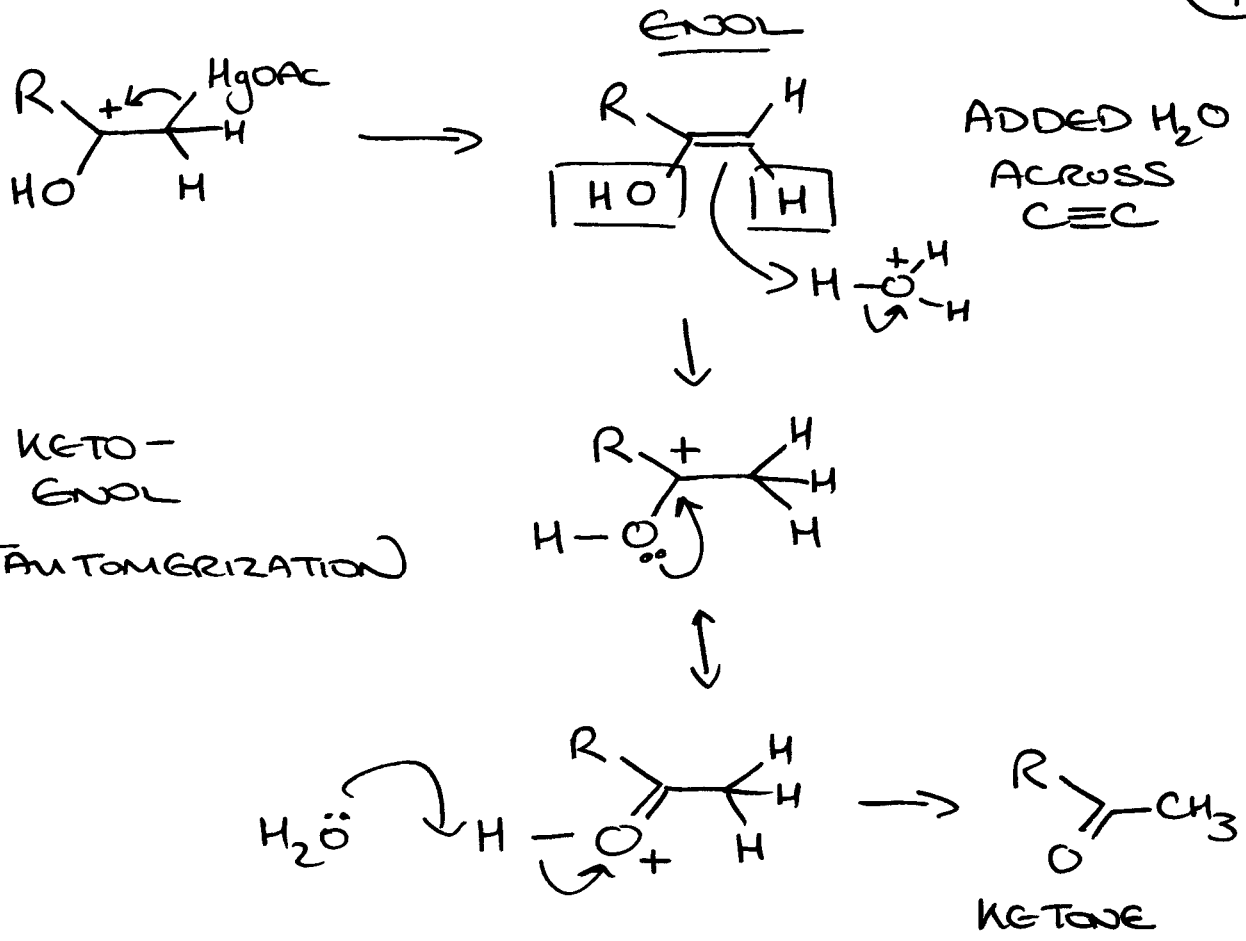


ACCOUNTS FOR OBSERVED TRANS SELECTIVITY

(iii) OXYMERCURATION



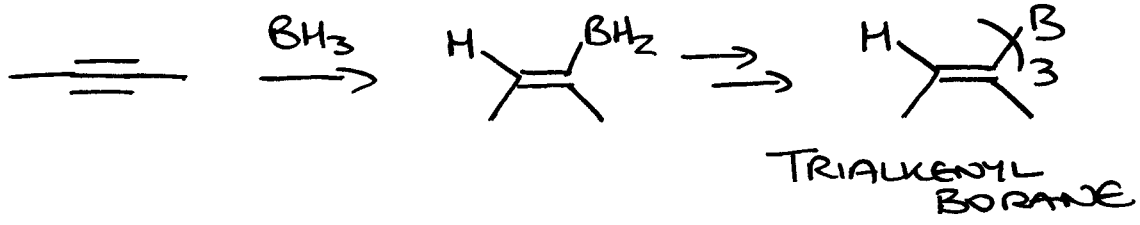


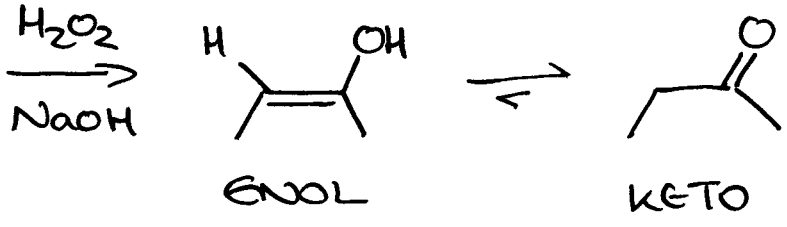


(iv) HYDROBORATION

($R-\equiv-H$, $R-\equiv-R$)

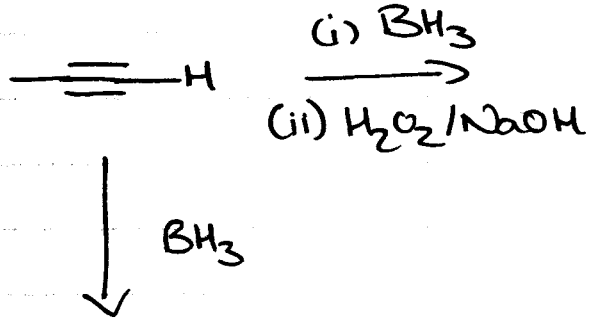
terminal non-terminal



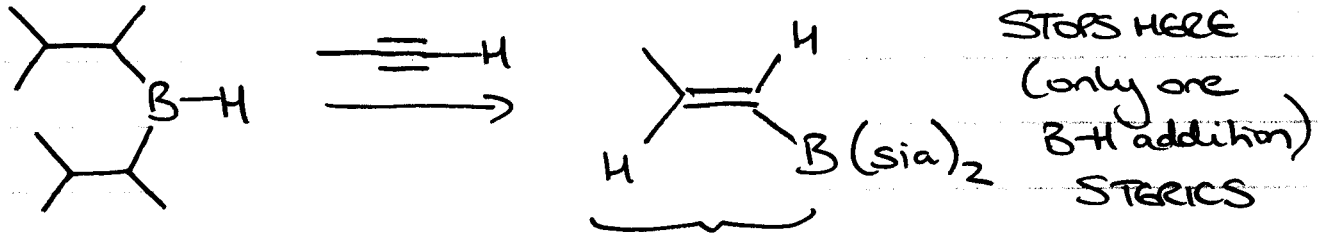


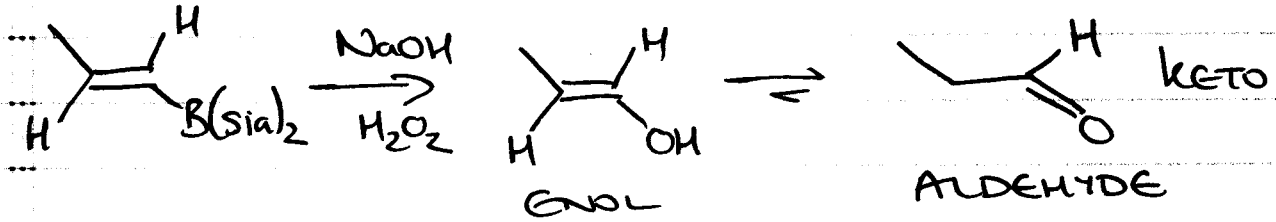
(SAME MECHANISM AS FOR ALKENES)

Terminal Alkynes

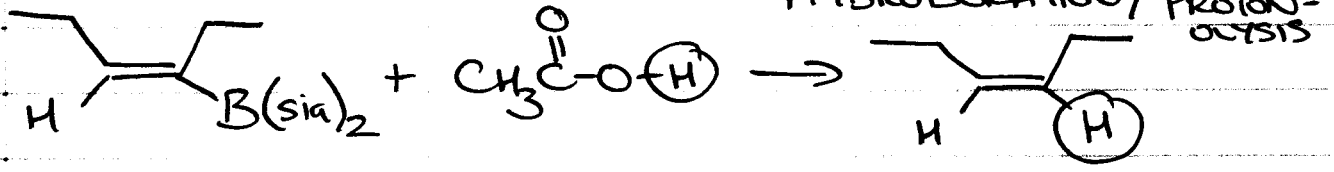


DISIAMYL BORANE $(sia)_2BH$





REACTION w/ ACETIC ACID



LEC (19) CHEM 30A Feb 25th

1. HX ADDITION
2. OXYMERCURATION
3. HYDROBORATION
4. REDUCTION

READ 10.7 – 10.9, 8.1 – 8.2
PROBLEMS 10.4, 10.16, 10.17, 10.21 – 23

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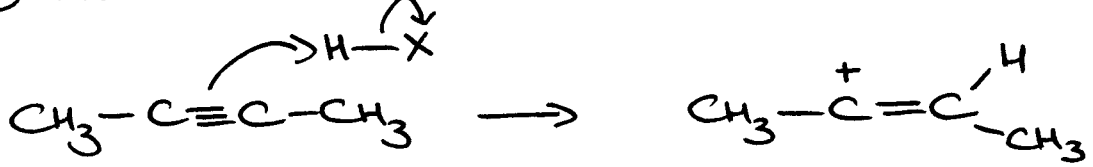
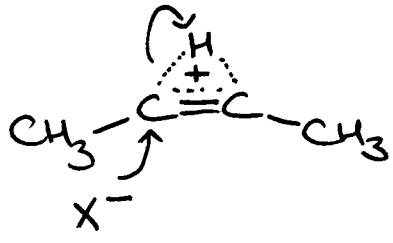
(1) HX

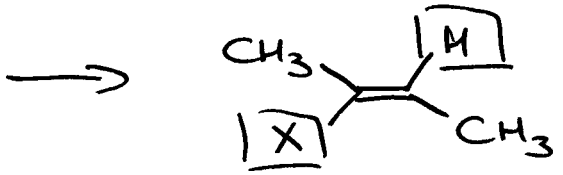


VINYLIC C^+ UNSTABLE, 2° C^+ VINYLIC $\simeq$ 1° C^+ and 1° C^+ not a viable rxn intermediate

PROPOSED INTERMEDIATE



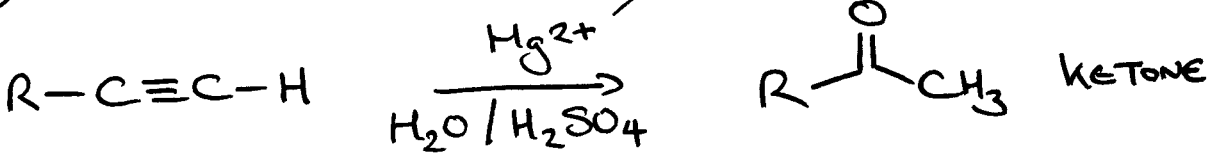
CYCLIC PROTONIUM ION



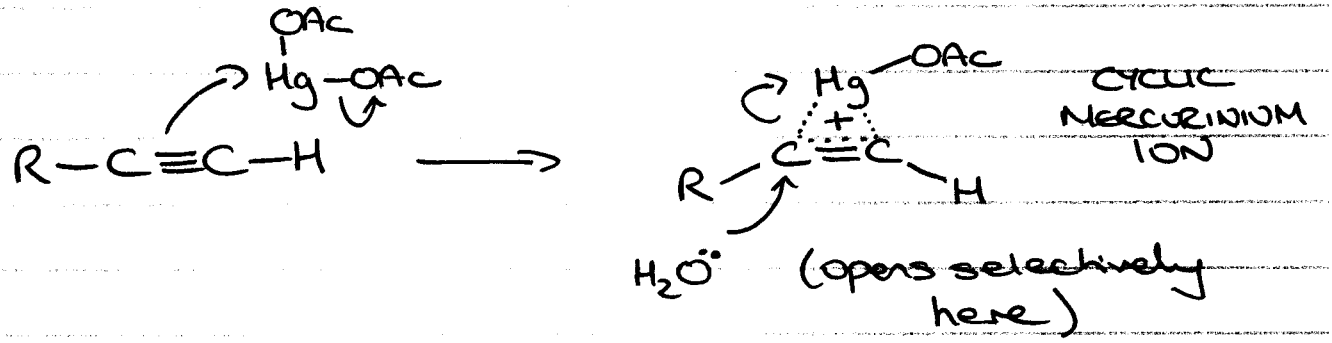
ACCOUNTS FOR TRANS SELECTIVITY

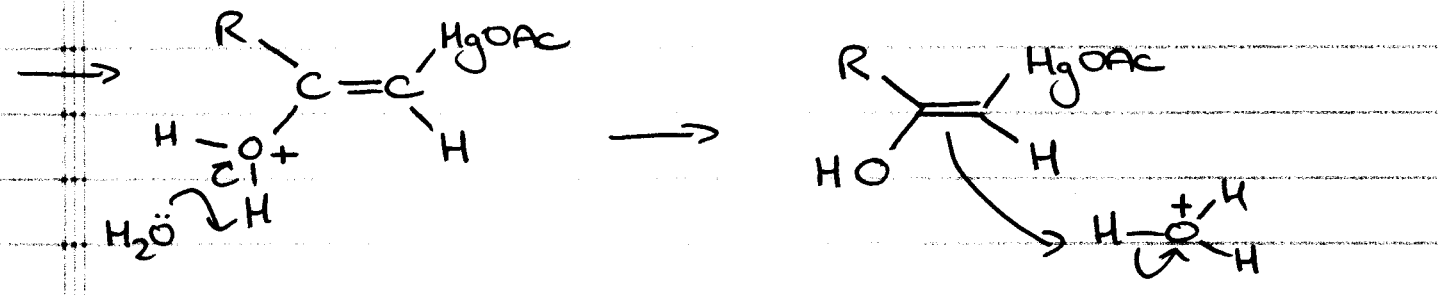
(2) OXYMERCURATION

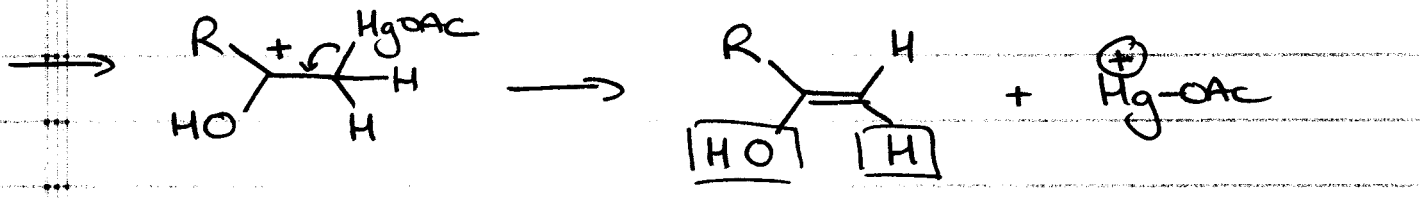
$Hg(OAc)_2$ or $HgSO_4$



Mechanism

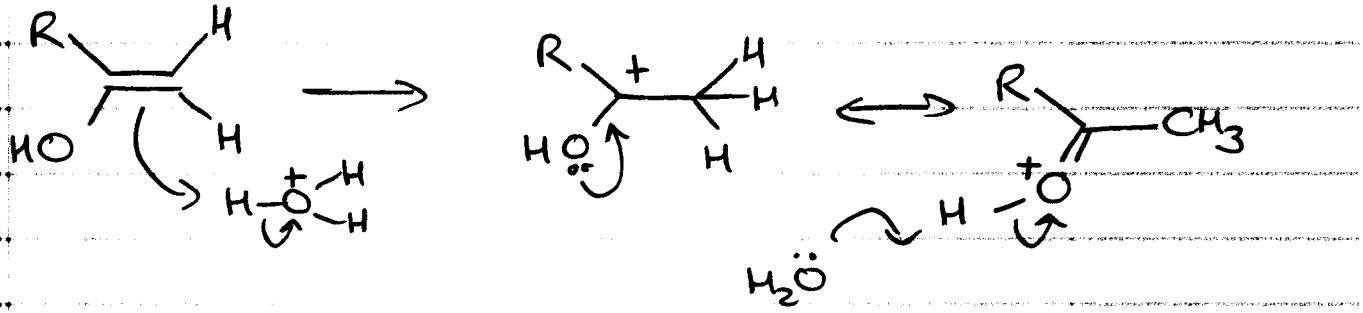


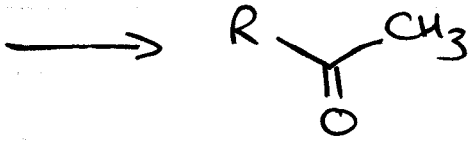




ADDED H_2O ⇒ ENOL ACROSS C≡C

KETO-ENOL TAUTOMERIZATION

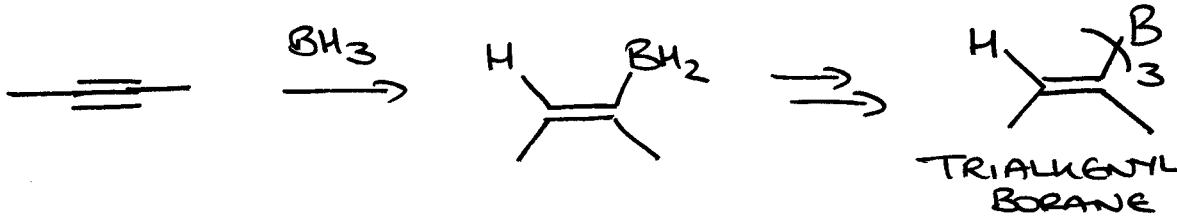




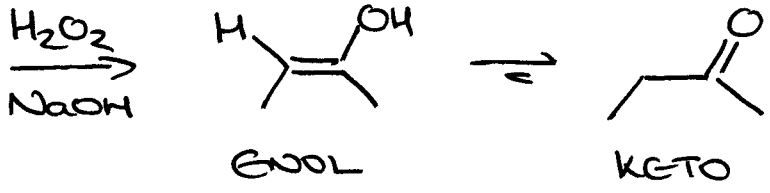
KETONE

(3) HYDROBORATION

(R—≡—H , R—≡—R)
terminal non terminal



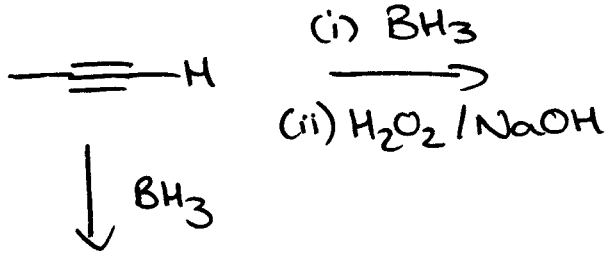
TRIALKENYL BORANE



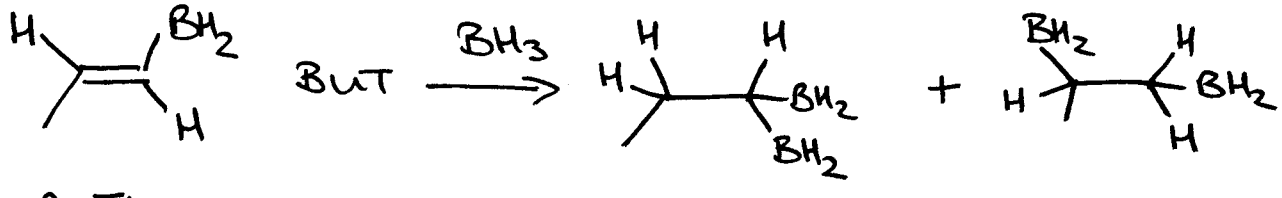
ENOL KETO

SAME MECHANISM AS FOR ALKENES

Terminal Alkynes

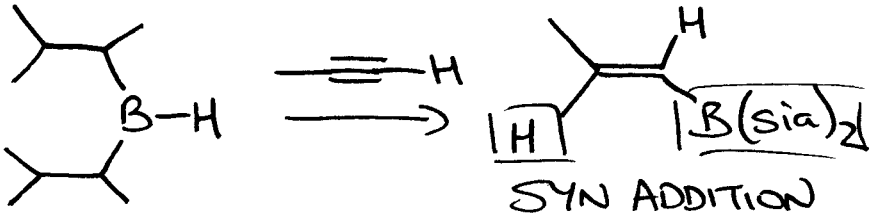


mixture of products



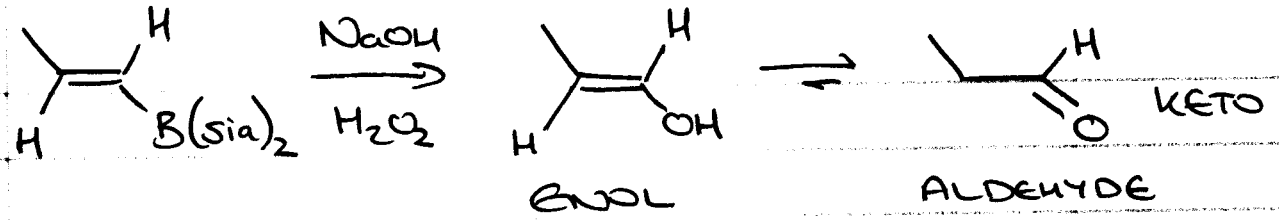
ANTI MARKOVNIKOV

DISIAMYL BORANE $(sia)_2BH$



SYN ADDITION

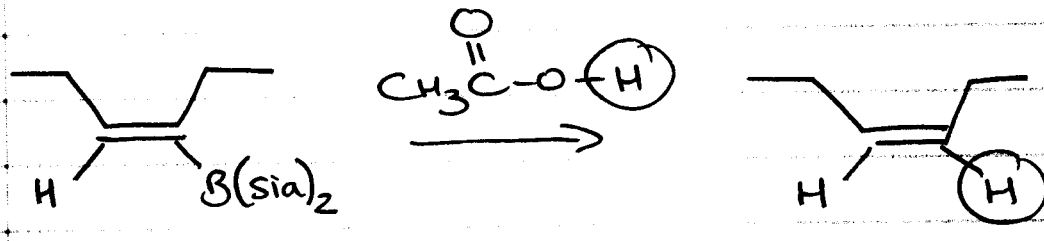
STOPS HERE, ONLY ONE B-H ADDITION (STERICS)



ENOL

ALDEHYDE

REACTION w/ ACETIC ACID



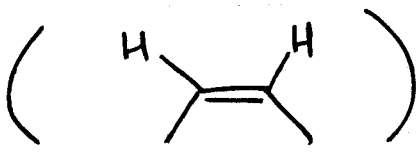
STEREOSPECIFIC
HYDROBORATION/PROTONOLYSIS

(4) REDUCTION

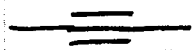
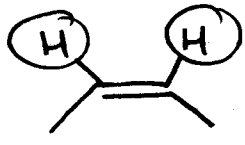
ALKYNE ⟶ [ALKENE] ⟶ ALKANE

(i)  H_2 (3 atm), Pd, Pt or Ni ⟶ 

NOT ISOLABLE

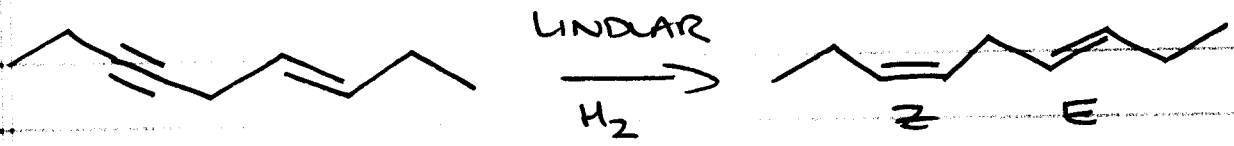


SYN

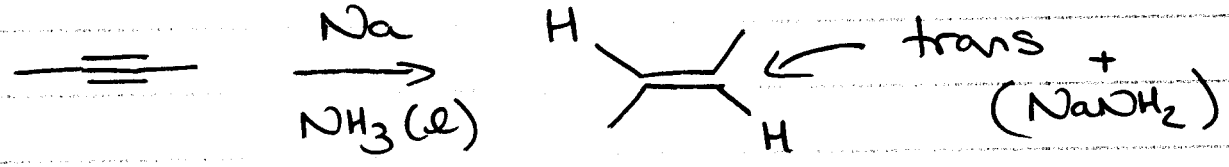
(ii)  H_2, LINDLAR ⟶  cis

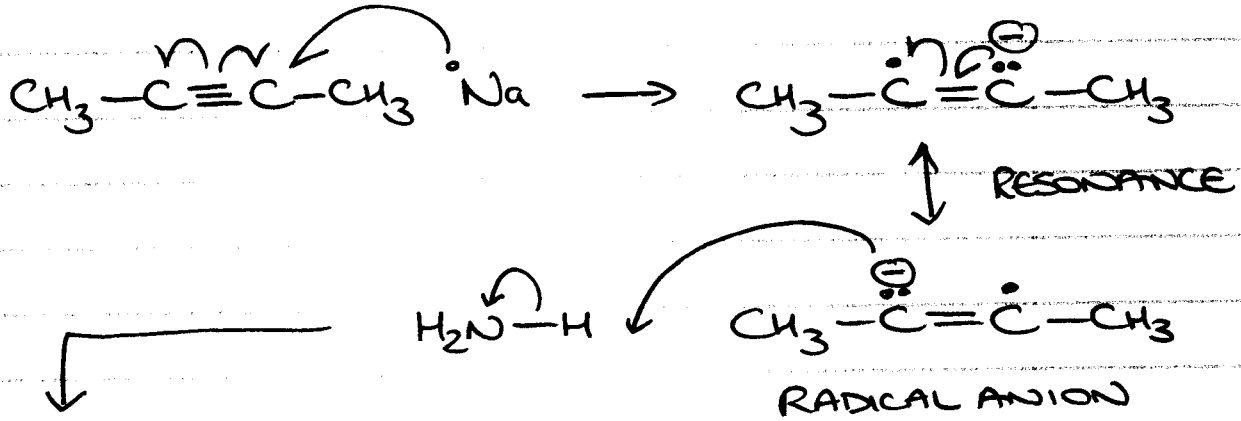
STOPS HERE

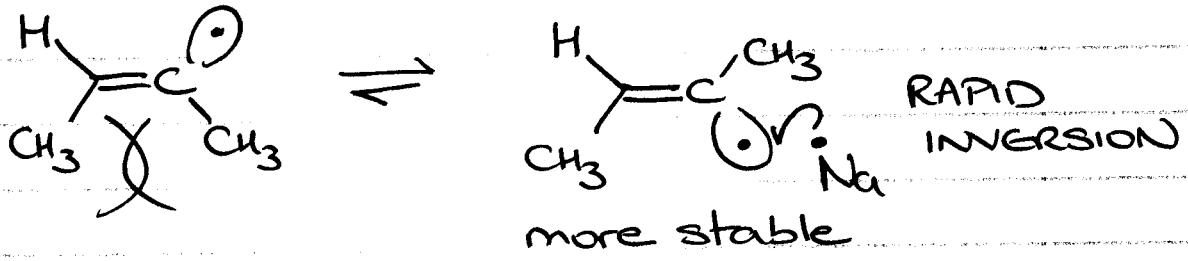
↳ ($Pd/CaCO_3/PbO$) POISONED CATALYST

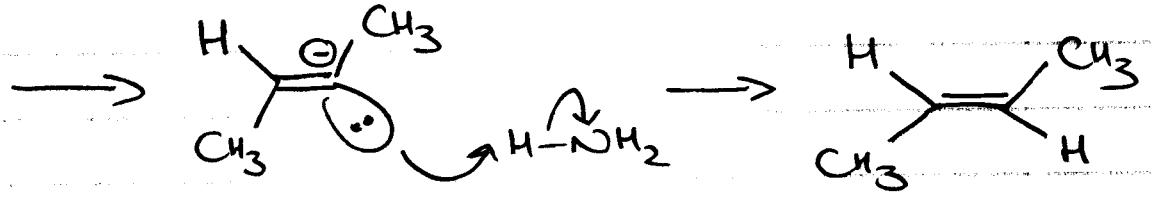


(iii) DISSOLVING METAL REDUCTION

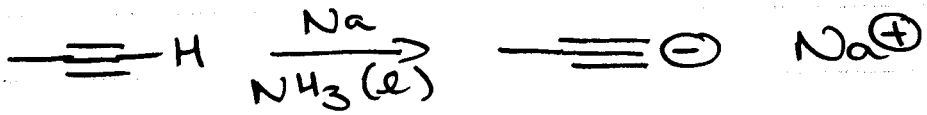








DOES NOT WORK WITH TERMINAL ALKYNES



LEC (20) CHEM 30A Feb 28th

- NUCLEOPHILIC SUBSTITUTION

(1) INTRODUCTION — READ 8.1–8.6

(2) MECHANISMS — PROBLEMS:

(3) ELECTROPHILE — 8.1-8.3, 8.9-8.13

(4) NUCLEOPHILE

- MIDTERM ON WEDS – usual rules
- NOTHING FROM TODAY'S CLASS ON MIDTERM

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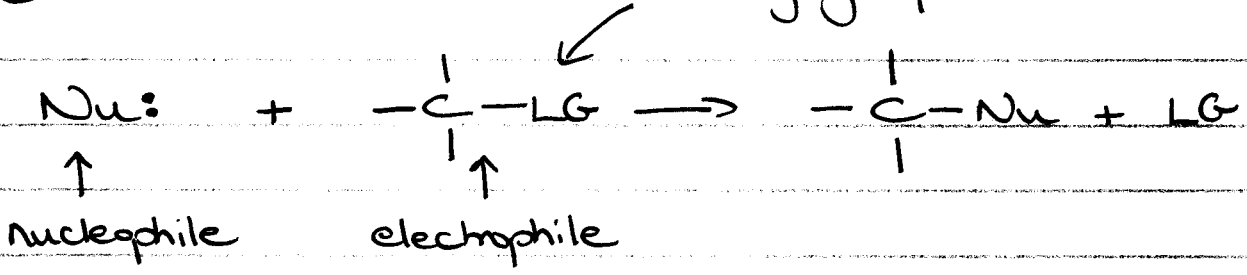
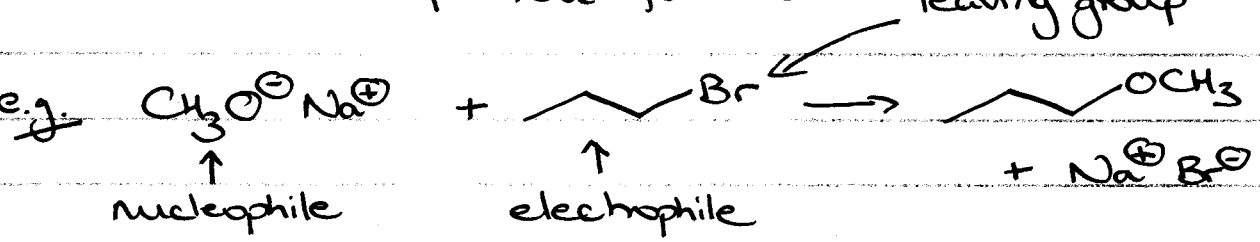
(1) INTRODUCTION

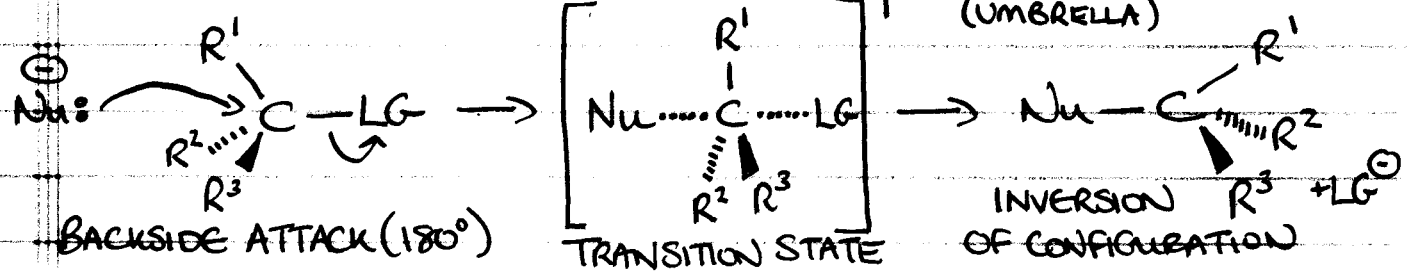


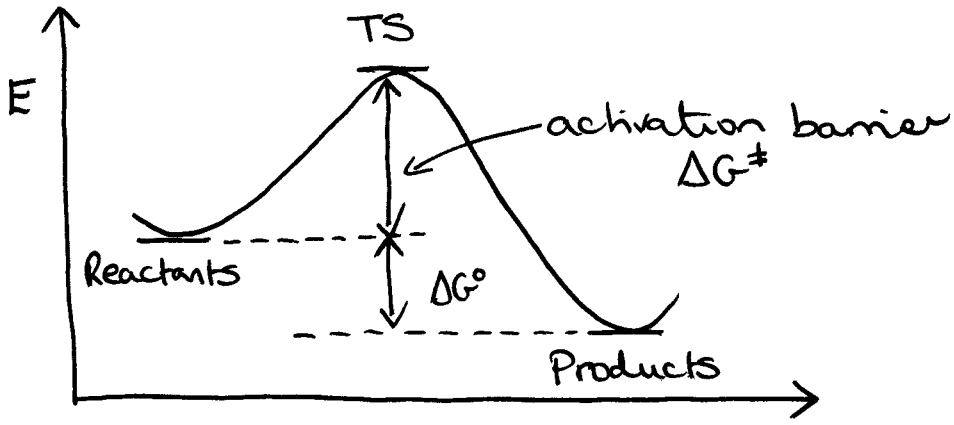
SUBSTITUTION of Nu for LG



(2) MECHANISMS (2 LIMITING MECHANISMS)

(i) S_N2





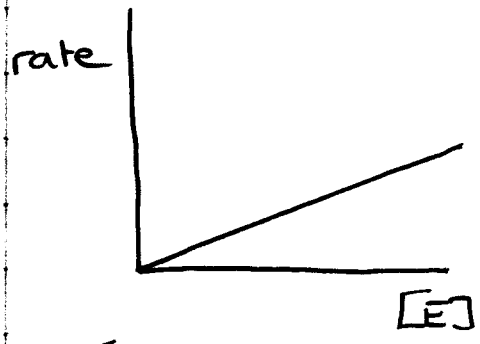
S_N2 = SUBSTITUTION, NUCLEOPHILIC, BIMOLECULAR

BIMOLECULAR – Rate of reaction is dependant upon the concentrations of both the NUCLEOPHILE and the ELECTROPHILE

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

↑ 2nd order rate constant

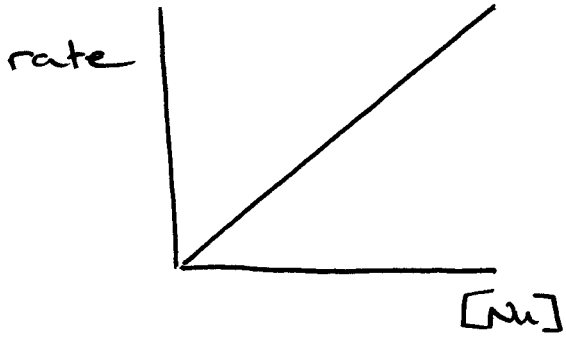
TWO DIFFERENT EXPERIMENTS



[Nu] CONSTANT

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

$k_a = k_2[Nu]$



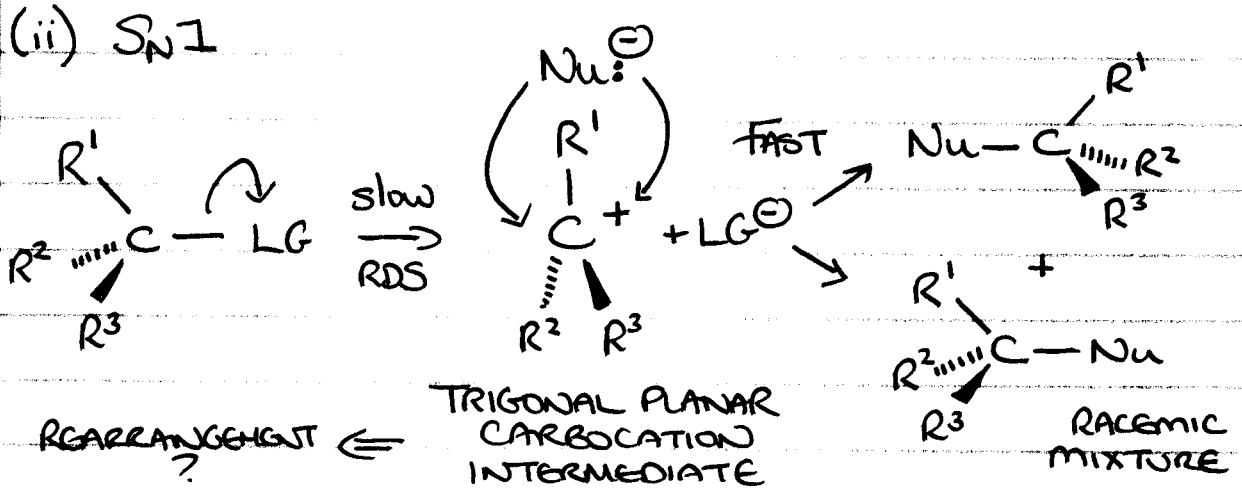
[E] CONSTANT

$\text{rate} = k_b[Nu]$

$k_b = k_2[E]$

↖ Same value ↗

(ii) S_N1

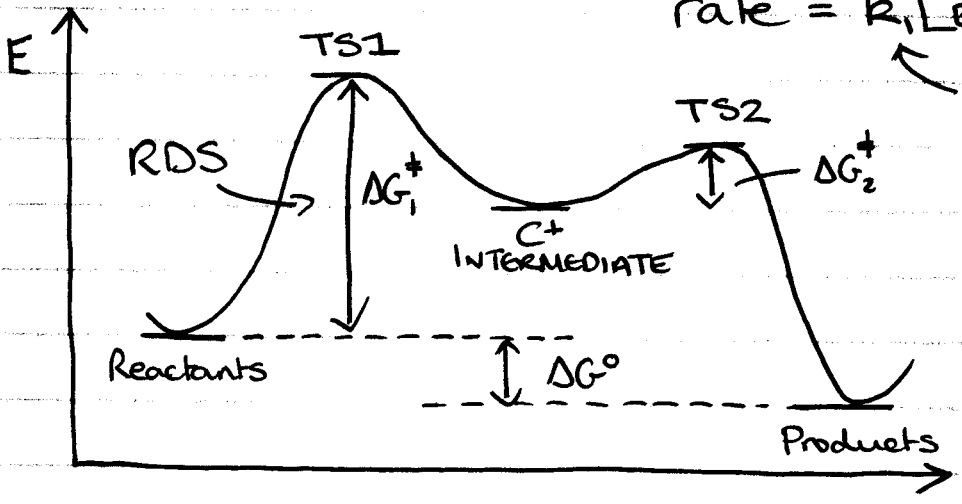


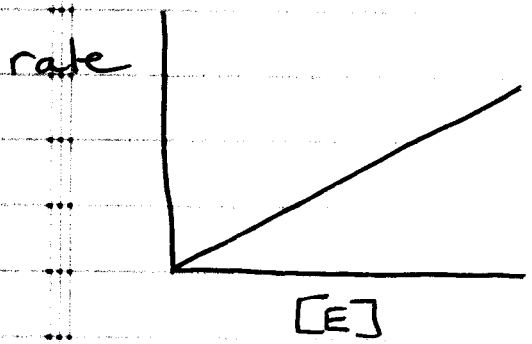
- ANY STEREOCHEMICAL INFORMATION IN THE STARTING MATERIAL IS LOST

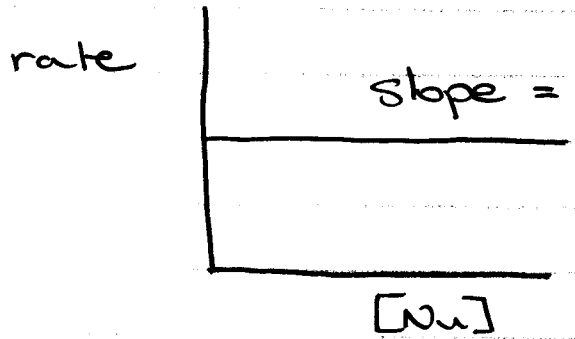
S_N1 - SUBSTITUTION, NUCLEOPHILIC, UNIMOLECULAR

RATE ONLY DEPENDS ON [E]

$rate = k_1[E]$ ← first order rate constant



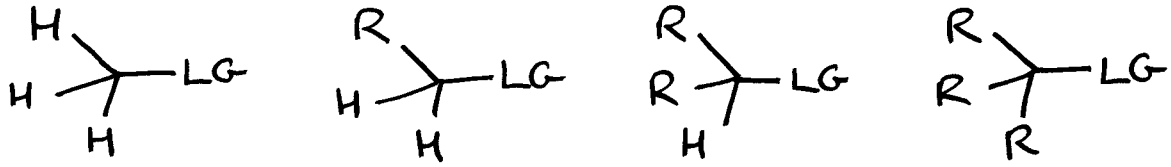




RDS does not involve the nucleophile, so adding more of it to the reaction does not affect the rate => ALSO, reactivity of NUCLEOPHILE does not matter.

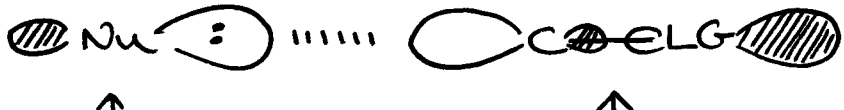
WHAT DECIDES SN1 vs SN2 ?

① THE ELECTROPHILE



methyl primary secondary tertiary

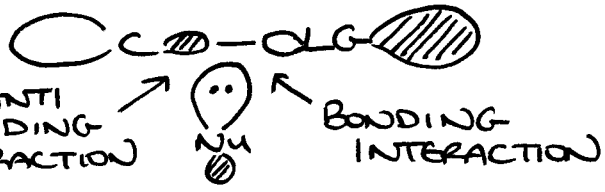
SN2 BACKSIDE ATTACK



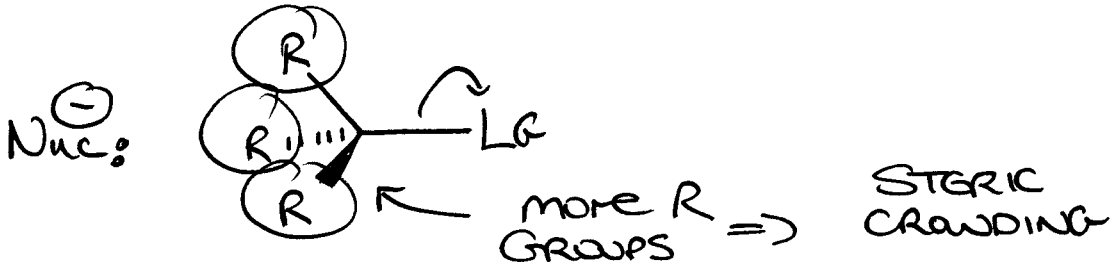
↑ filled orbital in nucleophile

↑ σ^* - empty antibonding orbital

FRONTSIDE ATTACK?



So

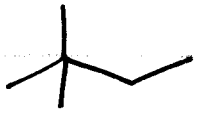


Relative Rates of S_N2 reactions

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

DECREASING RATE ↓

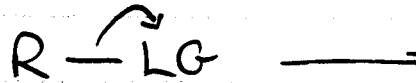
- Some 1° groups also slow things down



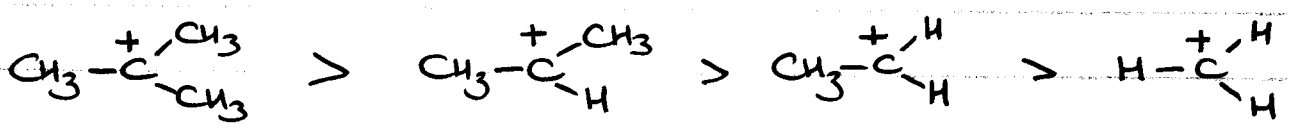
neo-pentyl

2×10^{-7}

CONSIDER S_N1 REACTIONS: OPPOSITE EFFECT



C^+ STABILITY



So, 1° and CH_3 electrophiles S_N2

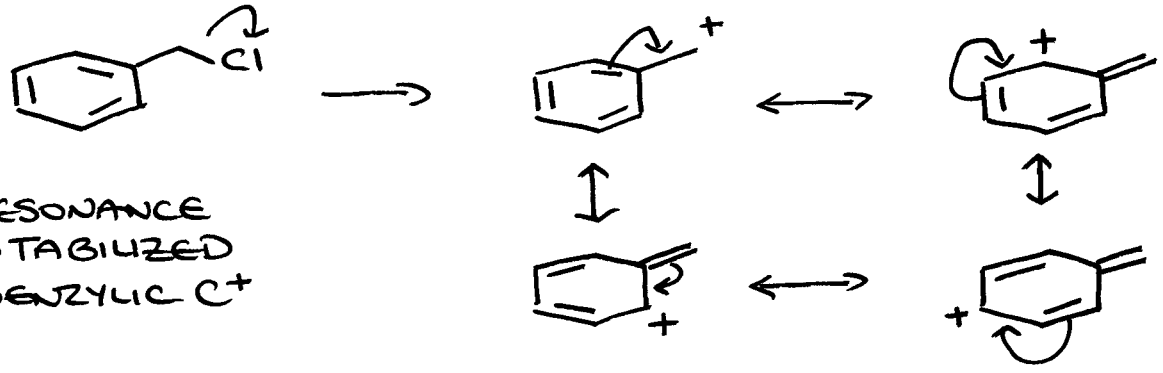
3° electrophiles S_N1

WHAT ABOUT SECONDARY?

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

– other types of C^+

RESONANCE STABILIZED 1° ALLYLIC



RESONANCE STABILIZED BENZYLIC C^+

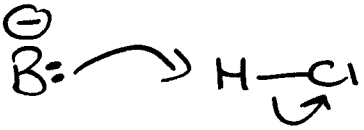
1° ALLYLIC / BENZYLIC electrophiles => S_N1 / S_N2 depends on other factors

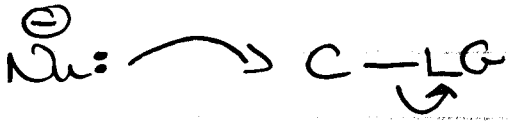
STERICS favors S_N2 ELECTRONICS favors S_N1

2°/3° ALLYLIC/BENZYLIC electrophiles => almost exclusively S_N1

(4) NUCLEOPHILE

consider BASICITY



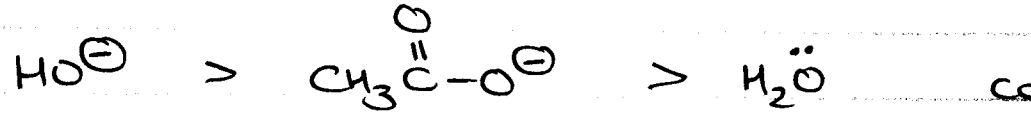
NUCLEOPHILICITY is similar 

- AFFINITY for C atom
- KINETIC rather than THERMODYNAMIC effect

IMPRECISE QUANTITY - for any given species can vary depending upon other factors (SOLVENT, ELECTROPHILE)

- General trends

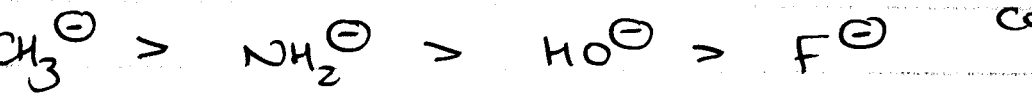
(i) SAME NUCLEOPHILIC ATOM (parallels BASICITY)



consider CHARGE & RESONANCE

pka of HX: 16 | 5 | 2

(ii) NUCLEOPHILES IN THE SAME ROW (parallels BASICITY)

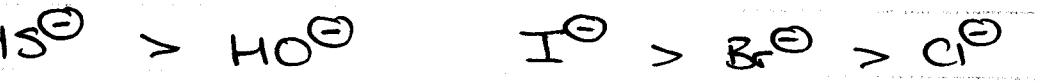


consider EN

(iii) NUCLEOPHILES IN THE SAME GROUP (COMPLICATED)

ALL COMES DOWN TO SIZE

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



OPPOSITE TO BASICITY – Why?

– many factors

(i) ENERGY LEVELS

Higher energy of lone pair electrons as you go down the periodic table => better overlap w/ σ^*

(ii) POLARISABILITY

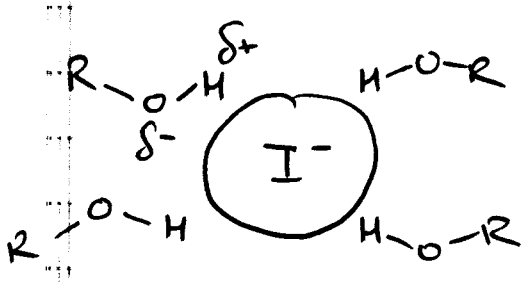
Larger atoms, more diffuse electron clouds => greater POLARISABILITY --> BONDS can begin to form at greater INTERATOMIC DISTANCES

(iii) SOLVENT (largest effect)

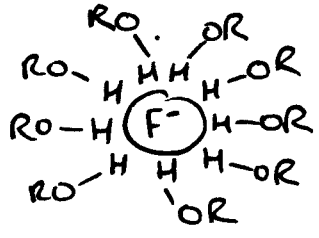
– POLAR PROTIC (H_2O, MeOH, EtOH)
– POLAR APROTIC (DMSO, DMF, MeCN, Acetone)

– POLAR PROTIC SOLVENTS

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



LOW CHARGE DENSITY (weak solvent cage)



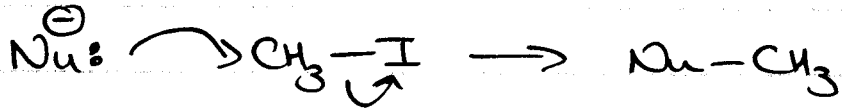
HIGH CHARGE DENSITY (strong solvent cage)

HYDROGEN BONDING – noncovalent interaction

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

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

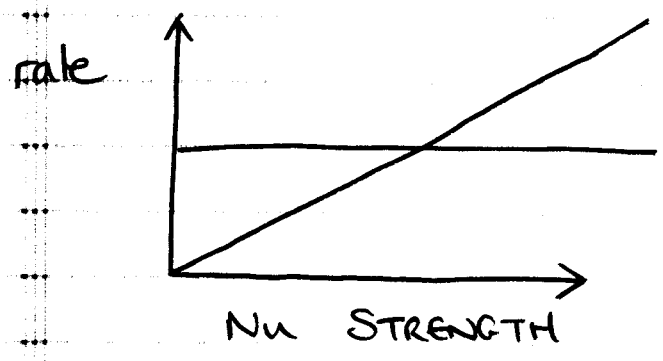
BUT IN POLAR APROTIC SOLVENTS
⟹ ANIONS WEAKLY SOLVATED, TREND IS REVERSED & CORRELATES w/ BASICITY



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

DMF/MeOH → equivalent polarities

S_N1 vs S_N2



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

S_N1 rate = $k_1[E]$

No effect on S_N1, but STRONGER Nuc favor S_N2 rxns

LEC (21) CHEM 30A Mar 4th

- NUCLEOPHILIC SUBSTITUTION

(1) NUCLEOPHILE
(2) LEAVING GROUP
(3) SOLVENT

MIDTERM LOW 4 MEAN 39 HIGH 77
READ 8.1–8.10 PROBLEMS 8.14–8.35

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(1) NUCLEOPHILE

Trends:

(i) Same nucleophilic atom (parallels basicity)

$HO^{\ominus}$ > $CH_3C(=O)-O^{\ominus}$ > $H_2\ddot{O}$ X

16 5 -2 pKa of H–X

consider CHARGE | RESONANCE

(ii) nucleophiles in same row (parallels basicity)

$CH_3^{\ominus}$ > $NH_2^{\ominus}$ > $HO^{\ominus}$ > $F^{\ominus}$

need to consider ELECTRONEGATIVITY

(iii) nucleophiles in the same group (complicated)

In general, NUCLEOPHILICITY increases down a group

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

opposite to basicity – WHY?

– MANY FACTORS

a) ENERGY LEVELS

Higher energy of lone pair electrons as you go down the group ⇒ better overlap w/ σ^*

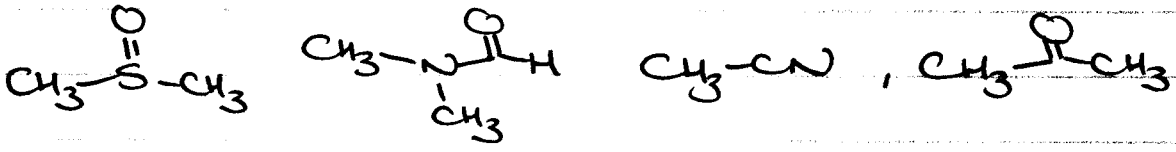
b) POLARISABILITY

Larger atoms, more diffuse electron clouds ⇒ greater POLARISABILITY → bonds can begin to form at greater interatomic distances.

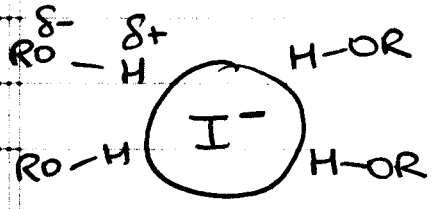
c) SOLVENT (v. large effect)

– POLAR PROTIC (H_2O, CH_3OH, CH_3CH_2OH)

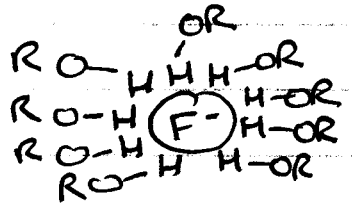
– POLAR APROTIC (DMSO, DMF, MeCN, Acetone)



POLAR PROTIC SOLVENTS $\quad I^- > Br^- > Cl^- > F^-$



LOW CHARGE DENSITY
(weak solvent cage)



HIGH CHARGE DENSITY
(strong solvent cage)

HYDROGEN BONDING – noncovalent interaction

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

So, smaller NUCLEOPHILE = higher charge density => less nucleophilic

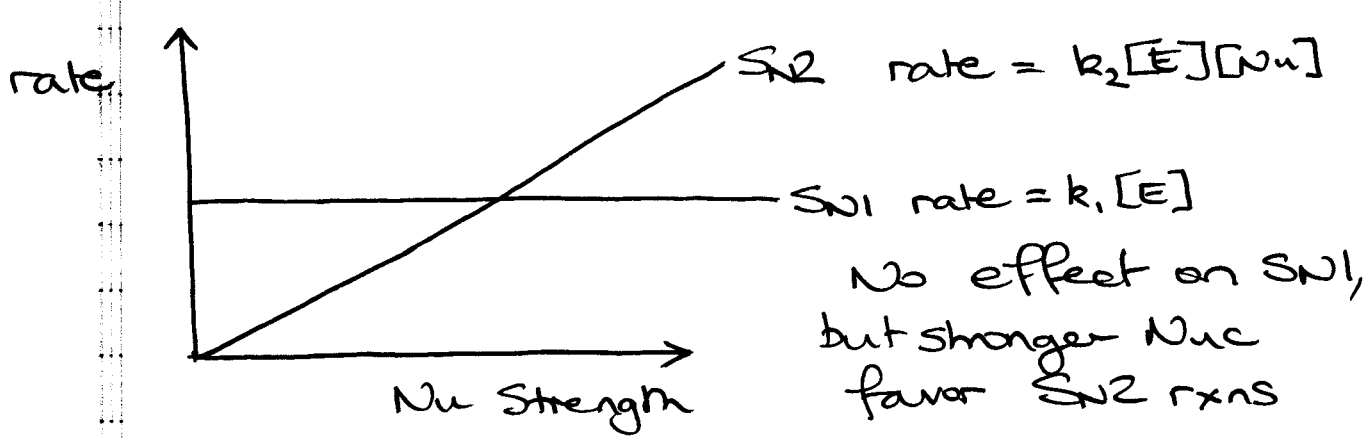
BUT IN POLAR APROTIC SOLVENTS
anions are only weakly solvated

TREND is REVERSED – correlates w/ BASICITY

consider: $Nu^{\ominus}_{s} \curvearrowright CH_3-I \longrightarrow Nu-CH_3 + I^{\ominus}$

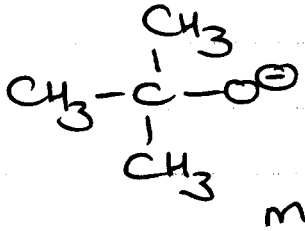
Nu	pka	MeOH (Time to complete RXN)	DMF (Time to complete RXN)	
I^-	-10	17min	8.7s	overall message
Br^-	-8	12h	8.7s	→
Cl^-	-6	13d	1.4s	POLAR APROTIC SOLVENTS ARE GOOD
F^-	3	>2yrs	<1.2s	

DMF/MeOH → equivalent polarities



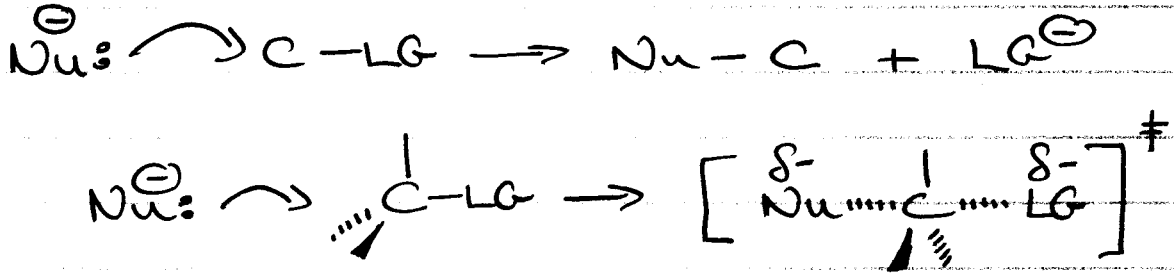
d) SIZE
consider:

$CH_3-O^{\ominus}$
methoxide
pKa 15.5



t-butoxide
pKa ~18
MORE BASIC but much LESS nucleophilic (STERICS)

(2) LEAVING GROUP



(also, IN SN1, form $LG^{\ominus}$ in RDS)

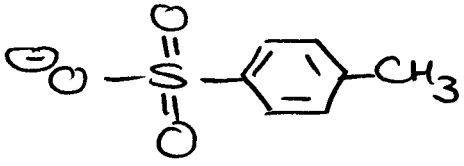
BETTER CHARGE STABILIZATION → BETTER LG
↳ reduces energy of TS, hence faster reaction

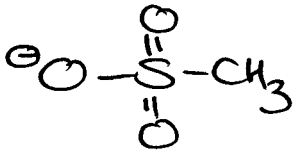
So, more ACIDIC H-LG, more stable $LG^{\ominus}$

GOOD / BAD LEAVING GROUPS
– relative reactivity

$NH_2^{\ominus}$	$OH^{\ominus}$	$OR^{\ominus}$	$F^{\ominus}$	$Cl^{\ominus}$	$Br^{\ominus}$	$I^{\ominus}$
$<<1$			1	200	10000	30000

- other good LG

tosylate  ~60,000

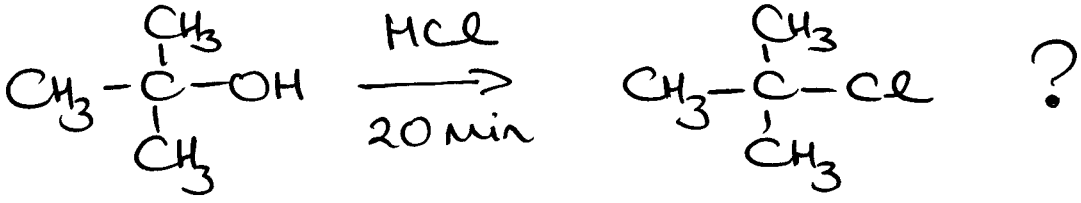
mesylate 

So, R-F, R-OH, R-OR', R-NH$_2$

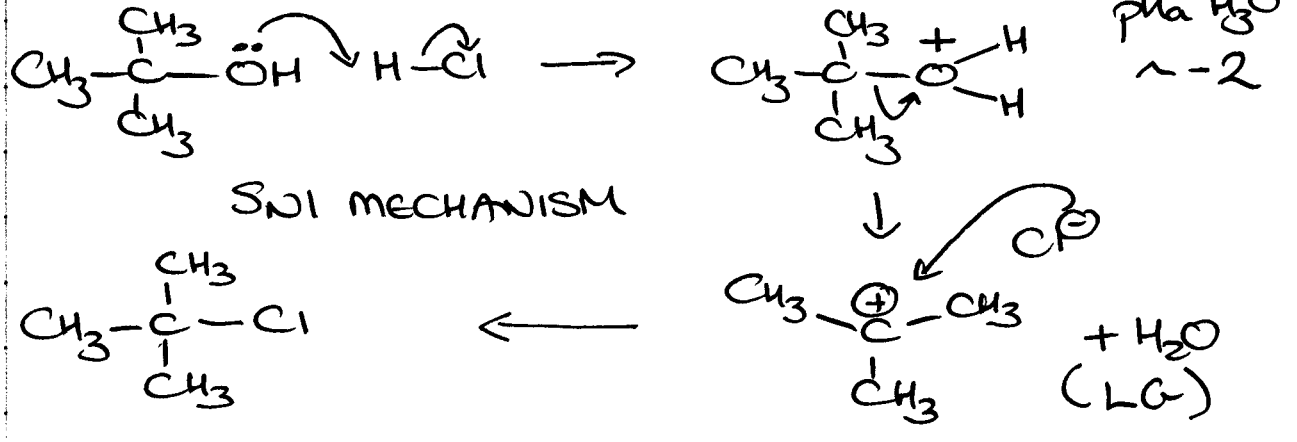
DO NOT UNDERGO SN2 reactions

DOES NOT HAPPEN

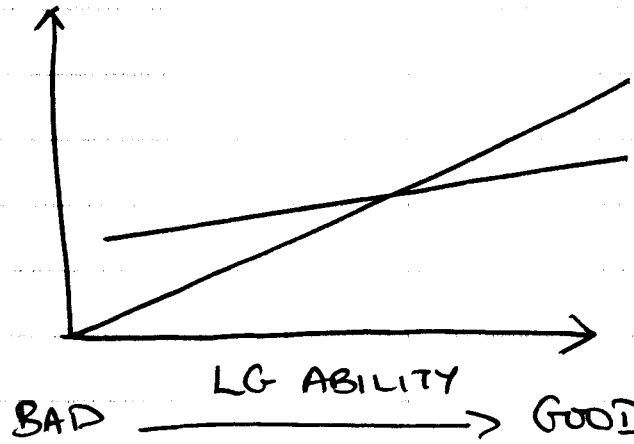
BUT



- converted OH into a better LG



SN1 vs SN2



SN1 rxn much more sensitive to LG ABILITY

RDS

$R\text{-}\overset{\curvearrowright}{LG} \rightarrow R^+ + LG^\ominus$

In SN2 reaction, as long as $LG^\ominus$ is more stable than $Nu^\ominus$, reaction can proceed

But on LG ABILITY alone, not possible to figure out SN1 vs SN2

(3) SOLVENT

SN2 RXNS → POLAR APROTIC SOLVENTS

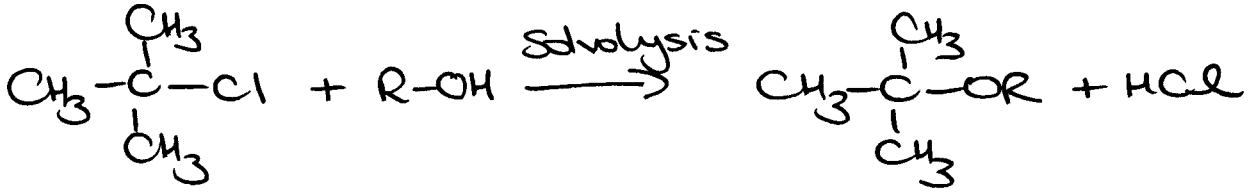
↳ solvate cations well, but not ANIONS

e.g. $NaBr \xrightarrow{\text{solvent}} Na^+ + Br^-$ (each ion surrounded by solvent molecules)

SN1 reaction $R\text{-}\overset{\curvearrowright}{LG} \rightarrow R^\oplus + LG^\ominus$

creation & 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

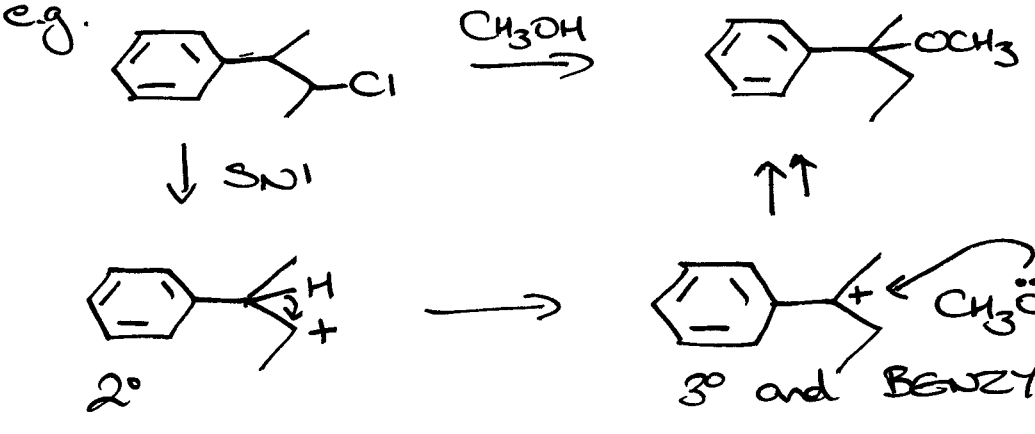
FAVORED IN PROTIC SOLVENTS

(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°	✓	✗
2°	FAVORED GOOD NUCLEOPHILES POLAR APROTIC SOLVENTS	FAVORED POLAR NUCLEOPHILES POLAR PROTIC SOLVENTS
3°	✗	✓

also helped by really GOOD LG

- it gets COMPLICATED

⇒ COMPETING ELIMINATION REACTIONS

LEC (22) CHEM 30 A Mar 7th

(1) SOLVENT
(2) REARRANGEMENT
(3) NEIGHBORING GROUP PARTICIPATION
(4) PHASE TRANSFER CATALYSIS Sect 8.7)
(5) INTRO to β ELIMINATION
(6) MECHANISMS (7) STEREOCHEMISTRY (8) SUMMARY

READ 8.8 - 8.11 PROBLEMS 8.4-8.8, 8.36-8.45

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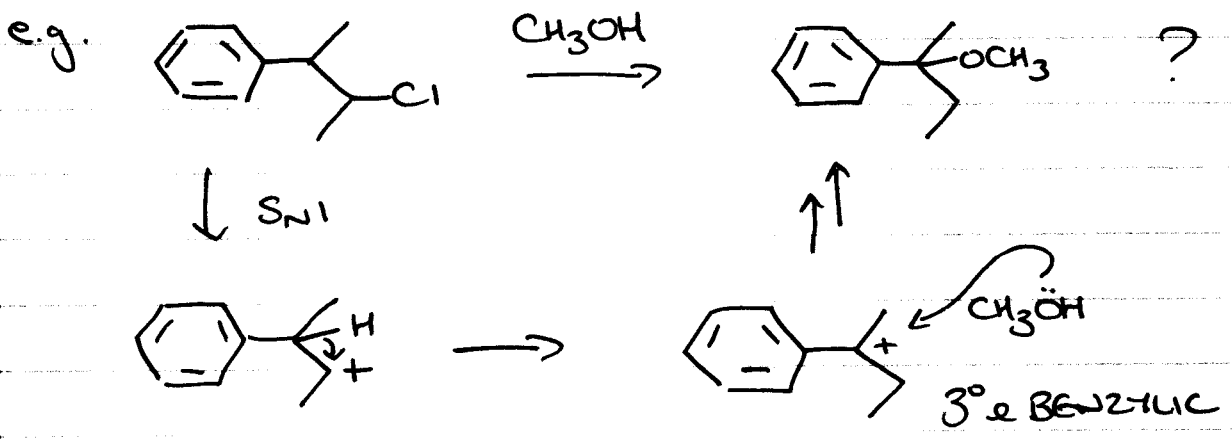
(1) SOLVENT

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

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

(2) REARRANGEMENT ($S_N1 - C^+$)

e.g.



Summary

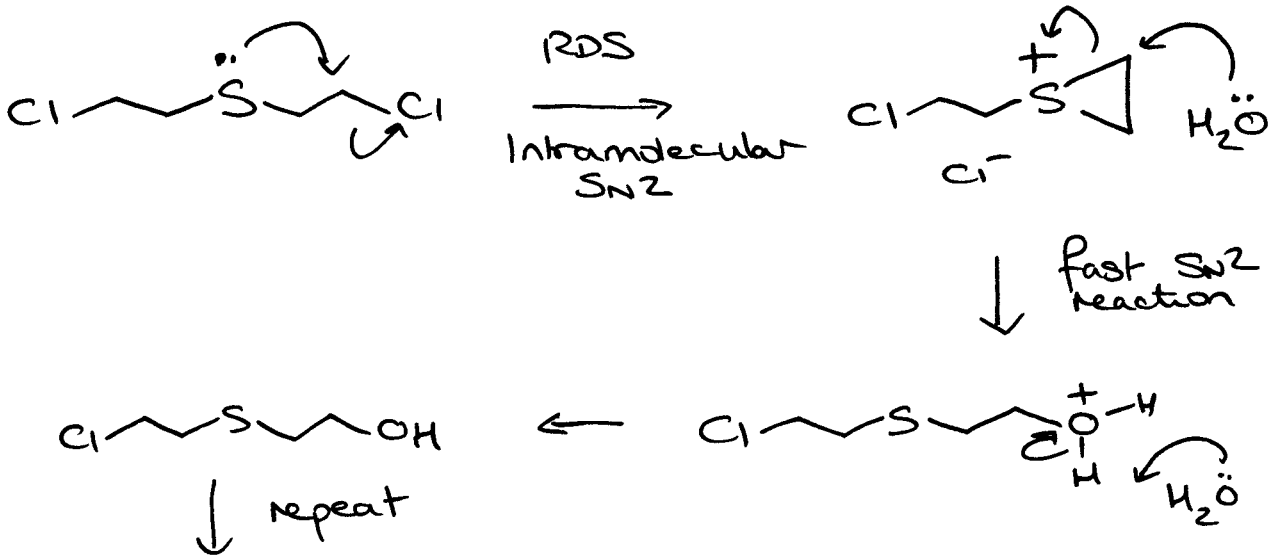
ELECTROPHILE	S_N2	S_N1
Me/1°	✓	X
2°	GOOD NUC POLAR APROTIC	POOR NUC POLAR PROTIC (GOOD LG)
3°	X	✓

- gets complicated => ELIMINATION

(3) NEIGHBORING GROUP PARTICIPATION

(mustard gas)

v. rapid reaction, even though H_2O poor nucleophile



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

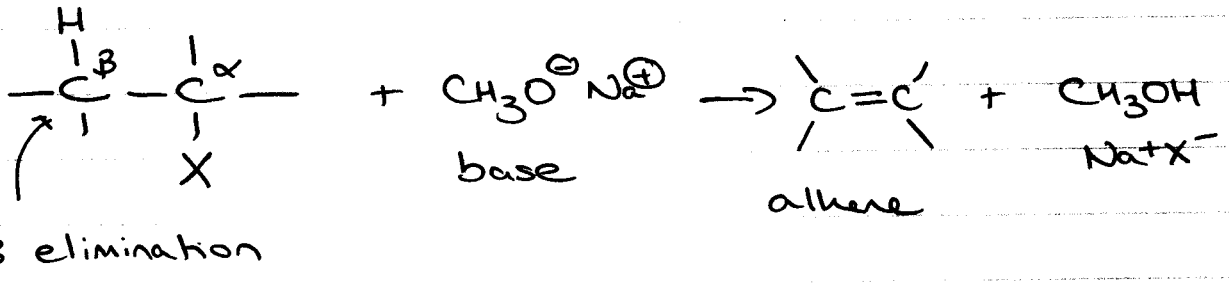
INDEPENDENT of [Nuc]

– Two consecutive S_N2 reactions with KINETICS of an S_N1 reaction

④ PHASE TRANSFER CATALYSIS (Read Sect 8.7)

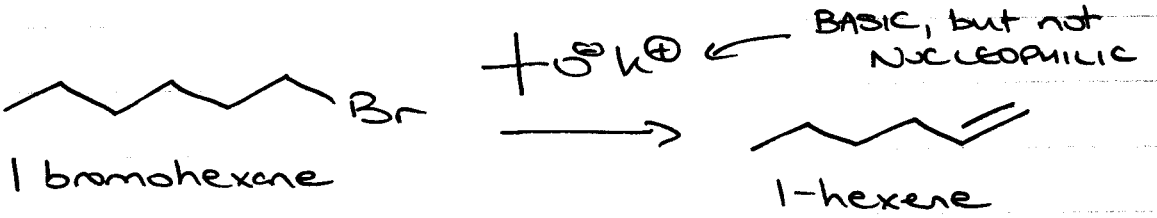
⑤ INTRO to β-ELIMINATION

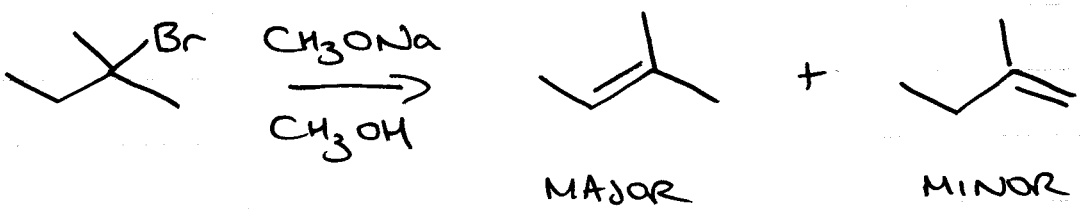
– DEHYDROHALOGENATION (one example)

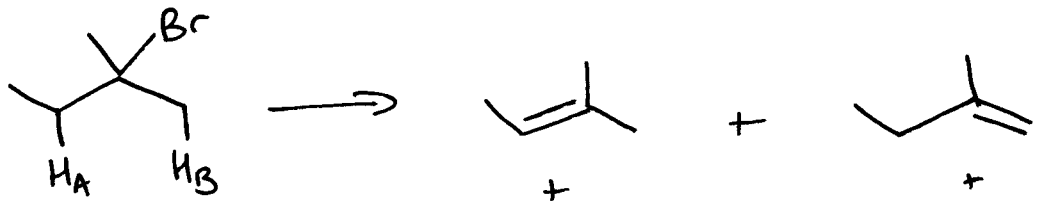


ELIMINATION competes w/ SUBSTITUTION

– examples of ELIMINATION reactions







β PROTONS

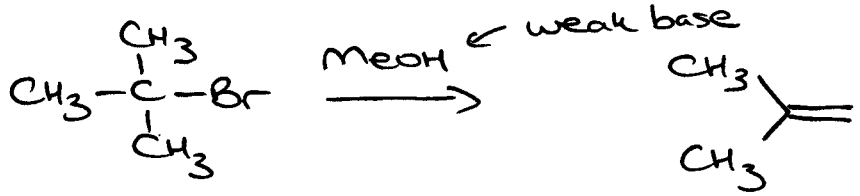
ZAITSEV'S RULE → major product is the MOST SUBSTITUTED ALKENE (more STABLE)

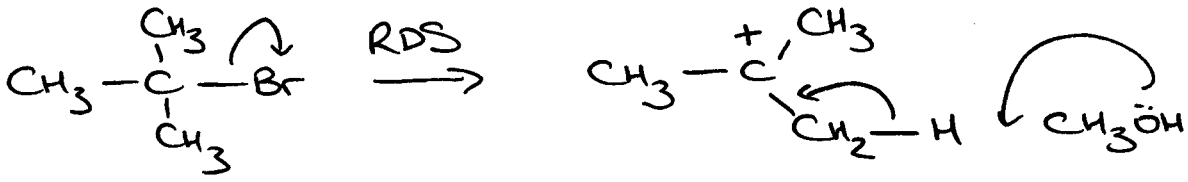
.... and there are EXCEPTIONS to this rule...

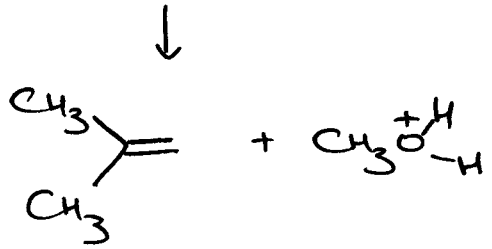
(6) MECHANISMS

(like S_N reactions, two limiting ones)

E1 (elimination unimolecular)



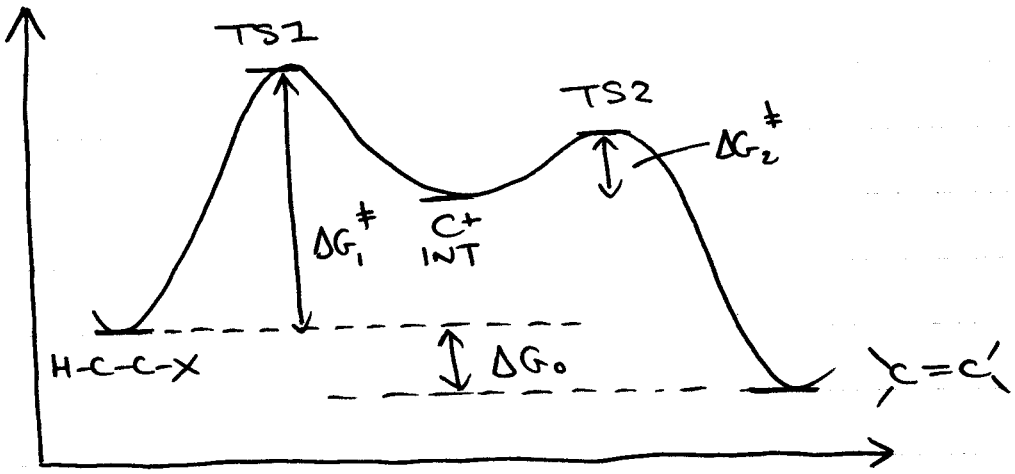




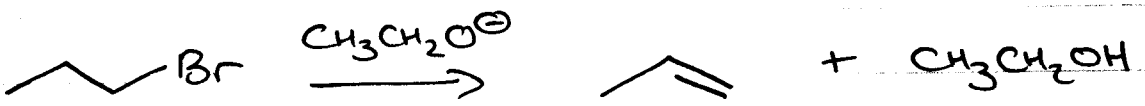
COMPETES WITH S_N1 REACTION

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

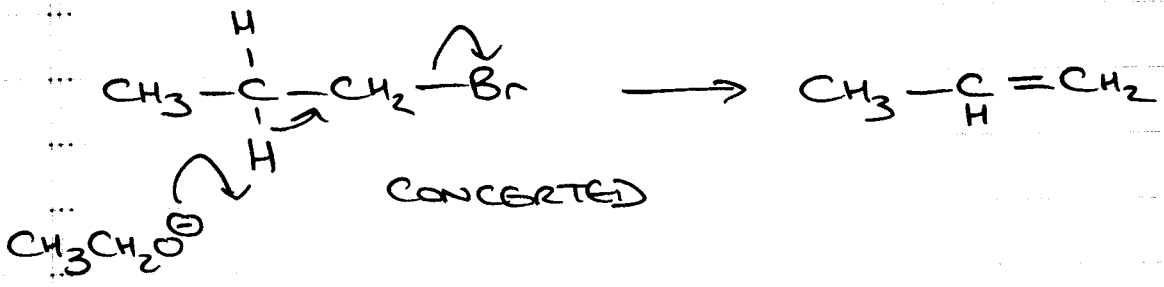
- energy profile

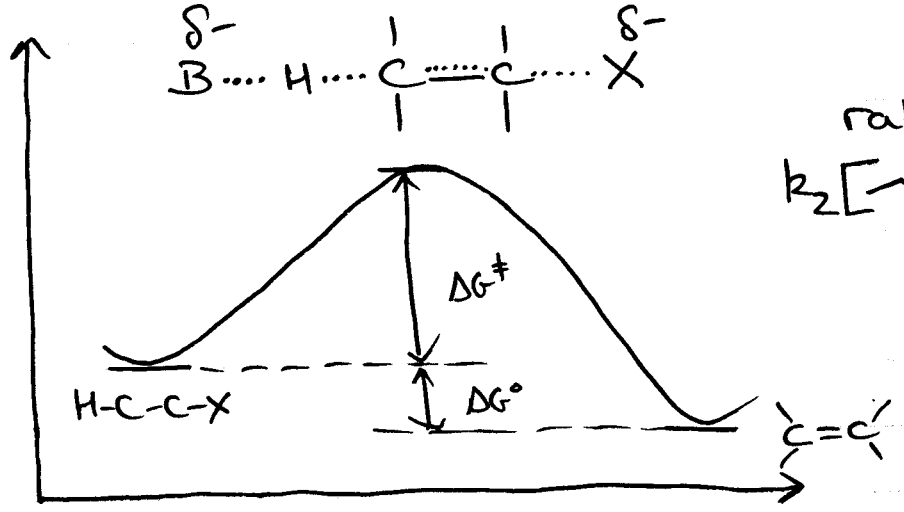


E2 (elimination bimolecular)



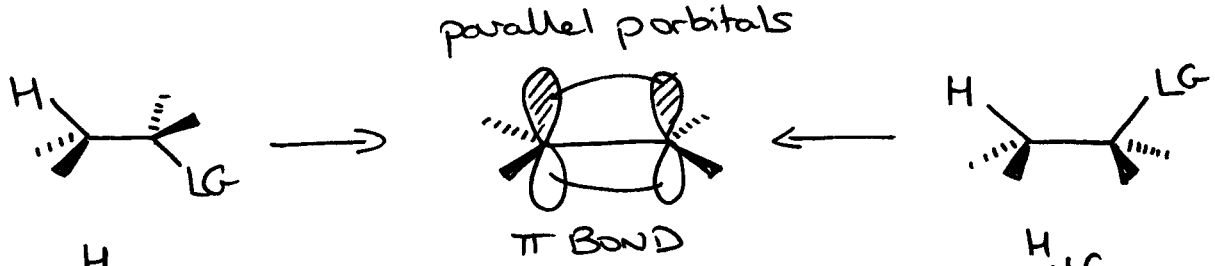
(competes w/ SN2)

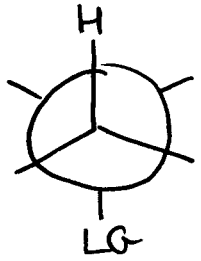




rate = k_2[Br][Base]

(7) STEREOCHEMISTRY



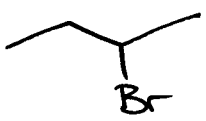


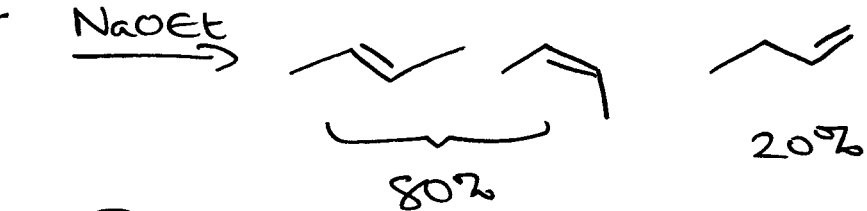
ANTI PERIPLANAR (staggered)

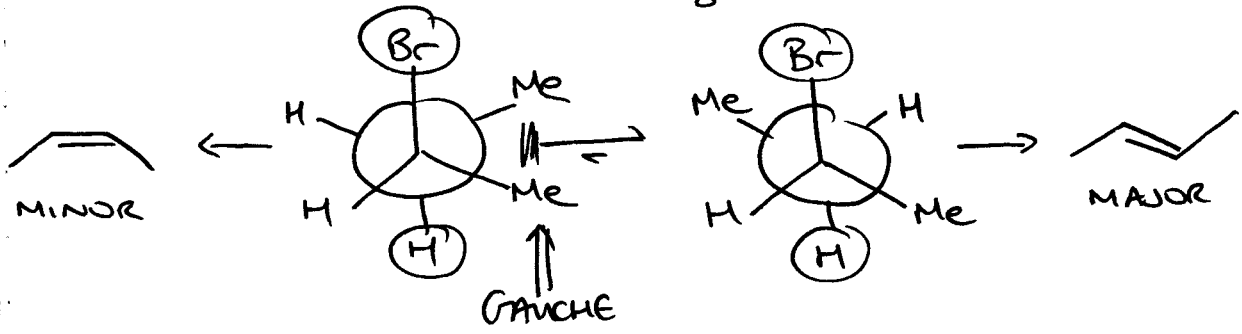
SYN PERIPLANAR (eclipsed)

Generally, antiperiplanar geometry is preffered in an E2 reaction (exceptions)

(i)







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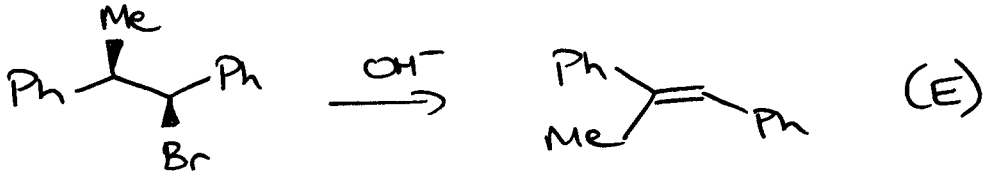
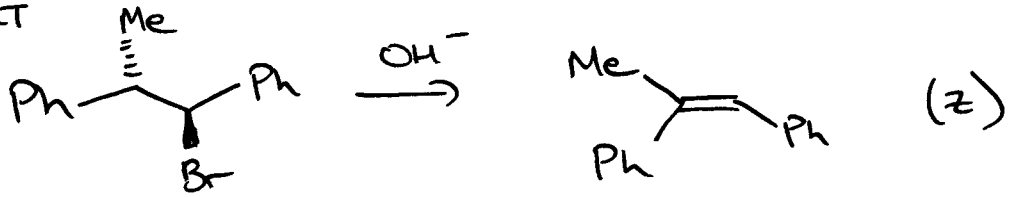


BUT



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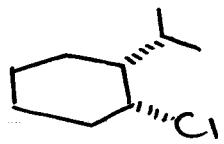
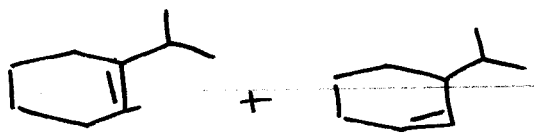


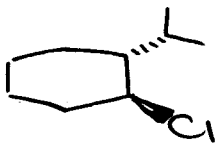
cis

CH_3ONa / CH_3OH



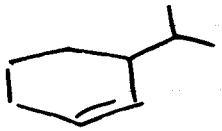
MAJOR

But



trans

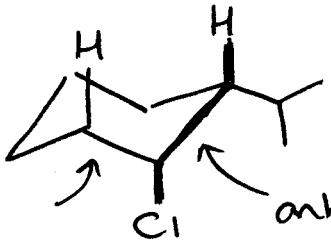
CH_3ONa / CH_3OH



only

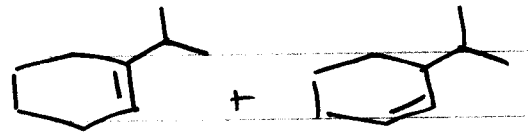
also: cis reacts faster than trans => WHY?

- cis



also anti periplanar

antiperiplanar

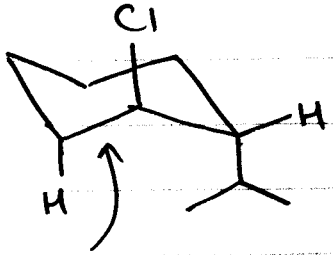


more sub

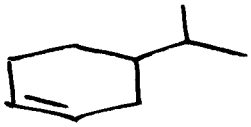
less sub

- trans

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



only one H is antiperiplanar

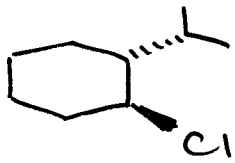


(slower because reacts through less stable chair)

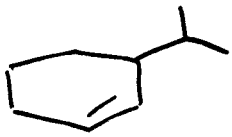
(8.) SUMMARY E1/E2

Alkyl halide	E1	E2
METHYL	— Elimination Impossible —	
1° (RCH_2X)	Does NOT happen	Favored elimination mode
2° (R_2CHX)	(H_2O/ROH) weak bases allylic, benzylic substrates	Strong bases (RO^- / HO^-)
3° (R_3C-X)	Weak bases	Strong bases

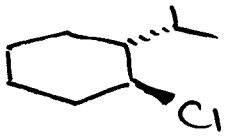
— Reaction conditions



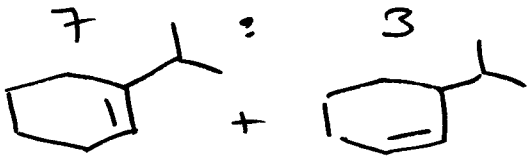
1.0M NaOEt
EtOH



E2 conditions

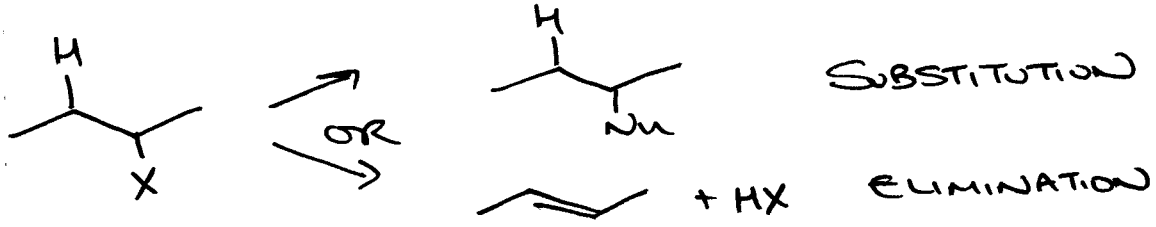


0.01 M NaOEt
80% EtOH
20% H_2O



E1 conditions

UP NEXT — SUBSTITUTION vs ELIMINATION



LEC (23) CHEM 30A Mar 9th

1. STEREOCHEMISTRY
2. REGIOSELECTIVITY
3. SYN ELIMINATION
4. E1 vs E2
5. S_N vs E
6. SYNTHESIS

Review Ch 8 PROBLEMS 8.42 – 8.50 (NOT 8.46 f, g, h)

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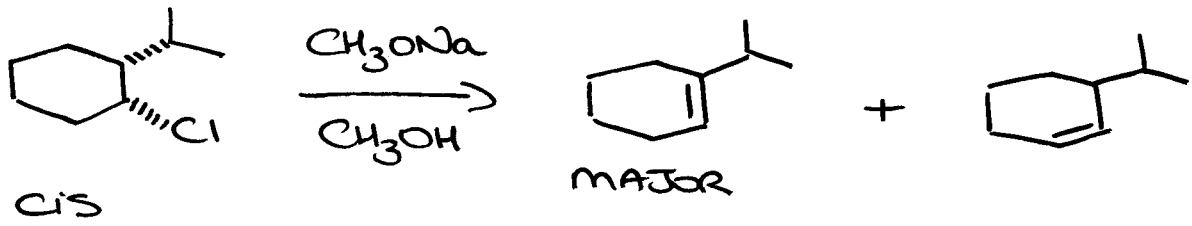
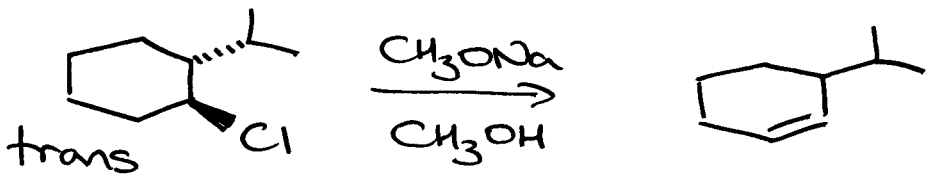
(1) STEREOCHEM cont...

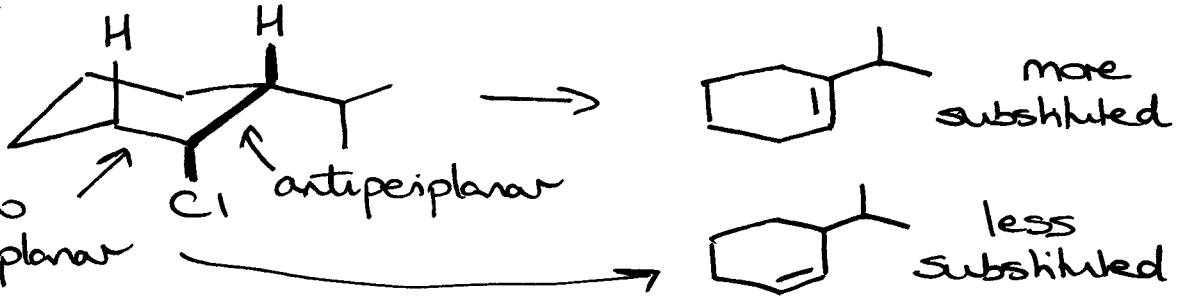


BUT

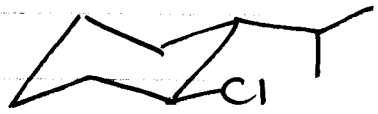


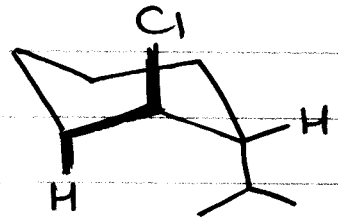
also: cis reaction FASTER than trans – WHY?

– cis



-trans



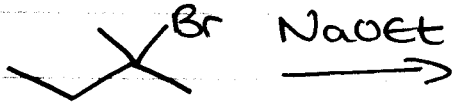


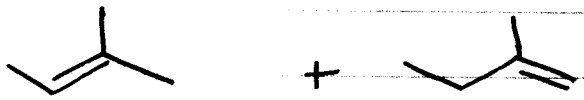
most stable chair (no Hs antiperiplanar to Cl)

only one H antiperiplanar

SLOWER b/c reacts thru LESS STABLE chair

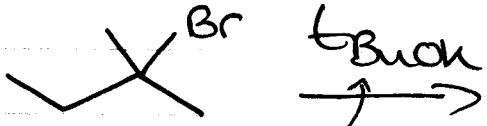
(2) REGIOSELECTIVITY

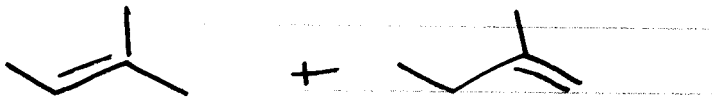




MAJOR (70%) + MINOR (30%)

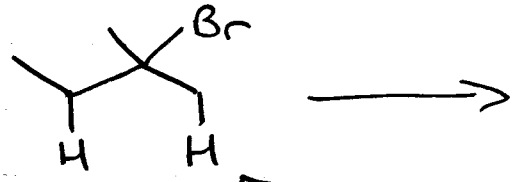
ZAITSEV selectivity → more substituted, more stable alkene

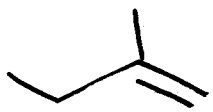




MINOR (30%) + MAJOR (70%)

HOFMANN → least substituted alkene preferred

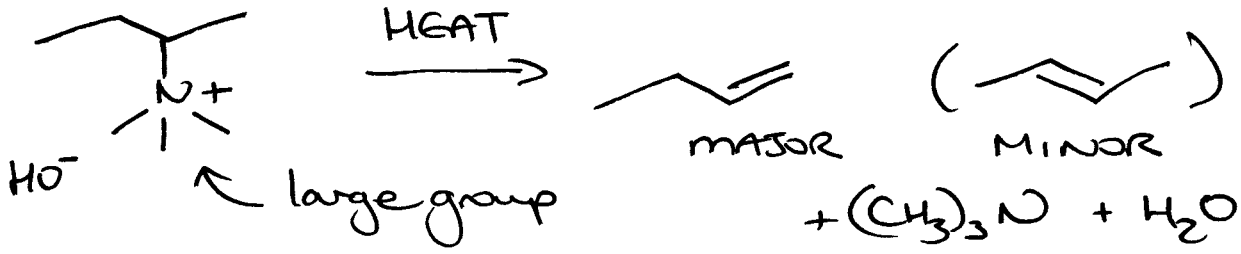




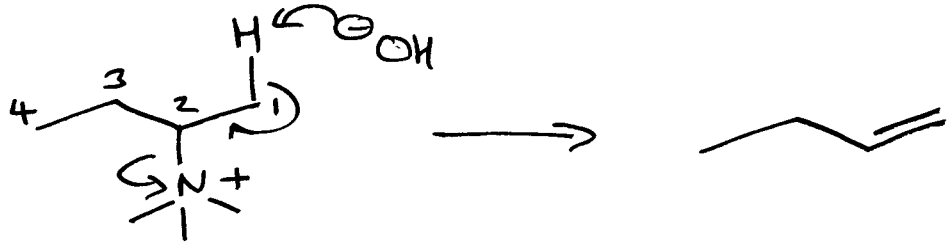
MAJOR

↖ most accesible β-H

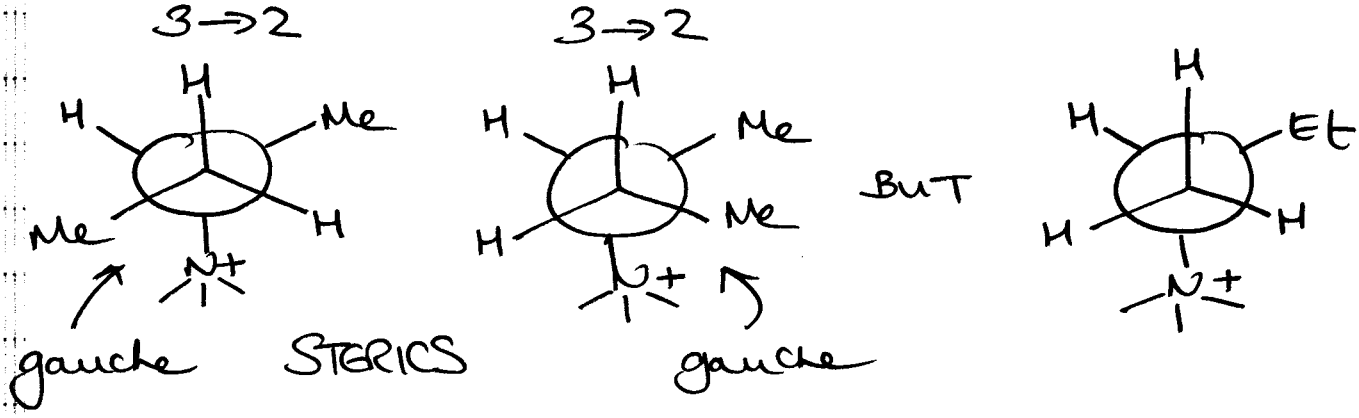
Common reaction w/ QUATERNARY AMMONIUM SALTS



Proceeds w/ ANTISTEREOSPECIFICITY

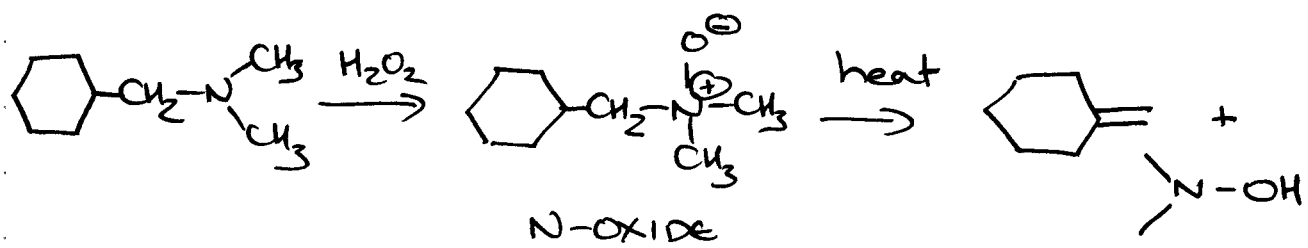


Consider NEWMAN projections

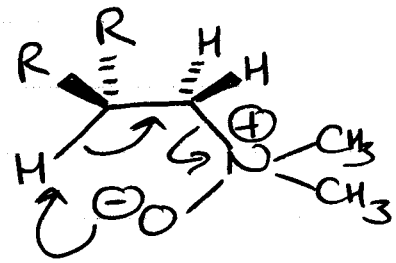


... also electronic effects

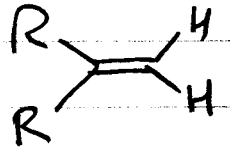
(3) SYN ELIMINATION (cope elimination)



mechanism

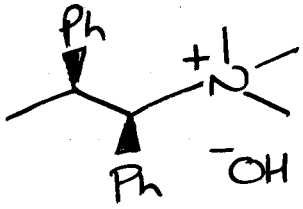


concerted rxn →

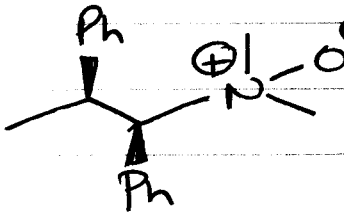


SYN

FIGURE out the PRODUCTS of these reactions

(i) 

heat → ?

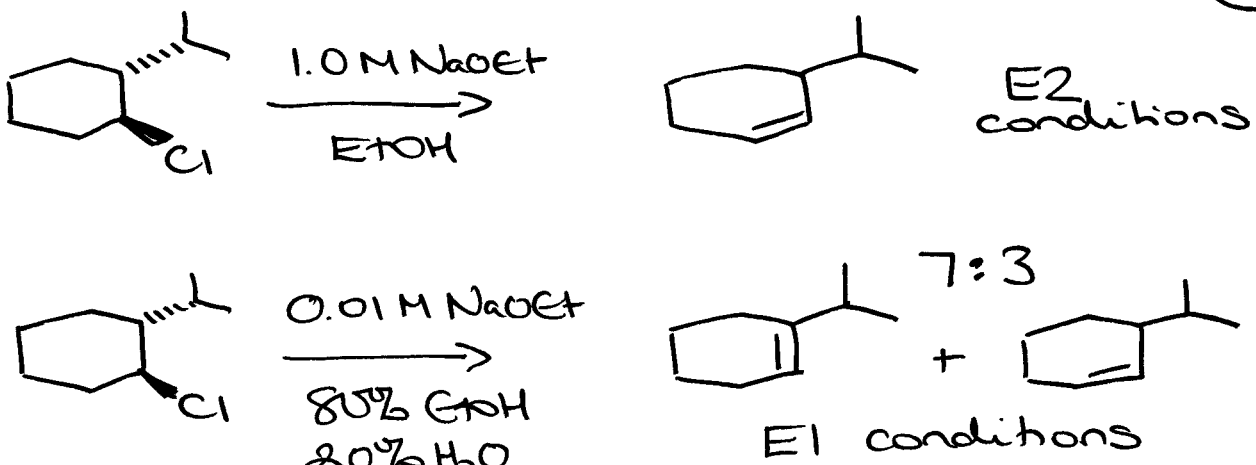
(ii) 

heat → ?

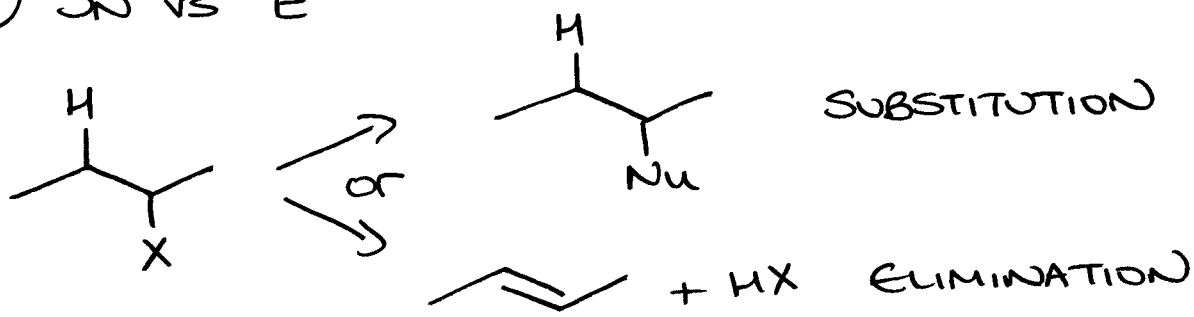
④ E1 vs E2

alkyl halide	E1	E2
methyl	– ELIMINATION IMPOSSIBLE –	
1° (RCH_2X)	DOES NOT HAPPEN ($1°C^+$)	FAVORED ELIM MODE
2° (R_2CHX)	H_2O/ROH (WEAK BASES) ALLYLIC/BENZYLIC	STRONG BASES ($RO^\ominus$/$OH^\ominus$)
3° (R_3CX)	WEAK BASES	STRONG BASES

– can also depend on reaction conditions

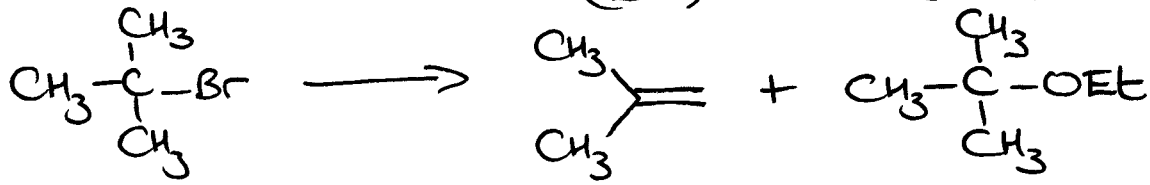


(5) S_N vs E



(i) S_N1 vs E1

e.g.



	(E1)	(S_N1)
EtOH	20%	80%

affinity for proton vs carbon ⇒ stronger base

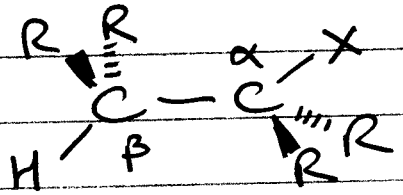
EtOH/EtONa	90%*	10%

↳ E2 mechanism

Generally S_N1 is favored over E1 except at higher temperatures (more later)

(ii) SN2 vs E2

- structure of substrate

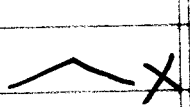
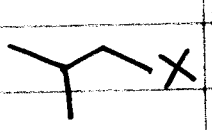
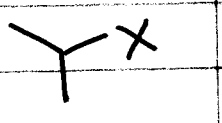


BRANCHING at α/β =>
SLOWS DOWN SN2 (Sterics)
SPEEDS UP E2 → more stable alkene

- Nucleophile

as nucleophilicity ↑ ratio SN2:E2 ↑
as basicity ↑ ratio E2:SN2 ↑

- SUMMARY

	Poor Nuc (H_2O, ROH)	Weakly basic Nuc (I^-, RS^-, RCO_2^-)	(UNHINDERED) Strongly basic Nuc (RO^-, HO^-)	(HINDERED) Strongly basic Nuc ($tBuO^-$)
CH_3X	NR	SN2	SN2	SN2
	NR	SN2	SN2	E2
	NR	SN2	E2	E2
	SN1/E1 (slow)	SN2	E2	E2
	SN1/E1	SN1/E1	E2	E2

- 2° SUBSTRATES

attacking Nuc → pka conjugate acid ≥ 11 ELIMINATION

attacking Nuc → pka conjugate acid < 11 SUBSTITUTION

Also Higher temp favors ELIMINATION

$\Delta G = \Delta H - T\Delta S$

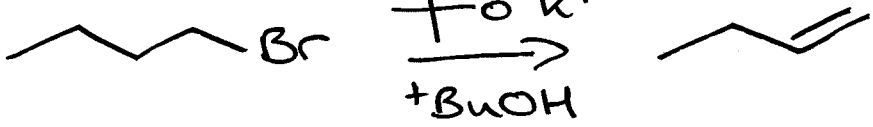
SN 2 molecules → 2 molecules

E 2 " → 3 " $+\Delta S$

- EXAMPLES

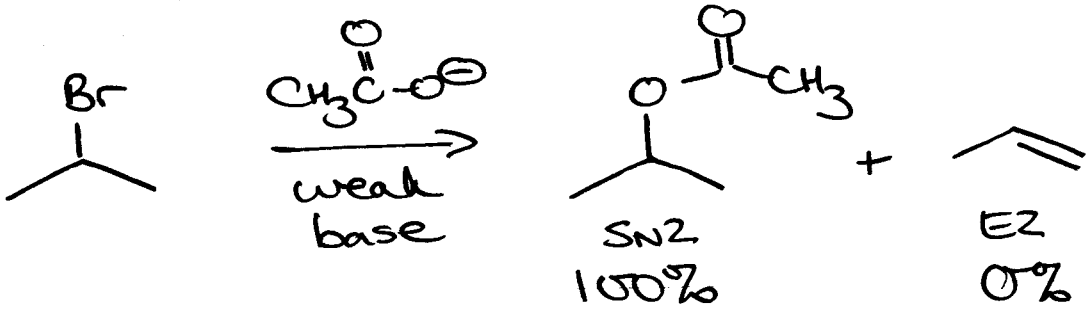
1°  SN2

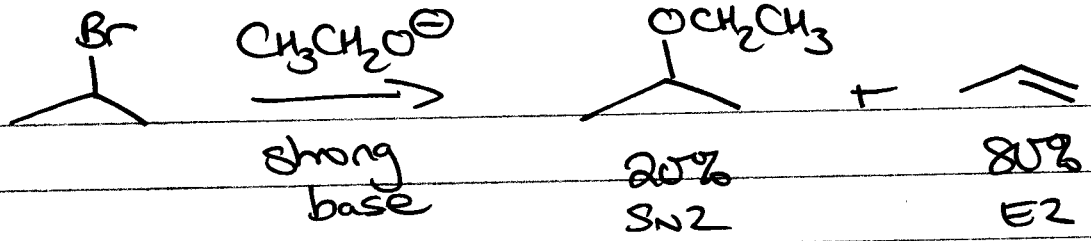
(CN⁻, RS⁻, N_3^-, NH_3, Br^-, I^-) good nucleophiles



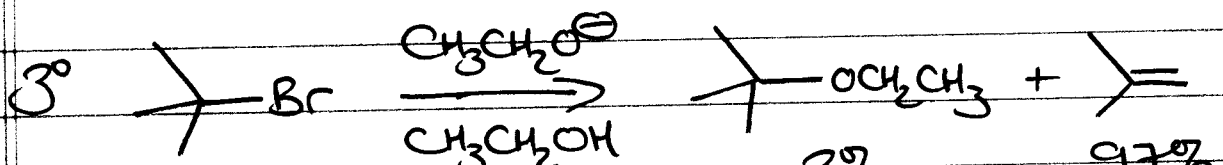
E2

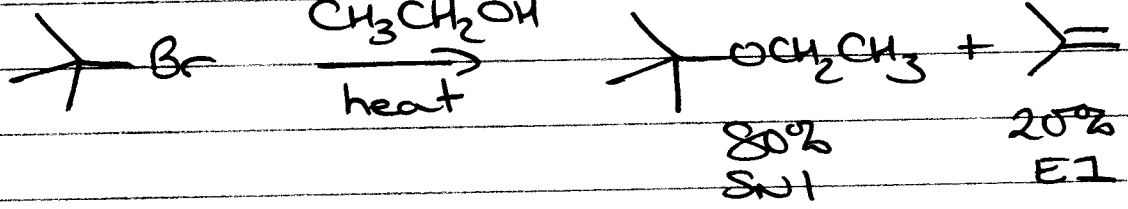
strong hindered bases

2° 

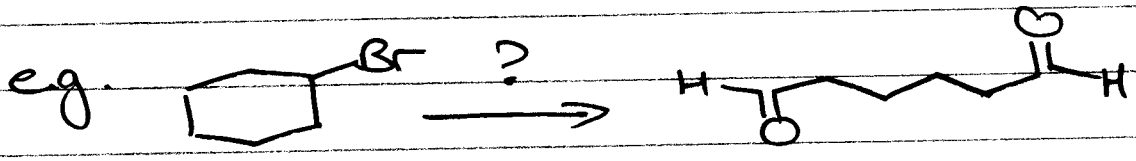


2° BENZYLIC/ALLYLIC SUBSTRATES can do SN1/E1 with weakly basic NuX in polar protic solvents



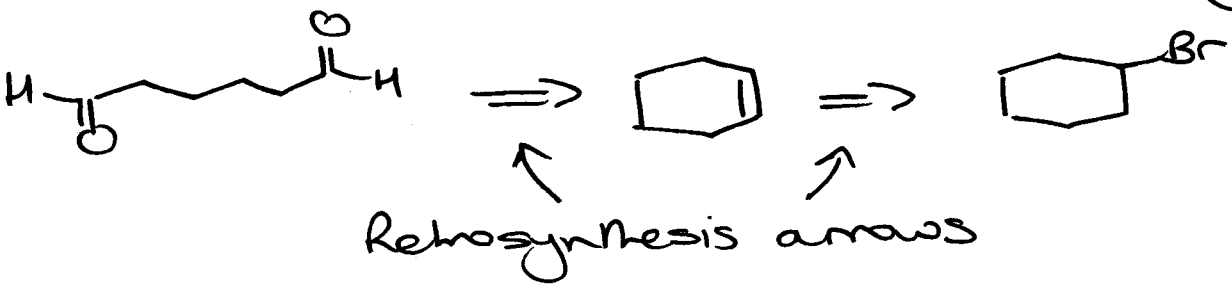


(6) SYNTHESIS
- sequences of reactions

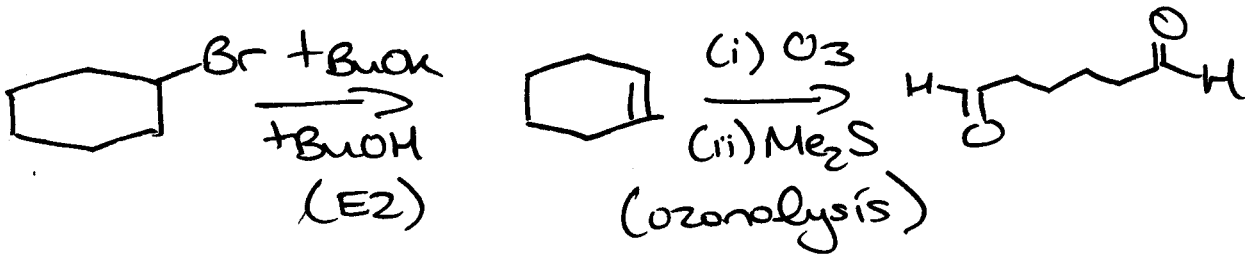


usually told if you need more than ONE STEP (here you do)

RETROSYNTHESIS → work backwards



So, forward synthesis:



LEC (24) CHEM 30A Mar 11th

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

READ 7.1–7.6
PROBLEMS 7.1–7.3

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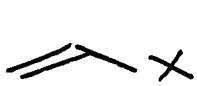
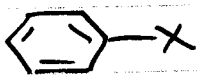
(1) } PAGES 7–9 of LEC (23)
(2) }

(3) HALOALKENES
(halogens F, Cl, Br, I)

R–X  

alkyl halide vinyl halide aryl halide

– read through naming rules (not so hard)

POLARITY $\overset{\delta+}{C} \longleftrightarrow \overset{\delta-}{X}:$ ← POLARISABILITY

charges
distance

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

Boiling Points

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

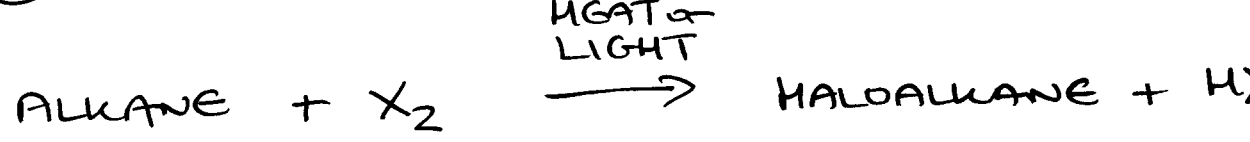
Polarisability (Dispersion forces)

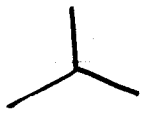
Bond lengths & strengths

Strength of bonds → Bond Dissociation Energies (BDE)

	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



eg.  + Br_2 $\xrightarrow{heat}$  + HBr

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

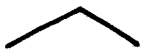
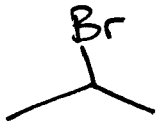
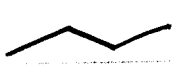
$CH_4 + Cl_2 \xrightarrow{heat} CH_3Cl + HCl$ $\Delta H = -24 kcal/mol$

Reaction continues:

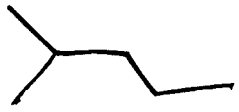
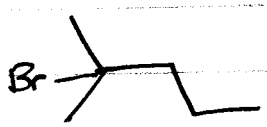
$CH_3Cl \xrightarrow[heat]{Cl_2} CH_2Cl_2 \xrightarrow[heat]{Cl_2} CHCl_3 \xrightarrow[heat]{Cl_2} CCl_4$

– REGIOSELECTIVITY

(STATISTICS SAY 25:75)

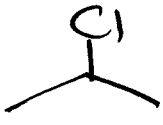
 $\xrightarrow[light/heat]{Br_2}$  (92%) +  (8%) + HBr

Sub of 2°H favored over 1° H
(also 3° favored over 2°)

So  $\xrightarrow[heat/light]{Br_2}$ 

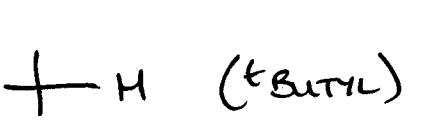
(almost exclusively)

REGIOSELECTIVITY LESS PRONOUNCED for CHLORINATION

 $\xrightarrow[heat/light]{Cl_2}$  (57%) +  (43%) + HCl

3°/2°/1° 1600 : 80 : 1 Br
5 : 4 : 1 Cl

ENERGETICS of RADICAL REACTIONS

C–H BOND	BDE (kcal/mol)
(ALLYL)	86
 (BENZYL)	88
 (tBUTYL)	93
 (iPROPYL)	96
 (ETHYL)	100
CH_3–H (METHYL)	105
 (VINYL)	106

RADICAL STABILITY INCREASES

So, for:

$$CH_4 + Cl_2 \longrightarrow CH_3Cl + H\text{–}Cl$$

BDE 105 59 −85 −103

164 + −188

$\Delta H = -24$ kcal/mol (EXOTHERMIC REACTION)

LEC 25 CHEM 30A Mar 14th

1. REGIOSELECTIVITY
2. BOND ENERGETICS
3. MECHANISMS
4. HAMMOND POSTULATE
5. RADICAL STRUCTURE/STABILITY
6. ALLYLIC HALOGENATION

Thurs 17th
Review Session
Young Hall 2200
Time: 1-3 pm

WEDS - Quiz 3 + EVALS
Read Ch 7
Problems 7.4, 7.5 - 7.27

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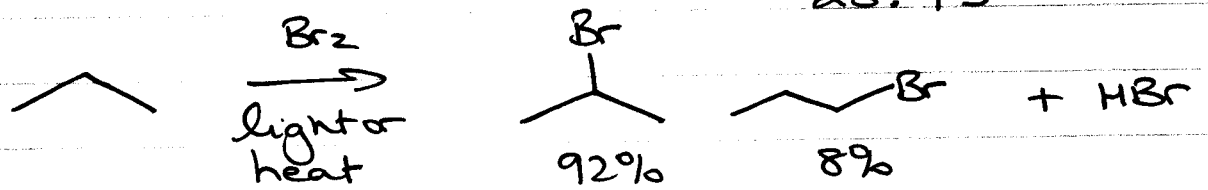
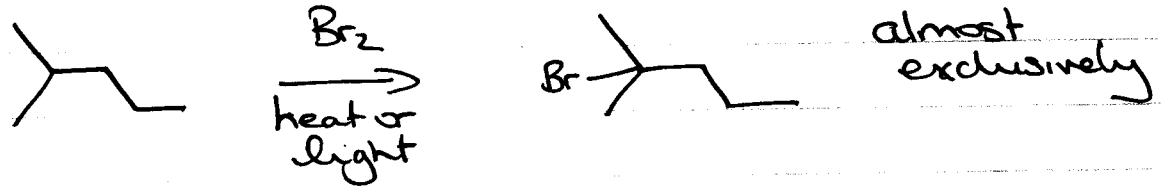
1. REGIOSELECTIVITY

(Statistics say 25:75)



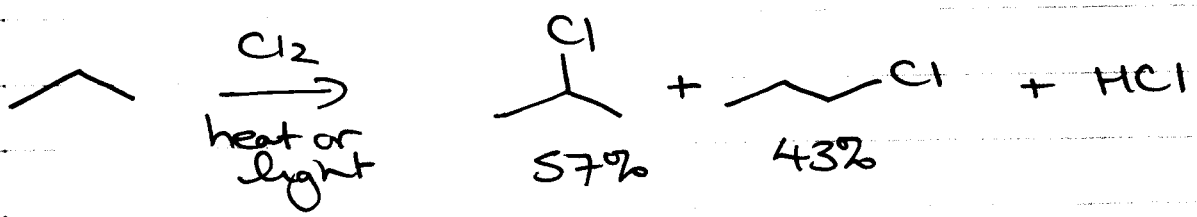
2° favored over 1° (also 3° favored over 2°)

So



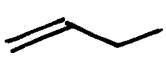
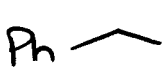
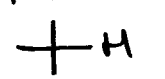
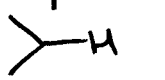
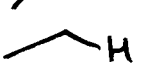
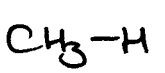
almost exclusively

REGIOSELECTIVITY LESS PRONOUNCED FOR CHLORINATION



3°/2°/1°	1600 / 80 / 1	Br
	5 / 4 / 1	Cl

(2) BOND 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

So, consider:

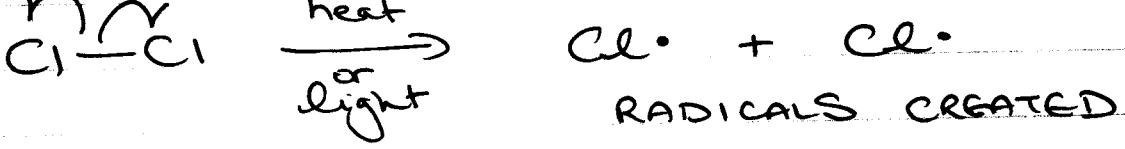
$\Delta H = -24$ kcal/mol (EXOTHERMIC REACTION)

(3) MECHANISMS

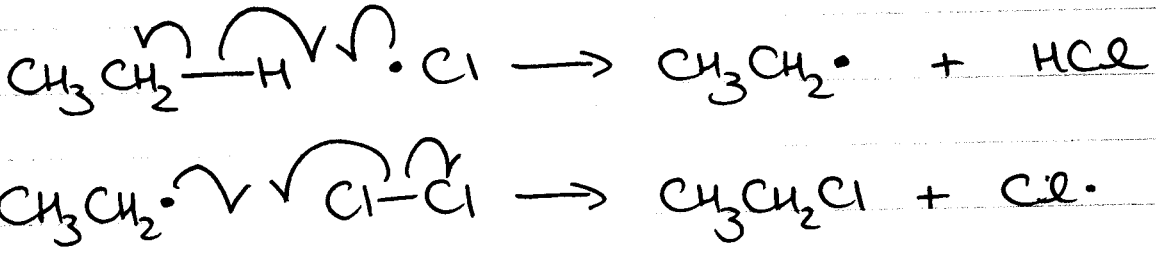
3 STEPS INITIATION / PROPAGATION / TERMINATION

e.g. $CH_3CH_3 \xrightarrow{Cl_2} CH_3CH_2Cl + HCl$

(i) CHAIN INITIATION

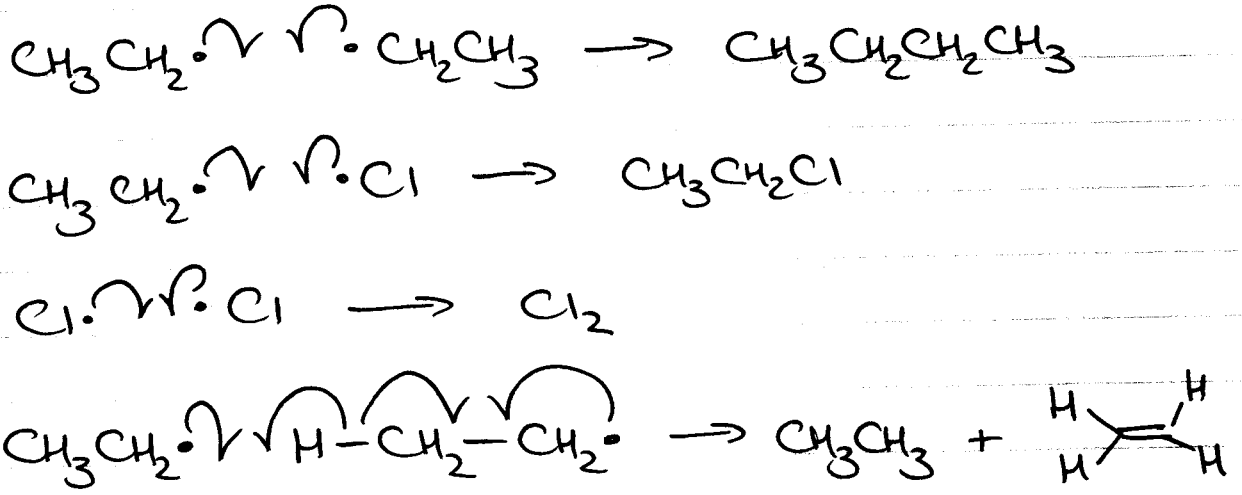


(ii) CHAIN PROPAGATION



PROPAGATES RADICALS

(iii) CHAIN TERMINATION



CONSUMES RADICALS

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

kcal/mol

$CH_3CH_2-H + Cl\cdot \rightarrow CH_3CH_2\cdot + HCl$ -3

(+100) (−103)

$CH_3CH_2\cdot + Cl-Cl \rightarrow CH_3CH_2Cl + Cl\cdot$ -21

(+59) (−80)

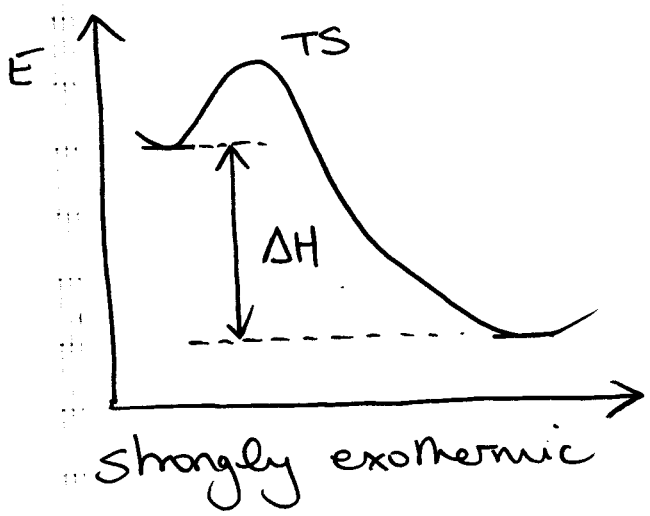
+

$CH_3-CH_3 + Cl_2 \rightarrow CH_3CH_2Cl + HCl$ -24

Gives: reaction stoichiometry and heat of reaction (ΔH)

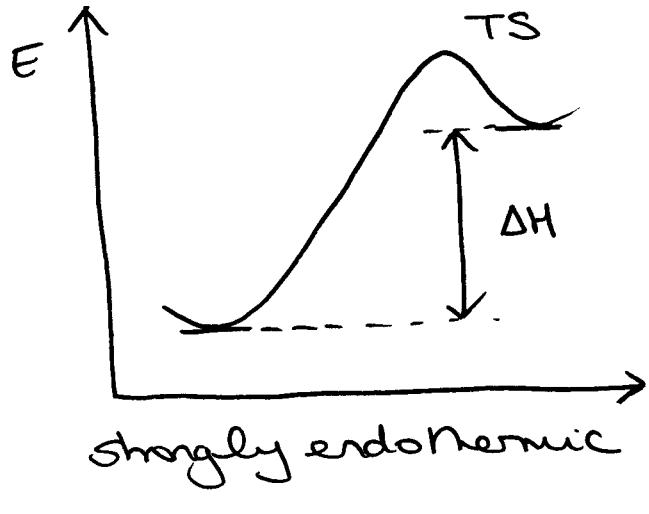
④ HAMMOND POSTULATE

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



strongly exothermic

TS looks like reactant

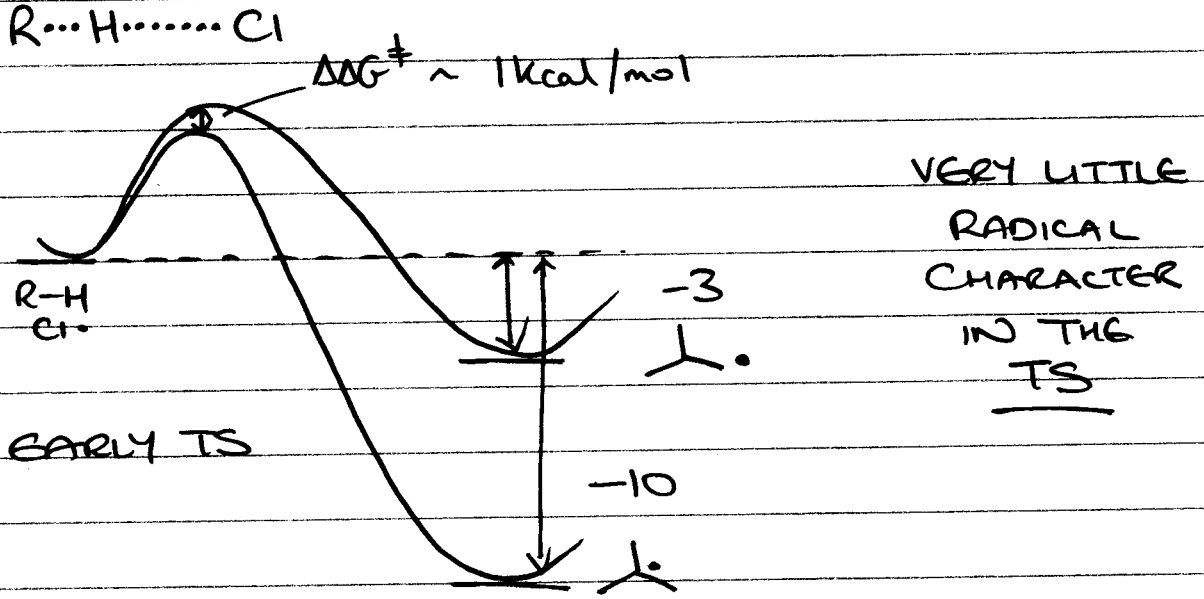


strongly endothermic

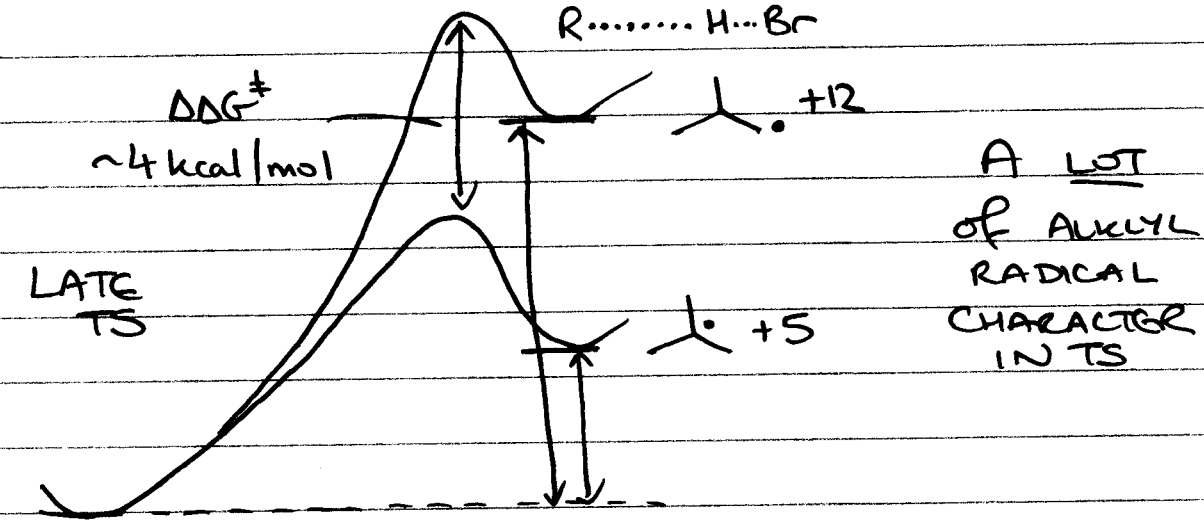
TS looks like product

- Abstraction of H is RDS, consider:

- CHLORINATION (exothermic RDS)

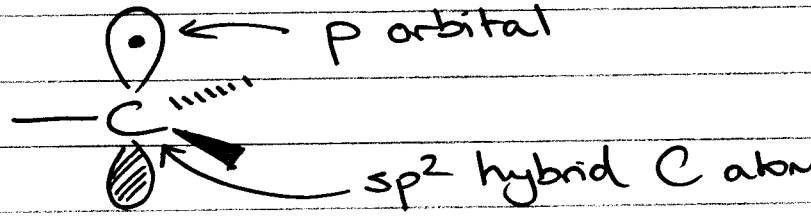


- BROMINATION (endothermic RDS)

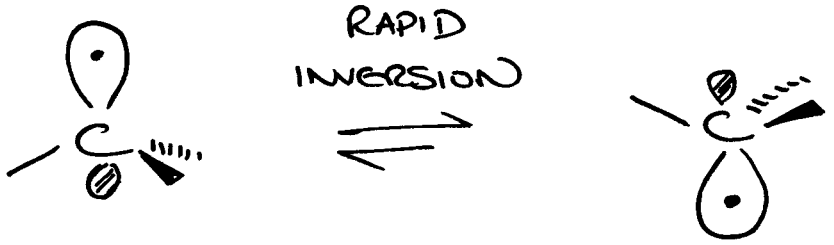


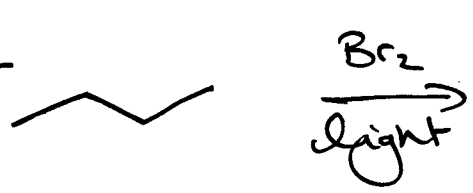
In BROMINATION, stability of radical is much more reflected in TS than in CHLORINATION, so REGIOSELECTIVITY much greater in BROMINATION

(5) RADICAL STRUCTURE

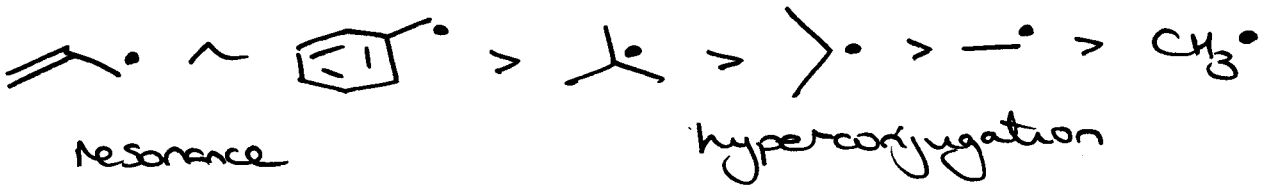


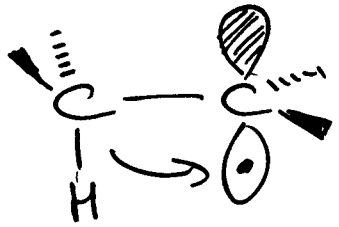
actually a Shallow Pyramid



So 

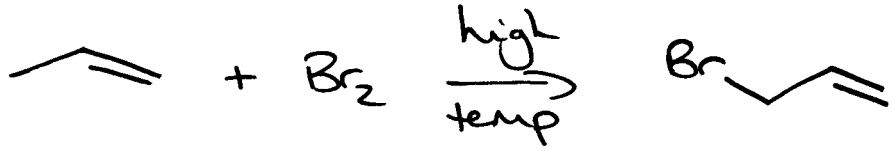
– STABILITY
(reflected in BDE values)



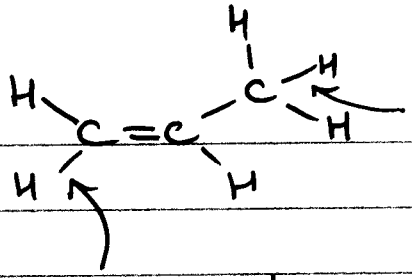


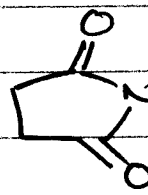
same effect as with CARBOCATIONS

(6) ALLYLIC HALOGENATION



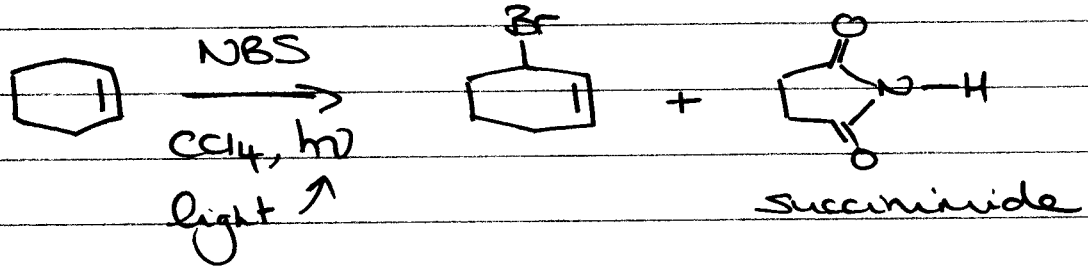
allylic substitution



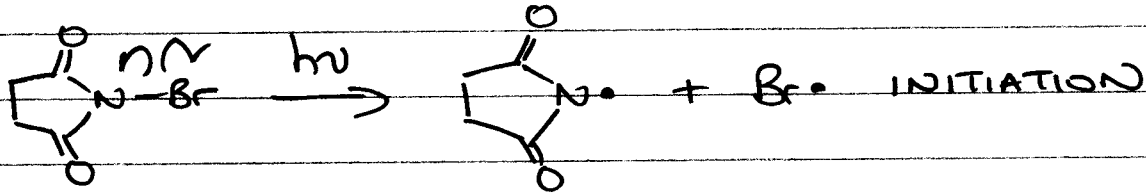
= more convenient reagent  NBS

N-Bromosuccinimide

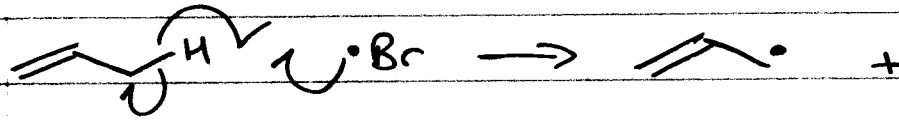
Reaction can be done at room temperature

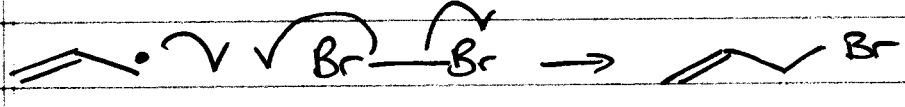


mechanism:



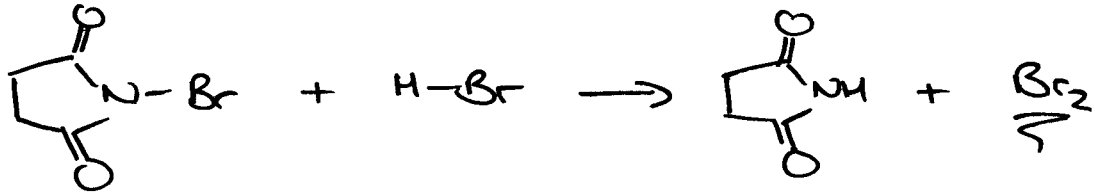
PROPAGATION





TERMINATION – combination of radicals to form non-radical species

Where did the Br_2 come from?



Why does Br_2 not do electrophilic sub?

- Low conc
- RADICAL REACTIONS ARE MUCH FASTER.