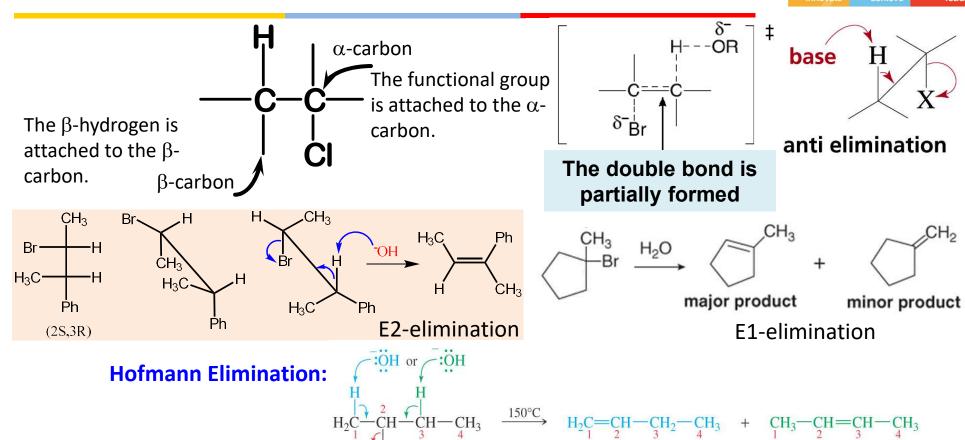


# CHEM F111: General Chemistry Semester II: AY 2017-18

**Lecture 40 (27-04-2018)** 

#### **Summary of Lecture 39**





 $^{\dagger}N(CH_3)_3$ 

#### **Cope Elimination:**

1-butene Hofmann product

95%

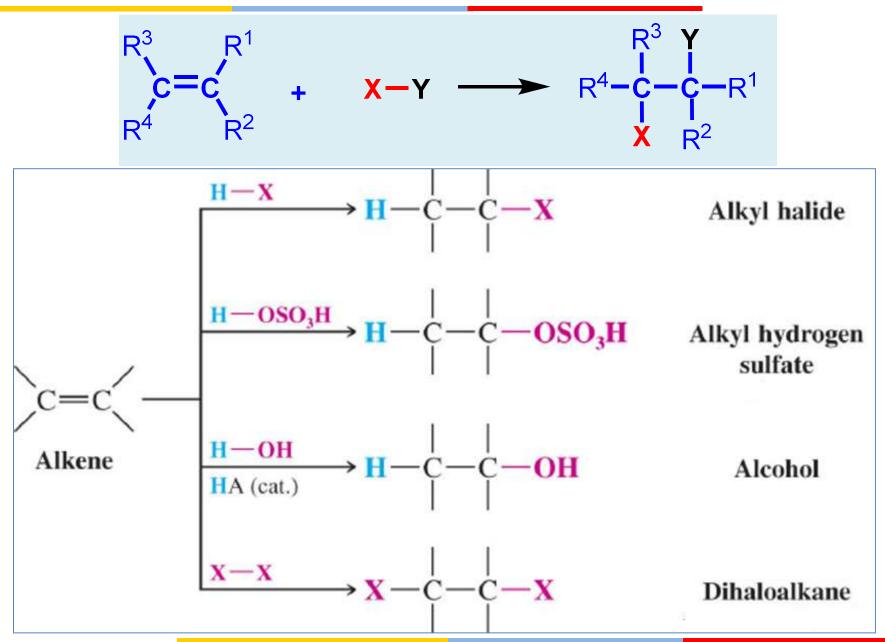
2-butene (E and Z)

Saytzeff product

5%

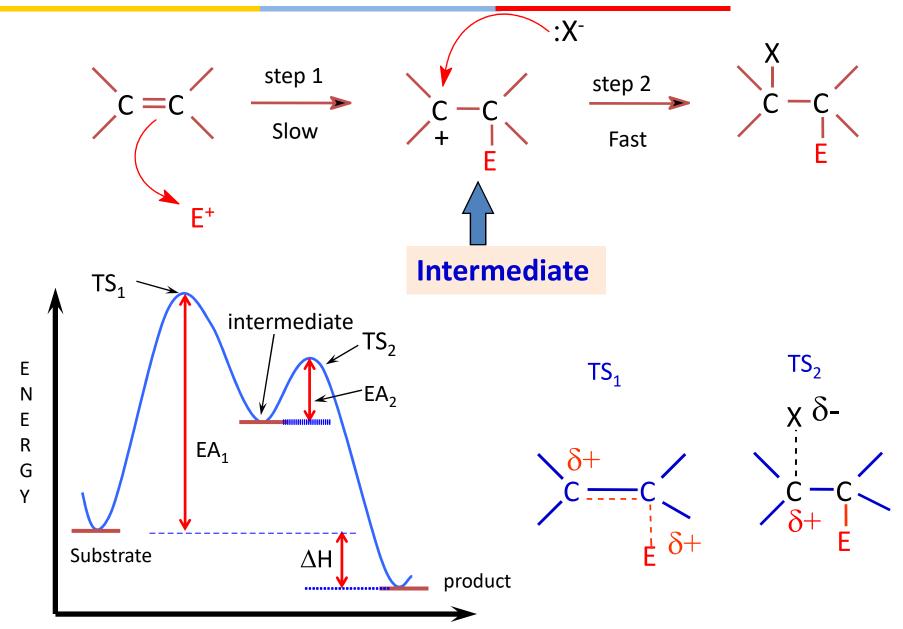
### **Electrophilic addition**





#### MECHANISM: STEP-BY-STEP ACCOUNT OF WHAT HAPPENS





#### **Carbocation Stability**

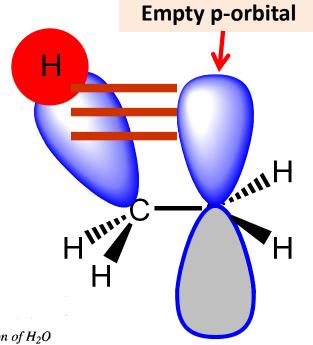


Most 
$$R \stackrel{\downarrow}{\sim} R > R \stackrel{+}{\sim} CH - R > R - CH_2$$
 Least stable tertiary secondary primary

electrons in an adjacent C-H  $\sigma$  bond help to stabilize the positive charge of the carbocation by proximity (overlap)

-HYPERCONJUGATION

#### Alkenes -Addition of water



### Addition of Hydrogen Halides: Markovnikov's rule

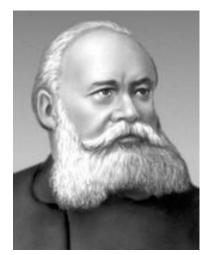


### Addition is regioselective

#### Markovnikov's Rule

In the ionic addition of an acid to the carbon-carbon double bond of an alkene, the hydrogen of the acid attaches itself to the carbon atom which already holds the *greater* number of hydrogens.

- -"Them that has, gets!"
- -"The richer get richer!"

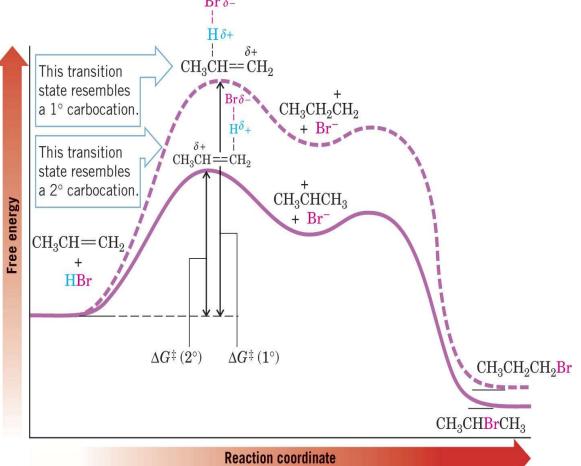


V. W. Markovnikov (1838 - 1904)

### Regioselectivity of HBr addition



$$H_{3}C \xrightarrow{CH_{3}} + CH_{3}CH_{2}CH_{2}OH \xrightarrow{HBr} H_{3}C \xrightarrow{CH_{3}} + CH_{3}CH_{2}CH_{2}Br \xrightarrow{HBr} H_{3}C - C = CH_{2}$$



In the dehydration of an alcohol it is best to use a concentrated acid so that the concentration of water is low.

The water can be removed as it is formed, and it helps to use a high temperature.

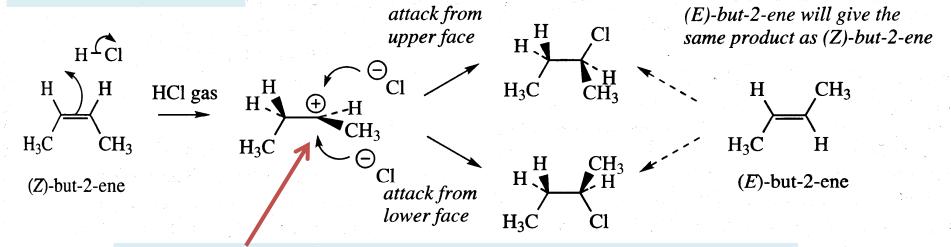
In the hydration of an alkene it is best to use dilute acid so that the concentration of water is high.

### **Stereochemistry of HX Addition**



**Rearrangement:** Intermediate carbocation rearranges to more stable carbocation.

#### Stereochemistry



Carbocations are planar -> attack from both sides possible!!

#### Anti-Markovnikov's addition of HBr



When alkenes are having trace amounts of peroxides then, reaction of HBr follows anti-Markovnikov addition.

Essence of the mechanism is that hydrogen and bromine add to the double bond homolytically rather than heterolytically.

The intermediate is a free radical rather than a carbocation.

Like halogenation of alkanes, this is a chain reaction, this time involving addition rather than substitution.

### Addition of ICl and H<sub>2</sub>SO<sub>4</sub>



CH<sub>3</sub>

2-Chloro-1-iodo-

2-methylpropane

#### **Addition of ICI**

$$\begin{array}{c} H_{3}C \\ C = CH_{2} + : \ddot{\mathbf{I}} - \ddot{\mathbf{C}} \ddot{\mathbf{C}} : \longrightarrow \\ H_{3}C \\ \mathbf{C} + CH_{2} - \ddot{\mathbf{I}} : \longrightarrow \\ H_{3}C \\ \mathbf{C} + CH_{2} - \ddot{\mathbf{I}} : \longrightarrow \\ \mathbf{C} + CH_{2} - \ddot{\mathbf{C}} : \ddot{\mathbf{C}} : - \mathbf{C} \\ \mathbf{C} + \mathbf{C} + \mathbf{C} + \mathbf{C} + \mathbf{C} + \mathbf{C} \\ \mathbf{C} + \mathbf{C} + \mathbf{C} + \mathbf{C} + \mathbf{C} \\ \mathbf{C} + \mathbf{C} + \mathbf{C} + \mathbf{C} \\ \mathbf{C} + \mathbf{C} + \mathbf{C} \\ \mathbf{C} + \mathbf{C} + \mathbf{C} \\ \mathbf{C} \\ \mathbf{C} + \mathbf{C} \\ \mathbf{C} \\ \mathbf{C} + \mathbf{C} \\ \mathbf{C} + \mathbf{C} \\ \mathbf{C} \\ \mathbf{C} + \mathbf{C} \\ \mathbf{C} + \mathbf{C} \\ \mathbf{C} + \mathbf{C} \\ \mathbf{C} \\ \mathbf{C} + \mathbf{C} \\ \mathbf{C} \\ \mathbf{C} + \mathbf{C}$$

Addition of H<sub>2</sub>SO<sub>4</sub>

H

Very reactive not favorable



#### **A Better Picture**

# This is an alcohol synthesis

### **Hydration of alkenes**



### Predict the product and draw a mechanism.

$$H_2SO_4$$
 $H_2O$ 
 $H_2O$ 
 $H_2O$ 
 $H_2O$ 
 $H_3$ 
 $H_4O$ 
 $H_4O$ 

#### **Consequence of carbocation rearragement**



☐ The occurrence of carbocation rearrangements limits the utility of alkene hydrations as a laboratory method for preparing alcohols.

# **Modern statement of Markovnikov rule**

☐ In the ionic addition of an unsymmetrical reagent to a double bond, the positive portion of the adding reagent attaches itself to a carbon atom of the double bond so as to yield the more stable carbocation as an intermediate.

# How do you avoid rearrangement problem?





#### WebElements: the periodic table on the world-wide web

http://www.webelements.com/

1	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
hydrogen																		helium
1																		2
H																		He
1.0079		Key:																4.0026
lithium 3	beryllium 4	element name atomic number											boron 5	carbon 6	nitrogen 7	oxygen 8	fluorine 9	neon 10
ı ı													Ď		NI I		100000	
LI	Be	symbol											B 10.811	C	N	0	F	Ne
6.941 sodium	9.0122 magnesium	atomic weight (mean relative mass)												12.011 silicon	14.007 phosphorus	15.999 sulfur	18.998 chlorine	20.180 argon
11	12												aluminium 13	14	15	16	17	18
Na	Mg												Al	Si	P	S	CI	Ar
22.990	24.305												26.982	28.086	30.974	32.065	35.453	39.948
potassium	calcium	K.	scandium	titanium	vanadium	chromium	manganese	iron	cobalt	nickel	copper	zinc	gallium	germanium	arsenic	selenium	bromine	krypton
19	20		21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
K	Ca		Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
39.098	40.078		44.956	47.867	50.942	51.996	54.938	55.845	58.933	58.693	63.546	65.39	69.723	72.61	74.922	78.96	79.904	83.80
rubidium 37	strontium 38		yttrium 39	zirconium 40	niobium 41	molybdenum 42	technetium 43	ruthenium 44	rhodium 45	palladium 46	silver 47	cadmium 48	indium 49	tin 50	antimony 51	tellurium 52	iodine 53	xenon 54
	Sr		v				C 1/4 2 11 11	1000		The second secon		172521			100000000000000000000000000000000000000	Te	ĭ	Xe
Rb				Zr	Nb	Мо	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb			
85.468 caesium	87.62 barium		88.906 lutetium	91.224 hafnium	92.906 tantalum	95.94 tungsten	[98] rhenium	101.07 osmium	102.91 iridium	106.42 platinum	107.87 gold	mercury	114.82 thallium	118.71 lead	121.76 bismuth	127.60 polonium	126.90 astatine	131.29 radon
55	56	57-70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
Cs	Ba	*	Lu	Hf	Ta	W	Re	Os	lr	Pt	Au	Hg	TI	Pb	Bi	Po	At	Rn
132.91	137.33		174.97	178.49	180.95	183.84	186.21	190.23	192.22	195.08	196.97	200.59	204.38	207.2	208.98	[209]	[210]	[222]
francium	radium	90 400	lawrencium	rutherfordium	dubnium	seaborgium	bohrium	hassium	meitnerium	darmstadtium	unununium	ununbium		ununquadium	v historian t		W 0.500-0'0.0 D	220000000
87	88	89-102 **	103	104	105	106	107	108	109	110	111	112		114				
Fr	Ra	~ ~	Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds	Uuu	Uub		Uuq				
[223]	[226]		[262]	[261]	[262]	[266]	[264]	[269]	[268]	[271]	[272]	[277]		[289]				

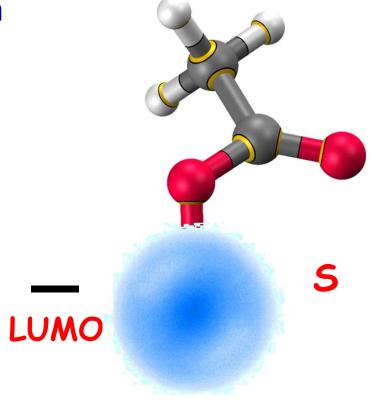
Hg 5d<sup>10</sup>6s<sup>2</sup>

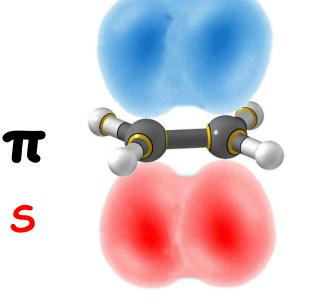
 $Hg^{+2}$   $5d^{10}6s^{0}$ 

### How do you avoid rearrangement problem?



A Hg<sup>+2</sup> ion can act like a giant proton







### **Oxymercuration-demercuration**



### **Oxymercuration-demercuration**



$$H_3$$
C
 $H_3$ C
 $H_4$ 
 $H_3$ C
 $H_4$ 
 $H_4$ 
 $H_5$ 
 $H_4$ 
 $H_4$ 
 $H_4$ 
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 $H_4$ 
 $H_4$ 
 $H_5$ 
 $H_5$ 
 $H_6$ 
 $H_6$ 
 $H_7$ 
 $H_8$ 
 $H$ 

Oxymercuration and simple acid catalysis have the same regiochemistry

But what if you want the primary alcohol?

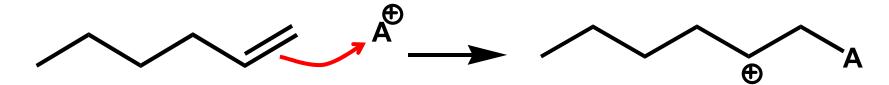
How can you reverse the Regiochemistry?

We need a trick!

#### How to reverse the regiochemistry?



We know that an acid will add to the primary carbon.



Because this makes a secondary carbocation

If A were  $OH^-$ , we would have no problem, but  $OH^-$ , is not an acid, it is a base.

But what if we find an acid that we can add to the alkene and then convert to a OH- in a second step?

Boron forms lots of 6e-compounds. Lewis acids. Boron should add to a primary Carbon.

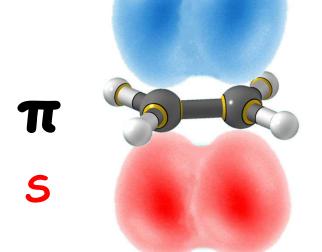
#### Addition of boron to alkene



BH<sub>3</sub>, boron trihydride, has a empty p orbital and is a good Lewis acid.



S

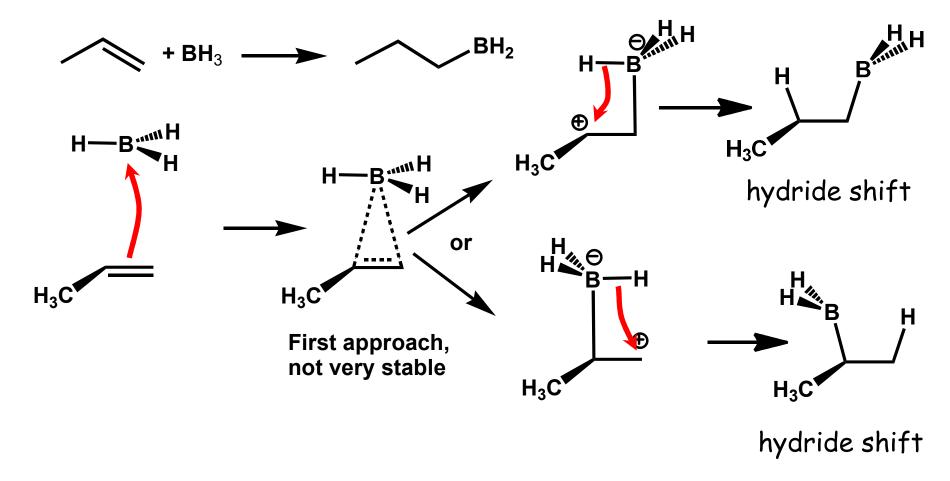


₩ HOMO

#### **Hydroboration**



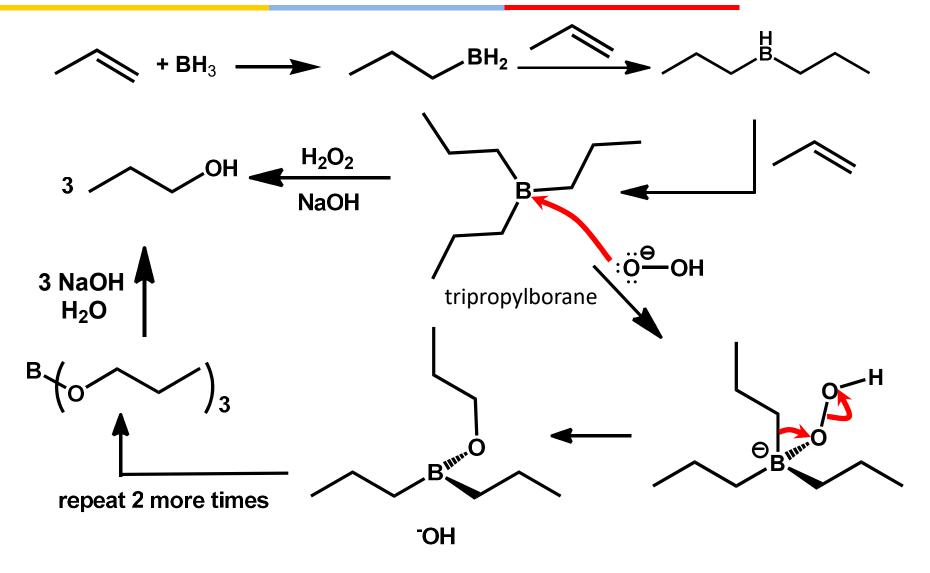
# BH<sub>3</sub> addition to an alkene



Steric effect is also very important, helping to direct the regiochemistry

### **Hydroboration-Oxidation**





Hydroboration gives anti Markovnikov's alcohol

### **Stereochemistry of Hydroboration**



- Hydroboration regiochemistry is opposite to Markovnikov orientation
  - OH is added to carbon with most H's
- H and OH add with syn stereochemistry, to the same face of the alkene.
- STEREOSPECIFIC

cyclopentene

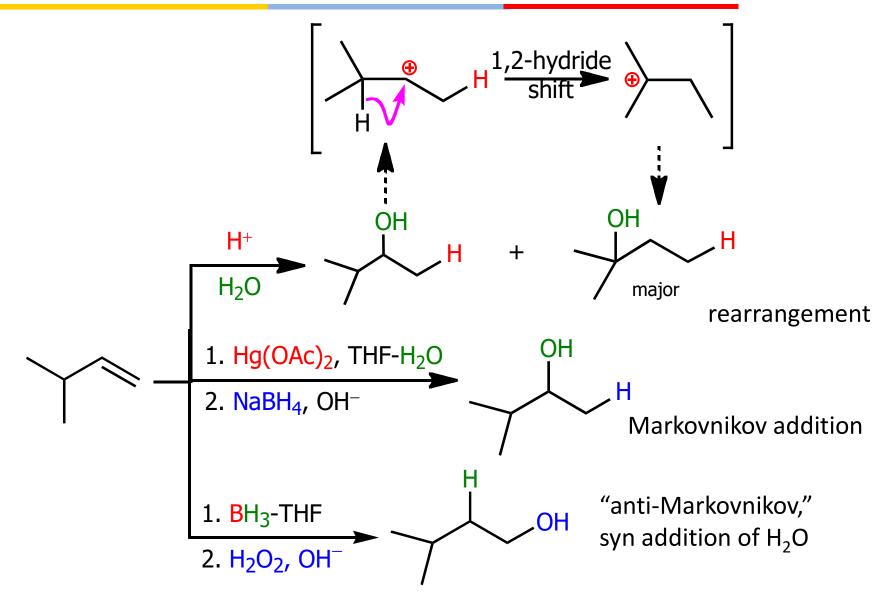
intermediate

cyclopentanol

(85% yield)

### **Summary of Alkene Hydration Methods**





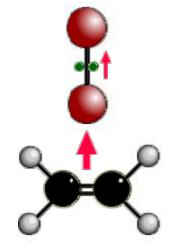
### **Addition of Halogen to Alkenes**

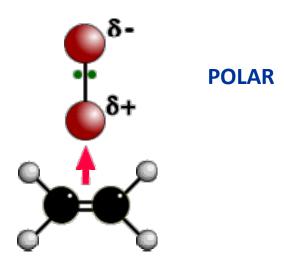


#### Why bromine acts as an **electrophile** even if it is non-polar?

 $\square$  As a bromine molecule approaches an alkene, electrons in the  $\pi$ bond of the alkene repel the electron pair in the bromine-bromine bond thus inducing a dipole.

# **NON-POLAR**



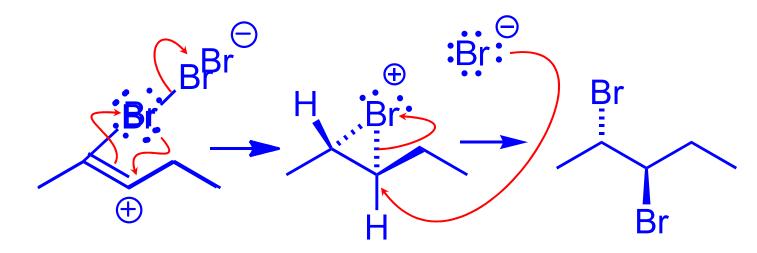


As a non-polar Br<sub>2</sub> molecule approaches an The electron pair is now nearer one end alkene, electrons in the pi orbital of the alkene repel the shared pair of electrons in becomes electrophilic. the Br-Br bond.

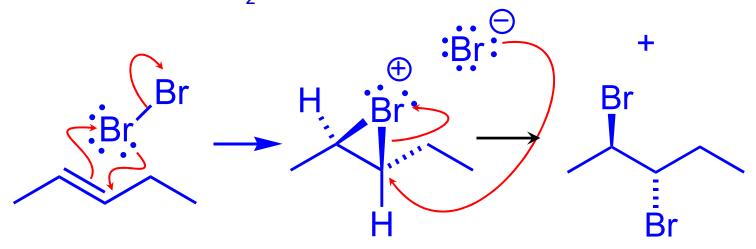
so the bromine molecule is polar and

## **Addition of Halogen to Alkenes**





Br<sub>2</sub> attack from bottom side



Br<sub>2</sub> attack from top side

#### **Stereospecificity of Halogenation**



$$H_3C$$
 $H$ 
 $CH_3$ 
 $+ Br_2$ 
 $H_3C$ 
 $H$ 
 $CH_3$ 
 $H$ 
 $H$ 
 $CH_3$ 

trans-2-butene

meso-2,3-dibromobutane

### **Halohydrin Formation**



Treatment of an alkene with a halogen  $X_2$  and  $H_2O$  forms a halohydrin by addition of X and OH to the double bond.

$$C = C \qquad \begin{array}{c} X_2 \\ -C \\ -C \\ \end{array}$$

Addition of X and OH occurs in an anti-fashion (trans-addition)

With unsymmetrical alkenes, the preferred product has the electrophile X<sup>+</sup> bonded to the less substituted carbon.

$$CH_3$$
 $C=CH_2$ 
 $H_2O$ 
 $CH_3$ 
 $CH_3$ 

Markovnikov's addition

### **Halohydrin Formation**



### Predict the product of the following reaction.

$$CH_3$$
 $Br_2$ 
 $H$ 
 $H_2O$ :

 $CH_3$ 
 $C$ 

only two are observed!!

#### **Halohydrin Formation**



The nucleophilic attack occurs at the more substituted carbon end of the bridged halonium ion because that carbon is better able to accommodate the partial positive charge in the transition state.

Halohydrin formation in an unsymmetrical alkene

$$\begin{array}{c} \vdots \ddot{\mathsf{Br}} - \ddot{\mathsf{Br}} \vdots \\ \vdots \ddot{\mathsf{Br}} \vdots \\ \mathsf{CH_3} \cdots \mathsf{C} = \mathsf{C} \cdots \mathsf{H} \\ \mathsf{H} \cdots \mathsf{C} = \mathsf{C} \cdots \mathsf{C} = \mathsf{C} \cdots \mathsf{H} \\ \mathsf{H} \cdots \mathsf{C} = \mathsf{C} \cdots \mathsf{C} = \mathsf{C} \cdots \mathsf{H} \\ \mathsf{H} \cdots \mathsf{C} = \mathsf{C} = \mathsf{C} \cdots \mathsf{C} = \mathsf{C} \cdots \mathsf{C} = \mathsf{C} \cdots \mathsf{C} = \mathsf{C} = \mathsf{C} = \mathsf{C} \cdots \mathsf{C} = \mathsf{C} = \mathsf{C} \cdots \mathsf{C} = \mathsf{C} = \mathsf{C} = \mathsf{C} = \mathsf{C} \cdots \mathsf{C} = \mathsf{C} = \mathsf{C} = \mathsf{C} = \mathsf{C} \cdots \mathsf{C} =$$

#### Summary: Conversion of Alkenes to Halohydrins

Mechanism

- The mechanism involves two steps.
- The rate-determining step forms a bridged halonium ion.
- No rearrangements can occur.

Regioselectivity

Markovnikov's rule is followed. X<sup>+</sup> bonds to the less substituted carbon.

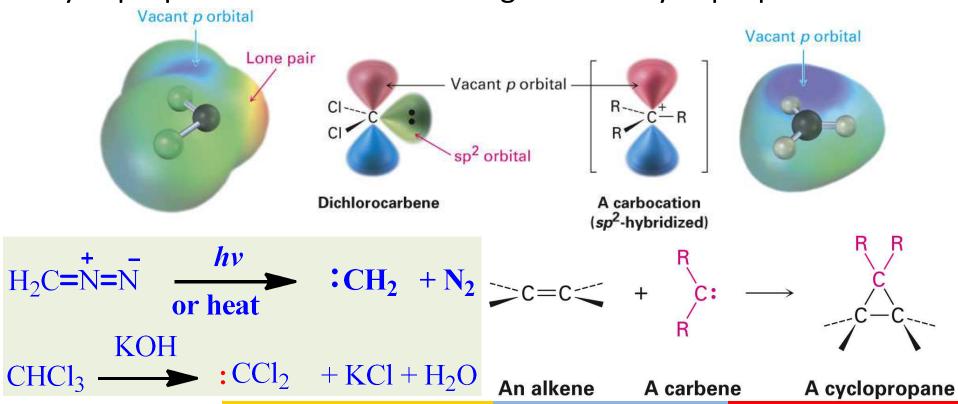
Stereochemistry

Anti addition occurs.

#### **Addition of Carbenes to Alkenes**



- Carbenes are electrically neutral with six electrons in the outer shell (carbocations also have six electrons).
- They add symmetrically across double bonds to form cyclopropanes.
- Addition of carbene is stereospecific: cis-alkenes give ciscyclopropanes and trans-alkenes give trans-cyclopropanes.



#### **Simmons-Smith Reaction**



- Equivalent of addition of CH<sub>2</sub>:
- Reaction of diiodomethane with zinc-copper alloy produces a carbenoid species
- Forms cyclopropanes by cycloaddition

$$CH_2I_2 + Zn(Cu) \longrightarrow ICH_2-ZnI$$
 ":  $CH_2$ "

Diiodomethane

(Iodomethyl)zinc iodide (a carbenoid)

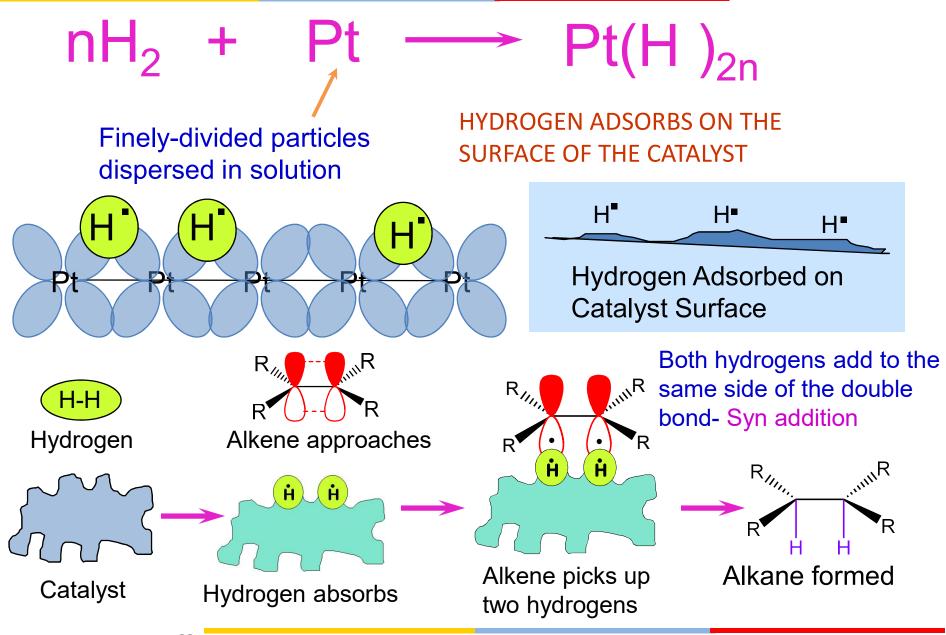
$$+ CH2I2 \xrightarrow{Zn(Cu)} Ether + ZnI2$$

Cyclohexene

Bicyclo[4.1.0]heptane (92%)

#### **Hydrogenation**





### **Sterochemistry of hydrogenation**



CH<sub>3</sub>

CH<sub>3</sub>

,,\CH<sub>3</sub>

Optically inactive Exist as mixture of enantiomers

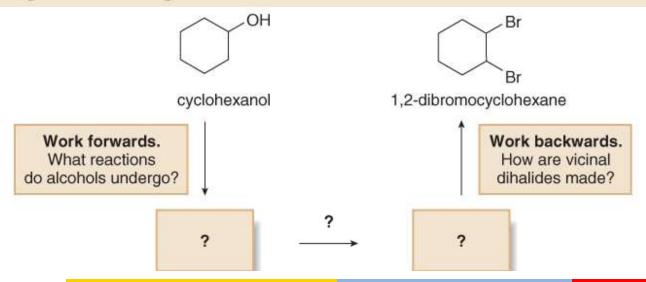
### **Problem solving**



#### Suppose we wish to synthesize 1,2-dibromocyclohexane from cyclohexanol.

#### To solve this problem we must:

- Work backwards from the product by asking: What type of reactions introduce the functional groups in the product?
- Work forwards from the starting material by asking: What type of reactions does the starting material undergo?



### **Problem solving**



# Working backwards from the product to determine the starting material from which it is made is called retrosynthetic analysis.

#### Working backwards:

 1,2-Dibromocyclohexane, a vicinal dibromide, can be prepared by the addition of Br<sub>2</sub> to cyclohexene.

#### Working forwards:

[2] Cyclohexanol can undergo acid-catalyzed dehydration to form cyclohexene.

$$H_2O$$
 $H_2SO_4$ 
cyclohexanol cyclohexene

Cyclohexene is called a **synthetic intermediate**, or simply an **intermediate**, because it is the **product of one step and the starting material of another.** We now have a two-step sequence to convert cyclohexanol to 1,2-dibromocyclohexane, and the synthesis is complete. Take note of the central role of the alkene in this synthesis.

A two-step synthesis

OH

$$H_2O$$
 $H_2SO_4$ 

a synthetic intermediate

Br

Br

#### **Problems**



Predict the products of the following reactions.

HBr [?] 
$$\xrightarrow{Br_2}$$
 ?

HBr ?

1. BH<sub>3</sub>,THF ?

2.H<sub>2</sub>O<sub>2</sub>, KOH ?