

Chapter 4: Reaction Pathways

Recall from Ch. 3:

Lewis Base = electron pair donor \Rightarrow "nucleophile"

Lewis Acid = electron pair acceptor \Rightarrow "electrophile"

NUCLEOPHILES = reagents seeking a nucleus (δ^+ or $(+)$)
to donate a pair of electrons

ELECTROPHILES = "electron seeking" reagents;
They have room in their orbitals to accept a pair of electrons

ex: $\text{CH}_3\text{-}\ddot{\text{O}}:^{\ominus}$ nucleophile

H^{\oplus} electrophile

H^{\ominus} nucleophile

NUCLEOPHILIC SUBSTITUTION RXNS

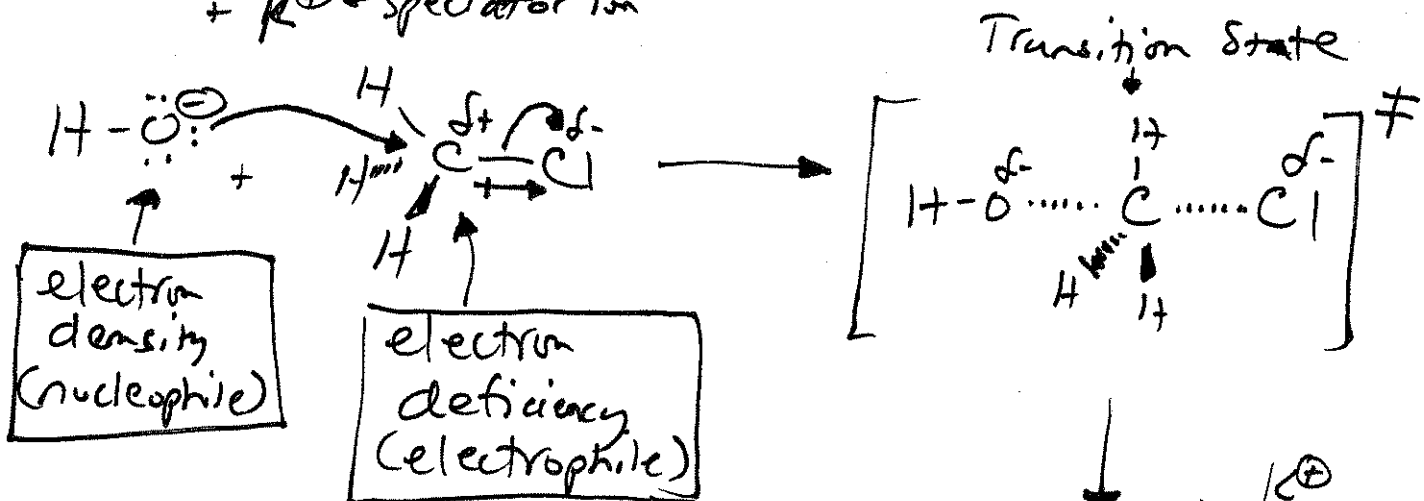
One type:



X = halogen M^{\oplus} = metal (I) cation (Na^{\oplus} , K^{\oplus} , Li^{\oplus}) (4-1)



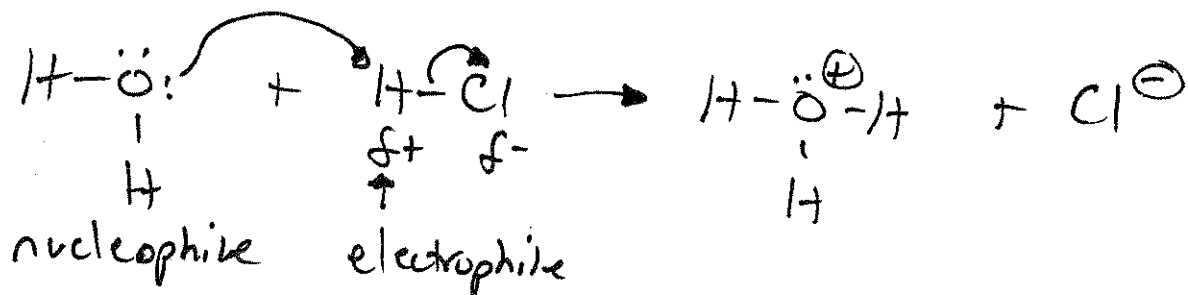
How does this rxn occur (what's the mechanism)?
 + K^+ ← spectator ion



- The simultaneous bond making and bond breaking that occur in this rxn are shown in the transition state structure.

- Cl is the LEAVING GROUP

⇒ Compare to H^+ as the electrophile



- The nucleophile "attacks" the electrophile
 (nucleophile arrows)

* Nucleophilic Substitution Rxns - very important in biological systems (4-2)

Energy Changes in The Rxn. Equilibrium

$\Delta G_{rxn}^{\circ} = \Delta G_{pdtts}^{\circ} - \Delta G_{reactants}^{\circ}$
 Change in Gibbs Free Energy

need to look up values in Table



$$\Delta G_{rxn}^{\circ} = (\Delta G_y^{\circ} + \Delta G_z^{\circ}) - (\Delta G_w^{\circ} + \Delta G_x^{\circ})$$

$$\Delta G_{rxn}^{\circ} = -2.303 RT \log K_{eq}$$

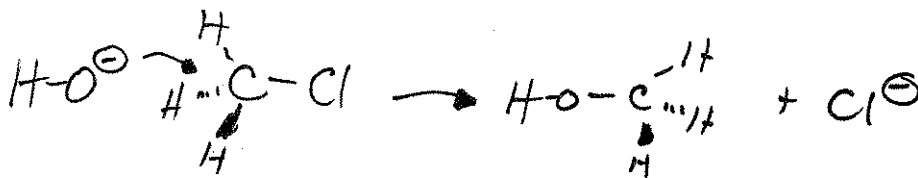
→ if ΔG_{rxn}° is negative, $K_{eq} > 1$ and then the rxn is favored to the right

KINETICS - The study of rxn rates

Reaction rates are dependent on:

- 1) solvent
 - 2) temperature
 - 3) concentration
- we will talk about these two now

Concentration



Rate Equation:

$$Rate = k_r [CH_3-Cl]^1 [OH^-]^1$$

brackets means concentration

k_r = rate constant

order of rxn = sum of exponents of
concentration terms in
rate equation
↑
determined
experimentally



This equation is a 2nd order rate equation
(1+1=2)

- Concentration affects rate
conc. ↑ rate ↑

For this rxn at 38°C in water (from book)

$$[\text{OH}^-] = 0.001 \text{ M}$$

$$[\text{CH}_3\text{Cl}] = 0.003 \text{ M}$$

$$\text{rate} = 1.07 \times 10^{-7} \frac{\text{mol}}{\text{L} \cdot \text{sec}} \quad \text{but } k_{eq} = 1.6 \times 10^{17}$$

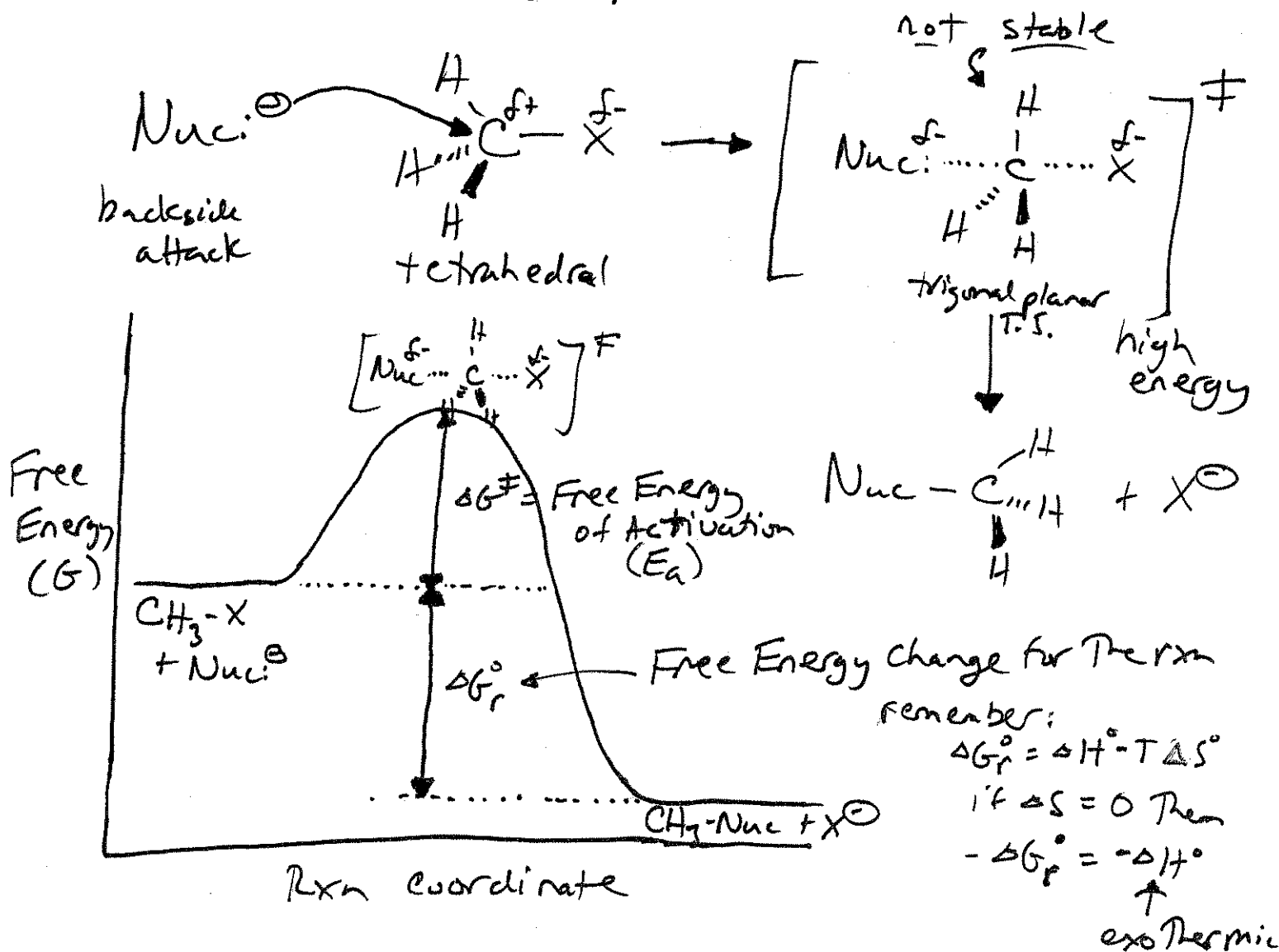
→ Can have a large k_{eq} but small rate constant, k_r . This rxn favors the right hand side of the equation but gets there very slowly.

- What factors allow a large k_{eq} but a small rate constant?

$\text{H-O}^\ominus = \text{nucleophile} = \text{Nuc:}^\ominus$

$X = \text{halogen} \rightarrow \text{Br, Cl, I}$ as a leaving group
(not F, although it is a halogen)

- A good leaving group has to be a STABLE ANION



- The rate constant, k_r , is related to the Free Energy of Activation, ΔG^\ddagger (or E_a)

by the relationship:

absolute rate constant

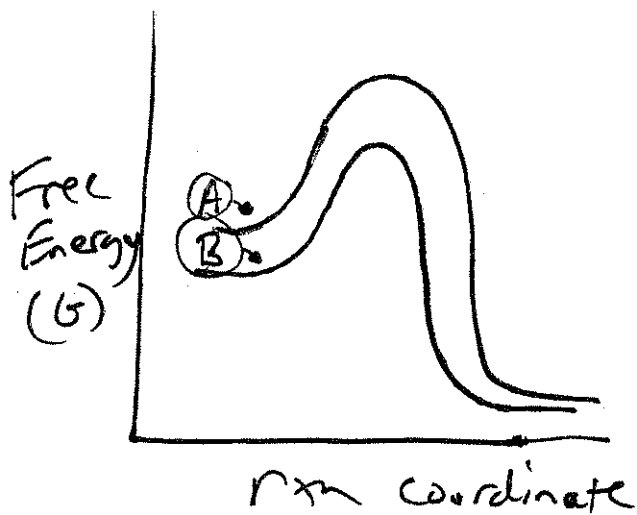
rxn rate constant

$k_r = k_0 e^{-\frac{\Delta G^\ddagger}{RT}}$

2.718 = base of natural logarithm

ΔG_r^\ominus also related to K_{eq}

(4-5)



Which rxn is faster, (A) or (B)?

Which rxn has a larger k_r ?

- As ΔG^\ddagger gets larger at constant temperature the observed rate of a rxn gets smaller.

What about the effect of temperature?

- The larger the Activation Energy the slower the rate

$$k_r = k_0 e^{-\frac{\Delta G^\ddagger}{RT}}$$

if Temp. is increased, k_r also increases.

- Can understand how temp. effects rate by looking at Fig 4.2, p 123 in text.

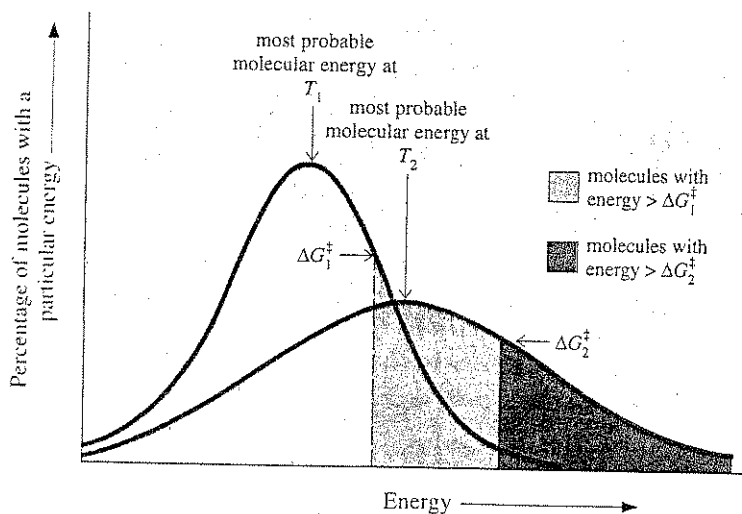


Figure 4.2
Distribution of energy among molecules at temperatures T_1 and T_2 .

Summary

- Reaction Rate effected by:
 - 1) conc. of reagents
 - 2) Energy of Activation ($\Delta G^\ddagger = E_a$)

3) Temperature

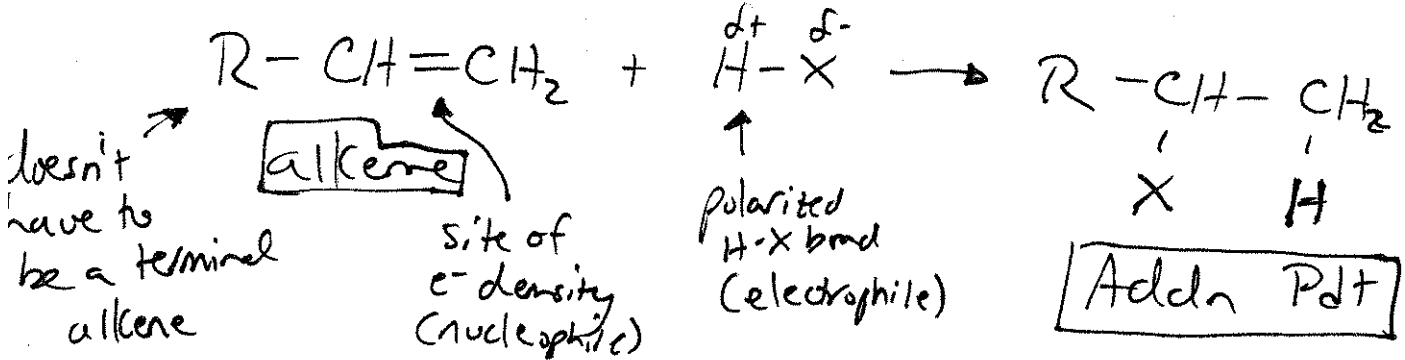
4) Special effects + anything that effects how the molecules collide

4-6

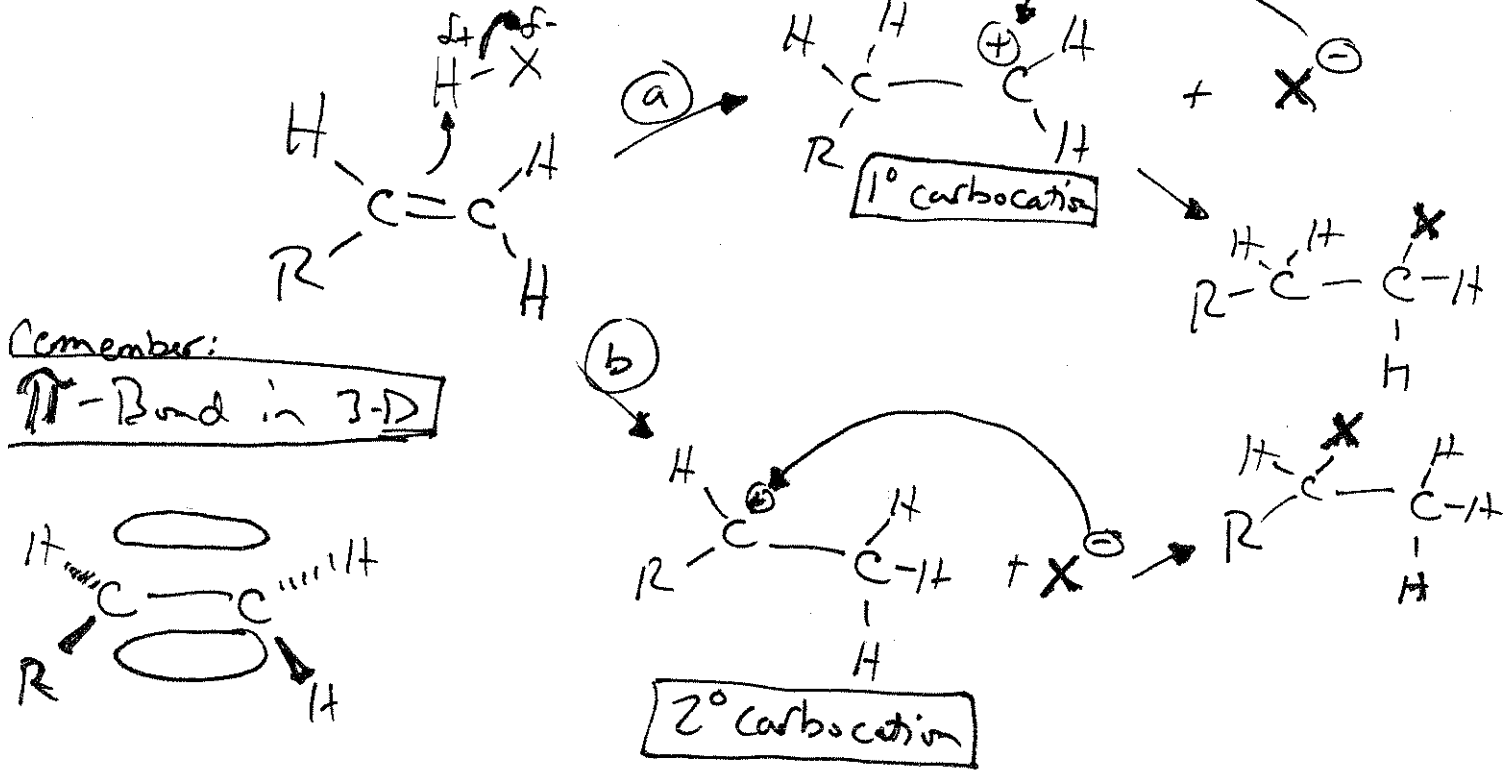
Electrophilic Addition Reactions

General Example:

$X = \text{Cl, Br, I}$ $R = \text{alkyl group}$

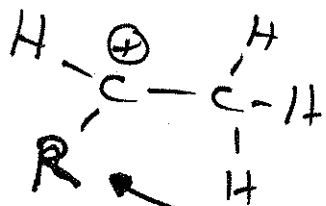


Mechanism: 2 possibilities

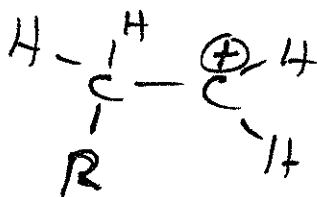


• Which pathway do you think is better, (a) or (b)?
 (more favorable)

Pathway **(b)** is more favorable because a 2° carbocation is more stable than a 1° carbocation

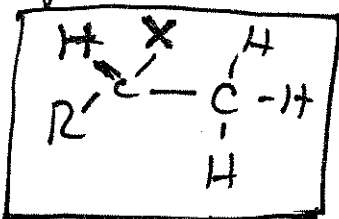


• 2° carbocation more stable because of electron donation by alkyl group.



• Carbocations are Reaction Intermediates (not transition state)

• So, the major product from this Electrophilic Addition Rxn is

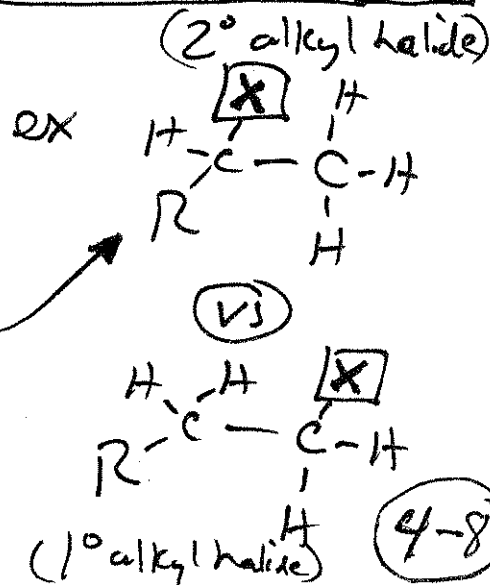


R group = alkyl group
donates electron density

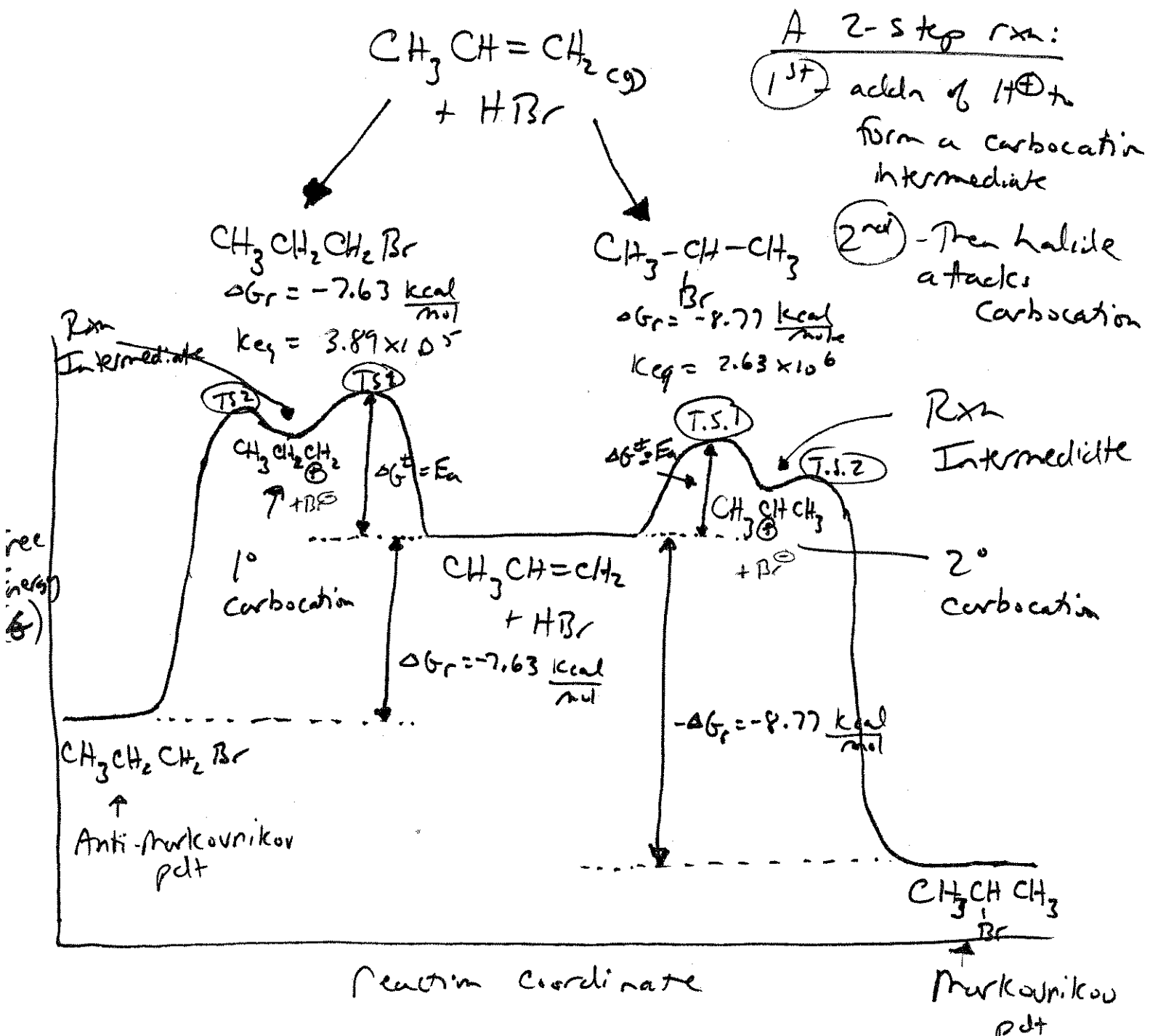
1° = R-CH₂-X
2° = R₂CH-X
3° = R₃C-X

Markovnikov's Rule

In an addition reaction of H-X to an unsymmetrical alkene, the H⁺ goes to the double bonded carbon that already has the greatest # of hydrogens (i.e. will form the most highly substituted alkyl halide)



Equilibria in The Addition of HBr to Propene



• **TS1** and **TS2** are transition state 1 ← 1st step of rxn mechanism
 transition state 2 ← 2nd step of rxn mechanism

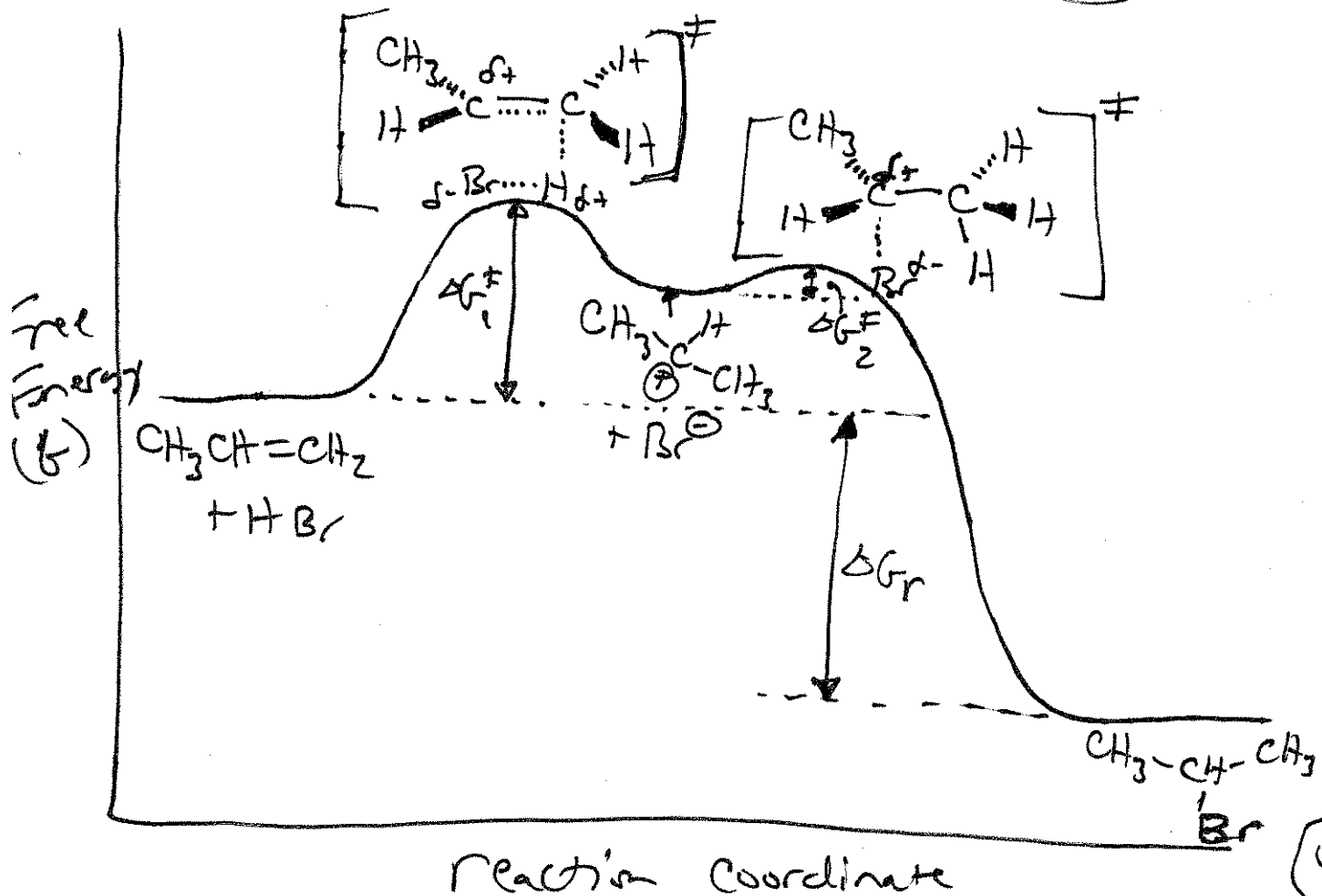
ratios of K_{eq} s = $\frac{2.63 \times 10^6}{3.89 \times 10^5} = \frac{6.76}{1} = \frac{87\%}{13\%}$ isopropyl bromide / n-propyl bromide

BUT - we don't see this ratio of pldts experimentally **(4-10)**

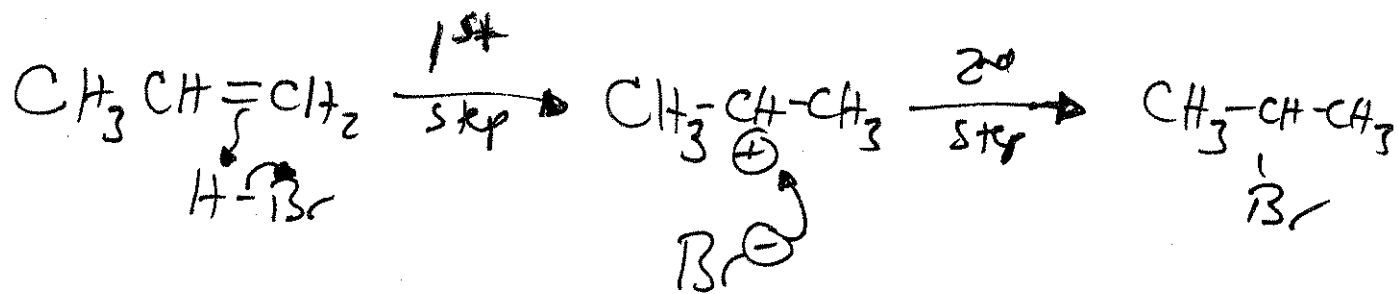
- Ratio of products in This reaction is NOT determined by The equilibrium constants. The ratio is determined by The relative ΔG^\ddagger (Free Energy of Activation) of The two pathways. (The product ratio is dependent on The Kinetics of The two reactions.)

\Rightarrow In This case, The Markovnikov p.d.t $\text{CH}_3\underset{\text{Br}}{\text{CH}}\text{CH}_3$, isopropyl bromide, is The ONLY p.d.t.

RXN ENERGY PROFILE

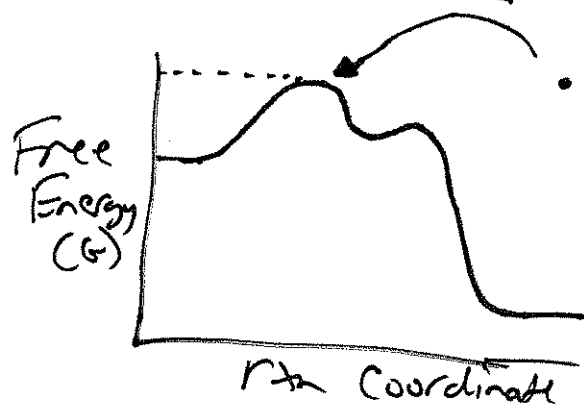


- The reaction energy profile shows 2-steps:



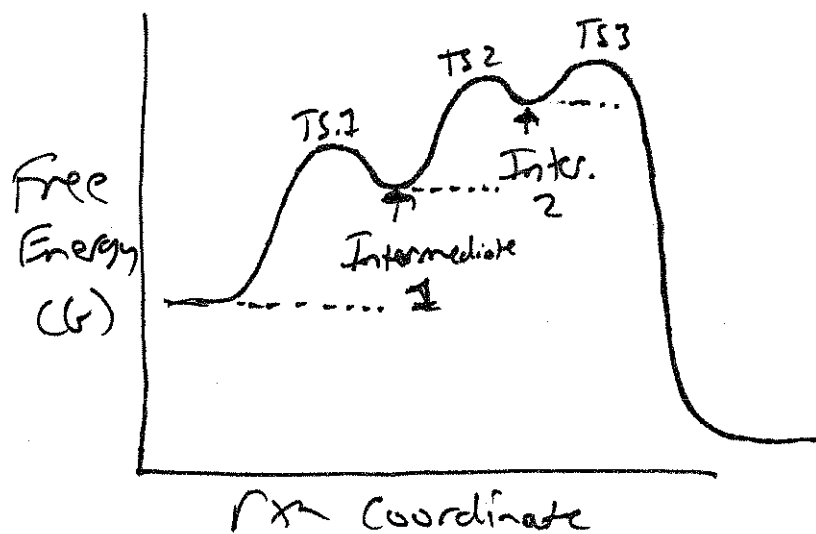
but only 1-step is the rate determining step.

⇒ Rate determining step is the step with the HIGHEST TRANSITION STATE ENERGY



In this case, it is the first step

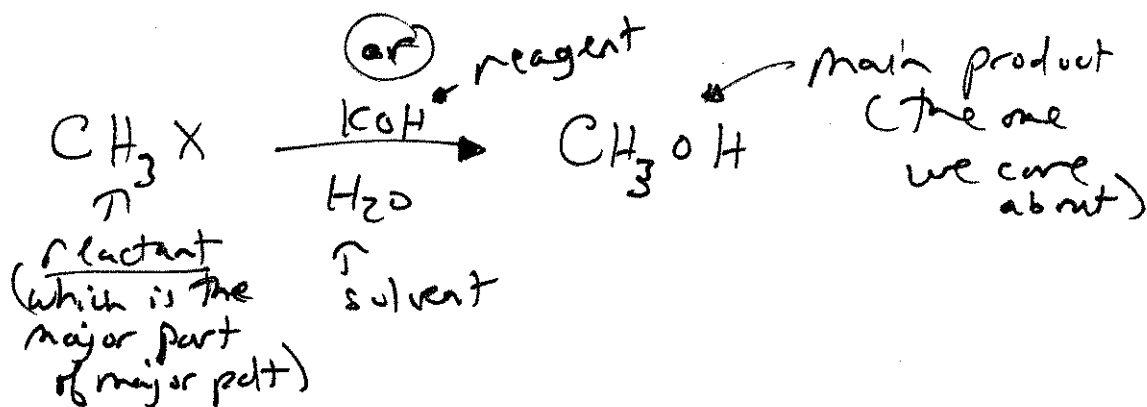
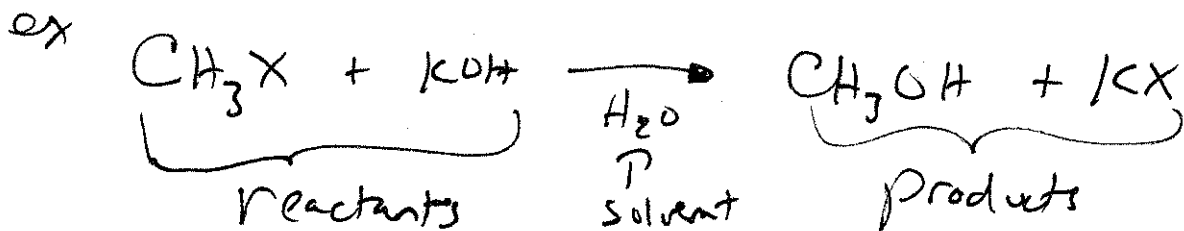
★ What is the rate determining step in the rxn described by the following rxn energy profile?



The 3rd step is the rate determining step in this case (It has the highest energy T.S.)

Chemical Transformations

- Two ways to write chemical equations:

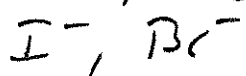
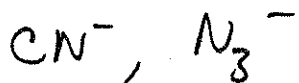
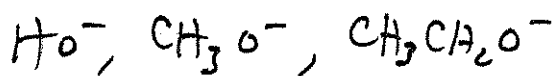


- Nucleophilic Substitution + Electrophilic Addn Rxns

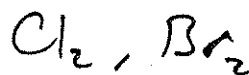
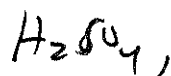
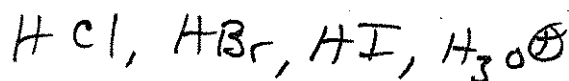
⇒ we can use other nucleophiles than OH^-
 & other electrophiles than H-Br

- Table 4.2 p136 in text

Nucleophiles



Electrophiles

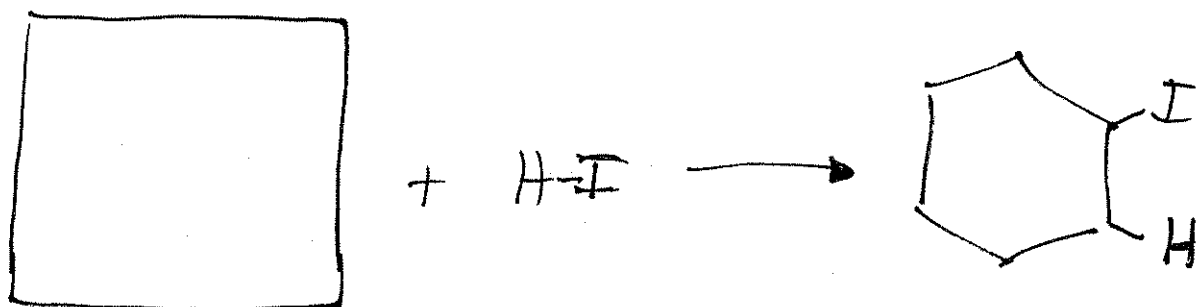


Example



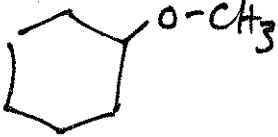
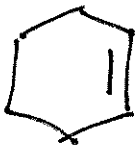
What type of rxn is this?

What reagent should be used?



What type of rxn is this? What is the other starting material?

Multistep Transformations

- How could one form  from  ?