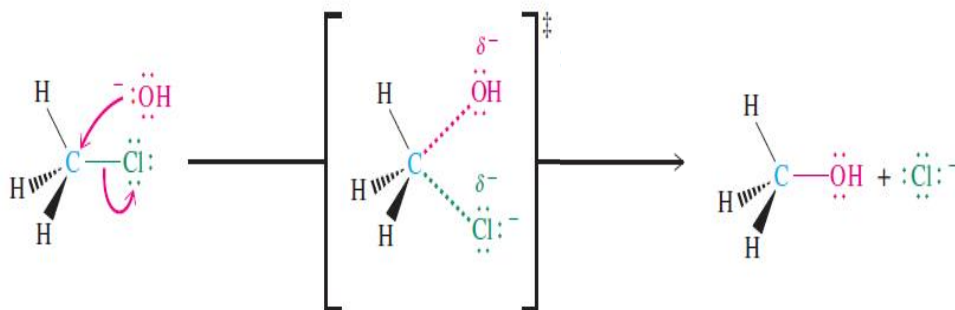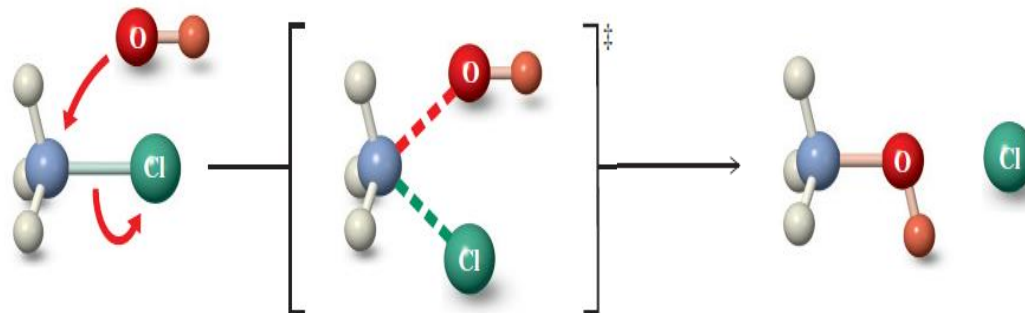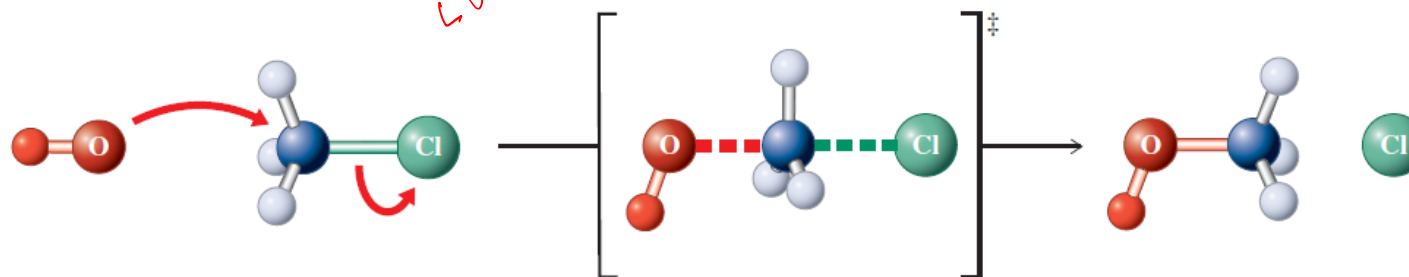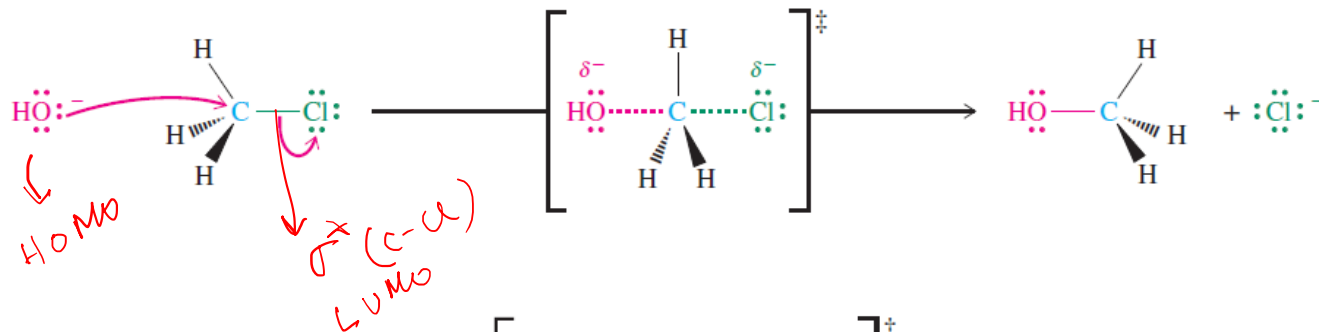# Approach of the Nucleophile

Front-side Displacement

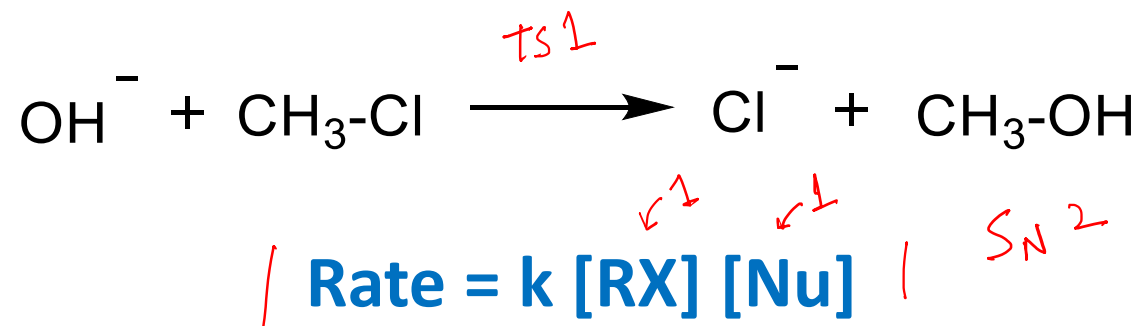## Back-side Displacement

HOMO

$\sigma^*(C-Cl)$

LUMO

Molecular Orbitals Support Back-side Approach

➤ The nucleophile attacks the σ*orbital of the C-X bond

filled orbital of nucleophile

empty σ* orbital of C–X bond

new σ bond being formed

p orbital on C atom

old σ bond being broken

new σ bond

ΔE (interaction energy) : Σ sterics − Σ orbital overlap/(E_{LUMO} −E_{HOMO}) + Σ charge interaction

S_N2: One Step

$$\left[\begin{array}{c} H \\ \overset{\delta^-}{HO} \cdots\cdots C \cdots\cdots \overset{\delta^-}{Cl} \\ H \quad H \end{array} \right]^{\ddagger}$$

Only one transition state

$CH_3Cl + {}^-OH$

$CH_3OH + Cl^-$

E

Reaction coordinate ⟶

A

$$OH^- + CH_3\text{-}Cl \xrightarrow{\quad ts1 \quad} Cl^- + CH_3\text{-}OH$$

Rate = k [RX] [Nu] S_N2
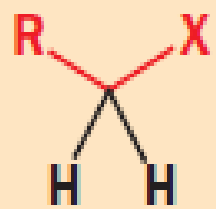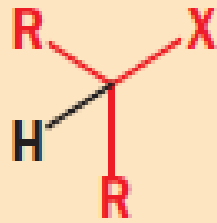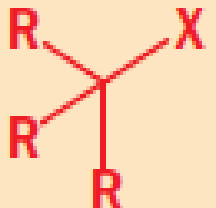
The reaction rate will depend on the following four factors:

1. Structure of alkyl halide
2. (Nature of nucleophile)
3. Nature of leaving group
4. Solvent

3

✓ *The rate of S_N2 reaction is critically dependent on the nature of alkyl halide*

structure	Me—X			
type	methyl	primary	secondary	tertiary
S_N2 reaction?	good	good	yes	no

ΔE (interaction energy) : Σ sterics – Σ orbital overlap/(E_{LUMO} –E_{HOMO}) + Σ charge interaction

Steric Factors in S$_N$2 Reactions

CH$_3$X

(CH$_3$)$_3$CX
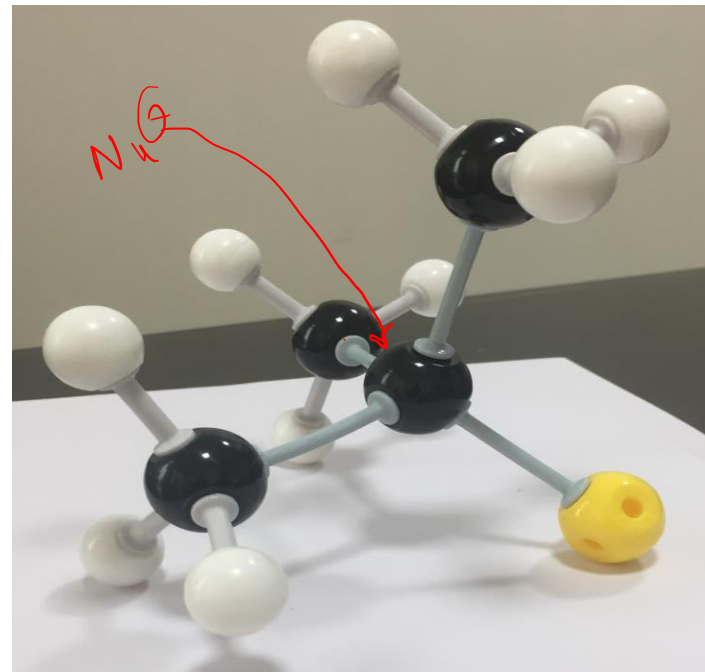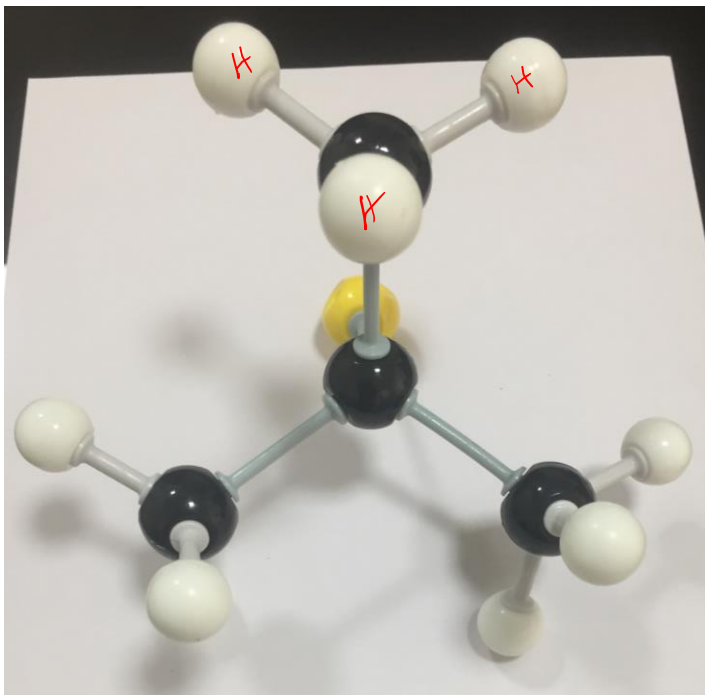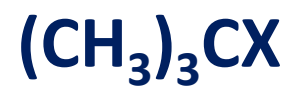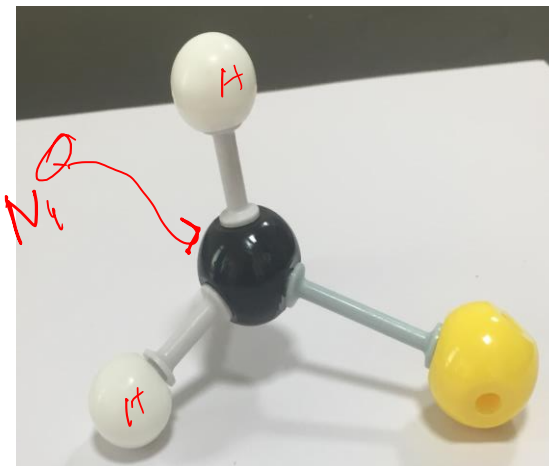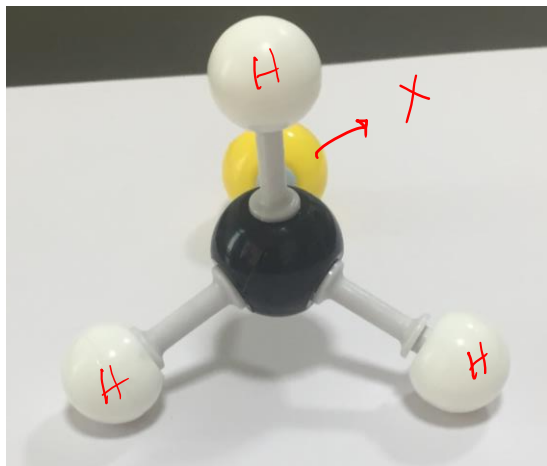
Nucleophilic Substitution Unimolecular (S_N1)

$$H_2O + (CH_3)_3C\text{-}Cl \longrightarrow HCl + (CH_3)_3C\text{-}OH$$

(t-Alkyl halide)

S_N1: Nucleophilic Substitution Unimolecular
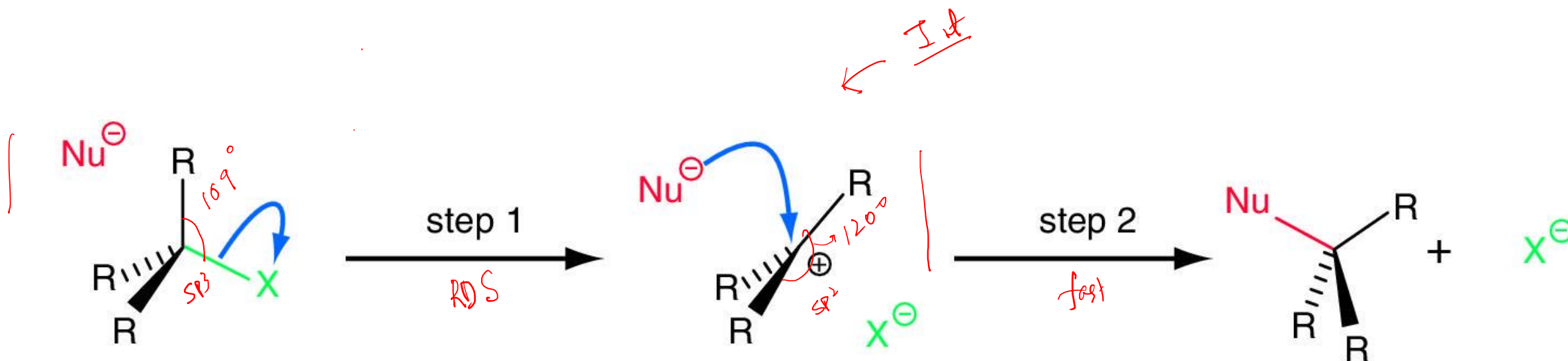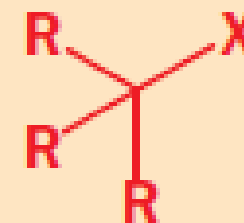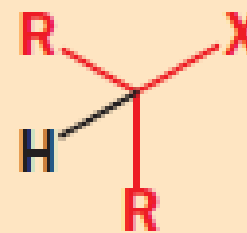

➤ The leaving group departs early; a carbocation is formed as the intermediate

➤ Step 1 is slow and the rate determining step (rds)

H_2O + $(CH_3)_3C$-Br $\longrightarrow$ HBr + $(CH_3)_3C$-OH

Rate = k [RX]

✓ When solvent is the nucleophile, it is called solvolysis

✓ Protonation/deprotonation steps are typically fast; small activation energy

S_N1: Three Steps

$$\left[\begin{array}{c} H_3C \\ H_3C\text{''''''}C^{\delta+}\text{------}X^{\delta-} \\ H_3C \end{array} \right]^{\ddagger}$$

E_{a_1}

Rate-determining transition state

$(CH_3)_3C^+$

$(CH_3)_3CBr$ + HOH

$(CH_3)_3CO^+$

H

$(CH_3)_3COH$ + HBr

$E_{a_1} > E_{a_2} > E_{a_3}$

Reaction coordinate

B

$(CH_3)_3C-Br \rightleftharpoons [(CH_3)_3C^+] + X^-$

$k = \frac{k_2}{k_1}$
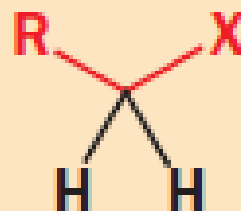
structure	Me—X	R, H, H (primary)	R, H, R (secondary)	R, R, R (tertiary)
type	methyl	primary	secondary	tertiary
S_N1 reaction?	no	no	yes	good ✓
S_N2 reaction?	good	good	yes	no ✗

S_N2 $R-X \rightarrow$ Rate $= k_1 [R_X][Nu]$

S_N1 $\rightarrow$ Rate $= k_2 [R_X]$

$k_2 \gg k_1 [Nu]$