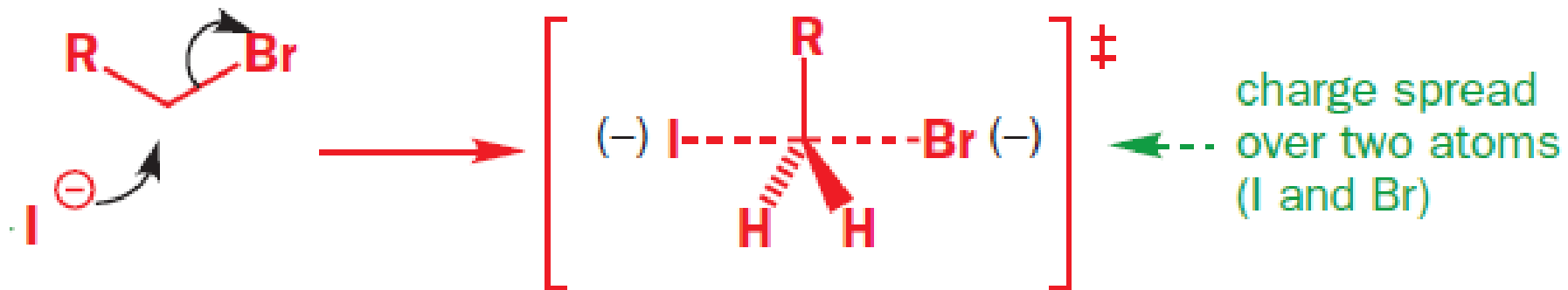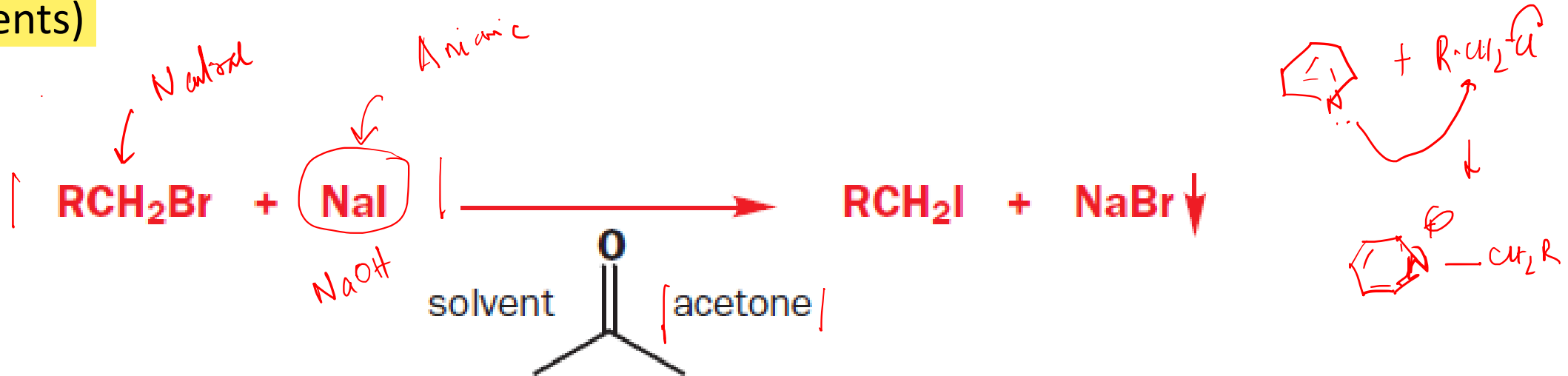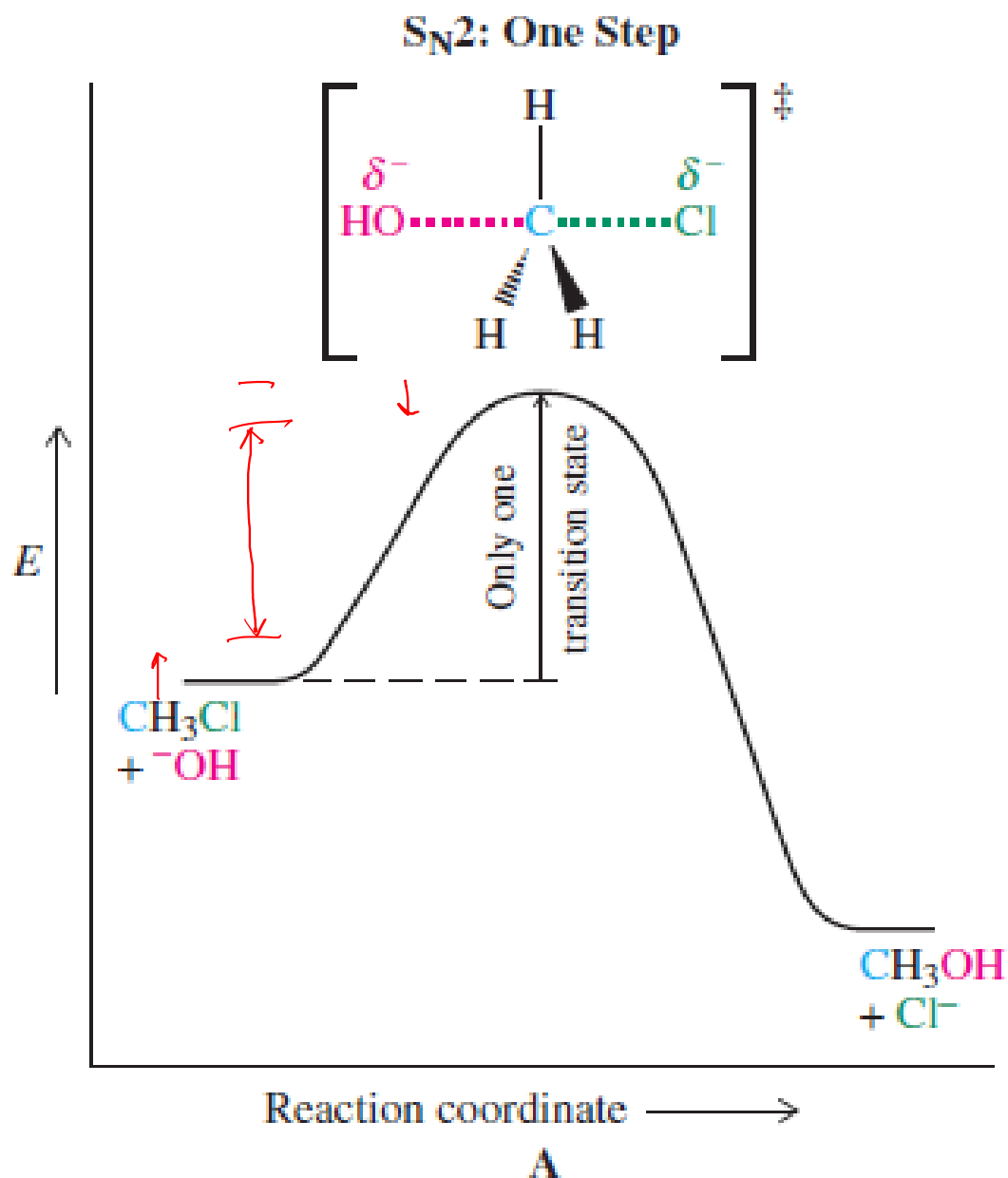# Solvent Effect: S_N2

✓ Typical choices: a less polar solvent for the S_N2 reaction (just polar enough to dissolve the ionic reagents)

SN2: One Step

$$\left[\text{HO} \overset{\delta^-}{\cdots\cdots} \text{C} \cdots\cdots \overset{\delta^-}{\text{Cl}} \right]^{\ddagger}$$

E

$CH_3Cl + {}^-OH$

Only one transition state

$CH_3OH + Cl^-$

Reaction coordinate →

A

✓ The most common S_N2 reactions use an anion as the nucleophile and the transition state is less polar than the localized anion as the charge is spread between two atoms

✓ A polar solvent solvates the anionic nucleophile and slows the reaction down

✓ A nonpolar solvent destabilizes the starting materials more than it destabilizes the transition state and speeds up the reaction

The following table presents rate data for the reactions of CH_3I with azide ion:

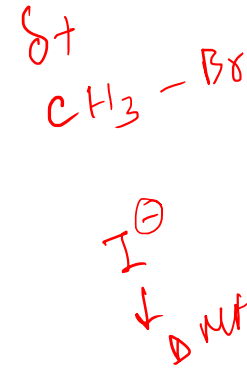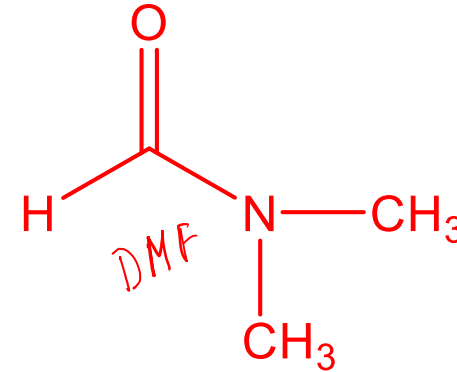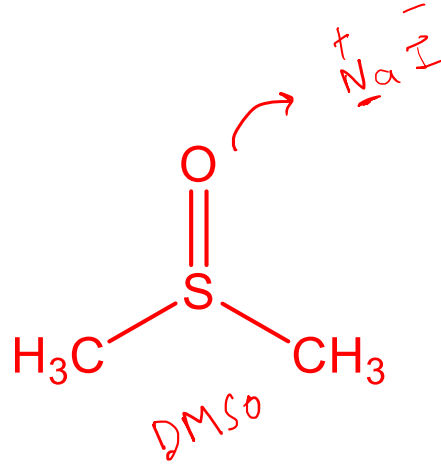$$CH_3I \xrightarrow{\quad N_3^- \quad} CH_3N_3$$
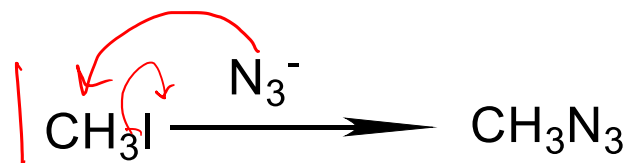
Solvent	Relative Rate	Dielectric Constant
Methanol	1	33
DMF	4.5×10^4	37

Polar protic solvents: H_2O, ROH, RCO_2H

δ^+
$CH_3 - Br$

$I^{\ominus}$
$\downarrow$ DMF

✓ Are able to form hydrogen bonds (hydroxylic solvents)

✓ They solvate both cations and anions well

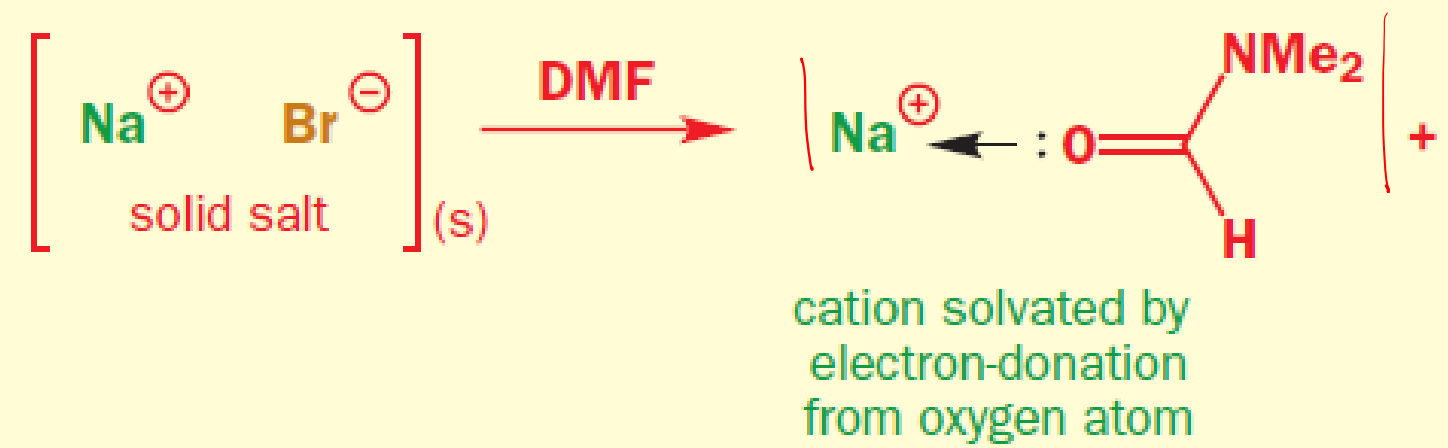Polar aprotic solvents:

$\overset{+}{Na}\overset{-}{I}$

DMSO

DMF

✓ Polar aprotic solvents, on the other hand, have dipole moments and are still able to solvate

cations by electron donation from an oxygen atom

✓ They don't solvate the anions

$$\left[\text{Na}^{\oplus} \quad \text{Br}^{\ominus} \right]_{(s)} \xrightarrow{\text{ROH}} \text{Na}^{\oplus} \leftarrow \text{:O} + \left(\text{Br}^{\ominus} \text{-----H} - \text{O} - \text{R} \right)$$

solid salt

R ... H

**cation solvated by
electron-donation
from oxygen atom**

**anion solvated by
electron-acceptance
through hydrogen bonding**
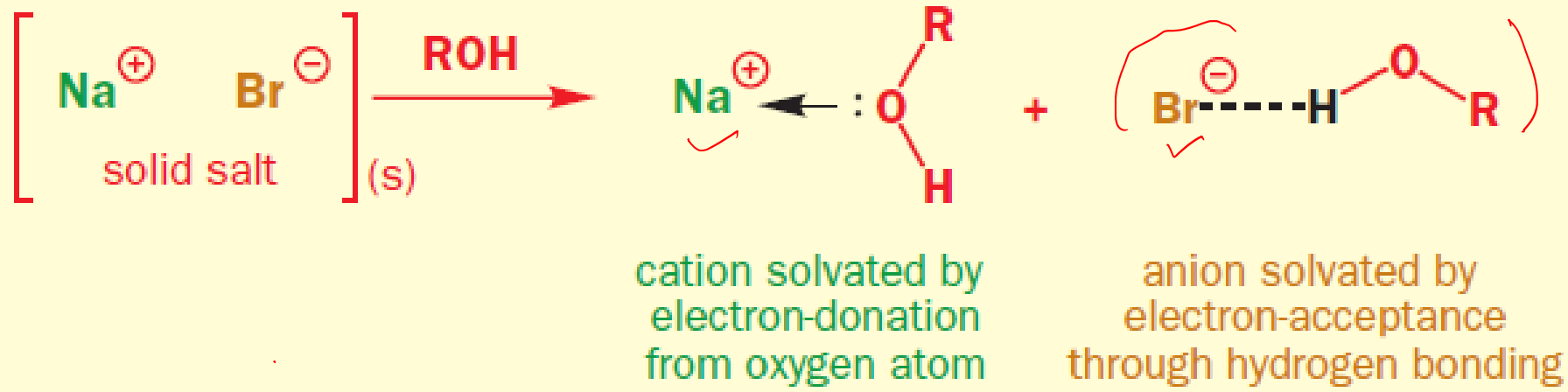
there are more than the
one solvent molecule
shown for each ion

solvation of salts by polar aprotic solvents

$$\left[\text{Na}^{\oplus} \quad \text{Br}^{\ominus} \right]_{(s)} \xrightarrow{\text{DMF}} \text{Na}^{\oplus} \leftarrow \text{:O} = \text{C} \overset{\text{NMe}_2}{\underset{\text{H}}{}} + \text{Br}^{\ominus}$$

solid salt

**cation solvated by
electron-donation
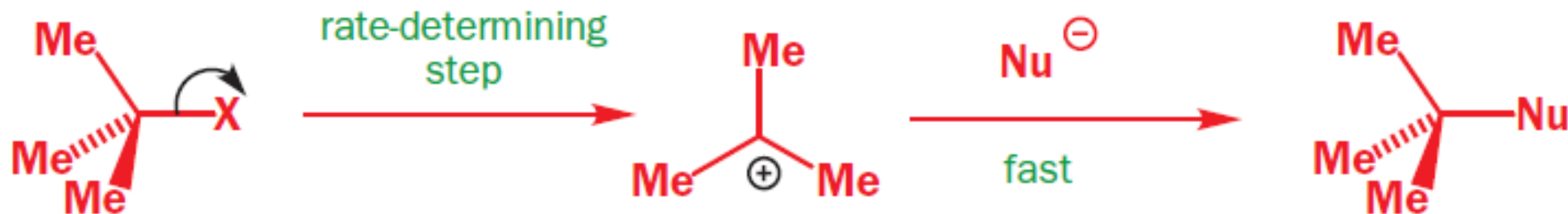from oxygen atom**

**anion not solvated -
no hydrogen bonding
is possible
the anion is "naked" and
hence more nucleophilic**

✓ *Can we rationalize the solvent effects based on the following equation?*

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

$$CH_3-Cl + OH^{\ominus} \longrightarrow CH_3OH + Cl^{\ominus}$$

$$\longrightarrow CH_3OH \rightarrow ①$$

$$\longrightarrow DMF \rightarrow ②$$

— C-Cl (σ*)

HOMO of OH⁻

HOMO OH⁻

KOH

DMF
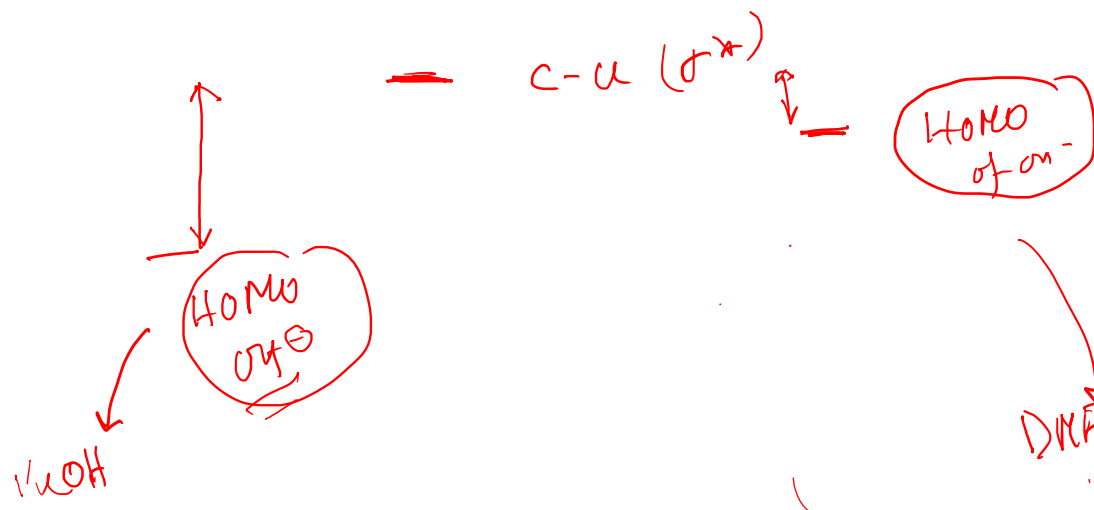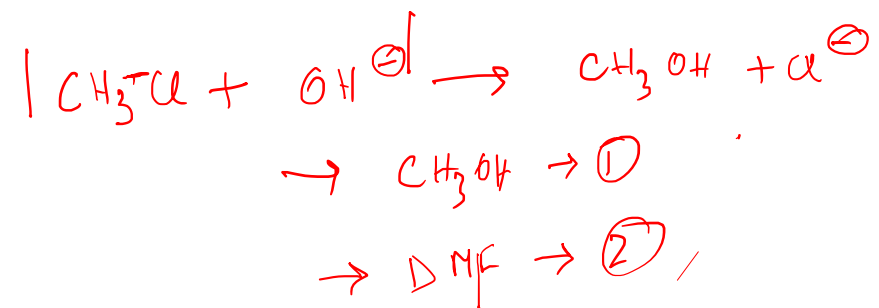
Solvent Effect: S$_N$1

✓ The transition state is more polar than the starting materials and so is stabilized by the polar solvent

✓ A polar protic solvent for the S$_N$1 reaction.

✓ *The rate-determining step usually involves the formation of ions and the rate of this process will be increased by a polar solvent*
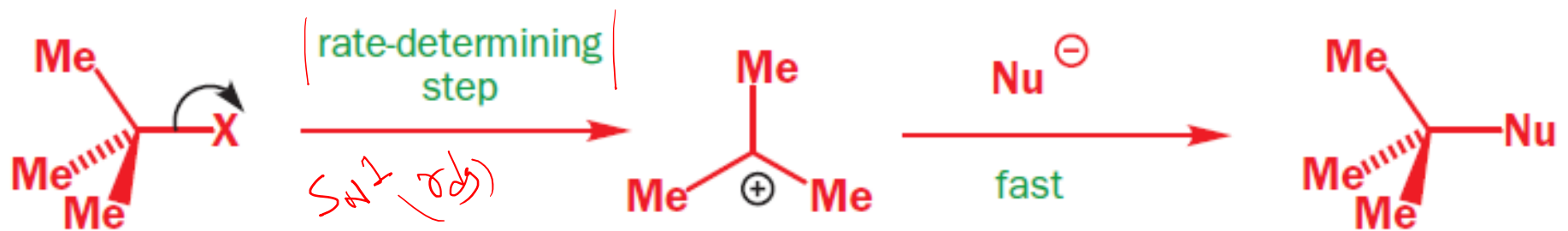
We have covered so far:

1. Structural factors (sterics)

2. Solvent effects

We will now look at two other factors:

Leaving groups

The Leaving Group

rate-determining step

$SN1$ (rds)

Nu⊖

fast

rate-determining step

Table 17.4 Halide leaving groups in the S$_N$2 reaction

Halide X in MeX	pK$_a$ of conjugate acid HX	Rate of reaction with NaOH
F	+3	very slow indeed
Cl	−7	moderate
Br	−9	fast
I	−10	very fast

Halide (X)	Strength of C–X bond, kJ mol$^-$
fluorine	118
chlorine	81
bromine	67
iodine	54

C–F

C–I

✓ In the Ethyl halide series, the rate follows the order:

Relative Rate: CH$_3$CH$_2$I > CH$_3$CH$_2$Br > CH$_3$CH$_2$Cl >> CH$_3$CH$_2$F

✓ It is clearly easiest to break a C–I bond and most difficult to break a C–F bond. Iodide sounds like the best leaving group

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

higher energy LUMO – therefore worse electrophile!

$\sigma^*(C-I)$

$\sigma^*(C-Br)$

$\sigma^*(C-Cl)$

$\sigma^*(C-F)$

EN

C: 2.5

$\begin{bmatrix} I: 2.5 \\ Br: 2.8 \\ Cl: 3.0 \\ F: 4.0 \end{bmatrix}$

close in energy but poor orbital overlap

far in energy but good orbital overlap

better bond – harder to break!

C   I   C   Br   C   Cl   C   F

energy