REACTANT(S)	REAGENT(S)	PRODUCT(S)

SN1 Reaction:

LG = leaving group

R₁ and R₂ are alkyl chains or rings

nucleophile
△

(racemic mixture of both enantiomers)

Mechanism:

carbocation

+ LG⁻

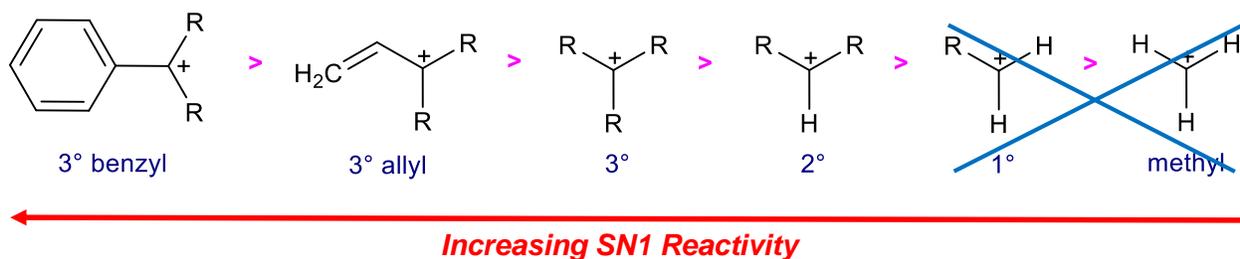**slow (rate-determining) step**

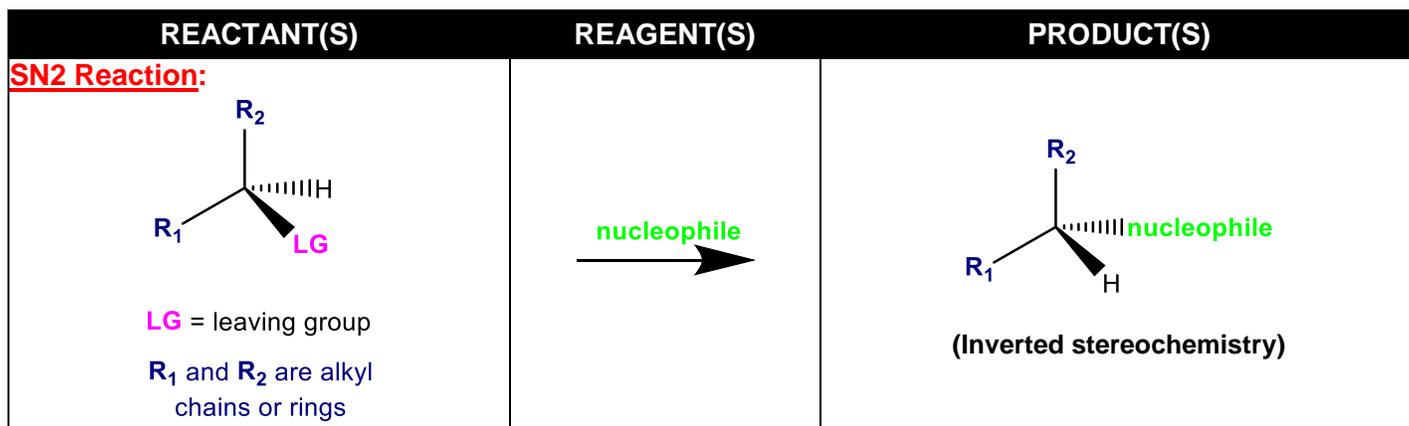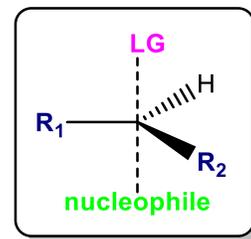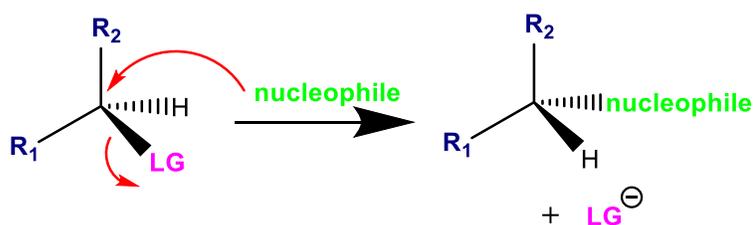(racemic mixture of both enantiomers)

SN1 Details:

1. **S_N1** stands for "substitution nucleophilic unimolecular."
2. Leaving group reactivity: I > Br > Cl > F
3. Solvent: polar **protic**
4. The **1** in **S_N1** does <u>NOT</u> mean that there is only one step in an **S_N1** reaction. It means that only one reactant is involved in the slow (rate-determining) step.
5. The rate-determining step is, of course, the step in which the **LG** separates to form a carbocation intermediate. The nucleophile then comes in.
6. Thus, the rate law for **S_N1** reactions looks like this: **rate = k[electrophile]**.
7. Furthermore:

| 3° benzyl | 3° allyl | 3° | 2° | 1° | methyl |

Increasing SN1 Reactivity

8. **S_N1** reactions nearly always involve weak nucleophiles, because strong nucleophiles are too reactive to allow a carbocation to form.
9. Because the **nucleophile** can attack the carbocation from either side (front or back), **S_N1** reactions give a racemic mixture of **enantiomers** in the product.
10. Because **S_N1** reactions involve a carbocation intermediate, carbocation rearrangements <u>*can*</u> happen in **S_N1** reactions. They do NOT happen in **S_N2** reactions.

REACTANT(S)	REAGENT(S)	PRODUCT(S)

SN2 Reaction:

LG = leaving group

R_1 and R_2 are alkyl chains or rings

nucleophile →

(Inverted stereochemistry)
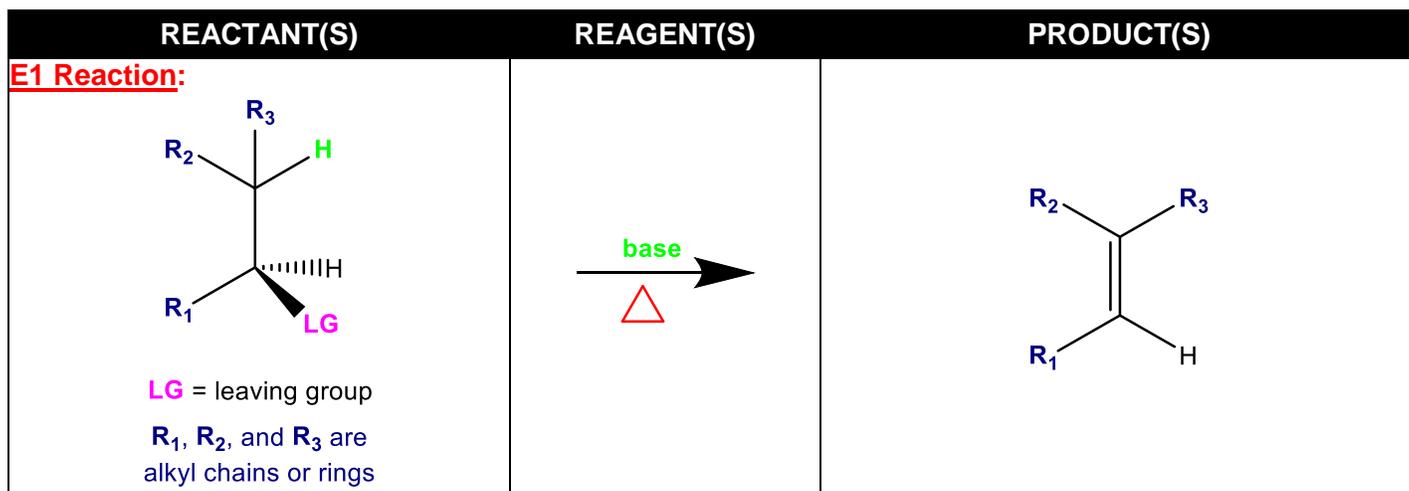
Mechanism:

+ $LG^{\ominus}$

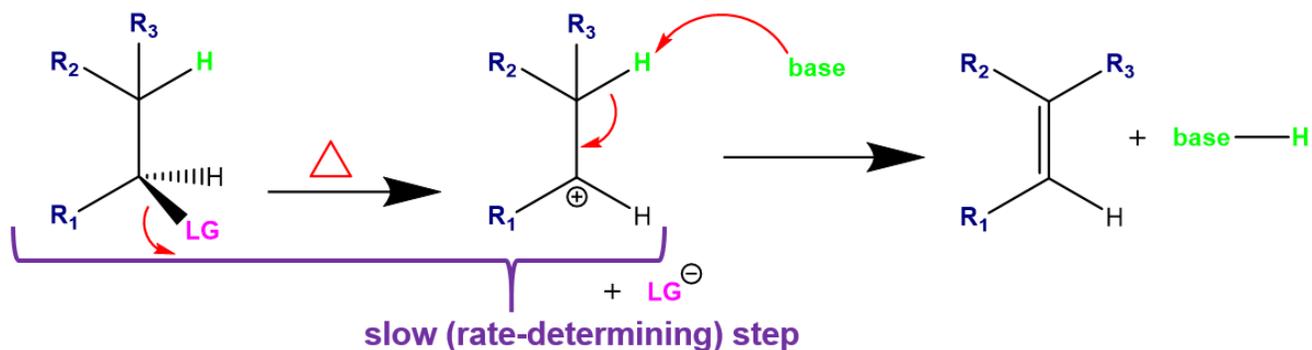**pentacoordinate transition state**

SN2 Details:

1. **S_N2** stands for "substitution nucleophilic bimolecular."
2. Leaving group reactivity: I > Br > Cl > F
3. Solvent: polar **aprotic**
4. Because the **nucleophile** attacks from the back side, **S_N2** reactions give an inverted stereochemistry in the product. The transition state is a pentacoordinate, with the central carbon being approximately (semi) sp^2-hybridized.
5. The **2** in **S_N2** does <u>NOT</u> mean that there are two steps in an **S_N2** reaction. It means that there are two reactants involved in the slow (rate-determining) step.
6. The rate-determining step is, of course, the step in which the **LG** is displaced by the **nucleophile**. These two molecules (the electrophile with the **LG** and the **nucleophile**) are both involved in the rate-determining step.
7. Thus, **S_N2** reactions' rate law looks like this: **rate = k[electrophile][nucleophile]**.
8. Furthermore:

Increasing S_N2 Reactivity

benzyl

allyl

stabilized

S_N2 or S_N1? Depends on nucleophile
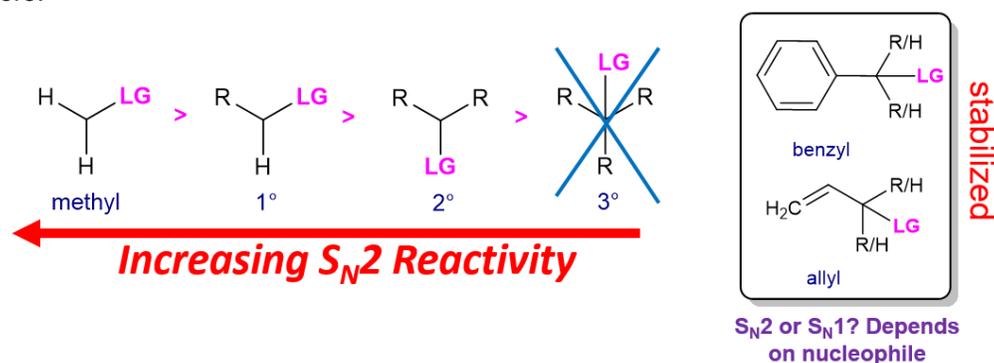
9. Because the nucleophile attacks the electrophile in a single step and NO carbocation forms, **S_N2** reactions involve **strong nucleophiles**.
10. Because **S_N2** reactions do NOT involve a carbocation intermediate, carbocation rearrangements do NOT happen in **S_N2** reactions.

REACTANT(S)	REAGENT(S)	PRODUCT(S)

E1 Reaction:

LG = leaving group

R₁, R₂, and R₃ are alkyl chains or rings

base, △

Mechanism:

+ LG⁻

slow (rate-determining) step

E1 Details:

1. *E1* stands for "elimination unimolecular."
2. Leaving group reactivity: I > Br > Cl > F
3. Solvent: polar **protic**
4. The **1** in *E1* does <u>NOT</u> mean that there is only one step in an *E1* reaction. It means that only one reactant is involved in the slow (rate-determining) step.
5. The rate-determining step is, of course, the step in which the **LG** separates to form a carbocation intermediate.
6. Thus, the rate law for *E1* reactions looks like this: **rate = k[substrate]**.
7. Furthermore:

| 3° benzyl | 3° allyl | 3° | 2° | 1° | methyl |

Increasing E1 Reactivity
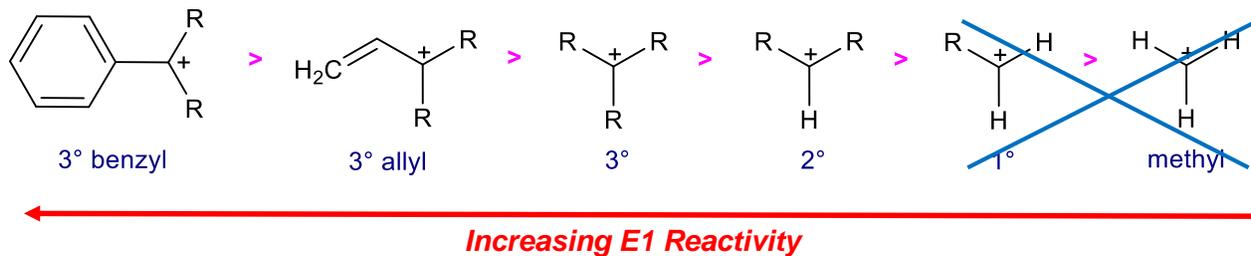
8. *E1* reactions nearly always involve **weak bases**, because strong bases are too reactive to allow a carbocation to form.
9. Unless sterically-bulky (*tert*-butoxy) bases are used, *E1* and *E2* reactions give the more substituted C=C bond and favor the *E*-alkene. This is called **Zaitsev's rule**.

major + minor

10. Because *E1* reactions involve a carbocation intermediate, carbocation rearrangements *can* happen in *E1* reactions. They do NOT happen in *E2* reactions.

REACTANT(S)	REAGENT(S)	PRODUCT(S)

E2 Reaction:

LG = leaving group

R_1, R_2, and R_3 are alkyl chains or rings
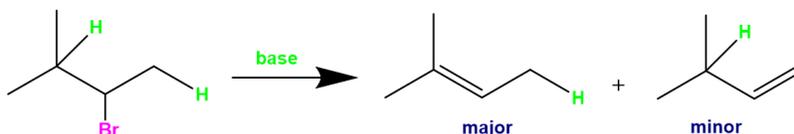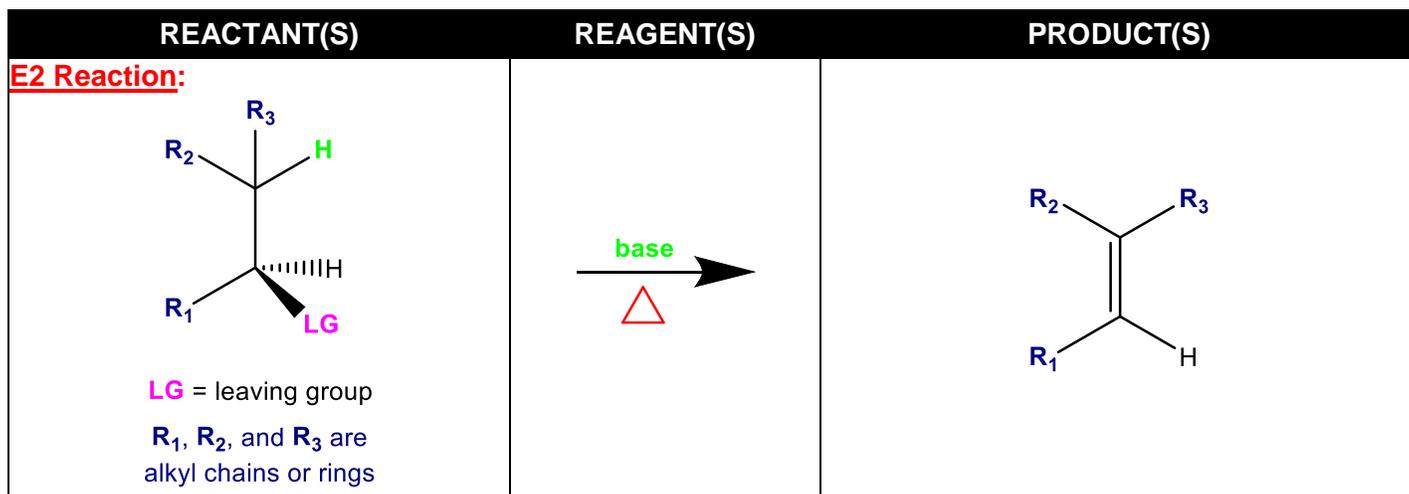
base, Δ

Mechanism:
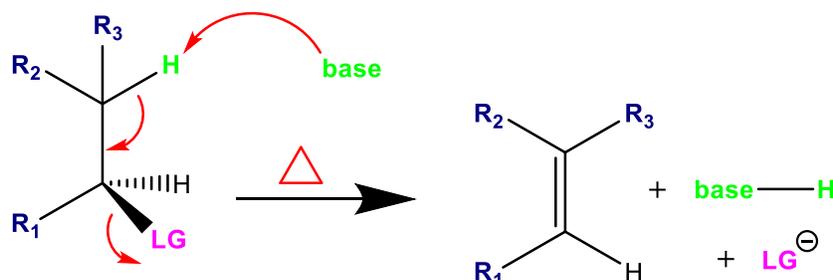
E2 Details:

1. **E2** stands for "elimination bimolecular."
2. Leaving group reactivity: I > Br > Cl > F
3. Solvent: polar **aprotic**
4. The **2** in **E2** does <u>NOT</u> mean that there are two steps in an **E2** reaction. It means that there are two reactants involved in the slow (rate-determining) step.
5. The rate-determining step is, of course, the step in which the **H** and **LG** are eliminated by the base. These two molecules (the electrophile with the **LG** and the base) are both involved in the rate-determining step.
6. Thus, **E2** reactions' rate law looks like this: **rate = k[substrate][base]**.
7. Furthermore: (**This is the opposite of SN2. The reason is because of Zaitsev's rule.**)

| 3° benzyl | 3° allyl | 3° | 2° | 1° | methyl |

Increasing E2 Reactivity
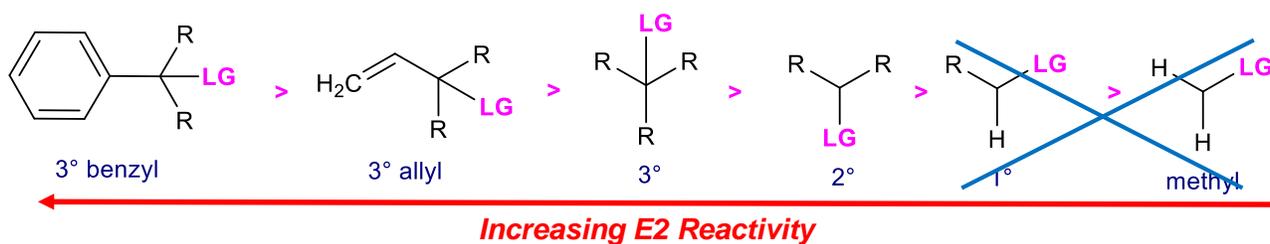
8. Because the base attacks the electrophile in a single step and NO carbocation forms, **E2** reactions involve strong bases.
9. Unless sterically-bulky (*tert*-butoxy) bases are used, **E1** and **E2** reactions give the more substituted C=C bond and favor the *E*-alkene. This is called **Zaitsev's rule**.

major + minor
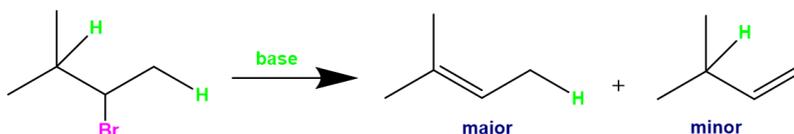
10. Because **E2** reactions do NOT involve carbocation intermediates, carbocation rearrangements can NOT happen in **E2** reactions.
11. In **E2** (not **E1**) reactions, the eliminated **H** and **LG** must be *anti-periplanar* (*anti-coplanar*) to each other. In cyclohexane rings, this means that the eliminated **H** and **LG** must both be axial and *anti-coplanar*.

Substitution/Elimination Decision Tree
(Follow this with any substitution/elimination question to identify the correct reaction pathway. rxn = reaction, questions are in blue boxes; answers are in yellow boxes)

Q0. Is your solvent protic or aprotic? → **Protic favors S_N1 and E1. Aprotic favors S_N2 and E2. This question isn't that important.**

Q1. Does the question's wording explicitly state the pathway (S_N1, S_N2, E1 or E2)? — **Yes** → **The rxn will proceed in whichever way the question explicitly states (S_N1, S_N2, E1, or E2).**

↓ **No**

Q2. Does the question's wording indicate the rxn is a "substitution" rxn? — **Yes** → **If the nucleophile is strong, the rxn is S_N2. If it's weak, the rxn is S_N1.**

Strong nucs have localized – charges (replace K, Na, or Li with a – charge). Weak nucs have – charges on halogens, resonance-delocalized – charges, or just lone pairs.

↓ **No**

Q3. Does the question's wording indicate the rxn is an "elimination" rxn? — **Yes** → **If the base is strong, the rxn is E2. If it's weak, the rxn is E1.**

Strong bases have localized – charges (replace K, Na, or Li with a – charge). Weak bases have – charges on halogens, resonance-delocalized – charges, or just lone pairs.

↓ **No**

Q4. Is the LG bonded to a 1° or 3° carbon, or to a 2° or resonance-stabilized carbon? — **3°** → **Your rxn may be S_N1, E1, or E2. Go to Q7.**

↓
Q7. Is your nucleophile/base strong or weak?
— **strong** → **Your rxn is E2.**
— **weak** → **Your rxn is either E1 or S_N1. Go to Q6.**

2° or stabilized ↓

Your rxn may be any of the above (S_N1, S_N2, E1, or E2). Go to Q5.

↓

Q5. Is your nucleophile/base strong or weak?

↓ **weak**

Your rxn is either E1 or S_N1. Go to Q6.

↓

Q6. Is your nucleophile/base a nuc or a base?

Nucs are smaller than CH_3CH_2OH on paper. Bases are CH_3CH_2OH or larger. <u>Exceptions</u>: Acetate is a nuc. Regardless of size, molecules with negatively-charged C atoms or nucleophilic S atoms are always nucs.

— **base** → **Your rxn is E1.**
— **nuc** → **Your rxn is S_N1.**

1° → **Your rxn is either S_N2 or E2. Go to Q8.**

↓

Q8. Is your nucleophile/base strong or weak?

— **strong** → **Your rxn is either S_N2 or E2. Go to Q9.**
— **weak** → **Impossible. Go back to the start.**

strong (from Q5) → **Your rxn is either S_N2 or E2. Go to Q9.**

↓

Q9. Is your nucleophile/base a nuc or a base?

— **base** → **Your rxn is E2.**
— **nuc** → **Your rxn is S_N2.**