Nucleophilic Substitution & Elimination: SN1, SN2, E1 & E2 Explained

Understanding Nucleophilic Substitution and Elimination Mechanisms

Organic chemistry is replete with reactions that determine the fate of a synthetic pathway. Among the most intellectually engaging and fundamentally important are nucleophilic substitution and elimination reactions. Both involve the breaking and forming of chemical bonds, yet they lead to very different products and follow distinct mechanistic pathways. ***Understanding Nucleophilic Substitution and Elimination Mechanisms is key to a solid understanding of many reactions you will learn in your course and therefore scoring well on exams.***

Checkout out the other reaction posts and if you need more help, **consider private, affordable, 1-on-1 tutoring with me!**

Overview

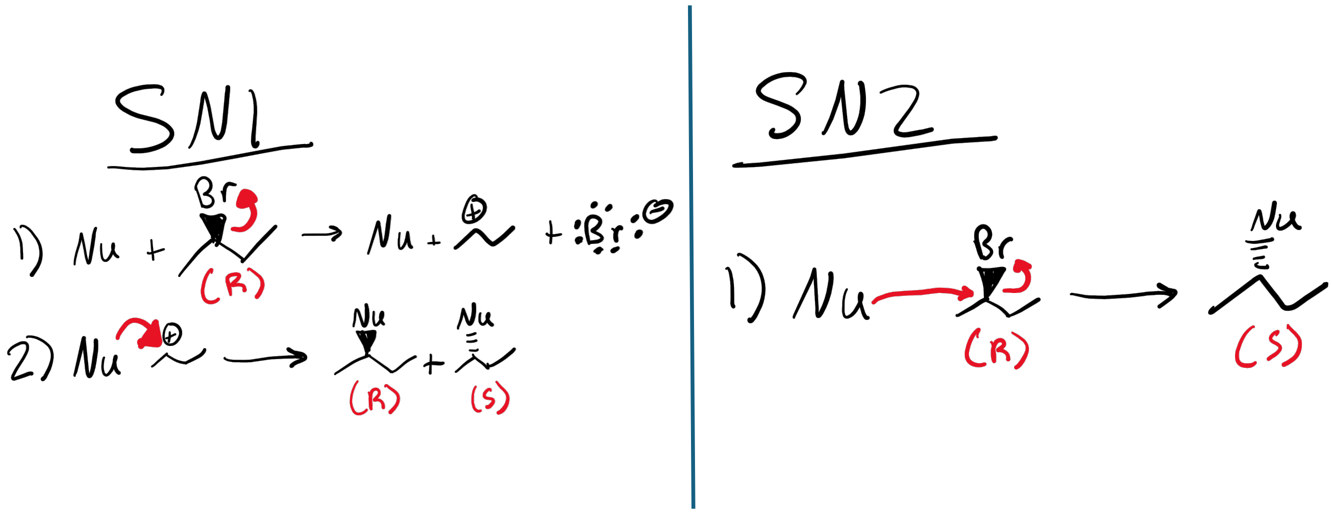
Nucleophilic Substitution: SN1 vs SN2

Substitution occurs when a nucleophile replaces a leaving group on the substrate.

- SN1 Reaction: This is a unimolecular mechanism in which the rate of reaction is determined by the electrophilic substrate, i.e. carbon with leaving group. SN1 reactions occur in two steps. SN1 reactions compete with E1 reactions and often occur together.
    1) Leaving group departs, forming a planar carbocation intermediate (which is very important for the reaction mechanism and leaves them vulnerable to rearrangements). This is the rate limiting step in the reaction.
    2) Nucleophile bonds to the carbocation site, from either side of the molecule. This results in complete racemization of the product (if the substrate is chiral)
- SN2 reaction: This is a bimolecular reaction in which the rate of the reaction is determined by the concentrations of both electrophile and nucleophile. SN2 reactions occur in one concerted step.

1) The nucleophile performs a backside attack (opposite direction from the way the leaving group is pointing), while the leaving group is removed from the substrate. This results in an <u>inversion of stereochemistry</u> at the site of SN.

The requirements for each mechanism are thoroughly discussed in our other posts. Briefly, they are structure, nucleophilic strength, and solvent effects. How each one effects outcome is described below. Before going on, *<u>consider the following</u>*: how might factors such as steric hinderance affect the backside attack of SN2? How may carbocations that are formed during SN1 mechanisms alter the final product?

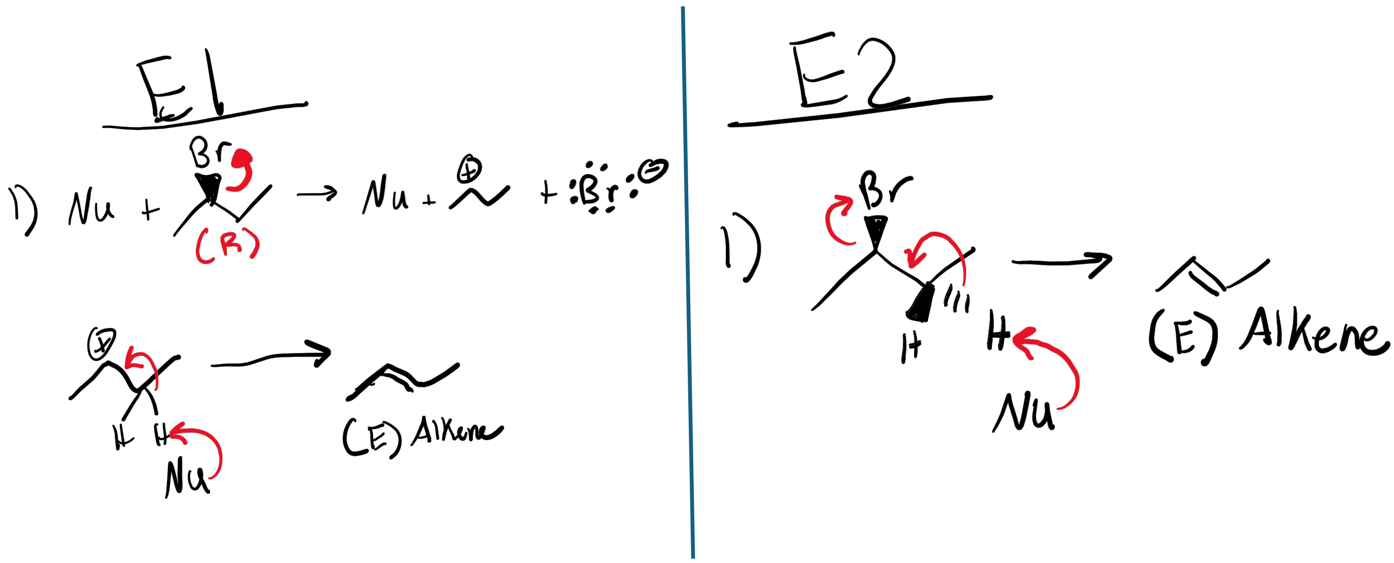


Nucleophilic Elimination: E1 vs E2

Elimination occurs when the leaving group and a neighboring carbon's hydrogen is removed, resulting in the formation of an alkene (carbon- carbon double bond)

- E1 Reaction: This is a unimolecular mechanism in which the rate of reaction is determined by the electrophilic substrate, i.e. carbon bonded to the leaving group. E1 reactions occur in two steps. E1 reactions compete with SN1 reactions and often occur together.
  1) Leaving group departs, forming a <u>planar carbocation intermediate</u> (which is very important for the reaction mechanism and leaves them <u>vulnerable to rearrangements</u>). This is the rate limiting step in the reaction and often occur together.
  2) Nucleophile acts as a base and takes hydrogen from a neighboring carbon. The lone pair left on the neighboring carbon forms another bond between it and the carbocation, forming a Zaitsev rule alkene (most substituted, and stable via E or Z alkene.)
- E2 Reaction: This is a bimolecular reaction in which the rate of the reaction is determined by the concentrations of both electrophile and nucleophile. E2 reactions occur in one concerted step.

1) The base strips hydrogen from a neighboring carbon that is aligned anti periplanar with the leaving group (example below). Therefore, it is important to identify reactive conformation. This will dictate whether the alkene product results in the Zaitsev product or not. Use of a bulky base can force the Hofmann (less substituted, less stable) alkene.



How to Choose Between Substitution and Elimination

Understanding reaction conditions that determine which mechanism will occur is instrumental to learning this section of organic chemistry and for exam questions such as predicting the product and synthesis. Deciding whether a reaction will proceed via a substitution or an elimination pathway depends on several interrelated factors:

1) **Substrate Structure:**
- Primary substrates tend to favor SN2 unless there is a high degree of β-branching or the nucleophile/base is bulky then it will prefer E2; Tertiary substrates are more susceptible to forming stable carbocations for SN1/E1 reactions.

2) **Nucleophile/Base Strength:**
- A strong, bulky base is more likely to favor elimination (E2) rather than substitution, due to steric hinderance that makes backside attack less favorable. Strong, charged nucleophiles will prefer SN2.

3) **Solvent Effects:**

- Polar protic solvents stabilize carbocations and thus favor SN1/E1 pathways, whereas polar aprotic solvents enhance nucleophilicity, thereby promoting SN2 reactions.

4) **Temperature:**

- Higher temperatures tend to increase the rate of elimination reactions relative to substitution reactions.

5) **Leaving Group Ability:**

- A good leaving group is essential for both mechanisms, but its influence is more pronounced in substitution reactions where nucleophilic attack is directly competitive.

This is a brief overview, and for further details, please check out the sections for each mechanism in which each is broken down in much more detail. We have also created a reaction roadmap for nucleophilic Substitution and Elimination Mechanisms that is free to download and use.

Wrapping Up and Further Considerations

This blog post has outlined the foundational ideas behind nucleophilic substitution and elimination reactions.

For further exploration, our other sections have discussed:

- More in-depth, mechanistic breakdowns of each reaction mechanism at a time
- Case studies where reaction conditions unexpectedly favor one pathway over the other.
- Advanced topics such as competing rearrangements in SN1/E1 reactions
- Practice on discussing different reaction conditions and deciding which mechanism will take place.

Finally, whether you are taking organic chemistry as part of a core curriculum or just as a prerequisite for graduate school, consider becoming a tutoring student. Spots are limited in order to guarantee quality tutoring for each student and their specific needs. Head over to availability or just contact me so that we can set up a call and discuss tutoring. Good luck!