Worksheet – Sₐ₁ and Sₐ₂

Alkyl halides, R-X, can undergo substitution reactions. These are described as a reaction between an electrophile and a nucleophile. Nucleophiles are electron rich species and often carry a negative charge. Electrophiles are electron deficient species and often carry a positive charge. Alkyl halides all have a polar C⁺⁻ - X⁻⁻. The C⁺ will be the electrophile. The nucleophile can be an anion like OH⁻, CN⁻, or an uncharged species like H₂O or NH₃. They all have lone pair electrons. The lone pair of electrons will make a bond to the C⁺ and the bonding electrons of the C – X bond will leave as X⁻.

\[
\text{Nu}^- + \text{R} – \text{X} \rightarrow \text{Nu} – \text{R} + :\text{X}^-
\]

This reaction proceeds via two different mechanisms, Sₐ₁ (substitution nucleophilic 1st order) and Sₐ₂ (substitution nucleophilic, 2nd order). The Sₐ₁ mechanism is first order in R – X and zero order in Nu⁻⁻. The rate determining step is unimolecular.

\[
\text{rate} = k [\text{R} – \text{X}]
\]

The intermediate R⁺ is a carbocation, a carbon with electrons in three \( sp^2 \) orbitals and an empty p orbital. It has a trigonal planar shape, which means that the Nu⁻⁻ can add to either side of the carbocation:

If a stereo center is made in the reaction, the products will be a racemic mixture (50/50) of both enantiomers and will be optically inactive.

1. 3-bromo-3-methylhexane will react via an Sₐ₁ mechanism with OH⁻. Draw the Fischer projection of the reactant and products(s). Assume that only one of the enantiomers of this compound is involved in the reaction.

\[
\begin{align*}
\text{R–X} & \quad \rightarrow \quad \text{R}^+ + \text{X}^- \\
\text{Nu}:^- & \quad \rightarrow \quad \text{Nu–R} \\
\end{align*}
\]
The $S_{N2}$ mechanism is first order in $R - X$ and first order in $\text{Nu}^-$:
\[
\text{rate} = k[R - X] [\text{Nu}^-]
\]
The rate determining step is bimolecular.

\[
\text{step 1} \quad \begin{array}{c}
\text{Nu}^- \quad \text{R} - \text{X} \quad \rightarrow \quad \text{Nu} - \text{R} + \text{X} \\
\text{slow}
\end{array}
\]

There is no intermediate. The transition state looks like:
\[
\text{Nu}^\text{-} ---- \text{R} ---- \text{X}^\text{-}
\]
In the transition state the nucleophile forms a bond near the small lobe of the $sp^3$ orbital bonded to $X$.

If a stereo center is made in the reaction, only one enantiomer is formed and the product will be optically active. The stereocenter will invert.

2. 2-bromobutane will react via an $S_{N2}$ mechanism with $\text{OH}^-$. Draw the Fischer projection of the reactant and products(s). Assume that only one of the enantiomers of this compound is involved in the reaction.

What determines which mechanism is followed?

The activation energy, $E_a$

$S_{N2}$ stability of carbocation
$3^0 > 2^0 > 1^0$
R groups bonded to $C^+$ stabilize it lower $E_a$

$S_{N1}$ stability of transition state
large R groups hinder approach small R groups lower $E_a$

3. Assume this is a diagram for a $2^0 \text{C}$. Draw energy levels for $1^0 \text{C}$, then $3^0 \text{C}$

4. Characterize 3-bromo-3-methylhexane and 2-bromobutane. Which $E_a$ is smaller for each?
5. Given the following reactions, decide which mechanism is followed, \( S_N1 \), \( S_N2 \) or if more information is needed.

\[ \begin{align*}
\text{a)} & \quad \text{CH}_2\text{CHCH}_2\text{CH}_2\text{CH}_2\text{Cl} + \text{NH}_3 & \rightarrow & \quad \text{CH}_2\text{CHCH}_2\text{CH}_2\text{CH}_2\text{NH}_2 + \text{HCl} \\
\text{b)} & \quad \text{CH}_2\text{CHCH}_2\text{CH}_2\text{CH}_2\text{Br} + \text{H}_2\text{O} & \rightarrow & \quad \text{CH}_2\text{CHCH}_2\text{CH}_2\text{CH}_2\text{OH} + \text{HBr} \\
\text{c)} & \quad \text{CH}_2\text{CHCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3 + \text{OH}^- & \rightarrow & \quad \text{CH}_2\text{CHCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{OH} + \text{I}^- 
\end{align*} \]

6. A certain alkyl halide is reacted with \( \text{OH}^- \) to form an alcohol. The alkyl halide is optically active but the product(s) is/are optically inactive. Which of the following could be the reactant? There may be more than one possible answer.

\[ \begin{align*}
\text{a)} & \quad \text{3-bromo-3-methylhexane} \\
\text{b)} & \quad \text{1-chlorobutane} \\
\text{c)} & \quad \text{2-bromo-2-methylbutane} \\
\text{d)} & \quad \text{3-bromo-2,3,4-trimethypentane} 
\end{align*} \]