Nucleophilic Substitution of Alkyl Halides
Experimental Procedures & Notes for Experiments A, B, and C
Chapter 17 in Bell, Clark and Taber, pgs 188 - 191

Experiment A. Structural Effects on S_N1 and S_N2 Reactivity

Series 1, NaI/acetone (S_N2 conditions)

1. Label two groups of five clean dry test tubes with numerals 1 to 5.
2. In each group of test tubes add 0.2 mL (use a syringe or add approximately 17 drops from a Pasteur pipet) of the following alkyl halides to the labeled tubes:
   a. n-butyl chloride
   b. n-butyl bromide
   c. sec-butyl chloride
   d. tert-butyl chloride
   e. crotyl chloride

3. Keep the tubes stoppered with corks or parafilm and leave them covered at all times, before and after adding reagents. **Carry out all experiments in your hood!**
4. Obtain 15 mL of each of the following solutions:
   a. 15% NaI/acetone (for Series 1 of Experiment A)
   b. 1% ethanolic AgNO_3 (for Series 2 of Experiment A)
5. Read/become familiar with steps 6-9 before continuing.
6. With one series of the tubes arranged in order, add rapidly and all at once 2 mL of 15% NaI/acetone solution to tube #1 and note the time of the addition on your table. **NOTE:** Record data/observations in your notebook in a table like that depicted on page 2.
   a. **NOTE:** after this and subsequent additions carefully watch each of the tubes for the formation (this may occur rapidly or slowly) of a precipitate (not turbidity or cloudiness) which indicates that the reaction has occurred.
   b. Record the time in your table if and when precipitation (look for solids on the bottom of the test tube) begins to occur in each of the test tubes. Cloudiness or a milky appearance is not precipitation.
   c. Remember to keep the tubes stoppered before and after adding the NaI.
7. After 2 to 3 minutes, add 2 mL of the NaI/acetone solution to tube #2 and note the time of the addition on your table.
8. Continue the process of adding 2 mL portions of the NaI/acetone solution to the remaining tubes in the series (#s 3, 4, and 5).
9. Allow this series of tubes to stand and observe them for precipitate formation periodically while the second series is run.

(Continued on page 2)
Series 2, AgNO$_3$/ethanol (S$_N$1 conditions)

\[
\begin{align*}
R\longrightarrow X & \xrightarrow{\text{AgNO}_3, \text{H}_2\text{O}, \text{EtOH}} \text{Ag}^+ + X^- & \xrightarrow{\text{ROH (and ROEt)}} \text{AgX} & \xrightarrow{\text{NO}_3^-}
\end{align*}
\]

1. Arrange the second series of tubes and, in the same manner as above, add 2 mL portions of the 1% ethanolic AgNO$_3$ to each tube at 2 to 3 minute intervals.
2. Note the time of each addition and, if possible, record the times (may be rapid or slow!) when the first appreciable turbidity (cloudiness) forms and when a definite precipitate occurs.
3. If any tubes in the Series 1 NaI series are still clear, unstopper the tubes and place them in a 50°C water bath for 10 - 15 minutes, noting any changes that occur.
4. When finished with these reactions, pour the contents into the organic waste container.
5. Explain your results from Series 1 and Series 2.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Time of addition</th>
<th>Time of precipitate formation</th>
<th>Time Elapsed</th>
<th>Time of addition</th>
<th>Time of turbidity appearance</th>
<th>Time of definite precipitate formation</th>
<th>Time elapsed</th>
</tr>
</thead>
<tbody>
<tr>
<td>n-butyl chloride</td>
<td>DO</td>
<td>NOT</td>
<td>RECORD</td>
<td>RESULTS</td>
<td>IN</td>
<td>THIS</td>
<td>TABLE</td>
</tr>
<tr>
<td>n-butyl bromide</td>
<td>RECORD</td>
<td>YOUR</td>
<td>RESULTS</td>
<td>DIRECTLY</td>
<td>IN</td>
<td>YOUR</td>
<td>NOTE-BOOK</td>
</tr>
<tr>
<td>sec-butyl chloride</td>
<td>DO</td>
<td>NOT</td>
<td>RECORD</td>
<td>RESULTS</td>
<td>IN</td>
<td>THIS</td>
<td>TABLE</td>
</tr>
<tr>
<td>tert-butyl chloride</td>
<td>RECORD</td>
<td>YOUR</td>
<td>RESULTS</td>
<td>DIRECTLY</td>
<td>IN</td>
<td>YOUR</td>
<td>NOTE-BOOK</td>
</tr>
<tr>
<td>crotyl chloride</td>
<td>DO</td>
<td>NOT</td>
<td>RECORD</td>
<td>RESULTS</td>
<td>IN</td>
<td>THIS</td>
<td>TABLE</td>
</tr>
</tbody>
</table>

Experiment B. Effects of Solvent on S$_N$1 Reactivity

\[
\begin{align*}
\text{t-Bu—Cl} & \xrightarrow{\text{Acetone/water}} \text{t-BuOH} + \text{HCl}
\end{align*}
\]

1. Label three clean dry test tubes with each of the acetone/water solvent mixtures that are available in the hood. The solvent mixtures available are:
   a. 55:45 acetone:water
   b. 60:40 acetone:water
   c. 65:35 acetone:water
2. From the three acetone/water solvent mixtures, add one 2 mL portion of each mixture to the properly labeled test tube.
3. Using a Pasteur disposable pipet add exactly 2 drops of 0.5 M NaOH and then 2-3 drops of phenolphthalein solution to each of the above test tubes containing the solvent mixtures.

(Continued on page 3)
4. Cover the tubes with parafilm or corks and place them in a water bath at 35 ± 1°C for 4 to 5 minutes to bring the solvent mixtures to the bath temperature. Use a Styrofoam cup in a beaker as an insulated container for your bath.

5. Using a disposable pipet add **exactly** 3 drops of tert-butyl chloride to each test tube.

6. Note the time of the addition (record in your notebook in a table like that shown below); then briefly swirl the test tubes to mix and replace the tubes in the bath, swirling intermittently to insure good mixing.

7. Add small amounts of hot water to the bath to maintain the temperature at 35 ± 1°C.

8. Record the time for the pink color to disappear in each of the solvent mixtures.

9. Explain your results.

<table>
<thead>
<tr>
<th>Solvent mixture used</th>
<th>Time of addition of tert-Butyl Chloride</th>
<th>Time pink color disappeared</th>
<th>Time elapsed, in seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>55:45 Acetone:Water</td>
<td>DO NOT RECORD RECORD YOUR</td>
<td>RESULTS IN THIS</td>
<td>TABLE IN YOUR NOTEBOOK</td>
</tr>
<tr>
<td>60:40 Acetone:Water</td>
<td>DO NOT RECORD RECORD YOUR</td>
<td>RESULTS IN THIS</td>
<td>TABLE IN YOUR NOTEBOOK</td>
</tr>
<tr>
<td>65:35 Acetone:Water</td>
<td>DO NOT RECORD RECORD YOUR</td>
<td>RESULTS IN THIS</td>
<td>TABLE IN YOUR NOTEBOOK</td>
</tr>
</tbody>
</table>

**Experiment C. Effect of Temperature on Reaction Rates**

1. From your results in Experiment B, choose the solvent system for which the neutralization time at 35°C was closest to 5 minutes; this usually should be the 55:45 acetone:water solvent mixture.

2. Add 2 mL of this solvent mixture to a test tube and add **exactly** 2 drops of the 0.5 M NaOH and then 2-3 drops of the phenolphthalein solution.

3. Place the test tube in a water bath at 25 ± 1°C for 4 to 5 minutes to allow the solvent to come to the bath temperature.

4. Using a disposable pipet, add **exactly** 3 drops of tert-butyl chloride to the test tube and note the time of the addition in your table.

5. Swirl the tube to mix, place the tube in the water bath and note the time (see table on page 4) in your notebook for the pink color to disappear at the 25 ± 1°C temperature.

6. Repeat this procedure with the same solvent system at 45 ± 1°C and record the times for color disappearance.

7. Use the times obtained for the samples at 25°C and 45°C and the time at 35°C from Exp. B to make a plot of log $t$ (time in seconds) versus 1/T(°K).

8. From the slope in the above plot, calculate the activation energy ($E_a$) for the solvolysis in the solvent used.

9. Note that a plot of log $t$ values versus 1/T(°K) should give a straight line with slope = $E_a$/2.3R [R = gas constant (1.99 cal/mole deg) and $E_a$ = activation energy]. See your lab text for this equation.

(Continued on page 4)
**Characteristic Properties of Substitution Reactions of Alkyl Halides**

<table>
<thead>
<tr>
<th></th>
<th><strong>S&lt;sub&gt;N&lt;/sub&gt;1 Reaction</strong></th>
<th><strong>S&lt;sub&gt;N&lt;/sub&gt;2 Reaction</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sn1 Reaction</strong></td>
<td>Stepwise mechanism forming a carbocation intermediate</td>
<td>One-step concerted mechanism; no intermediates formed</td>
</tr>
<tr>
<td></td>
<td>Unimolecular rate-determining step</td>
<td>Bimolecular rate-determining step</td>
</tr>
<tr>
<td></td>
<td>Carbocation rearrangements occur</td>
<td>No carbocation rearrangements occur</td>
</tr>
<tr>
<td></td>
<td>Configurations both retained and inverted relative to the reactant</td>
<td>Configuration inverted relative to the reactant</td>
</tr>
<tr>
<td><strong>Reactivity order:</strong></td>
<td>RI &gt; RBr &gt; RCl &gt; RF</td>
<td>RCH&lt;sub&gt;2&lt;/sub&gt;Br &gt; RCH&lt;sub&gt;2&lt;/sub&gt;Cl &gt; RCH&lt;sub&gt;2&lt;/sub&gt;F</td>
</tr>
<tr>
<td></td>
<td>allyl, 3° &gt; 2° &gt; 1° &gt; methyl</td>
<td>Methyl, allyl &gt; 1° &gt; 2° &gt; 3°</td>
</tr>
<tr>
<td></td>
<td>3° Alkyl halides undergo only Sn1</td>
<td>Methyl halides and 1° alkyl halides undergo only Sn2</td>
</tr>
<tr>
<td></td>
<td>1° Alkyl and methyl halides do not undergo Sn1</td>
<td>Tertiary halides can not undergo Sn2</td>
</tr>
<tr>
<td><strong>Increasing solvent polarity increases rate of reaction. Sn1 reactions do not occur in nonpolar solvents</strong></td>
<td>Increasing solvent polarity decreases the rate of reaction if nucleophilic reactant(s) is(are) charged</td>
<td></td>
</tr>
<tr>
<td><strong>Favored by low concentration of a nucleophile or by a poor nucleophile in polar protic solvent</strong></td>
<td>Favored by a high concentration of a good nucleophile in polar aprotic solvent</td>
<td></td>
</tr>
</tbody>
</table>

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Example of plot of log t versus 1/T

![Example of plot of log t versus 1/T](image)

\[
\text{Slope} = \frac{E_a}{2.3R} \\
R = \frac{1.99 \times 10^{-3}}{\text{mol} \cdot \text{°K}} \\
\text{°K} = \text{°C} + 273
\]