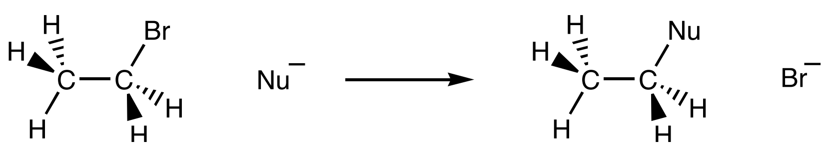
Nucleophilic Substitution and Halogenated Hydrocarbons

Objective

To perform a series of nucleophilic substitutions to determine the roles that the structure of the alkyl halide and the identity of the halogen play in the rate of the substitution reactions.

Background

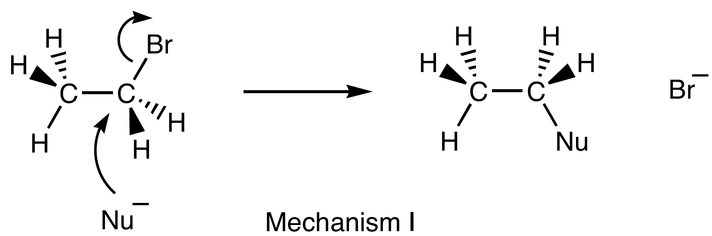
Alkyl halides are an interesting class of molecules because they contain, in the case of fluoro-, chloro-, and bromohydrocarbons, an electrophilic carbon atom. Additionally, the halogen atoms on the alkyl halides are capable of forming stable anions. This interesting combination of properties gives rise to a class of molecules that can undergo nucleophilic substitution. The reaction is summarized in equation 1; the attacking, electron rich, nucleophile is substituted for the bromine which leaves as a bromide ion.



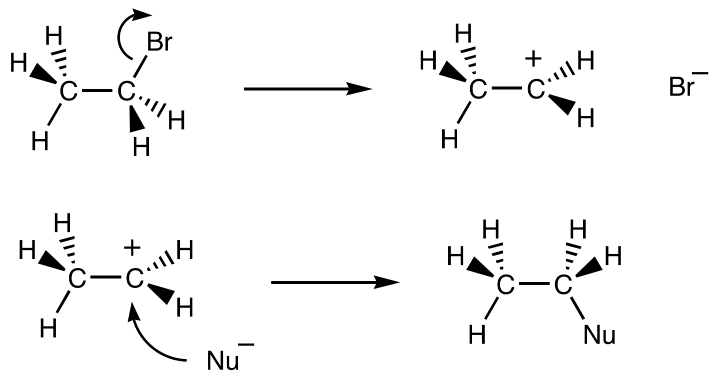
eq 1

In one possible mechanism, the nucleophile attacks the carbon atom and pushes the bromide ion off the other side (see Mechanism 1). In another possible mechanism, the bromide ion simply falls off. Once the bromide ion has left, the nucleophile can fill in the hole that was created when the bromide ion left (see Mechanism 2). Each mechanism has implications for the reaction.

Since, both reactions involve the loss of a halogen (as a halide) one might expect that the nature of the halide will play a similar role in both reactions. On the other hand, one mechanism involves the formation of a carbocation whereas the other doesn't. Thus, Mechanism II implies that molecules that can better support carbocations should be better substrates for nucleophilic substitution reactions. Conversely, Mechanism I does not implicate a carbocation intermediate. Further, since the nucleophile attacks before the halogen leaves, access to the reactive site is going to be an issue for any reaction that proceeds via Mechanism I.

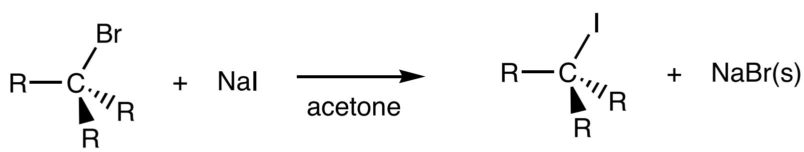


Mechanism I

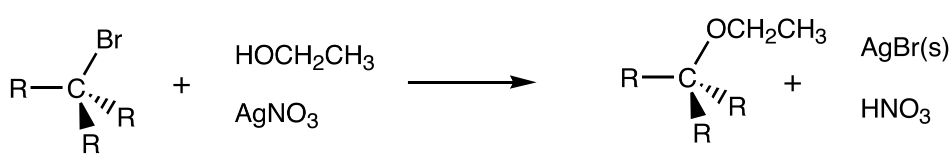


Mechanism II

In this experiment, a variety of alkyl halides will be tested to determine the roles that the structures of the molecules and the identity of the halogens play during a nucleophilic substitution. In one series of experiments, conditions will be used that encourage substitution reactions to occur via Mechanism I (S_N2 conditions). In another series of experiments, conditions that encourage the formation of carbocations will be used (S_N1 conditions). The reactions have been designed so that a successful substitution reaction will produce a precipitate. Thus, the progress of the reaction can be monitored qualitatively with great ease. (We will discuss why the reaction conditions support S_N1 or S_N2 a little later.)



S_N2 conditions



S_N1 conditions

Procedure[1]

Reactions with NaI in acetone

Label eight small test tubes (10 x 75-mm) 1–8, and place 2 mL of the 15% NaI in acetone solution in each test tube. To test tube one, add four drops of 1-chlorobutane. To test tube two, add four drops of 1-bromobutane. To test tube three, add four drops of 2-chlorobutane. Continuing with test tubes four through eight, add four drops of 2 bromobutane, 2-chloro-2-methylpropane (*t*-butylchloride), 1-chloro-2-butene (crotyl chloride), benzylchloride (α-chlorotoluene), and bromobenzene respectively. Carefully "flick" the test tube to mix its contents and record the time required for the formation of any cloudiness or precipitate. After about five minutes, transfer any reaction that has not formed a precipitate to a hot water bath (max 50 °C). Since acetone has such a low boiling point, be careful not to heat the solutions too strongly. Heat for a couple of minutes, remove the test tubes from the hot water bath, cool the test tubes to room temperature, and note whether a precipitate has formed. Ignore any color changes. It is useful to note the degree to which the reaction proceeds. That is, did the solution merely become cloudy or did a precipitate collect at the bottom of the tube.

Reactions with $AgNO_3$ in ethanol

Label eight small test tubes (10 x 75-mm) 1–8 and place 2 mL of the 1% silver nitrate in ethanol solution in each test tube. To test tube one, add four drops of 1-chlorobutane. To test tube two, add four drops of 1-bromobutane. To test tube three add four drops of 2-chlorobutane. To test tubes four through eight, add four drops of 2 bromobutane, 2-chloro-2-methylpropane (*t*-butylchloride), 1-chloro-2-butene (crotyl chloride), benzylchloride (α-chlorotoluene), and bromobenzene respectively. Carefully "flick" the test tube to mix its contents and record the time required for the formation of any cloudiness or precipitate. After approximately 5 minutes, place any tubes that have not reacted in a 100 °C water bath. Heat the test tube for two minutes, remove it from the hot water bath, cool it to room temperature and determine whether a reaction has occurred. Once again, it is useful to note the degree to which the reaction proceeds.

Experimental Report

For your report, (1.) create a table listing the sixteen reactions that you performed and your observations concerning those reactions. The table on the following page is meant as an example; do not merely fill in the example provided on page two. The table should include the name of the compound and the structure of the compound. In the appropriate column, indicate whether a substantial or small amount of precipitate formed. Note anything unexpected.

2. Choose one S_N2 reaction and one S_N1 reaction from the sixteen reactions performed in this experiment and write a balanced chemical equation for each reaction. When writing the equations, do not use formulae; draw structures.

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[1] Adapted from Pavia, Lampman, Kiz, and Engel, "Reactivities of Some Alkyl Halides", *Introduction to Organic Laboratory Techniques: A Microscale Approach.* Saunders College Publishing, 1999.

3. Answer the following questions.

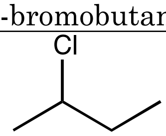
a. Which is a better leaving group, Cl^- or Br^-? Provide three pieces of evidence to support your response.

b. Which is a better substrate for an S_N2 reaction, a 1° or 2° alkyl halide? Provide evidence for your response.

c. Are 3° substrates suitable substrates for an S_N2 reaction? Provide evidence for your answer.

d. Rank 1°, 2°, and 3° alkyl halides by their ability to participate in S_N1 reactions. Provide evidence for your ranking.

e. Are any 1° chlorohyrdrocarbons used in this experiment reactive toward S_N1 reactions? Explain why these 1° chlorohydrocarbons behave differently than 1-chlorobutane.

Compound	Acetone-NaI Reaction		Ethanol-$AgNO_3$ Reaction	
	Cold	Hot	Cold	Hot
1-chlorobutane				
1-bromobutane				
 2-chlorobutane				
2-bromobutane				
2-chloro-2-methylpropane (*t*-butylchloride)				
1-chloro-2-butene (crotyl chloride)				
benzylchloride (α-chlorotoluene)				
bromobenzene				