**Structure and Reactivity Relationships - Nucleophillic Substitution Reactions (41 marks)**

Together, you and your TA are comparing the reactivity of an assortment of alkyl halides under SN1 and SN2 reaction conditions. Watch the required videos of the experiment when noted. These will help you to determine what you will see when performing the reaction. Experimental details will be provided where necessary. Please use ChemDraw for all of your figures and schemes.

Answer the following questions:

1. Complete the following table: **(8 marks)**

|  |  |  |
| --- | --- | --- |
| **Compound** | **Structure** | **Reaction Site: Sp3 (3°, 2°, 1°) or sp2** |
| *n*-Butyl chloride | * 0.5 for each structure * 0.5 for each reaction site |  |
| *n*-Butyl bromide |  |  |
| *Sec*-Butyl chloride |  |  |
| *Sec*-Butyl bromide |  |  |
| *Tert*-Butyl chloride |  |  |
| *Tert*-Butyl bromide |  |  |
| Chlorobenzene |  |  |
| Benzyl Chloride |  |  |

1. Define leaving group. What makes a good leaving group? **(2 marks)**

* molecular fragment that departs with a pair of electrons in heterolytic bond cleavage.
* A good leaving group is stable on its own, eg. Can support a negative charge or is neutral

1. Draw the general mechanisms for a SN1 and SN2 reaction. **(4 marks)**

SN1:

* Shows the leaving group leaving to form a carbocation
* Show the nucleophile attacking the carbocation

SN2:

* Shows the nucleophile attacking to form a 5-centered transition state
* Shows inversion of stereochemistry and leaving group leaving

1. Explain the naming for SN1 and SN2 (eg. What does the acronym mean)? **(2 marks)**

* SN1: Substitution , Nucleophillic, rate determining step is unimolecular
* SN1: Substitution, Nucleophillic, rate determining step is bimolecular

1. What is the rate limiting step for an SN1 reaction? What is the rate limiting step for an SN2 reaction? What affects the rate in each case? **(4 marks)**

SN1:

* Carbocation formation
* Carbocation stability

SN2:

* Formation of a 5-centered transition state
* Sterics around the carbon center

1. How can you assess whether a reagent will promote SN1 or SN2 chemistry? Consider nucleophilicity in your answer. **(1 mark)**

* Nucleophilicity of the incoming nucleophile and stability of the leaving group. If the nucleophile is not strong, but the leaving group is a good one, SN1 reactivity is more likely. If the nucleophile is strong and the leaving group is reasonable, SN2.

Time for the lab to commence! You have 8 unknown sample vials. You know that the contents of each of the vials corresponds to one of alkyl halides you outlined above. Assess the following reactions to help you determine which unknown number belongs to which alkyl halide!

1. To a 0.1 mL sample of each unknown you add 1 mL of NaI in an acetone solution in a single dose. The test tubes are shaken, and the time recorded for each reaction. Watch the following video and assess your in-lab data in the table below to help you determine which alkyl halide belongs to which unknown number.

<https://www.youtube.com/watch?v=o-Cl88fLixs>

|  |  |  |
| --- | --- | --- |
| **Unknown Number** | **Observations** | **Reaction Time (minutes)** |
| 1 | The solution became cloudy | 26.00 |
| 2 | A white precipitate formed | 1.30 |
| 3 | The solution became cloudy and slowly precipitated | 15.20 |
| 4 | A white precipitate formed instantly | 0.02 |
| 5 | Reaction solution remained clear | 60.00 |
| 6 | A white precipitate formed | 1.00 |
| 7 | A white precipitate formed slowly | 12.00 |
| 8 | The solution become cloudy | 24.02 |

1. What are the two products formed during this reaction? Which is the precipitate? **(2 marks)**

* 0.5 marks for each product (NaX and alkyl iodide)
* 1 mark for identifying that NaCl or NaBr is the precipitate

1. Is this an SN1 or an SN2 reaction? Explain. **(2 marks)**

* SN2
* Iodine is an excellent nucleophile and bromine and chlorine are reasonable leaving groups

1. To a 0.1 mL sample of each unknown you add 1 mL of AgNO3 in an ethanol/water solution in a single dose. The test tubes are shaken, and the time recorded for each reaction. Re-watch the following video and assess your in-lab data in the table below to help you determine which alkyl halide belongs to which unknown number.

<https://www.youtube.com/watch?v=o-Cl88fLixs>

|  |  |  |
| --- | --- | --- |
| **Unknown Number** | **Observations** | **Reaction Time (minutes)** |
| 1 | A white precipitate formed quickly | 0.75 |
| 2 | The solution became cloudy | 24.60 |
| 3 | A white precipitate formed | 6.50 |
| 4 | A white precipitate formed instantly | 0.50 |
| 5 | No change to the solution | 60.00 |
| 6 | The solution became cloudy and a yellow precipitate slowly formed | 16.00 |
| 7 | A bright yellow precipitate formed | 5.00 |
| 8 | A yellow precipitate formed instantly | 0.50 |

1. What are the three products formed during this reaction? Which is the precipitate? **(2 marks)**

* 0.5 marks for each product (AgX, alcohol, HNO3)
* 0.5 mark for identifying that AgCl or AgBr is the precipitate

1. Is this an SN1 or an SN2 reaction? Explain. **(2 marks)**

* SN1
* NO3- is NOT the nucleophile, water is. Water is not a good nucleophile but Br and Cl are good leaving groups. Water can attack the carbocation and is deprotonate by NO3- to form HNO3.

1. Complete the following table assigning each alkyl halide to an unknown number. **(4 marks)**

|  |  |
| --- | --- |
| **Unknown Number** | **Hydrocarbon** |
| 1 | Tert-butyl chloride |
| 2 | n-butyl chloride |
| 3 | Sec-butyl chloride |
| 4 | Benzyl chloride |
| 5 | Chlorobenzene |
| 6 | n-butyl bromide |
| 7 | Sec-butyl bromide |
| 8 | Tert-butyl bromide |

1. Describe how you assigned each alkyl halide to an unknown number. Take into consideration the reaction type, the reaction intermediates, what controls the rate of each reaction, factors that affect the stability of various intermediates, and the colour of products. A well-rounded discussion will make it clear *chemically* why a reaction order or type is expected for each of the alkyl halides. **(8 marks)**

* SN1 is dictated by the stability of the resulting carbocation.
* Expected SN1 general reactivity: resonance stabilized > 3° > 2° > 1°
* Chlorobenzene should not react since carbocations are not stable on sp2 carbons
* Bromine is a better leaving group than chlorine, so the alkyl bromides are expected to react faster
* AgBr is yellow and AgCl is white. This can help to differentiate the alkyl bromides from the chlorides
* SN2 is dictated by the ability to form the 5-centered intermediate and is affected by sterics
* Expected SN2 reactivity: 1° > 2° > 3°
* Benzyl chloride in an outlier due to the planarity of the benzene ring. Chlorobenzene should not react since 180° approach of the nucleophile is not possible.

**BONUS QUESTIONS: (Add 1 mark for each to total lab mark)**

2-bromobutane is reacted with NaI in an acetone solution. Draw the product(s) showing stereochemistry. Explain your choice.



* Due to the 5-centered transition state, the bromine leaves at the same time iodine approaches. This results in an inversion of stereochemsitry

2-bromobutane is reacted with AgNO3 in an ethanol/water solution. Draw the product(s) showing stereochemistry. Explain your choice.



* Stereochemistry in the molecule is lost due to the formation of the planar carbocation intermediate.
* On the planar carbocation intermediate, the water can attack either side of the molecule leading to a racemic mixture