SANTA ROSA JUNIOR COLLEGE
Chemistry & Physics Department

Mechanisms: Nucleophiles, Electrophiles, and Leaving Groups

Learning Outcomes

1. Understand the connectivity between energy and reactivity

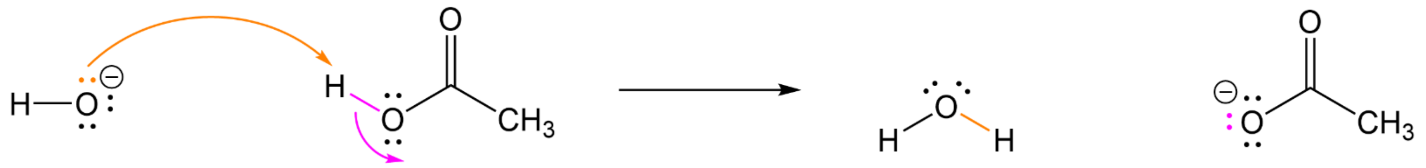
2. Since ***chemical equations*** are ***chemical sentences***, read ***mechanisms*** as ***annotated chemical sentences***

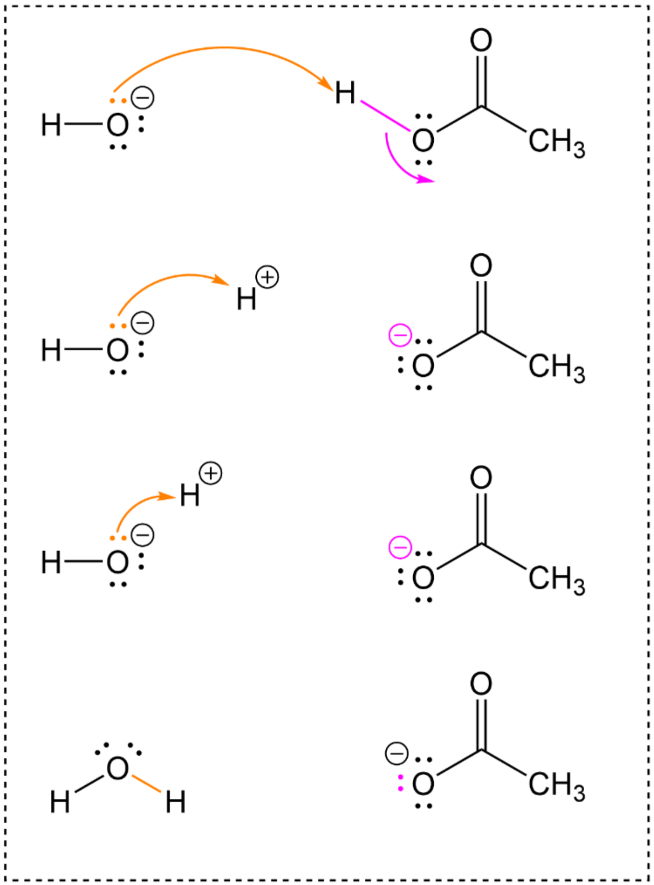
3. Identify a nucleophile and an electrophile

4. Predict which nucleophile is stronger from a set and predict which electrophile is more electrophilic from a set

5. Identify a leaving group and identify which leaving group is the best leaving group from a given set

Curved Arrows



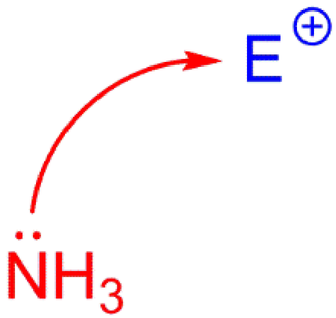


A Nucleophile is an Electron Source and an Electrophile is an Electron Sink

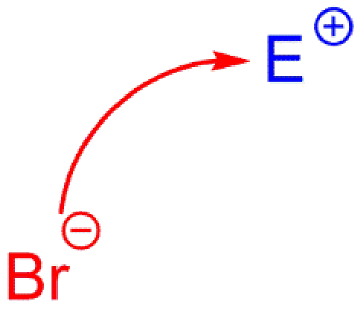
Nucleophile (Nu^-): A reactant that ***provides*** a pair of electrons to form a new covalent bond.

Electrophile (E^+): A reactant that ***accepts*** an electron pair to form a new covalent bond.

Nucleophiles Donate High-Energy Electrons



Lone Pair

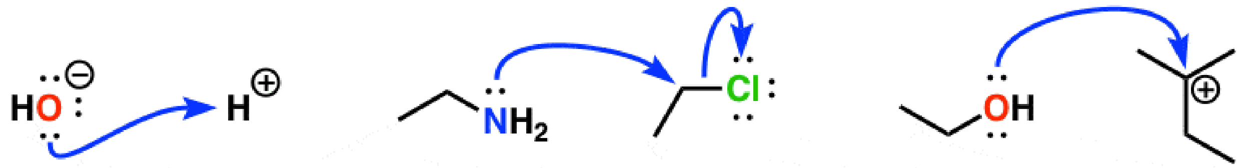


Negative Charge

Electron Lone Pairs Are Nucleophiles

Lone pairs are nucleophiles

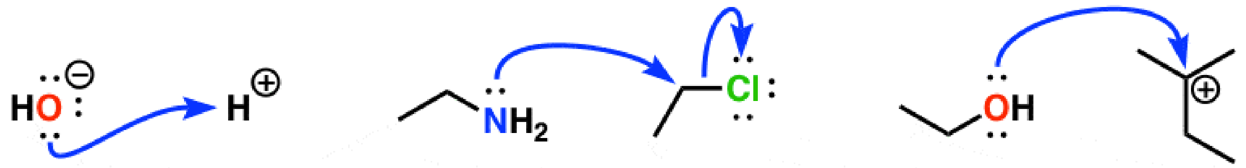
Each of these atoms donates a lone pair to an electrophile



Trends in Nucleophilicity: Charge

Lone pairs are nucleophiles

Each of these atoms donates a lone pair to an electrophile



Three important trends:

1) Nucleophilicity increases as the charge on the atom becomes more negative:

$^{\ominus}OH$ > H_2O

Food for Thought

Consider the following two questions.

1. What is a base?

2. What makes one base stronger than another (this is the concept of basicity)

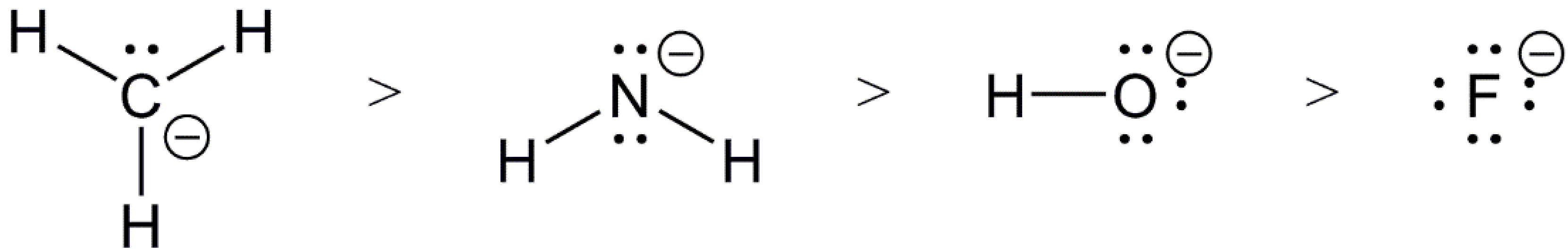
Bases

Higher-energy electrons are more reactive electrons. More reactive electrons are more ***basic***.

Electrons are higher in energy when:

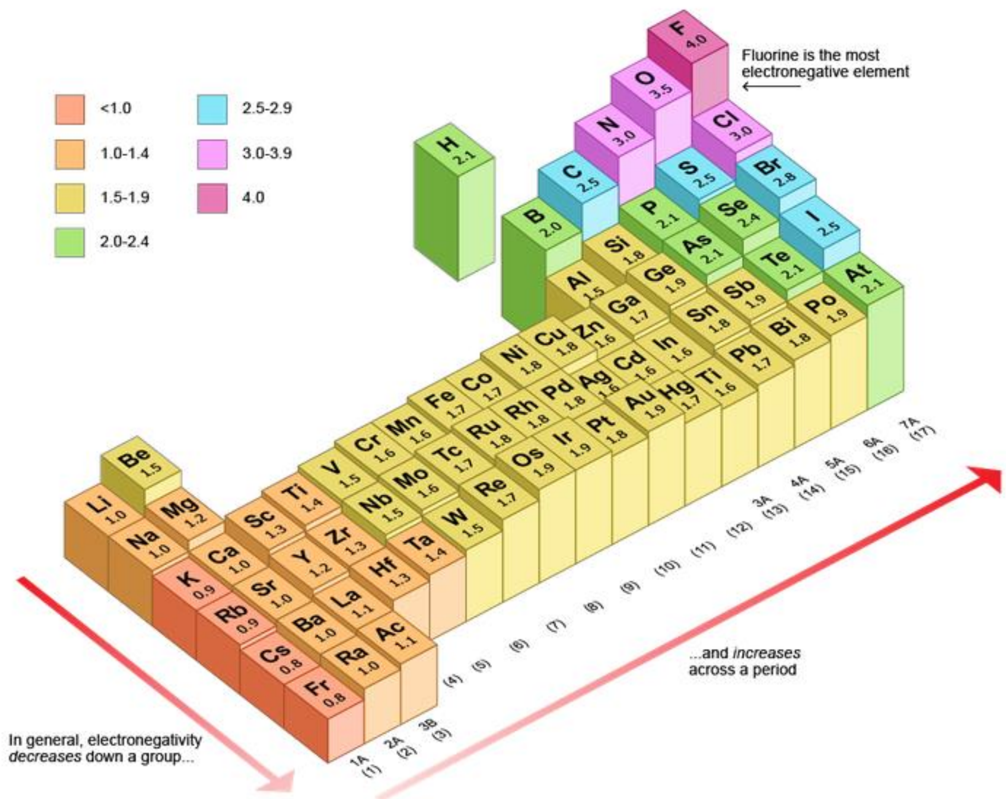
1. They associate with less electronegative atoms
2. They are localized (confined to a small volume)

A Lone Pair on a ***Less*** Electronegative Atom is More Basic



Most Basic

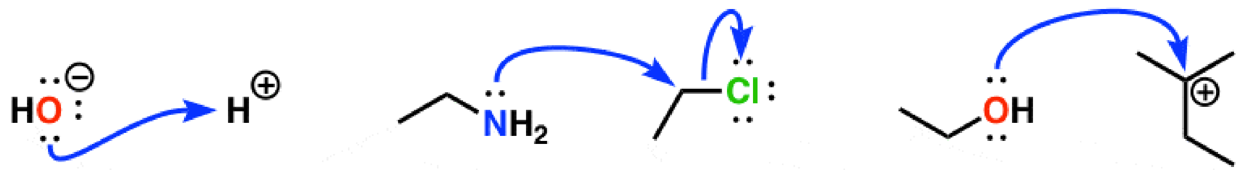
Least Basic



Trends in Nucleophilicity: Basicity

Lone pairs are nucleophiles

Each of these atoms donates a lone pair to an electrophile



Three important trends:

1) Nucleophilicity increases as the charge on the atom becomes more negative:

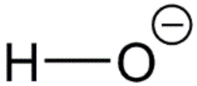
$^{\ominus}OH$ > H_2O > $H_3O^{\oplus}$

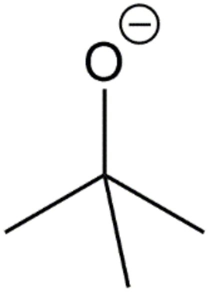
2) Nucleophilicity increases with basicity:

$^{\ominus}CH_3$ > $^{\ominus}NH_2$ > $^{\ominus}OH$ > $^{\ominus}F$

Trends in Nucleophilicity: Accessibility

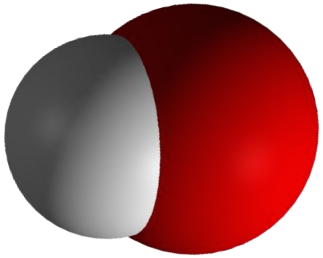
More accessible lone pairs are more nucleophilic.

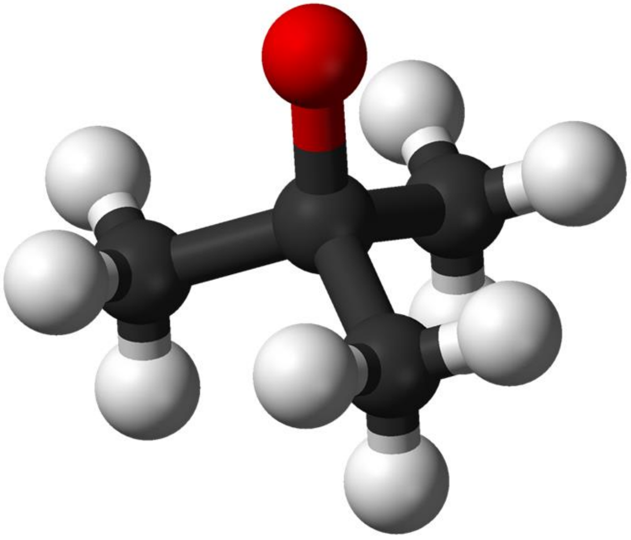




Hydroxide

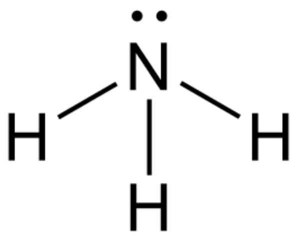
t-Butoxide



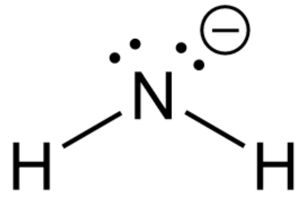


Problem 1

Is ammonia or the amide ion a stronger nucleophile? Explain.

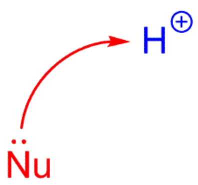


Ammonia

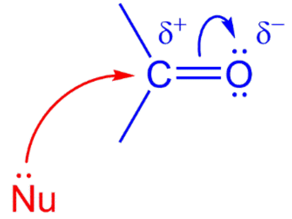


Amide Ion

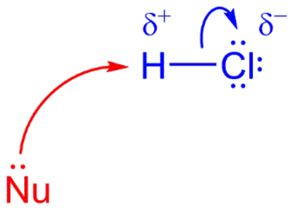
Electrophiles Have an Electropositive Atom



A positive charge
representing an
empty orbital



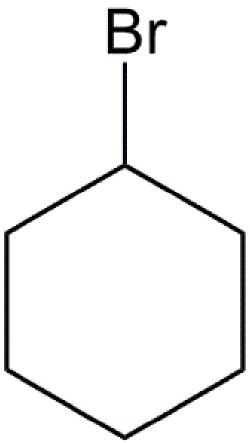
A double bond
to an electronegative
element

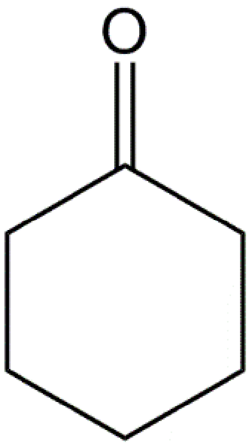


A single bond to
an electronegative element

Problem 2

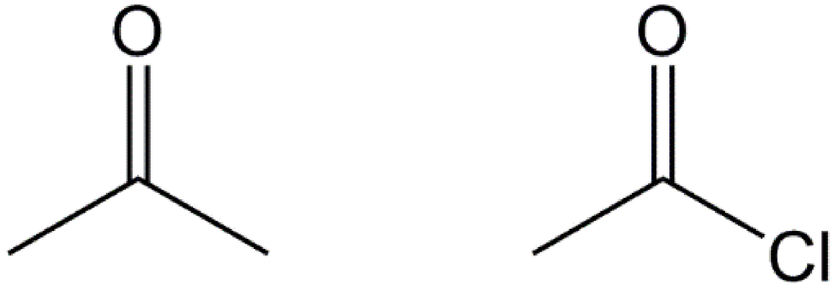
Identify the electrophilic atom in each of the following structures.





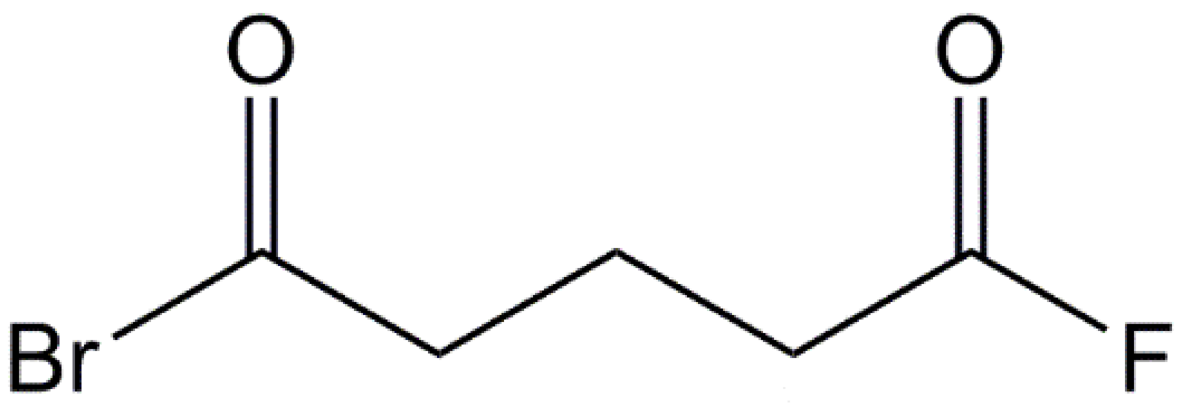
Problem 3

Which molecule is more electrophilic? Explain.



Problem 4

Identify the ***most*** electrophilic atom in the following molecule.

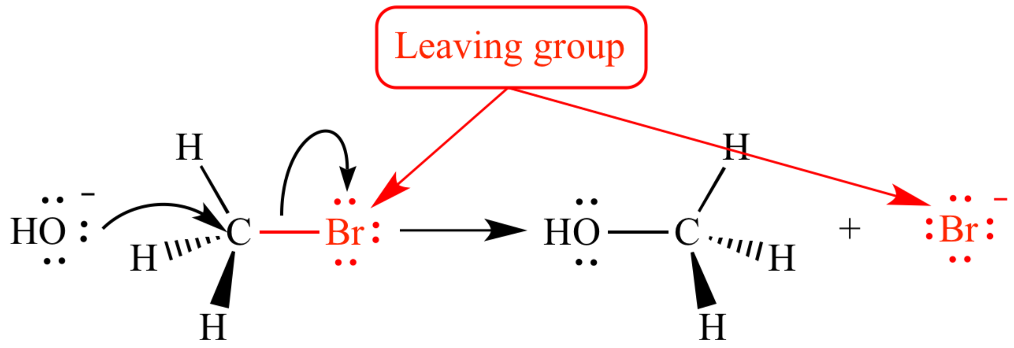


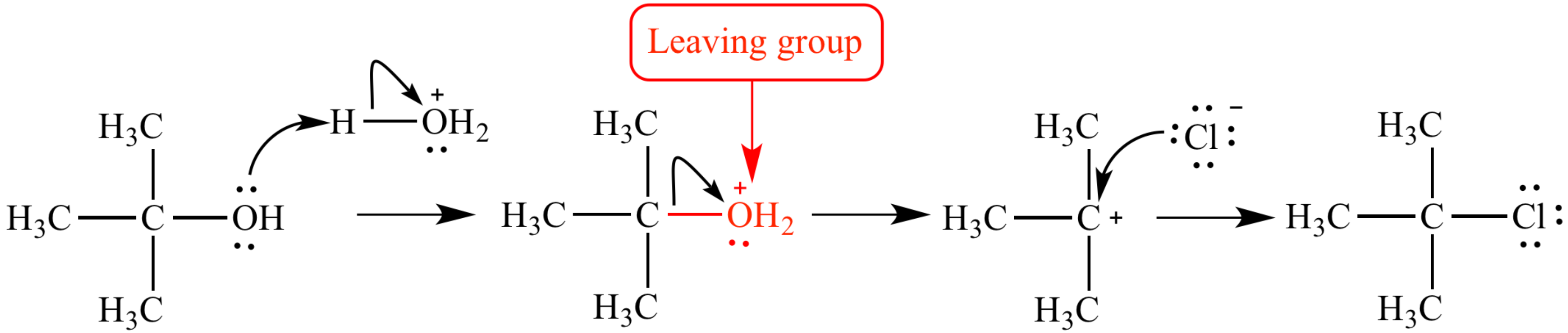
Leaving Groups

Leaving Group: An atom or group of atoms that breaks away from the rest of the molecule, taking with it the electron pair which used to be the bond between the leaving group and the rest of the molecule.

Good leaving groups will distribute negative charge well (i.e. they are relatively stable after leaving)

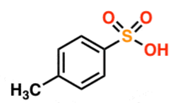
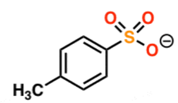
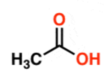
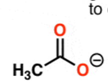
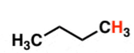
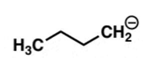
Leaving Group Examples





Better Leaving Groups are More Stable Species

A pK_a table is a handy guide to leaving groups

Functional group / Example		pKa	Conjugate base (Leaving group)	
Hydroiodic acid	HI	–10	$I^{\ominus}$	*Excellent leaving groups (extremely weak bases)*
Hydrobromic acid	HBr	–9	$Br^{\ominus}$	
Hydrochloric acid	HCl	–6	$Cl^{\ominus}$	
Sulfuric acid	H_2SO_4	–3	$HSO_4^{\ominus}$	
Sulfonic acids	 (tosic acid)	–3		
Hydronium ion	$H_3O^{\oplus}$	–1.7	H_2O	
Hydrofluoric acid	H–F	3.2	$F^{\ominus}$	**Exception:** $F^{\ominus}$ is typically an extremely poor leaving group (forms strong bonds to carbon)
Carboxylic acids		4		*Moderate leaving groups (weak bases)*
Protonated amines	$NH_4^{\oplus}$ $Cl^{\ominus}$	9-11	NH_3	
Water	HO–H	14	$HO^{\ominus}$	*Poor leaving groups (strong bases)*
Alcohols	CH_3O–H	16-18	$CH_3O^{\ominus}$	
Amine	NH_3	~35	$NH_2^{\ominus}$	*Extremely poor leaving groups (very strong bases)*
Hydrogen	H–H	42	$H^{\ominus}$	
Alkane		~50		

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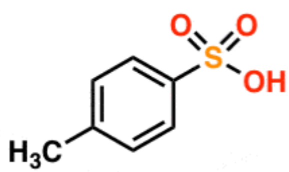
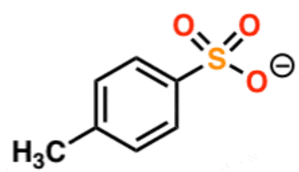
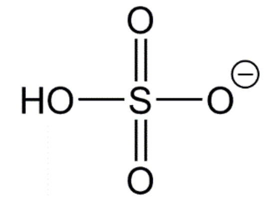
Sulfonic acids	 (tosic acid)	–3	
Hydronium ion	$H_3O^{\oplus}$	–1.7	H_2O

Excellent leaving groups (extremely weak bases)



Hydrogen Sulfate Ion

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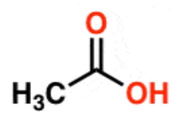
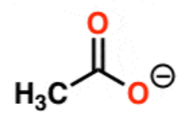
Carboxylic acids		4		***Moderate leaving groups (weak bases)***
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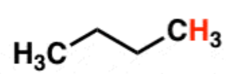
Alkane		~50