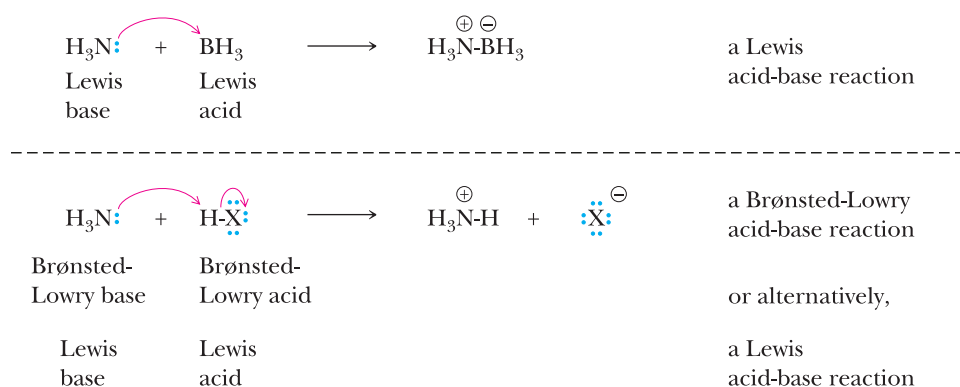


Things You Should Know II

Nucleophiles and Electrophiles

One of the unifying principles of organic chemistry is that molecules with electron-rich areas, generally lone pairs, or in many cases bonds, have characteristic patterns of reactivity. Similarly, molecules with electron-poor areas or weak bonds also have characteristic patterns of reactivity. Such electron-rich and electron-poor species are described by three different sets of terms. The following section is intended to clarify the confusion students often experience when they initially encounter these somewhat overlapping sets of terms.

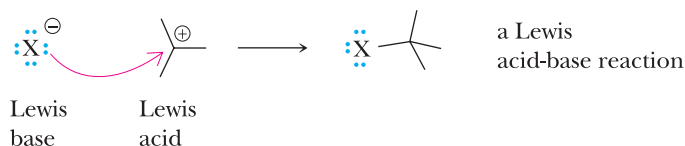
In the context of acid-base chemistry, Chapter 4 introduced Brønsted-Lowry and Lewis acid and base definitions. The Brønsted-Lowry definitions are restricted to proton transfers. For other reactions, chemists can refer to the reactants as being Lewis acids and bases (Section 4.7). Recall that a Lewis acid is a species that can accept an electron pair from a Lewis base by virtue of the fact that the Lewis acid has an empty orbital while the Lewis base has the electron pair. An exemplary case is the coordination of ammonia to borane (see below). Importantly, Section 4.5C showed that a Brønsted-Lowry acid, such as $\text{H}-\text{X}$, also has an empty orbital (i.e., the antibonding $\text{H}-\text{X}$ sigma orbital) that can accept a lone pair from a base, thereby breaking the $\text{H}-\text{X}$ bond leading to proton transfer. Thus, strictly speaking, a proton transfer reaction might *also* be classified as a Lewis acid-base reaction.



Clearly, then, the Lewis acid-base definition is broader—in fact, it is so broad that many chemists consider most reactions (excluding those involving radicals, Chapter 8) as falling under the definition of a Lewis acid-base interaction. However, in practice, most chemists commonly refer to Brønsted-Lowry acid-base reactions as proton transfers, and this is the terminology we will use throughout this book. In fact, from Chapter 6 onward, the Brønsted-Lowry base will commonly be an organic functional group, such as an alkene, alcohol, or ester. In writing reaction mechanisms, we will use terminology such as “add a proton” or “take a proton away” (see “Things You Should Know III” on Reaction Mechanisms immediately following this section) to describe proton transfers.

While the Lewis terminology is very broad, it is the most common way to describe a situation in which a new bond is created by electron-donation from the base to the acid without breaking other bonds and when the newly formed bond is dative. A **dative bond** (alternatively called a *coordinate covalent bond*, see Section 1.2F) occurs when the two electrons shared between the atoms derive from only one of the two reactants (in this case the Lewis base). The ammonia-borane interaction involves formation of a dative bond because it fits both criteria; the bond is created without breaking other bonds and the new bond is best thought of as having the two electrons coming from only the nitrogen atom of the ammonia.

Looking forward to Chapter 6, addition of a lone pair from a halogen ($X = F, Cl, Br, I$) to a carbocation might be considered to be a Lewis acid-base reaction. Once again, the bond is created without the breaking of other bonds and is formed solely from the addition of a lone pair from the halogen to the carbocation carbon. All chemists recognize this as a type of Lewis acid-base interaction, as we briefly mentioned in Section 4.7. Yet, a $C-X$ bond is not considered dative. Thus, as we describe below, while organic chemists might recognize this as a Lewis acid-base reaction, we have a different set of more specific terms that are more commonly used because the new bond being formed is not considered to be a dative bond.



Before looking at these new terms in detail, we need to explain why the $C-X$ bond is not dative. This can best be seen by considering Lewis dot structures. Recall that Lewis dot structures are generated from neutral groups for any molecule, independent of the chemical reactions that could create that molecule. In constructing a Lewis dot structure for H_3N-BH_3 from two neutral groups (NH_3 and BH_3), the two electrons in the $N-B$ bond arise from the nitrogen due to the electron count on ammonia (eight electrons) and borane (only six electrons). Hence, the $N-B$ bond is dative. However, for a $C-X$ bond, let's say in CH_3-Cl , the Lewis dot structure constructed from neutral groups would have seven electrons on $CH_3\cdot$ and seven coming from the chlorine atom ($Cl\cdot$), and thus the bond is considered to arise from a sharing of one electron from each group. Therefore, the $C-Cl$ bond is considered to be covalent, not dative.

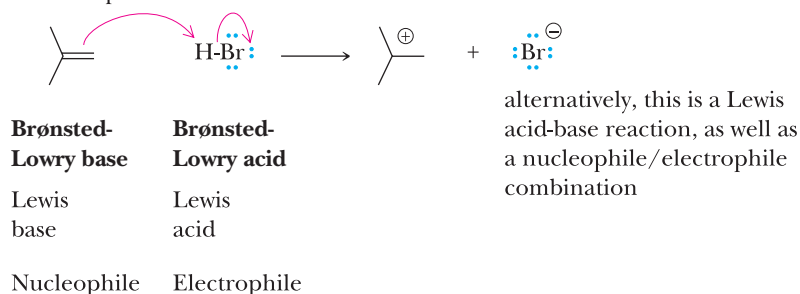
Nucleophiles and Electrophiles: A Comparison to Lewis and Brønsted-Lowry Definitions

When discussing reaction mechanisms in which a new covalent (as opposed to dative) bond is created and the reaction is not a proton transfer, a third set of terms is often used to describe the reactants. The electron-rich species is often referred to as the *nucleophile* and the electron deficient species as the *electrophile*. As we introduced

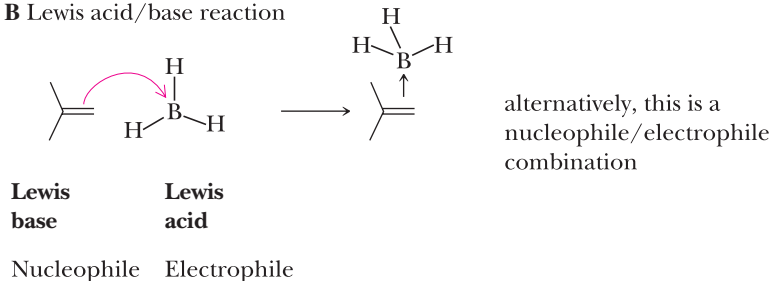
briefly in Chapter 4, nucleophile means, “nucleus loving,” or seeking positive charge. Electrophile means, “electron loving,” or seeking negative charge. Further, the region of the molecule that is electron rich, commonly a lone pair or a bond, will be referred to as nucleophilic. Analogously, the electron-poor region of a molecule, typically carrying a partial positive charge or a weak bond, will be referred to as electrophilic. Moreover, the relative reactivity of nucleophiles or electrophiles is referred to as the nucleophilicity or electrophilicity of the reactants, respectively. The above terms are commonly evoked for *polar reactions*, those involving reactions between full or partial negative charges with full or partial positive charges. In this book, we describe mechanistic steps that create new covalent bonds that are not proton transfers as “make a new bond between a nucleophile and electrophile” (the next “Things You Should Know III” section discusses this in detail).

The confusing part is that although the three sets of terms are distinct, they are overlapping and can be used somewhat interchangeably by chemists in certain situations. Let’s take a look at some examples of how the various terms are used in mechanisms that are coming up in Chapter 6. In example A, shown below, an alkene acts as a Brønsted-Lowry base, and thus we will refer to this as “add a proton,” even though some chemists might call it a reaction between Lewis acids and bases or electrophiles and nucleophiles. Because example B does not involve a proton transfer and the bond formed is dative, we will refer to this as a Lewis acid-base reaction. Here, the arrow between the π bond of the alkene and the boron signifies that the bond is dative. Note that some chemists might refer to this as a combination between a nucleophile and an electrophile, but we will not. Next, example C is a repetition of the one given in the discussion of Lewis interactions and dative bonds, but we can now appreciate that it is best described as “make a bond between a nucleophile and an electrophile” because a covalent bond is formed. Nevertheless, some chemists might refer to this as a Lewis acid-base reaction. Lastly, in example D the alkene is again acting as a nucleophile because it is donating electrons to the bromine molecule, which, in turn, must be considered the electrophile. (What makes molecules electrophilic is discussed in Chapter 6 and briefly below.) Once again, because the Lewis definition is so broad, this reaction could be considered a Lewis acid-base combination by some chemists. In this later example, a bond is also breaking to expel a stable ion (bromide).

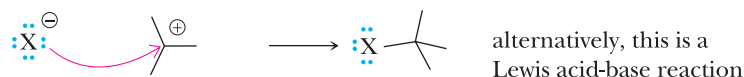
A “Add a proton”



B Lewis acid/base reaction



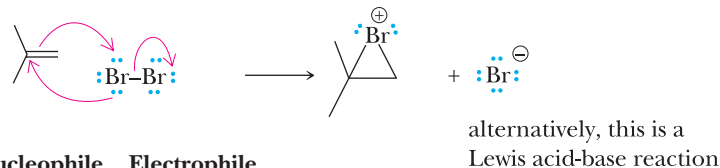
C “Make a bond between a nucleophile and an electrophile”



Nucleophile Electrophile

Lewis Lewis
base acid

D “Make a bond between a nucleophile and an electrophile”



Nucleophile Electrophile

Lewis Lewis
base acid

Although a full or partial negative charge, or alternatively a bond or lone pair, are all possible nucleophilic sites in a molecule, it is sometimes harder to recognize what makes a compound electrophilic. The most obvious is an empty orbital or a full/partial positive charge. Yet, weak bonds are also electrophilic. In the last example, Br_2 is the electrophile due to the relative weak $\text{Br}-\text{Br}$ bond. In actuality, there is a unifying principle in operation here. Weak bonds have low-energy empty antibonding orbitals that can accept electron density from a nucleophile. Hence, these bonds are also electrophilic due to an empty orbital. Filling this orbital leads to breakage of that bond.

In summary, we have classified three sets of related and sometimes overlapping terms to describe chemical reactions in which electron-rich regions of molecules react with electron-poor regions of molecules. Although having three overlapping sets of terms might seem confusing at first, the numerous examples laid out in every chapter of this book will clarify the terminology. As a starting point, it is best to keep the following in mind:

Although all these reactions can in some sense be considered Lewis acid-base combinations, those involving proton transfer are best referred to as Brønsted-Lowry reactions, those involving covalent bond formation are best referred to as combinations of nucleophiles and electrophiles and only those involving dative bond formation are best referred to as Lewis acid-base combinations.

Things You Should Know III

Reaction Mechanisms

Mastering reaction mechanisms is a critical step you must take to begin to understand, as opposed to simply memorize, chemical reactions in organic chemistry. Being able to rationalize reaction outcomes on the basis of a surprisingly small number of fundamental principles will provide you with the ability to group reactions according to common mechanisms and even predict reaction products for unfamiliar reactions. This section teaches you the formal notation used by chemists to describe chemical reaction mechanisms, shows you how to avoid making common mistakes, and presents the four fundamental mechanistic elements found in the majority of chemical reactions. This information is so important to your ultimate success in understanding organic chemistry that it was put in this format for special emphasis and easy reference.

A. Developing a Reaction Mechanism

To develop an understanding of a reaction mechanism, chemists begin by first using a combination of experience and intuition to propose several sets of steps, or mechanisms, each of which might account for the overall chemical transformation. Next, chemists test each proposed mechanism by designing and carrying out experiments that provide experimental observations that will allow them to exclude those mechanisms that are not consistent with the facts. Modern computational methods now allow detailed predictions of mechanistic pathways more accurately than ever before, but the results must still be compared with experiment for confirmation.

A mechanism becomes generally established by excluding reasonable alternatives and by showing that it is consistent with every test that can be devised. This, of course, does not mean that a generally accepted mechanism is a completely accurate description of the chemical events, only that it is the best mechanism chemists have been able to devise. It is important to keep in mind that as new experimental evidence is obtained, it may be necessary to modify a generally accepted mechanism or possibly even discard it in favor of an alternative.

Before we go on to consider reactions and reaction mechanisms, we might ask why chemists go to the trouble of establishing them and why you must spend time learning about them. One reason is very practical: mechanisms provide a framework within which to organize a great deal of descriptive chemistry. For example, with insight into how reagents add to particular alkenes, it is possible to generalize and then predict how the same reagents might add to other alkenes. A second reason lies in the intellectual

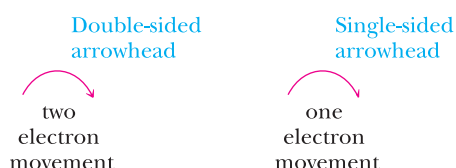
satisfaction derived from constructing models that accurately reflect the behavior of chemical systems. Finally, to a creative scientist, a mechanism is a tool to be used in the search for new information and new understanding. A mechanism consistent with all that is known about a reaction can be used to make predictions about chemical interactions as yet unexplored, and experiments can be designed to test these predictions. Thus, reaction mechanisms provide a way not only to organize knowledge but also to extend it.

B. The Correct Use of Arrows to Indicate Electron Movement

The ability to write an organic reaction mechanism properly is key to student success in organic chemistry classes. Organic chemists use a technique called **electron pushing** (sometimes called arrow pushing) to depict the flow or movement of electrons during chemical reactions. Arrow pushing helps chemists keep track of the way in which electrons and their associated atoms redistribute as bonds are made and broken. The first essential rule to keep in mind is the following:

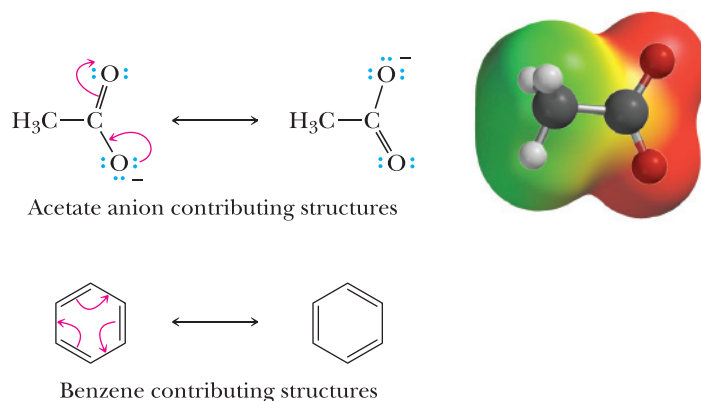
First Rule: Arrows are used to indicate movement of *electrons*.

A regular arrow (double-sided arrowhead) is used to indicate the movement of two electrons, while a line with a single-sided arrowhead (sometimes called a “fish hook arrow”) is used for single electron movement involved with radical reactions that are first described in Chapter 8.



The majority of reactions discussed in this book will involve movement of pairs of electrons. Hence, the mechanisms will be represented by double-sided arrowheads.

Arrow pushing was first introduced in Section 1.8A in the discussion of resonance contributing structures. Recall that in a comparison of two or more contributing structures, an arrow was used to show how two electrons (lines representing bonds or pairs of dots representing lone pairs) could be redistributed within a single chemical structure to create an alternative Lewis line structure representation of the bonding. By convention, arrows are used to keep track of *all* pairs of electrons that are in different locations in the two different contributing Lewis line structures, shown here for the acetate anion and benzene molecule.



Keep in mind that in the case of resonance, (1) the atoms do not move between contributing structures and (2) the electrons are not actually moving. The true chemical structure should be thought of as a hybrid of the contributing Lewis line structures. It is worth pointing out that when used with contributing structures, arrows generally

Electron pushing

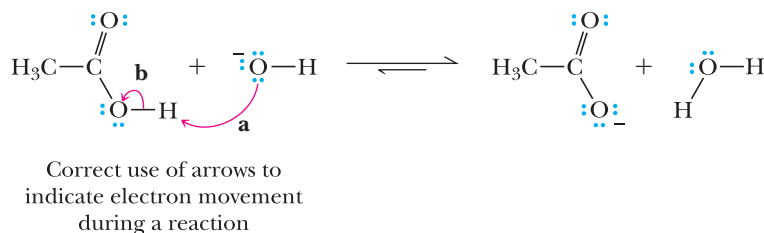
The use of arrows in organic chemistry mechanisms to indicate the flow or movement of electrons.

indicate only the interconversion of π bonds and lone pairs (acetate anion) or just π bonds (benzene), not the formation or breaking of σ bonds.

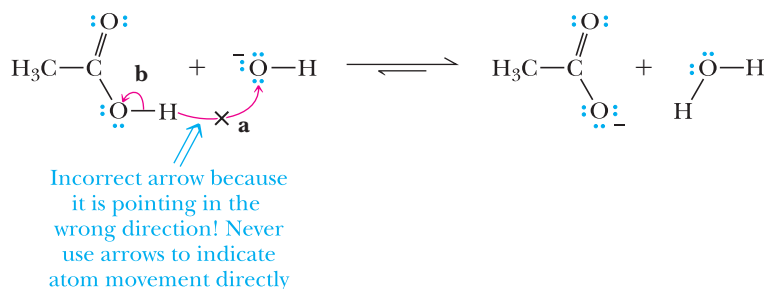
In chemical reactions, both electrons and atoms change positions as both π and σ bonds are formed and broken. Arrow pushing is used to keep track of the movement of all electrons involved with each step of the overall transformation. Because electrons are located in orbitals surrounding atoms, when bonds are formed or broken, the movement of electrons between orbitals is necessarily accompanied by the movement of the associated atoms, which leads to the second rule of arrow pushing when depicting chemical reaction mechanisms.

Second Rule: Arrows are never used to indicate the movement of atoms directly. The arrows only show atom movement indirectly as a consequence of electron movement when covalent bonds are made and broken.

We already used arrow pushing to show proton transfer several times in Chapter 4. The example below shows the transfer of a proton from the relatively acidic acetic acid molecule to the relatively basic hydroxide anion. We show this process with one arrow (labeled “a” in the diagram) that starts at a lone pair of electrons on the basic oxygen atom of the hydroxide anion and then points to the acidic H atom of acetic acid to indicate formation of the new bond being made. A second arrow originates at the line representing the breaking O—H bond and points to the O atom to denote creation of a lone pair (arrow “b”). In this reaction, the proton is being transferred between molecules, whereas the arrows indicate movement of the electrons involved.



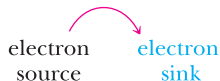
A common mistake for beginning students is to erroneously write an arrow pointing *from* the H of the acetic acid *to* the O atom of the hydroxide anion. This is wrong, because such an arrow would be indicating the H *atom* movement directly, not *electron* movement. Other common mistakes in arrow pushing are given in Things You Should Know IV.



C. Electron Sources and Sinks: How to Predict What Will Occur in an Organic Reaction Mechanism

We have now seen all three of the situations illustrated by arrows with double-sided arrowheads, namely the redistribution of π bonds and/or lone pairs, formation of a new σ bond (generally from a lone pair or π bond), and breaking of a σ bond (generally to form a new lone pair or sometimes a new π bond). Often, as in the case of the acetic acid–hydroxide ion reaction, more than one arrow is used in a given mechanism step. Now that you have seen all of the important types of arrows, we can point out their most important common feature.

Third Rule: Arrows always start at an **electron source** and end at an **electron sink**.



An **electron source** is a bond or a lone pair of electrons. It is most commonly a π bond or a lone pair on an atom of relatively high electron density or a σ bond that must break during a reaction. An **electron sink** is an atom on a molecule or an ion that can accept a new bond or lone pair of electrons.

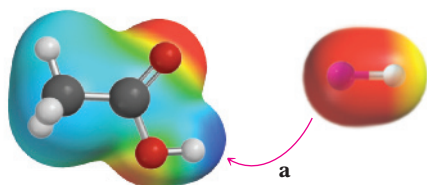
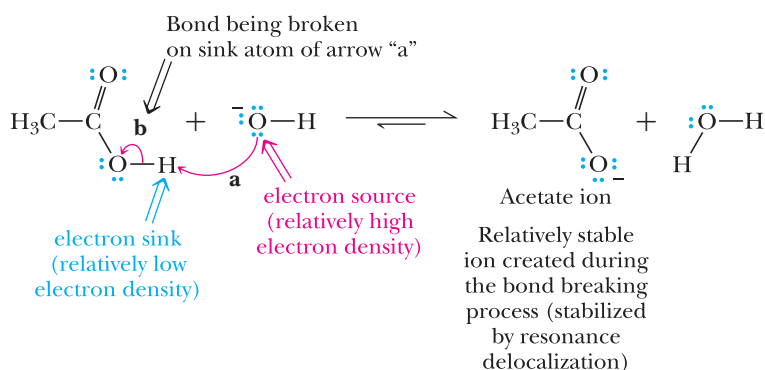
Learning to identify the characteristic sources and sinks in different functional groups is the key to learning organic chemistry reaction mechanisms. For example, for arrows that depict the formation of a new σ bond between two molecules, the electron source is often readily identified as being a lone pair on the most electron-rich atom of one molecule or ion and the electron sink is readily identified as the most electron-poor atom of the other molecule or ion. Thus, the prediction of many of the most important electron sources and sinks comes down to lessons concerning the differences in electronegativity between atoms that were presented in Section 1.2, which allow you to identify the most electron-rich and electron-poor atoms in molecules. As an aid to your analysis, the red and blue colors of the various electrostatic surface maps given throughout this book indicate the negative (electron-rich) and positive (electron-poor) regions of molecules. We will have more to say about this reactivity pattern a little later.

This leads us to another commonly encountered type of process that deserves mention. As you will see in many later chapters, making a new bond to an electron sink often requires the simultaneous breaking of one of the bonds present at the sink atom to avoid overfilling its valence orbitals, a situation referred to as hypervalence.

Fourth Rule: Bond breaking will occur to avoid overfilling valence (hypervalence) on an atom serving as an electron sink.

In these cases, the electron source for the arrow is the bond being broken and the sink is an atom able to accommodate the electrons as a lone pair, generally an electronegative atom such as an O atom or a halogen. If an ion is created, that ion is often stabilized by resonance delocalization or other stabilizing interactions.

Returning to the proton transfer reaction between acetic acid and hydroxide, we can now summarize our analysis of this simple one-step mechanism.



Considering the arrow used to make a new σ bond (arrow "a"), the hydroxide O atom is the electron source (most negatively charged atom) and the acetic acid H atom is the

Electron source

A bond or lone pair of electrons, usually an area of relatively high electron density, that serves as the origin of a mechanism arrow. An electron source characteristically interacts with an electron sink in an organic mechanism.

Electron sink

An atom that accepts a new bond or lone pair of electrons. An electron sink is what an arrow points toward in an organic chemistry mechanism.

electron sink (atom with highest partial positive charge). In the electrostatic molecular surfaces depicted above, the oxygen in the hydroxide ion has the greatest localized negative charge. This is indicated by the most intense red color. Meanwhile, the acetic acid proton being transferred has the largest positive charge, which is indicated by the most intense blue color. To avoid overfilling the valence of the H atom during the reaction the O—H bond of acetic acid must be broken (arrow “b”). In so doing, the acetate ion is formed. Note that the acetate ion is stabilized by resonance delocalization.

You should now appreciate that the transfer of a proton (a so-called Brønsted acid-base reaction) is really just a special case of the common pattern of reactivity between an electron source (the base) and the proton as an electron sink, combined with the breaking of a bond to satisfy valence and create a relatively stable ion.

The addition or removal of protons during chemical reactions is common and is often referred to as “adding a proton” or “taking a proton away.”

Meanwhile, a broader terminology is also applied to reactions in which new σ bonds form between electron-rich and electron-poor regions of molecules. **Nucleophiles** (meaning nucleus seeking) are molecules that have lone pairs or relatively electron-rich π bonds that act as electron sources for arrows making new bonds. **Electrophiles** (meaning electron seeking) are molecules with relatively electron-poor atoms that serve as sinks. Analogously, a molecule (or region of a molecule) that is a source for such an arrow is called nucleophilic, while a molecule or region of a molecule that is a sink for these arrows is referred to as being electrophilic. The term *nucleophile* is analogous to Lewis bases, and the term *electrophile* is analogous to Lewis acids. The choice of terminology depends on context. Nucleophile and electrophile are used more commonly in kinetics discussions, while Lewis acid and Lewis base are used in discussions of reaction thermodynamics.

It is helpful to summarize the appropriate use of key terms associated with arrow pushing and reaction mechanisms. The terms *source* and *sink* are used to identify the start and end, respectively, of each reaction mechanism arrow, which is indicating the change in location of electron pairs. The terms *nucleophile* and *electrophile* (as well as *Lewis base* and *Lewis acid*) are used to describe molecules based on their chemical reactivity and propensity to either donate or receive electrons when they interact. Protons can be thought of as a specific type of electrophile, and for reactions in which a proton is transferred, the nucleophile is called a base.

Nucleophile

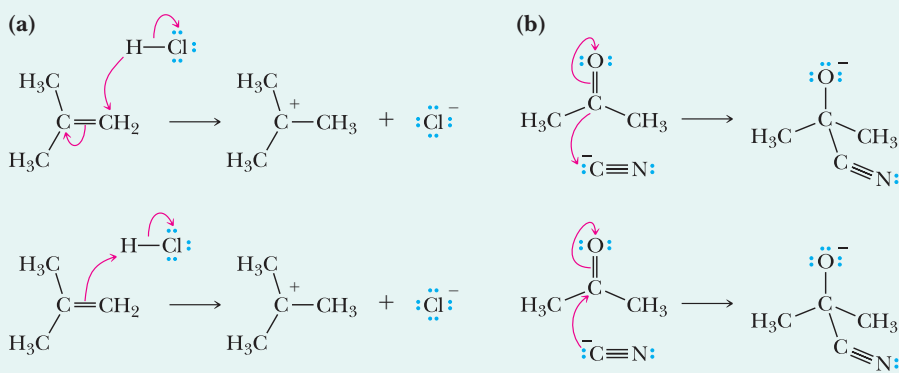
From the Greek meaning nucleus loving, seeking a region of low electron density. An electron source that can donate a pair of electrons to form a new covalent bond; alternatively, a Lewis base.

Electrophile

From the Greek meaning electron loving, seeking a region of high electron density. An electron sink that can accept a pair of electrons to form a new covalent bond; alternatively, a Lewis acid.

Example 1 Avoiding Arrow Pushing Mistakes I

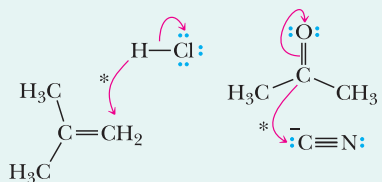
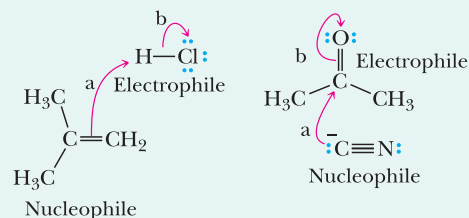
The following two sets of reactions [(a) and (b)] show possibilities for arrow pushing in individual reaction steps. Identify which is wrong and explain why. Then using arrow pushing correctly, label which molecule is the nucleophile and which is the electrophile.



Solution

In each case, the first arrow pushing scenario is wrong. The arrows shown below with stars over them do not start at a source of electrons; rather, they start

at positions of relative positive charge, which is incorrect. In the correct arrow pushing, the arrow labeled “a” depicts the interaction of a region of relatively high negative charge (a π -bond or lone pair) with an atom of relatively high partial positive charge on the other reactant. Therefore, the molecule acting as the source for the σ bond-forming arrow “a” is the nucleophile, while the molecule containing the sink atom is the electrophile.

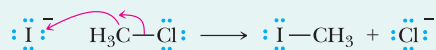
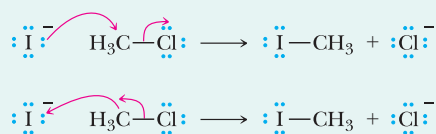
Incorrect**Correct**

The arrow labeled “b” is needed to satisfy valence and is not considered when defining the nucleophile and electrophile.

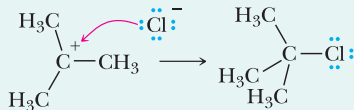
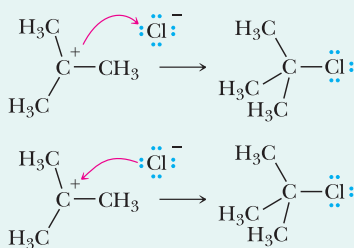
Example 2 Avoiding Arrow Pushing Mistakes II

The following two sets of reactions [(a) and (b)] show possibilities for arrow pushing in individual reaction steps. Identify which is wrong and explain why. Then using the correct arrow pushing, label which molecule is the nucleophile and which is the electrophile.

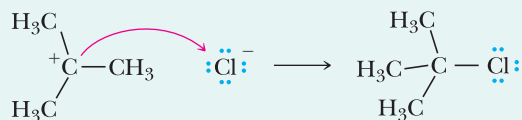
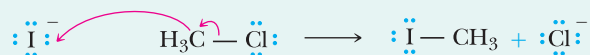
(a)



(b)

**Solution**

The incorrect scenarios have arrows pointing the wrong way, namely from electron sinks to electron sources.

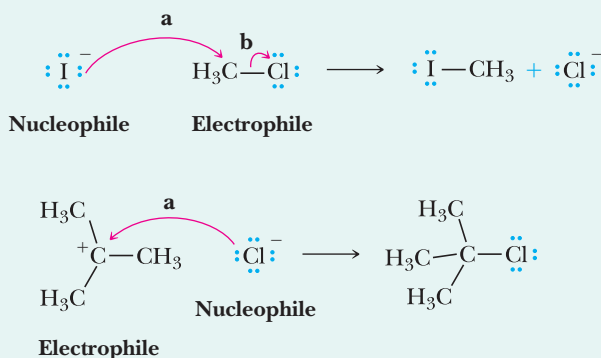
Incorrect

The correct scenarios have arrows pointing from electron sources, areas of relatively high electron density, to electron sinks, atoms of relatively low electron density. In each case, the arrows labeled “a” indicate a lone pair on the

(Continued)

halide anion (nucleophile) reacting with an electrophilic carbon atom, a carbon with a full or partial positive charge. The arrow labeled “b” on methyl chloride is needed to satisfy valence.

Correct



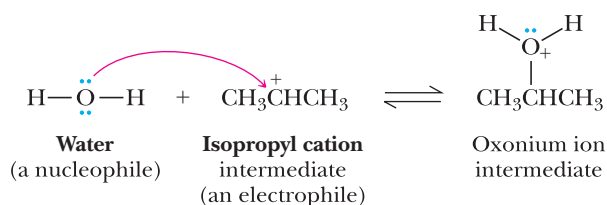
D. Putting it All Together: A Multiple-Choice Situation

In the sections and chapters that follow, many different reaction mechanisms will be described in a stepwise fashion. Each arrow can be classified according to one of the three overall situations we already encountered: (1) redistribution of π bonds and/or lone pairs, (2) formation of a new σ bond from a lone pair or π bond, and (3) breaking of a σ bond to give a new lone pair or π bond. When learning new mechanisms, focus on the overall transformation that takes place. It might be a reaction in which atoms or groups are added (an addition reaction), a reaction in which atoms or groups are removed (an elimination reaction), a reaction in which atoms or groups replace an atom or a group (a substitution reaction), or other processes we will encounter. Often, the overall process is composed of multiple steps. Once you have the overall process in mind, think about the individual steps that convert starting material(s) into product(s). Predicting complete multistep mechanisms, then, comes down to learning how to predict the individual steps.

Understanding, as opposed to memorizing, mechanisms is critical to mastering organic chemistry. Although the mechanisms you encounter throughout the course may seem different, they are actually related in fundamental ways. In fact, almost all of the organic reaction mechanisms you will learn are composed of only a few different individual elements (steps) that are put together in various combinations. Your job is to learn these individual mechanism elements and then understand how to assemble them into the steps of the correct mechanism for an overall reaction.

Fortunately, there are a surprisingly small number of different types of characteristic mechanism elements (patterns of arrows) to be considered when trying to predict individual steps of even complex chemical reactions. For this reason, you should view the prediction of each step in an organic mechanism as essentially a *multiple-choice* situation in which your most common choices are the following four:

1. **Make a new bond between a nucleophile (source for an arrow) and an electrophile (sink for an arrow).** Use this element when there is a nucleophile present in the solution as well as an electrophile suitable for reaction to occur.



-
- 2-Bromo-2-methylpropane**
- tert*-Butyl cation
 intermediate
 (stabilized by inductive
 and hyperconjugation
 effects. See Section 6.3A)
- Bromide ion**
 (relatively stable anion)

-
- $\text{H}_3\text{C}-\text{C}(=\text{O})-\ddot{\text{O}}-\text{CH}_2\text{CH}_3 + \text{H}-\overset{+}{\text{O}}(\text{H})_2 \rightleftharpoons \text{H}_3\text{C}-\text{C}(=\overset{+}{\text{O}}\text{H})-\ddot{\text{O}}-\text{CH}_2\text{CH}_3 + \text{H}_2\text{O}$
- Ethyl acetate** (a carboxylic ester) **Hydronium ion** (a strong acid) A protonated intermediate **Water**

- $$\begin{array}{ccccccc}
 \begin{array}{c} \text{H} \quad \text{H} \\ \diagdown \quad / \\ \text{O}^+ \\ | \\ \text{CH}_3\text{CHCH}_3 \end{array} & + & \begin{array}{c} \text{:}\ddot{\text{O}}\text{--H} \\ | \\ \text{H} \end{array} & \rightleftharpoons & \begin{array}{c} \text{HO}\text{:} \\ | \\ \text{CH}_3\text{CHCH}_3 \end{array} & + & \begin{array}{c} \text{H--}\ddot{\text{O}}^+\text{--H} \\ | \\ \text{H} \end{array} \\
 \text{Oxonium ion} & & \text{Water} & & \text{2-Propanol} & & \text{Hydronium ion} \\
 \text{intermediate} & & \text{(can act as a base)} & & & & \\
 \text{(strong acid)} & & & & & &
 \end{array}$$

When you are able to predict which of the common mechanistic elements is/are most appropriate for a given step in a mechanism, you will be able to push electrons correctly without relying on memorization. Moreover, you will have taken a major step toward mastering organic chemistry. Throughout the rest of this book, we will label each mechanistic step as one of the common ones when appropriate, emphasizing analogous features even between complex mechanisms.