

Organic Chemistry II

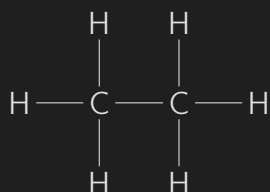
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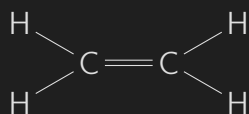
14: Alkenes

Alkenes Basics/Review

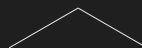
▷ Alkanes vs alkenes:



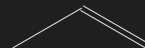
Saturated
alkanes ethane



Unsaturated
alkenes ethene



propane



propene

▷ We will fully investigate the nomenclature of alkenes ↗ later.

▷ Some relevant facts to start:

- **Alkene**: a hydrocarbon that contains a carbon-carbon double bond.
 - IUPAC recommends using alkene for only acyclic hydrocarbons with just one double bond; an **olefin** is a hydrocarbon with one or more double bonds.
- Generally prepared through beta elimination, which results in the formation of alkenes from alkanes.

Types of Alkenes

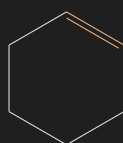
- Basic types of alkenes:



Terminal Alkene

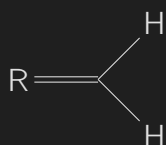


Internal Alkene

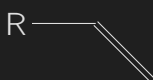


Cycloalkene

- Types of terminal alkenes:



Methylene



Vinyl

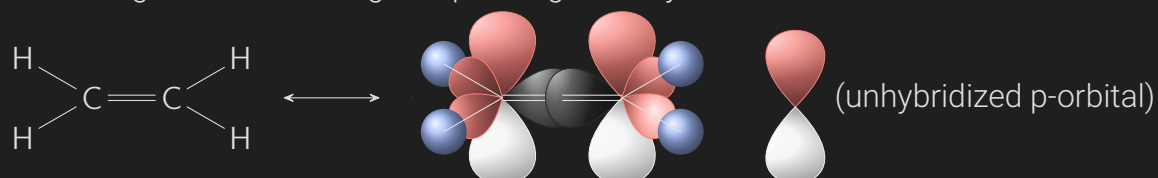


Allyl

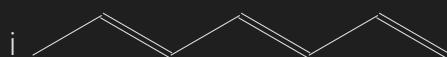
- "R" always tells you it's a carbon containing functional group, or hydrogen.
- "A" can be used to represent any functional group.

Relevant Review

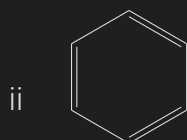
- **Electronegativity:** negative charges on atoms with lower hybridization result in greater stability due to proximity (overlap) to positive nucleus. More s character results in greater stability.
 - I.e., sp (50% s) > sp^2 (33% s) > sp^3 (25% s)
 - E.g., ethene has two carbons that are both sp^2 due to one unhybridized p-orbital. This gives ethene a trigonal planar geometry.



- **Hydrogen deficiency index (HDI):** the measure of degrees of unsaturation.
 - E.g., two degrees of unsaturation results in a HDI of 2.
 - Degrees of freedom help represent possible structures, indicating possible double bonds, triple bonds, rings, or various combinations of each.
 - Only helpful when molecular formula is known for certainty.
 - Formula: $HDI = \frac{1}{2}(2C + 2 + N - H - X)$
 - X: halogen atoms.
- What is the HDI for the following molecules?

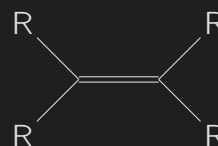
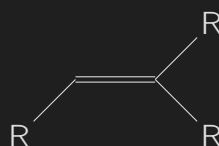


i $\frac{1}{2}(2(7) + 2 + (0) - (3 + (5(1)) + 2) - 0) = 3$



ii $\frac{1}{2}(2(6) + 2 + 0 - (6(1)) - 0) = 4$

- **Degree of substitution:** not a substitution reaction, but the number of groups connected to the double bond.



Monosubstituted

Disubstituted

Trisubstituted

Tetrasubstituted

Common Patterns Between Formal Charge and Lone Pairs

- **Associated Patterns for Oxygen**
 - A negative (\ominus) charge corresponds with 1 bond and 3 lone pairs.

- The absence of charge corresponds with 2 bonds and 2 lone pairs.
- A **positive** (\oplus) charge corresponds with 3 bonds and 1 lone pair.
- **Associated Patterns for Nitrogen**
 - A **negative** charge corresponds with 2 bonds and 2 lone pairs.
 - The absence of charge corresponds with 3 bonds and 1 lone pair.
 - A **positive** charge corresponds with 4 bonds and 0 lone pairs.

Chirality

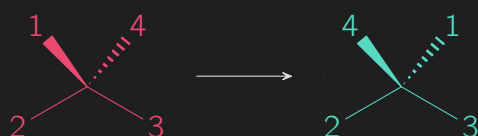
- **Achiral (nonsuperimposable)**: when an object's mirrored version is identical to the actual object.
- **Chiral**: objects that are not superimposable.
 - The most common source of molecular chirality is the presence of a **carbon bearing four different groups**.
- All three-dimensional objects can be classified as either chiral or achiral.
- **Enantiomer**: the nonsuperimposable mirror image of a chiral compound.
 - Can be used in speech the same way the word **twin** is used
 - The easiest way to draw enantiomers is to simply change wedges and dashes, but there are multiples ways to mirror a molecule, so it can be more complex.
- **Diastereomers**: non-identical stereoisomers (nonsuperimposable) that are **not mirror images** of one another.
 - Enantiomers have the same physical properties, while diastereomers have **different physical properties**.
 - Differences between enantiomers and diastereomers are especially relevant when comparing compounds with **more than one chiral center**.
 - **Maximum** (could be less) number of stereoisomers: 2^n
 - n : number of chiral centers
 - $\frac{2^n}{2}$: max pairs of enantiomers.

Cahn-Ingold-Prelog System

- **Cahn-Ingold-Prelog system**: a system of nomenclature for identifying each enantiomer individually.
 1. Assign priorities to each of the four groups based on atomic number; the highest atomic number has the highest priority.
 2. Rotate the molecule so that the fourth priority group is on a dash (behind)

3. Determine the configuration, i.e., sequence of 1–2–3 groups;
 - clockwise (*R*, *rectus*, right) or counterclockwise (*S*, *sinister*, left).
- If there is a tie between the atoms connected, then continue outward until a difference is found.
 - Do not add the sum all atomic numbers attached to each atom, just the first in which the atoms differ.
 - Any multiple bonded atom, (2 or 3) is treated as if connected to multiple atoms equal to number of bonds.

- Switching any two groups on a chiral center will invert the configuration, e.g.,



- Switching twice results in a change without changing configuration, e.g.,



- **Configuration in IUPAC nomenclature:**

- The configuration of the chiral center is indicated at the beginning of the name, italicized, and surrounded by parentheses.
- When multiple centers are present, then each must be preceded by a locant.

Rearrangements

- There are several kinds of rearrangements, but only those relating to carbocation rearrangements are focused here.
- **Hyperconjugation:** carbocations that can be stabilized by neighboring groups due to molecular orbitals that slightly overlap with empty *p* orbitals, placing some of its electron density there.
 - **Primary (1°), secondary (2°), and tertiary (3°):** refers to the number of groups directly attached to the carbocation.
 - Tertiary are the most stable (more slight overlap) and primary are the least (less overlap)
- **Hydride shift:** involves the migration of a H^- .
 - Involves the rearrangement of the carbocation to a more stable variant due to change migration of the H^- .

- **Methyl shift:** similar to a hydride, except a whole methyl group is migrated instead.
 - The methyl group must be attached to the carbon atom that is adjacent to the carbocation for this to occur.

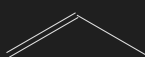
Nomenclature of Alkenes

Basic Alkene Nomenclature Rules

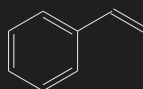
- Alkenes are named using the same four steps in the previously used nomenclature, though the suffix of "ane" is replaced with "ene."
- When choosing the parent chain, choose the parent chain that **includes** the double bond.
- When numbering the parent chain, the double bond should receive the **lowest** number possible.
 - Define the location k of the double bond as being the number of its first carbon.
 - The locant (k) of the double bond should be placed right before the suffix of "ene," though, it was previously recommended before the parent (both are acceptable), e.g., 2-pentene = pent-2-ene
- Name and the side groups (other than hydrogen) according to the appropriate rules.
- Define the position of each side group as the number of the chain carbon it is attached to.
- E-Z notation:** recommended instead of *cis* and *trans* in order to account for cases that has more than two different groups attached to the double bond by first determining the **CIP priority** ↗.
 - E**, *entgegen*, "opposite".
 - Z**, *zusammen*, "together"; "on ze same side."
- Commonly recognized alternative names:



Ethylene



Propylene



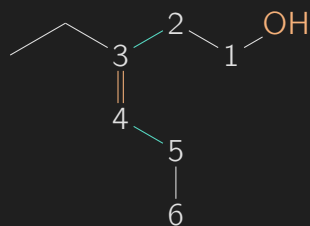
Styrene

- Groups containing C=C have common names as well, which can be found under **types of alkenes** ↗.

Alkenes Containing an Alcohol

- If there is **more than 1** functional group, then the **alcohol** has the **higher priority** over alkenes.
- There are more rules depending on functional groups, but for now the distinction between alcohol and alkenes are all that is needed.
- I.e., find the longest chain and number in a way that the carbon **containing the OH** gets the **lowest** possible number while still including both the OH and alkene.

- An example with alcohol:

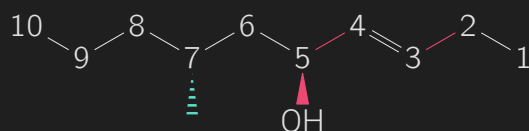


(3Z)-3-propyl-hex-3-en-1-ol

or

(3Z)-3-propyl-3-hexen-1-ol

- An example with OH still being lowest (name still ends with -ol), but alkene happens to be lower:



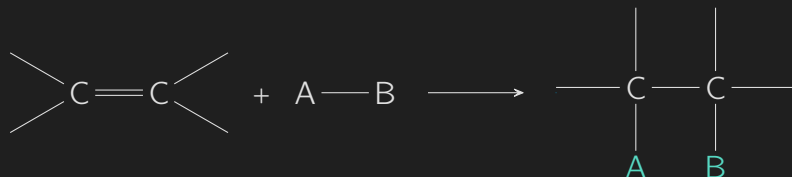
(3E,5S,7R)-4-methyl-3-en-5-ol

- Note: if planar geometry was not given, R and S could not be determined. Check out the [Cahn-Ingold-Prelog System](#) for review.

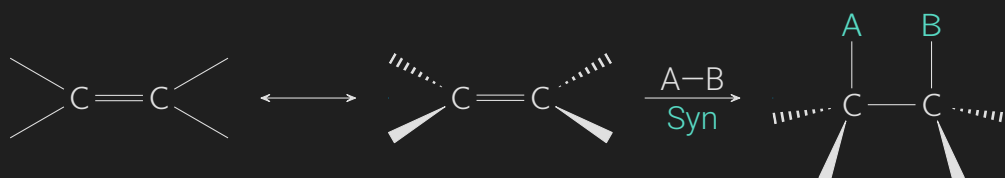
Addition Reactions of Alkenes

Syn Addition

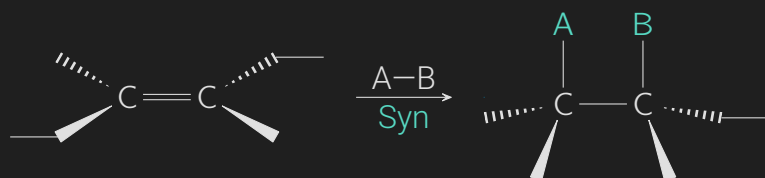
- Syn addition means that both components (A & B) came in from the same side.



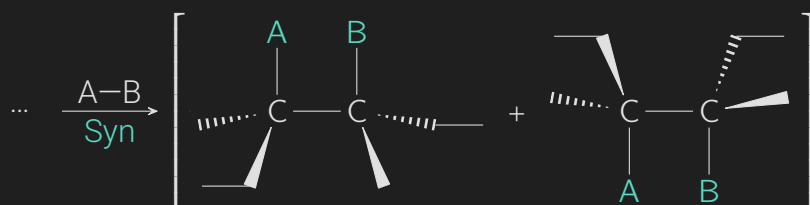
- When there is mixture of products, then the stereochemistry is important—A & B could come from different directions.
- Switching to a 3D perspective, with groups pointing towards and away from the viewer, rather than a flat view:



- The final product above results in no chiral compounds (no carbons contain four different groups). If a product does have chiral compounds, you must show the other possible products.

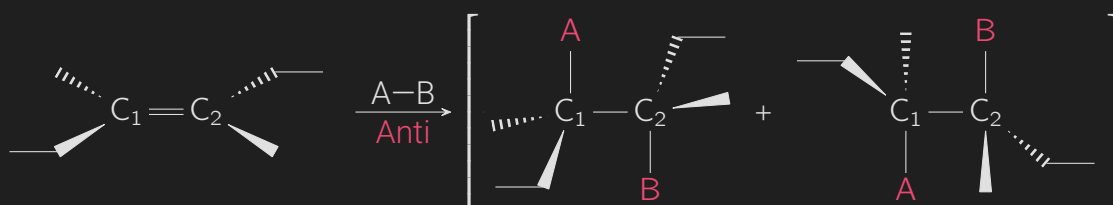


- The product in this case has **chiral centers**, so enantiomers must be considered.



Anti Addition

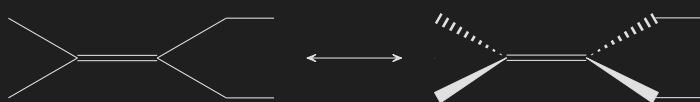
- Anti addition means that the added components come in from different sides.



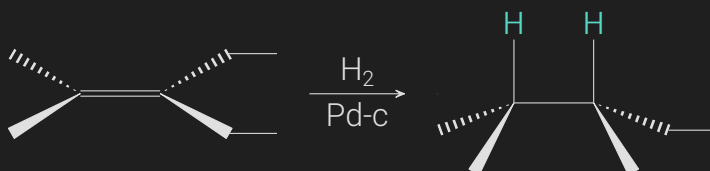
Hydrogenation

- **Hydrogenation:** a chemical reaction between molecular hydrogen H_2 and another compound or element, usually in the presence of a catalyst such as nickel, palladium (typically Pd , due to cost) or platinum.
 - Commonly employed to **reduce** (π bonds) or **saturate** (add hydrogens) organic compounds.
 - Usually constitutes the addition of pairs of hydrogen atoms to a molecule, often an alkene.
 - Catalysts are required for the reaction to be usable; non-catalytic hydrogenation takes place only at very high temperatures.
 - Always occurs with **syn addition**, with hydrogen entering from the least hindered side.
- Hydrogenation of 2-methyl-3-ethyl-2-pentene:

- First convert to 3D view:

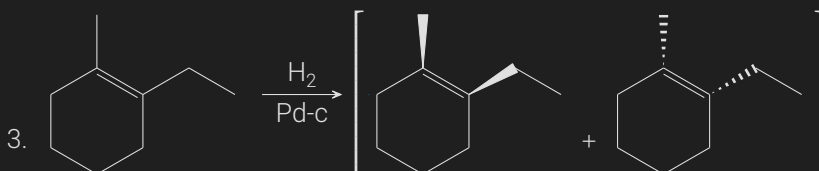
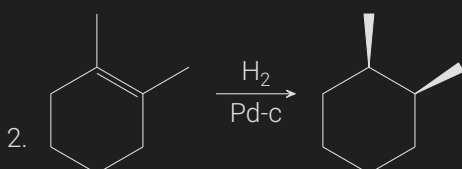
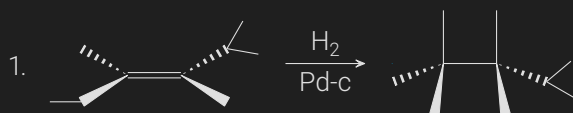


- Then apply H_2 with catalyst to trigger syn addition:



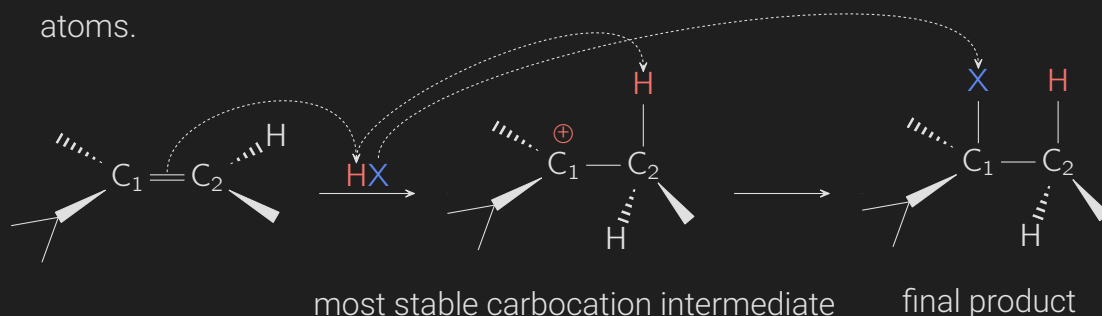
- Product is achiral; no enantiomers. Bottom would attack just flips the orientation; not a different product.

Hydrogenation Practice Problems

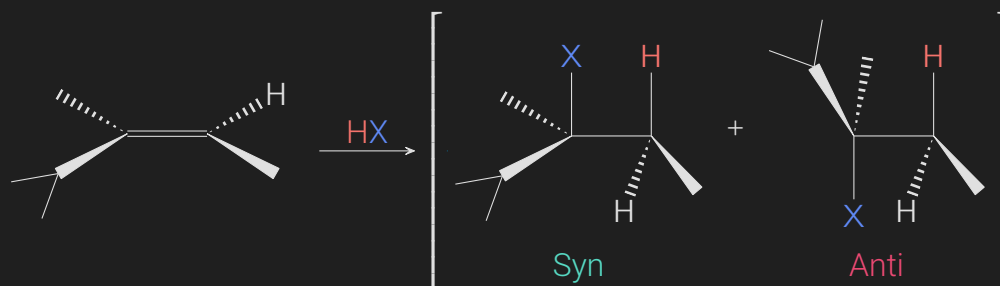


Hydrohalogenation

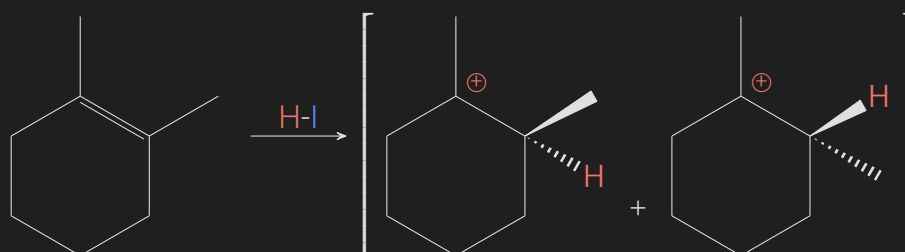
- **Hydrohalogenation:** the electrophilic addition ($\pi \rightarrow 2\sigma$ bonds) of hydrohalic acids (HX, e.g., HCl or HBr) to alkenes to yield the corresponding haloalkanes.
- **Markovnikov's Rule:** an addition of a protic acid (HX) or other polar reagent to an asymmetric alkene results in the **electropositive part (usually H)** gets attached to the carbon with **more hydrogen substituents**, and the **electronegative part (usually the halide)** attaches to the carbon with **more alkyl substituents**.
 - Alternatively: H^+ is added to the carbon with the **greatest** number of hydrogen atoms while the X^- **component** is added to the carbon with the **fewest** hydrogen atoms.



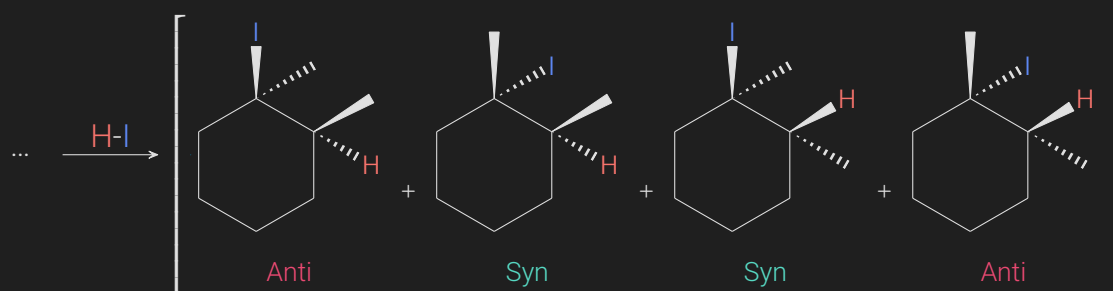
- However, we have a chiral carbon, so we have to take enantiomers into account:



- The previous example is an example of a regioselective reaction, i.e., it's a chemical reaction where one reaction site is preferred over another.
 - Markovnikov additions are common examples of regioselective reactions since there is a specific region in where the hydrogen is supposed to go.
- Another example that contains multiple products:

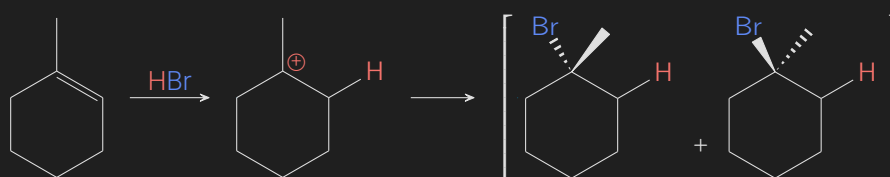


- Again, this first step shows the most stable carbocation intermediate, which helps determine where the H^+ will attach to. In this case either location works, so four products are formed, each with syn and anti enantiomers.



- The above products are all **stereoisomers** of each other. Note: not all chemical reactions produce all possible stereoisomers.

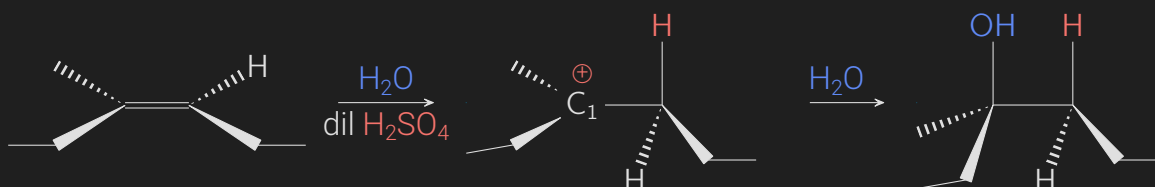
Hydrohalogenation Practice Examples



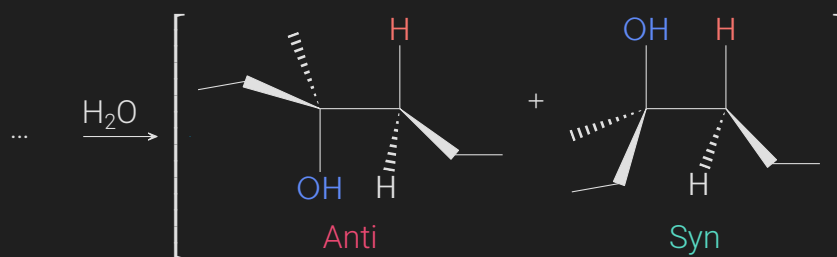
Addition of Water or Alcohol

Addition of Water or Alcohol (ROH): analogous to that of hydrohalogenation (HX); both of which involve a carbocation intermediate, syn/anti stereochemistry, and Markovnikov regioselectivity.

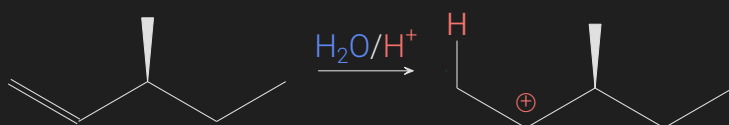
- Note: the hydronium ion (H_3O^+) forms via the reaction of H_2SO_4 with H_2O , and is the source of the proton that reacts with the starting alkene.
- $\text{H}-\text{OH}$ and $\text{RO}-\text{H}$ helps to visualize where the proton is coming from. What ever works with water also works with alcohol and vice versa.
- An example that is very similar to the example from **hydrohalogenation** \nearrow :



- Note: H_2SO_4 is a **strong acid** and can be generalized to H^+ or HA .
- Note: I occasionally use **red** for **cations**, **acids**, and E^+ (electrophile). I also use **blue** for **anions**, **bases**, and nu^- (nucleophile) to help easily keep track of things. This is an arbitrary color choice, but it holds weight in these notes. However, not all bases/acids are nucleophile/electrophiles, so keep that in mind.
- Again, this reaction is stereoselective, so there is actually more than one product:

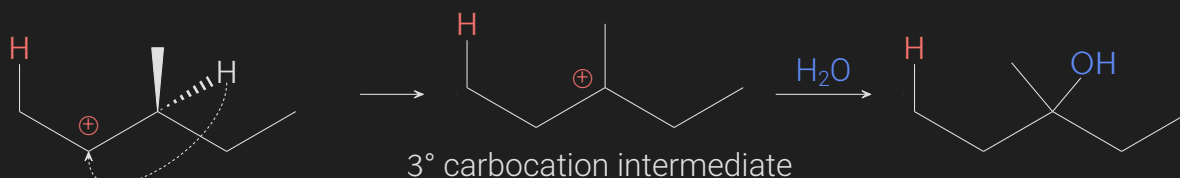


- Example 2:

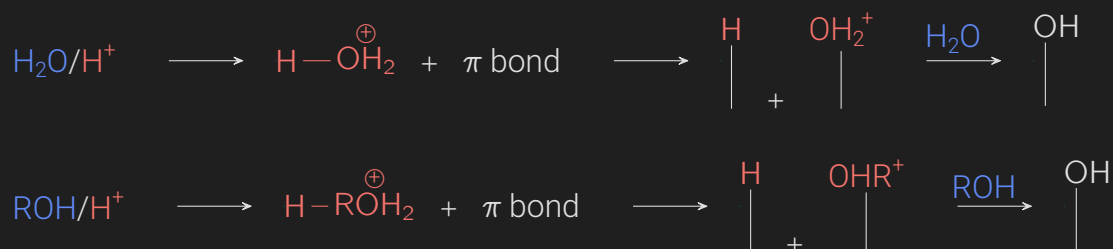


- **Rearrangement** \rightarrow is always a possibility to be considered when cation are generated. In this case, a 2° carbocation was generated, but we can do better:

- Note: showing H is not necessary, but useful to visualize the hydride shift and avoid the urge to move the methyl. "Why move a sofa when you can move a chair?"



- Note: the carbocation intermediate changes planar geometry due to change in hybridization ($sp^3 \rightarrow sp^2$).
- Top and bottom attacks do not need to be considered in this case, as there are chiral centers; no enantiomers.
- Reminder, H_2O and alcohols (ROH) behave very similarly; the reduction of the π bond generates 2 σ bonds, one of which that takes a **hydrogen**, and the other (with possible carbocation rearrangement first) which first takes up the **cation** generated in the medium, then interacts with **base**, removing an **H** and leaving **OH**.
- Note: the OH is not actually negatively charged on the end, I just keep the blue there to help show where it's coming from; it helps determine syn/anti if needed.



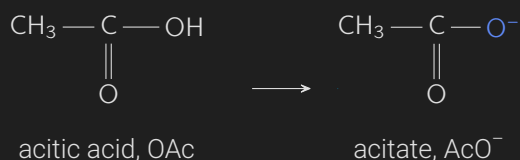
- **Problems of going through carbocation intermediate:**

- Carbocations are sp^2 , which makes them trigonal planar, so nu^- can attack from top or bottom.

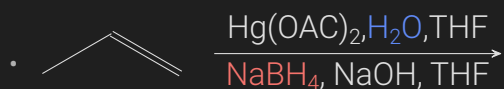
- C^+ can cause rearrangements leading to **multiple products**.

Oxymercuration-Demercuration

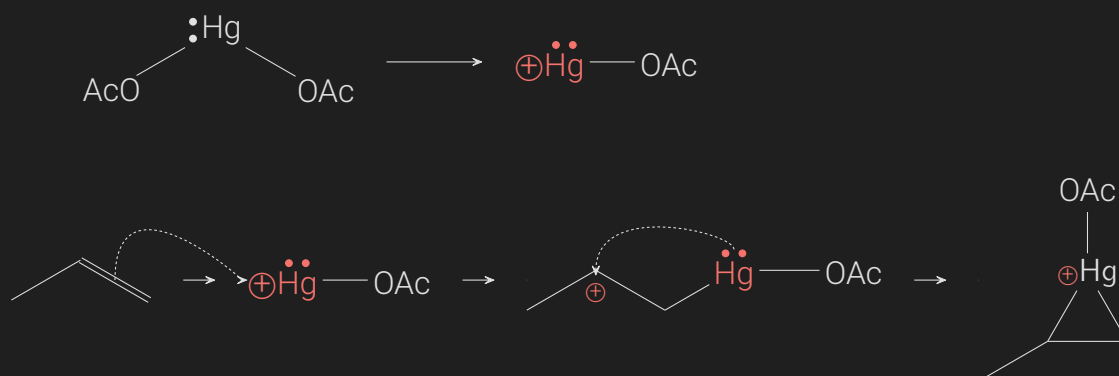
- **Oxymercuration-Demercuration** is another electrophilic addition organic reaction that transforms an alkene into a neutral alcohol.
- Reacts with mercuric acetate ($AcO-Hg-OAc$) in aqueous solution to yield the addition of an acetoxymcury ($HgOAc$) group and a hydroxy (OH) group across the double bond.



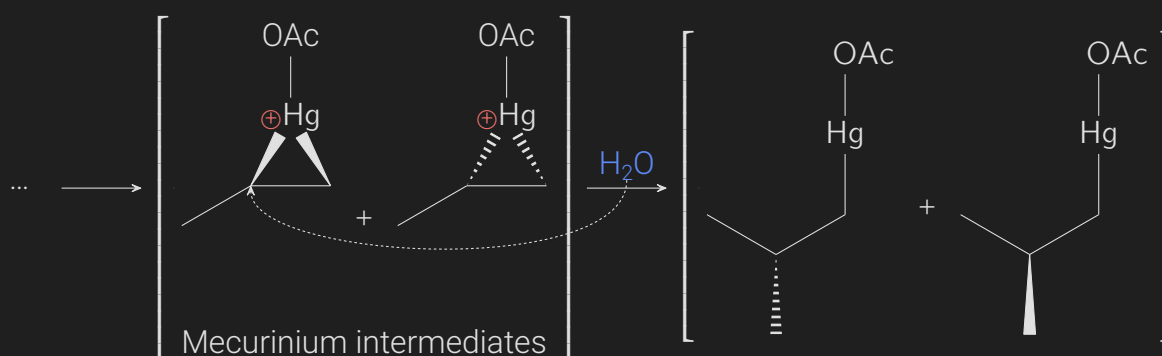
- Carbocations are not formed in this process and thus rearrangements are not observed.
- The reaction follows **Markovnikov's rule**.
- The reaction is stereospecific—it is always an **anti addition**.
- Example using propylene:



- H_2O is nu^- ; ROH can be used instead.
- THF has no function directly; it is the solvent.
- $NaBH_4$ is the reducing agent.

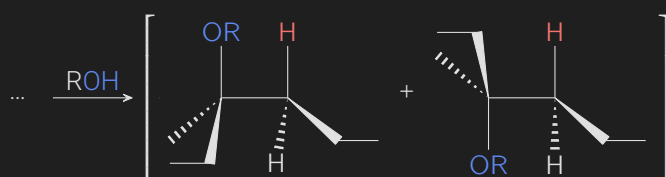
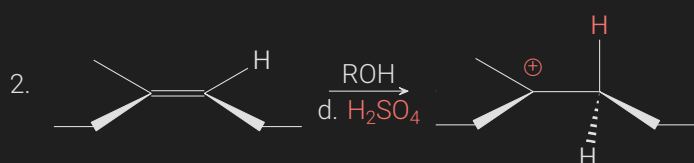


- Note: the above is a concerted (one step) process, but drawn out for illustration.
- Also, we are not done, we have a chiral center that forms, plus it is just an intermediate step, a nucleophilic attack will occur on the strained (highly reactive) epoxide:

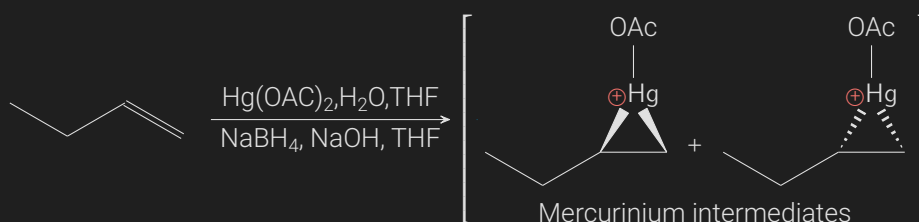


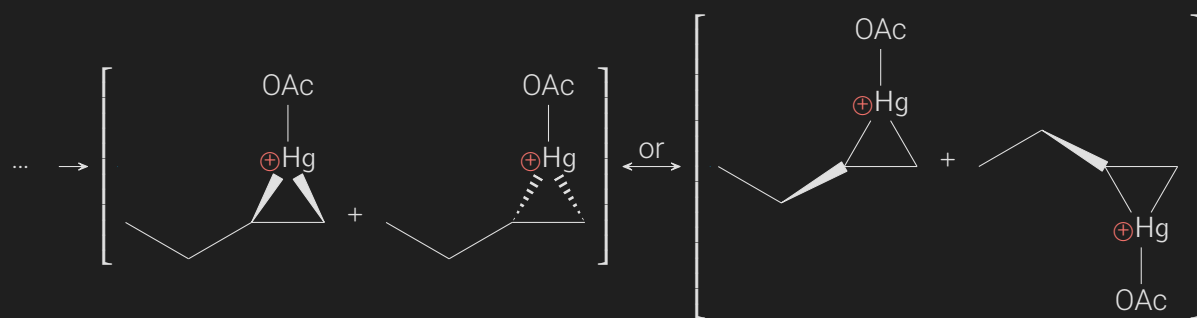
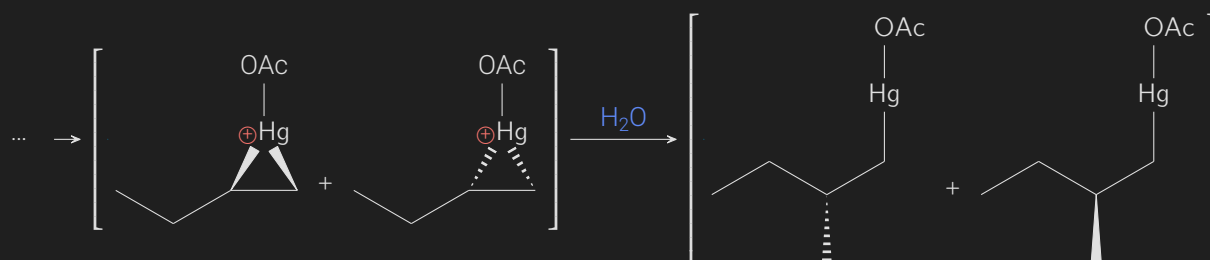
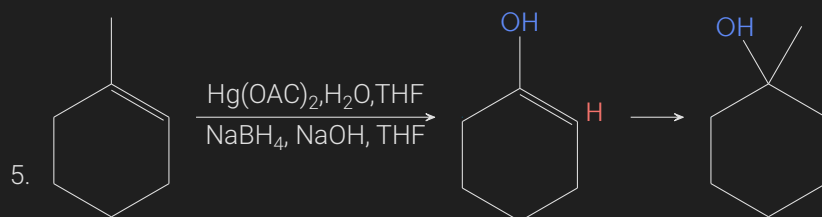
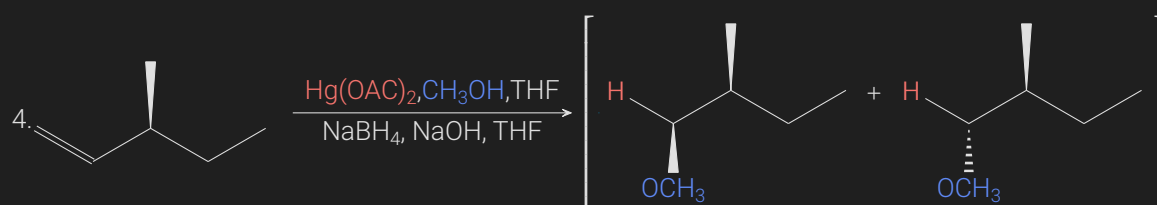
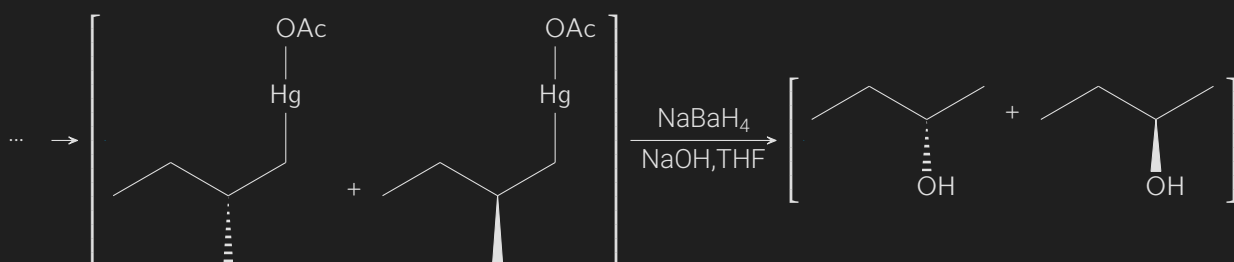
- Notice the nucleophile attack the carbon with the greater flow of electrons (more substituted), since there was a positive charge on mercury. Epoxides with no charge are attacked on the side with less steric hindrance.
- Also, the nucleophilic attack occurs on the opposite side of the plane since there is less hindrance on that side.

Related Practice Problems

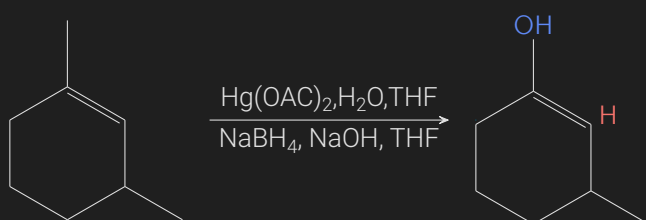


3. + Alternate ways of drawing rings (was done in lecture):

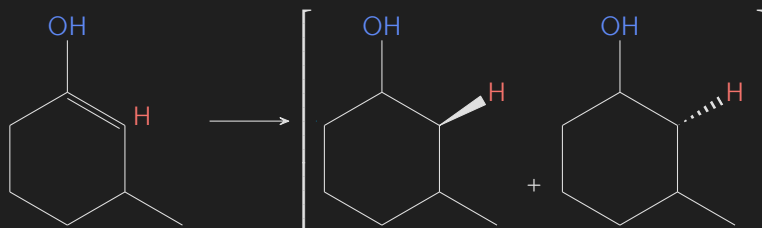


**Oxymercuration:****Demercuration:**

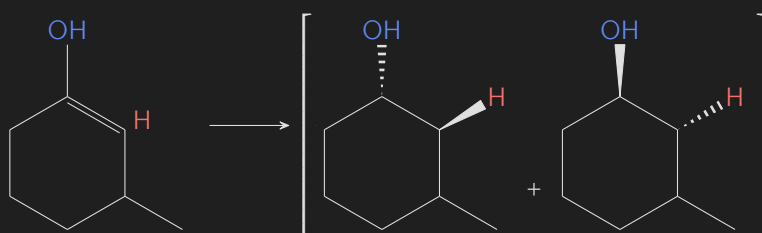
6. (was done in lecture)



- We know these are the locations of the H and OH, so we can start by labeling them.



- The methyl will be the same no matter what, so we can ignore that.
- H has two options, which gives us the above.
- Since oxymercuration-demercuration is always an **anti addition**, then we know OH must be **anti** to the hydrogen in both of the products:

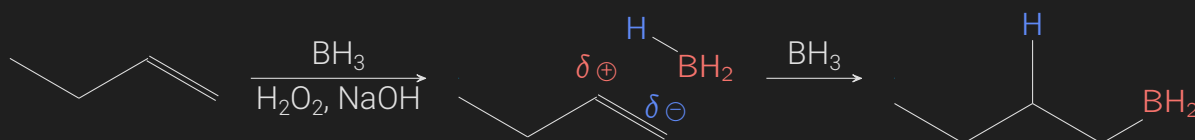


Hydroboration-Oxidation

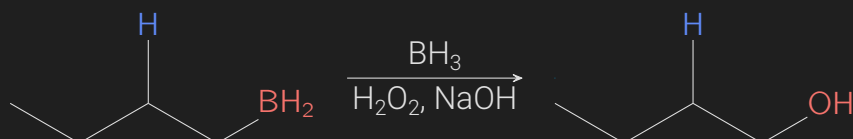
- Hydroboration-Oxidation:** a two-step hydration reaction that converts an alkene into an alcohol.
 - Results in the **syn addition** of a hydrogen and a hydroxyl group where the double bond had been.
 - An **anti-Markovnikov reaction**—the hydroxyl group attaches to the less-substituted carbon.
 - Provides a more stereospecific and complementary regiochemical alternative to other hydration reactions such as acid-catalyzed addition (stereoselective) and oxymercuration-demercuration (stereospecific for anti).
 - Usually BH_3 , B_2H_6 , R_2BH are used. The presence of Boron is key.
- Like H_2O and ROH , it's useful to think of them in the following way:



- Unlike water/alcohol, the hydrogen is now the partial negative component and the boron is the positive.



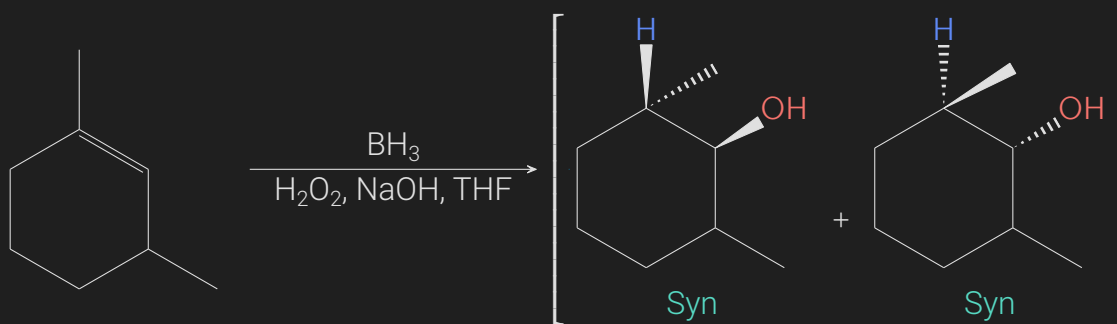
- There are no chiral centers, but there is still one more step—the oxidation:



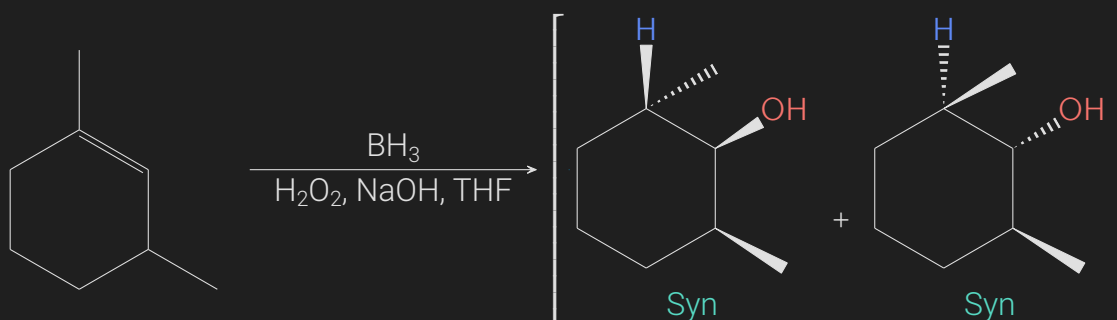
- If we had used $\text{Hg}(\text{OAc})_2$, then the above reaction would be different; partial charges change the possible final products: $\overset{\delta^-}{\text{H}}-\overset{\delta^+}{\text{BH}_2}$ vs. $\overset{\delta^+}{\text{H}}-\overset{\delta^-}{\text{OH}_2}$:



- Revisiting a practice example, using different reagents:

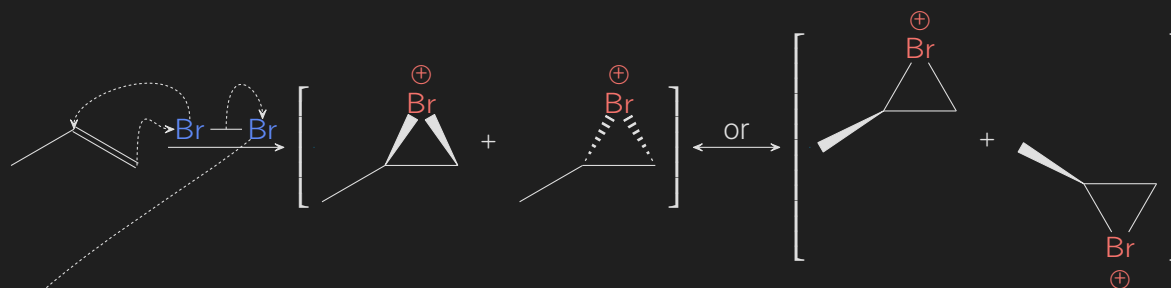


- If the untouched methyl happened to be above or below the plane initially, then you would keep that the same, e.g:

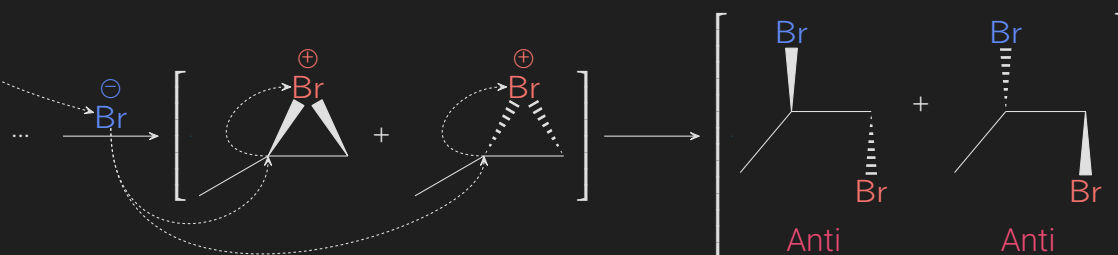


Halogenation

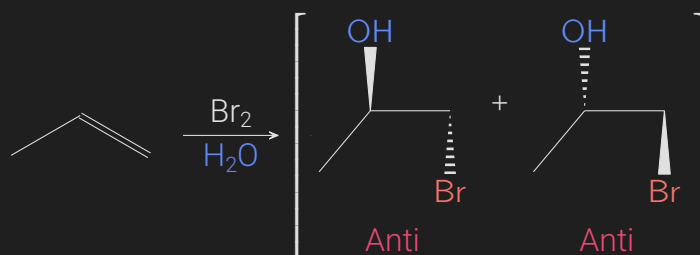
- Halogenation:** a reaction that involves the addition of one or more halogens to a compound or material.
 - The addition of halogens to alkenes proceeds via intermediate halonium ions.
 - Halonium ion:** any onium ion containing a halogen atom carrying a positive charge. This cation has the general structure: $\text{R}-\text{X}^+-\text{R}'$
 - Onium ion:** a cation formally obtained by the protonation of mononuclear parent hydride of a pnictogen (group 15 of the periodic table), chalcogen (group 16), or halogen (group 17).



- In the above example we see a cyclic bromonium ion intermediate being formed. Next, one bromine is now left to act as the nu^\ominus :



- Alternatively, if you did the reaction in H_2O , then water would become the dominant nu^\ominus , leaving OH.



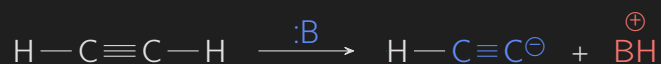
15: Alkynes

Alkynes Basics/Review

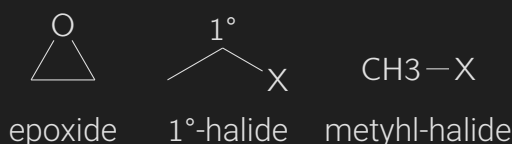
- ▷ **Alkynes**: an unsaturated hydrocarbon containing at least one carbon—carbon triple bond.
 - Contains two unhybridized p-orbitals (sp) on each carbon.
- $$\begin{array}{ccccccc} \delta+ & \delta- & \delta- & \delta+ \\ \text{H} & -\text{C} & \equiv & \text{C}-\text{H} \end{array}$$
- Large amount of s character (sp: 50% s) makes the hydrogens very acidic and the carbons very basic.
 - 1 mole of base takes off 1 hydrogen (1 equivalent, equiv, eq), which can be done twice to take off both (2 equivalent).
 - Traditionally known as acetylenes, though acetylene refers specifically to C₂H₂ (ethyne)

Acetylides

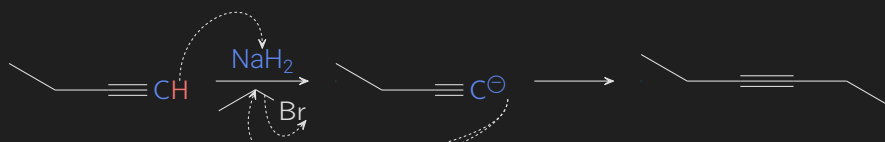
- ▷ **Acetylide**: an alkyne with a negatively charged carbon on one end, e.g.,



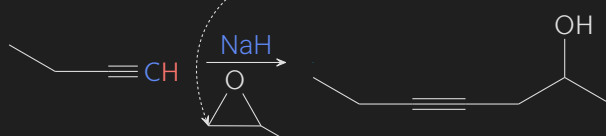
- :B is a name of generic base, typical bases used:
 - NaNH₂ → sodamide, or NaH → sodium hydride.
- Acetylide acts as a **nucleophile** when it reacts with an epoxide, 1°-halide, or a methyl-halide.



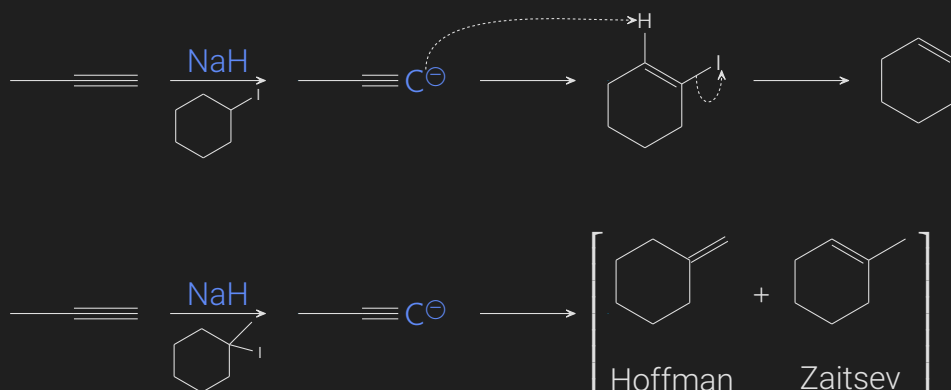
- Is a S_N2 reaction.
- Can be used for chain extension, e.g.,



- Example two:



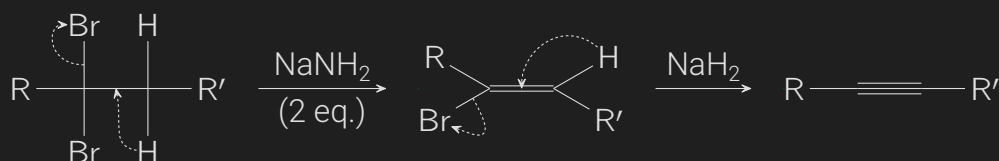
- Acetylide acts as a **base** when it reacts with 2°-halide or a 3°-halide due to steric crowding.
 - Is an E2 reaction.



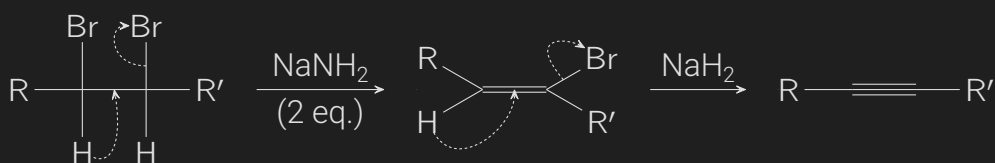
- The Zaitsev product is more likely to be the major product due to the thermodynamics (more energetically stable) than the Hofmann product; a bulkier base would likely increase the Hofmann product.

Preparation of Alkynes

- Introductory example of a geminal dihalide going through two E2 reactions to generate an alkyne:



- Related example with a vicinal dihalide (halide on adjacent carbons):



Regioselectivity and Stereospecificity of E2 Reactions

- **Regiochemistry**: when a chemical reaction is said to produce two different regiochemical outcomes.
 - **Regiochemical**: preference of chemical bonding or breaking **direction**.
- **Regioselective**: when there is a preference in products of a regiochemical reaction.
- **Zaitsev product**: name of the **more substituted** alkene that is generally observed to be the major product.
- **Hofmann product**: name of the **less substituted** alkene.

- There ratio between the Zaitsev and Hofmann product is dependent on a number of factors and often difficult to predict.
 - Steric hindrance of the base often plays a major role, often increasing the Hofmann product.
 - The outcome of E2 reactions can often be carefully **controlled by choosing the base**, despite difficulty in overall prediction.
- **Stereospecific**: when the stereoisomeric product of the E2 process depends on the configuration of the starting stereoisomeric substrate.
 - The stereospecificity is only relevant when the **β position has only one proton**.
- **Stereoselective**: when the substrate itself is not necessarily stereoisomeric, but can yield two stereoisomeric products, one of which that often has a higher yield.
 - Occurs when there are **more than one proton in the β position**.
- **Coplanar**: when the proton in the β position, the leaving group, and the two carbons atoms that form a double bond lie on the same plane.
 - Often leads only one stereoisomer product being formed, thus more often stereospecific.
 - If it stereoselective, then usually *trans* conformation is favored.
 - **Periplanar**: when the proton and leaving group are **nearly coplanar**; often is used in place of coplanar to incorporate both situations.
- **Syn-coplanar**: when the proton and the leaving group are **eclipsed** in a coplanar conformation.
 - Elimination in this state involves a higher energy transition state due to eclipsed geometry, and is **slower** than anti-coplanar arrangement.
- **Anti-coplanar**: when the proton and the leaving group are **staggered** in a coplanar conformation.
 - Elimination in this state involves a lower energy transition state due to staggered geometry, leading to a **faster** reaction relative to syn-coplanar.

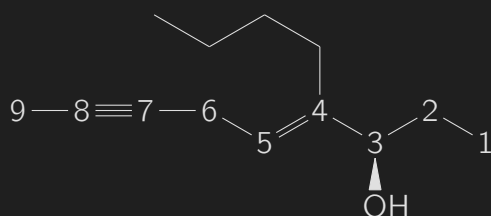
Alkyne Nomenclature

Basic Alkyne Nomenclature

- All other basic IUPAC rules still apply; the suffix is "yne".
- Find the longest carbon chain that includes both carbons of the triple bond.
- Number the longest chain starting at the end closest to the triple bond.
- Compounds with > 1 triple bond are called diynes, triynes, etc.
- Enynes are compounds that contain both double and triple bonds, and enynols also contain an alcohol.
- The functional groups have their assigned carbon numbers written directly before their name.

Priority Rules

- More functional groups will change the as we get introduced to more, but for now we only need to know the following (somewhat follows electronegativity):
 1. Alcohol
 2. Alkenes
 3. Alkynes
 4. Alkyls
 5. Halogens
- Preference for naming order if multiple functional groups are present in the same chain: OH + DB + TB > OH + DB > OH + TB.
- When alkynes are substituents, then they are named as *k*-alkynyl. (*k* = locant)
- Example containing all three:

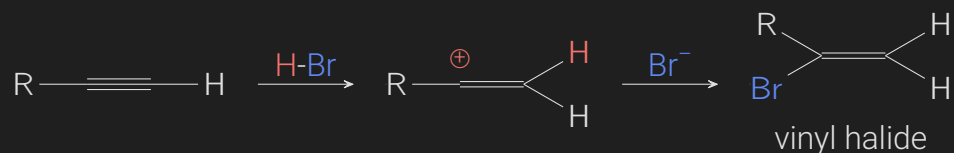


(3R,4E)-butylnon-4-en-7-yn-3-ol

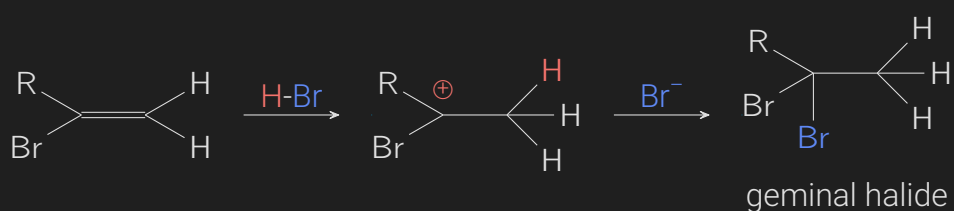
Addition Reactions of Alkynes

Hydrohalogenation of Alkynes

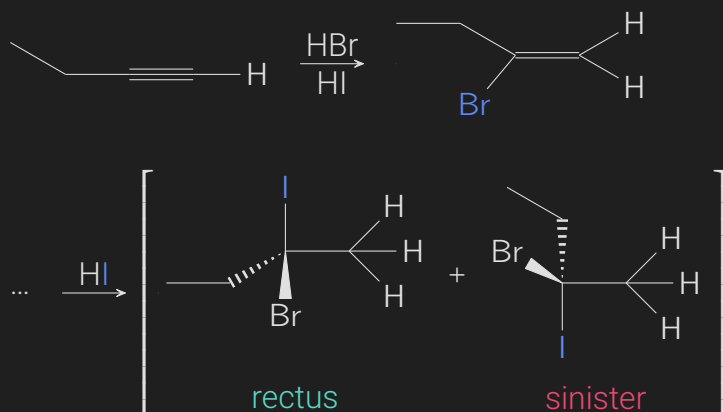
- Introductory example:



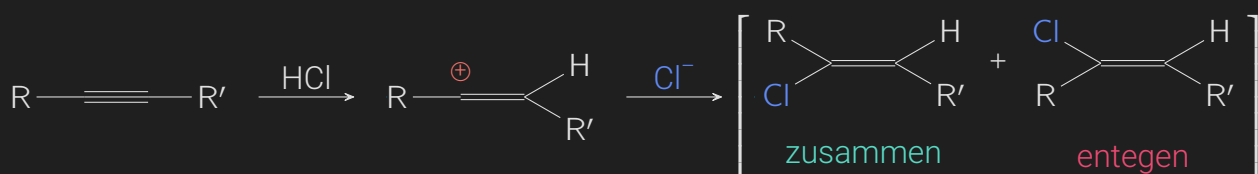
- Is **Regioselective** ↗
- Follows **Markovnikov's Rule** ↗
- This reaction can be done again (2 equiv):



- Geminal halide: a carbon that contains two halides.
- Related practice problem that generates chiral carbon due to use of different reagents for each equivalence (needs to be verified still, I might be wrong):

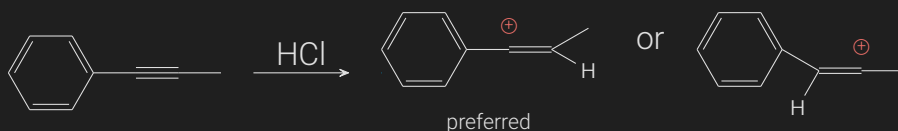


- Example with an internal alkyne; either side can be chosen if the R groups are not specified:

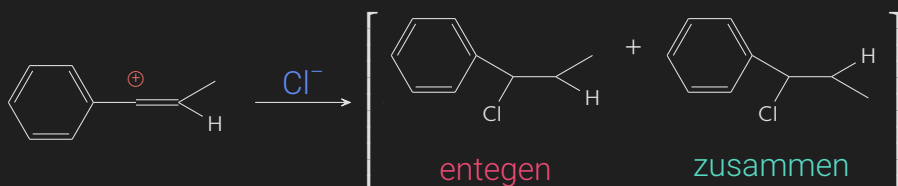


- Cl is higher priority than any carbon containing group (R), and any R' is higher than H, so both top and bottom attacks are possible.

- Related practice problem:

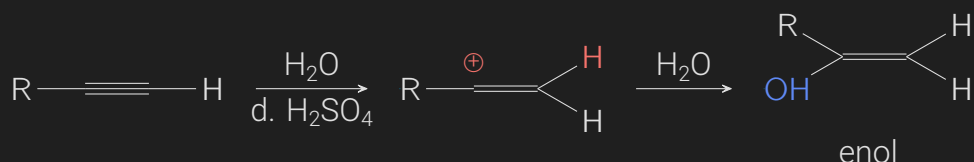


- The former carbocation intermediate is preferred due to resonance of the benzene ring, which does a better job stabilizing the carbocation.
- Continuing the reaction:

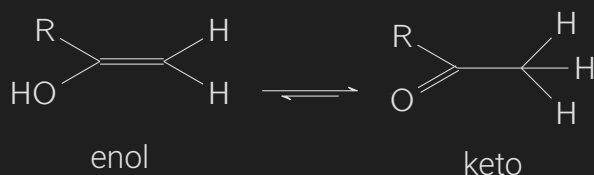


Hydration of Alkynes

- Introductory example:



- Follows **Markonikov's Rule** ↗
- However, enols readily interconvert with more stable form:



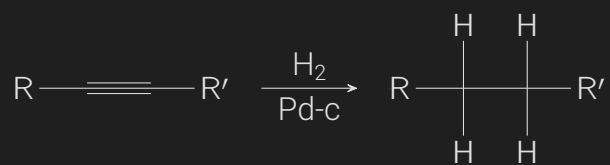
- **Tautomers:** a class of structural isomers (constitutional isomers) that readily interconvert, commonly due to the relocation of a proton (protonation-deprotonation) across a π bond.
 - The chemical reaction is called tautomerization; the concept is referred to tautomerism, which is sometimes desmotropism.
- Keto-enol tautomerism major product is the keto form, which does not allow for a second addition reaction.
- HgSO_4 is frequently used instead of d. H_2SO_4 , due to the mercurinium intermediate vs. the carbocation intermediate, which is both **faster** and a means to **reduce the probability** of byproducts.

- Example of an alkyne in a hydroboration-oxidation reaction ↗:

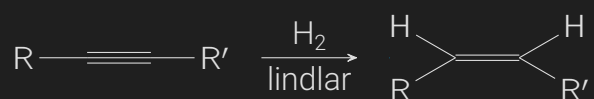
- o **Aldehyde:** generally created by removing a hydrogen from an alcohol; in our case it is generated by the **anti-Markovnikov** reaction that results in a terminal enol, which then undergoes tautomerization and produces the aldehyde as the major product.

Hydrogenation of Alkynes

- Complete hydrogenation of an alkyne:



- Alkyne \rightarrow cis-alkene; use of lindlar catalyst (Pd-c poisoned with lead) limits further reduction by controlling hydrogens available:

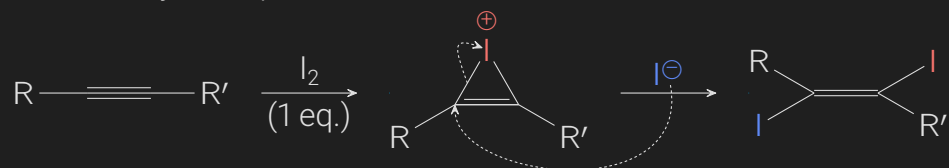


- Alkyne → **trans**-alkene; using generation of free radicals (•, single electron) that pair up with another electron generated by the dissociation of $\text{Na} \rightarrow \text{Na}^+ + \text{e}^-$ to create a free pair of electrons that then receive a hydrogen from NH_3 :

- Note, in lecture the added hydrogens were drawn separately; I am unsure, but I assume they happen near-simultaneously.

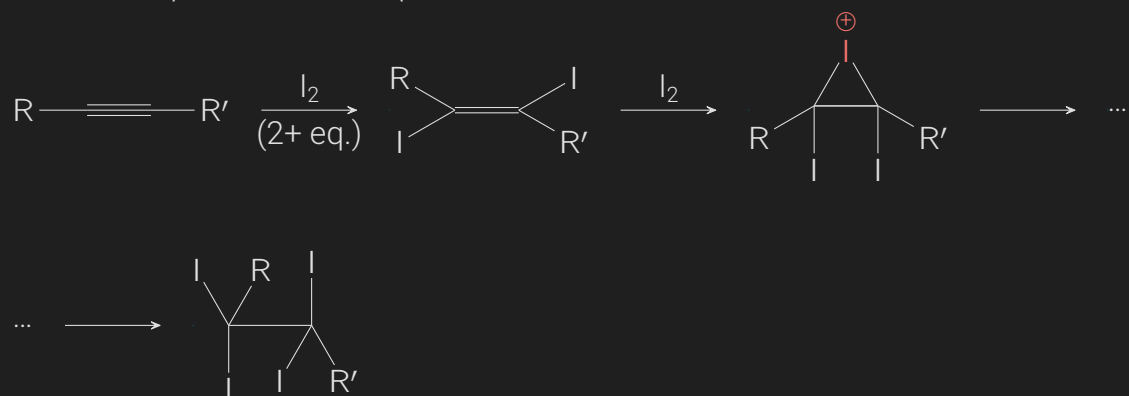
Halogenation of Alkynes

- Introductory example:



- The 3-membered cationic ring with a double bond is not very stable, so it does not form readily with a rate that is 10^3 – 10^7 times slower than that on an alkene.

- Same example, but with 2 equivalent or excess:

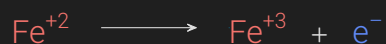


- Note: if you had controlled the second addition and added a different halide, then stereochemistry would have been important to consider since the products would have had chiral carbons.

16: Oxidation and Reduction

Redox Basics/Review

- ▷ **Oxidation:** is the **loss of electrons** or an **increase in the oxidation state** of an atom, an ion, or of certain atoms in a molecule.



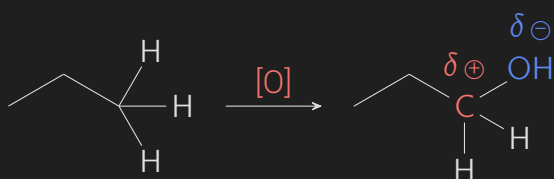
- ▷ **Reduction:** is the **gain of electrons** or a **decrease in the oxidation state** of an atom, an ion, or of certain atoms in a molecule (a reduction in oxidation state).



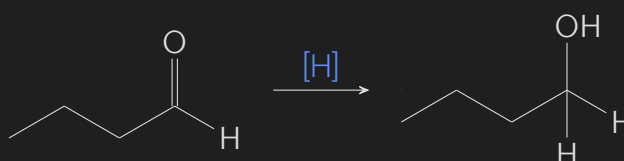
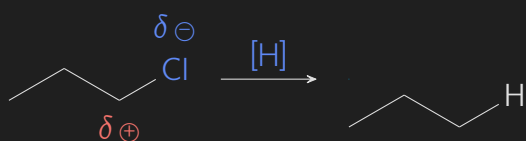
- ▷ **Redox (reduction-oxidation):** a type of chemical reaction in which the oxidation states of atoms are changed.
- Characterized by the actual or formal transfer of electrons between chemical species.
 - Most often one species (**the reducing agent**) undergoing **oxidation** while another species (**the oxidizing agent**) undergoes **reduction**.
- ▷ Many reactions in organic chemistry are redox reactions due to changes in oxidation states but without distinct electron transfer; rather changes in **electron density**.
- **Oxidation [O]:** going from a C–H → C– δ^{-} bond; pulls **electron density away** from the carbon.
 - **Reduction [H]:** going from a C– δ^{-} → C–H bond; pulls **electron density towards** the carbon.

Redox Practice Examples

- Examples of oxidation reactions:



- Examples of reduction reactions:



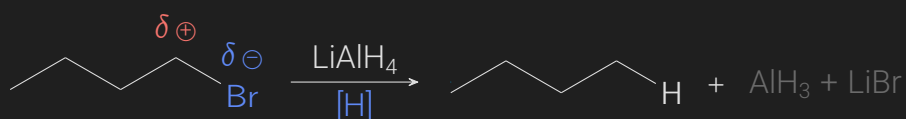
Reduction Reactions

Reduction Agents

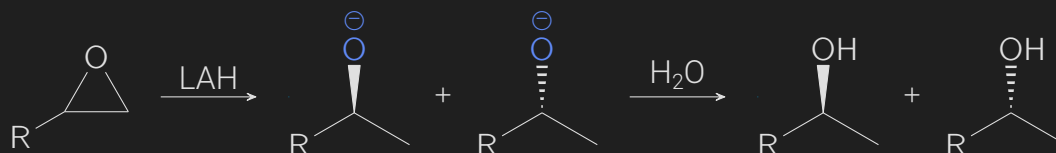
- **Hydride:** H^- , a negatively charged hydrogen ion (anion); commonly used as a **strong base** that react with **weak acids**, releasing H_2 .
- NaBH_4 : sodium borohydride.
- LiAlH_4 (LAH): lithium aluminum hydride.
- Both NaBH_4 and LiAlH_4 are **hydride donors**; they give up a hydride to become neutral.
 - Boron < aluminum in terms of size; electrons are attracted to boron to a greater degree, making it harder to remove the hydride for boron vs. aluminum. Thus:
 - LiAlH_4 is a **stronger** reducing agent.
 - NaBH_4 is a **weaker** reducing agent.

Reduction with LiAlH_4

- Example with an alkyl halide:



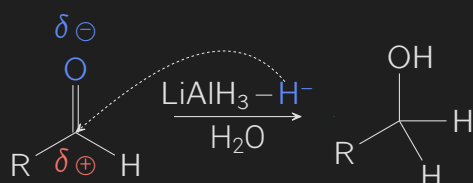
- Example with an epoxide:



- Remember: epoxide rings **no positive charge** will have the **less sterically hindered** side attacked.
- **Quenching:** deactivation of any unreacted reagents (adding a hydrogen source using H_2O for the negatively charged oxygen in this case).

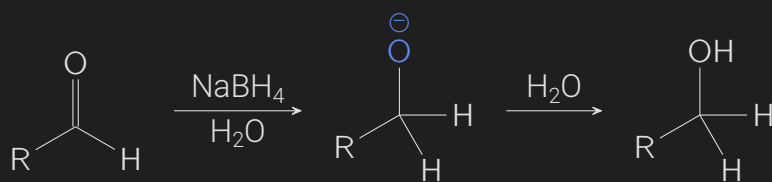
Reduction of Aldehydes

- Example of reduction to 1° alcohol:



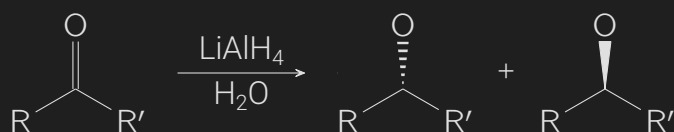
- Note: the reaction is done in two steps, but the addition of water was omitted here.

- The partial charge on the carbon double bonded to oxygen gives a slight **electrophilic** center for the **hydride** to attack due to the **inductive effect**.
- Same example as above, but with NaBH_4 and showing the intermediate step:



Reduction of Ketones

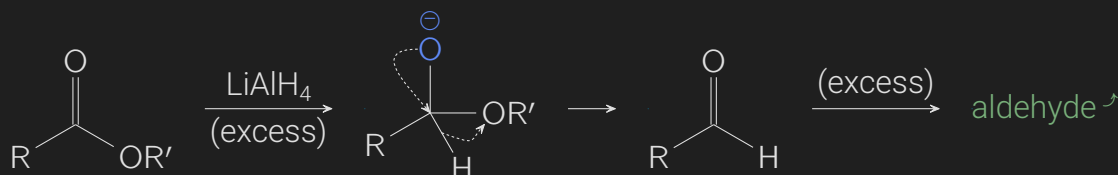
- Examples of generating racemic mixtures of 2° alcohols:



- Note: the above can be done with NaBH_4 , it's just slower.
- The inductive effect is slightly increased vs. aldehydes, since there are now two alkyl groups pushing electron density.

Reduction of Esters

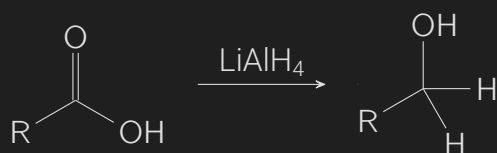
- First the ester is reduced to an aldehyde, then in presence of excess it will be further reduced from an aldehyde to a 1° alcohol.



- Resonance (shared electron density due to delocalization of electrons between either oxygen) is stronger than inductive effect, so **only reduction using LiAlH_4** works.

Reduction of Carboxylic Acids

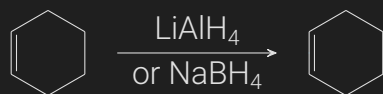
- Very similar to Esters, which ends up producing a 1° alcohol:



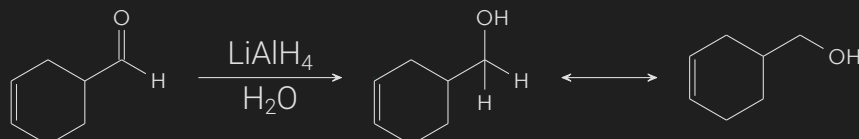
- Again, the presence of resonance will only allow the use of LiAlH_4 ; the first step will not occur if NaBH_4 is used as it is too weak to be a reagent.

Reduction Practice Problems

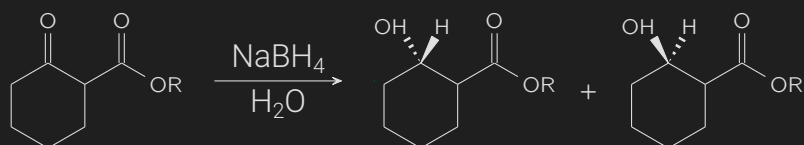
1. No reaction, needs carbonyl (C=O) functional group to proceed:



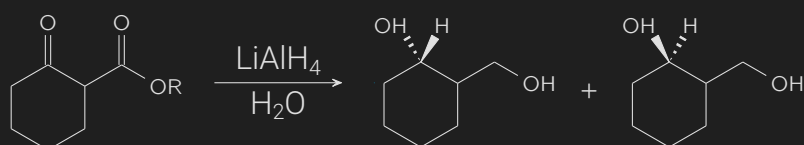
2. Example that contains a carbonyl group:



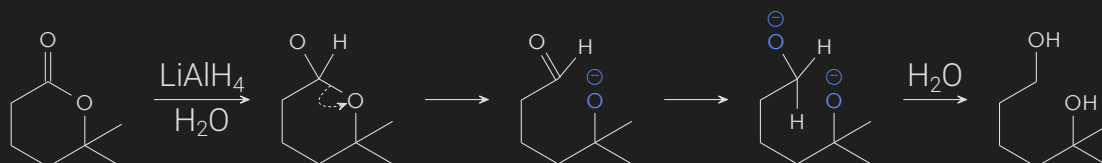
3. Example with a ketone and an acyclic ester:



- 3b. Same example as above but with LiAlH₄ (assuming excess):



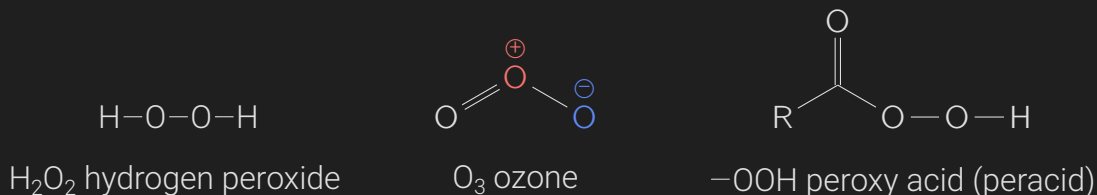
4. Example with a cyclic ester (assuming excess):



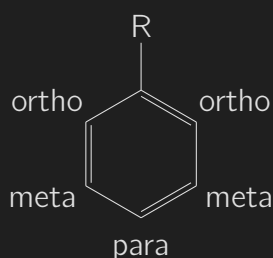
Oxidation Reactions

Oxidizing Agents

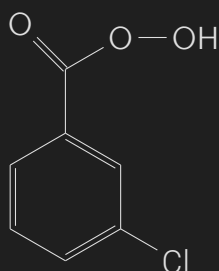
- **Peroxide reagents:** reagents that contain O—O linkage of some kind:



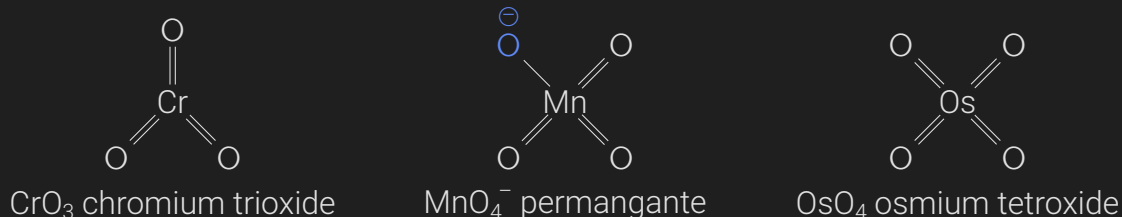
- **Arene substitution patterns:** IUPAC nomenclature for naming substituents other than hydrogen in relation to each other on an aromatic hydrocarbon:



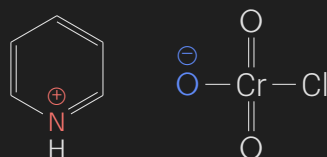
- **meta-Chloroperoxybenzoic acid (mCPBA):** a strong and widely used oxidant in organic synthesis due to relative ease of handling.



- **Metal based** oxidizing agents:

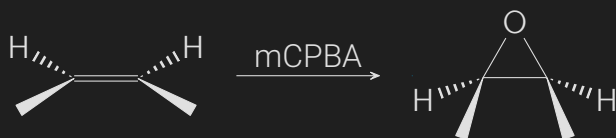


- Note: MnO_4^- comes as KMnO_4 . The anion must be created in order to be used as a reagent.
- **Pyridinium chlorochromate (PCC):** $[\text{C}_5\text{H}_5\text{NH}]^+[\text{CrO}_3\text{Cl}]^-$ — a **mild** oxidizing reagent primarily used for **selective** oxidation of alcohols to aldehyde or ketones.

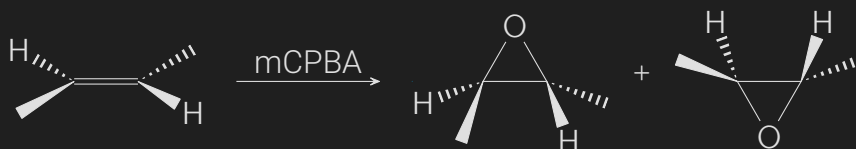


Epoxidation

- Example of oxidizing a *cis*-alkene to a *cis*-epoxide:



- Note: epoxide rings are always (commonly?) made when using mCPBA.
- The epoxide ring is an example of a **meso compound**, where there are chiral centers, but there is a plane of symmetry making it **superimposable on its mirror image**, so no other products are made.
- Similar to example of above, but with a *trans*-alkene to a *trans*-epoxide:



- The *trans*-epoxide ring is no longer a meso compound, so you must show both products; one when the ring forms on the top and one where the ring forms on the bottom.
- These examples show that epoxidation reactions are **concerted** reactions, since there is no mixture of products between *cis* and *trans* products; it's dependent on the starting compound.

Epoxidation Practice Problems

1.



2.

