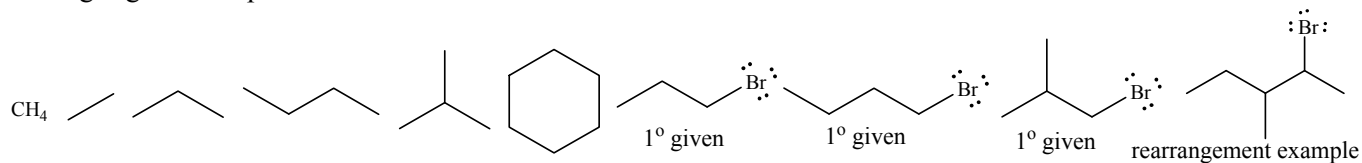


## Starting organic compounds

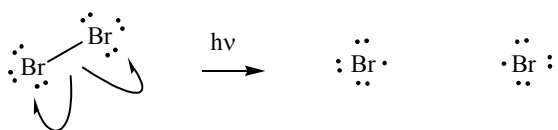


## R-X Compounds (synthesis and reactions = R-Br in our course)

1. Make other R-Br compounds (nine examples for us, 3 primary examples given above and six more made below)

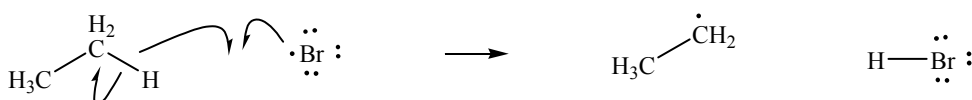
a. R-Br from alkanes using free radical substitution (three part sequence: 1. Initiation 2. Propagation (2 steps) 3. termination)

1. initiation - high energy photon ruptures the weakest bond (= halogen bond = homolytic cleavage)

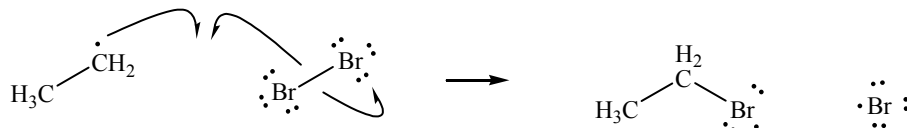


atoms	bond energy
Br-Br	46
sp <sup>3</sup> H <sub>3</sub> C-H	105
sp <sup>3</sup> 1° C-H	98
sp <sup>3</sup> 2° C-H	95
sp <sup>3</sup> 3° C-H	92
sp <sup>3</sup> C-Br	≈ 68
H-Br	88

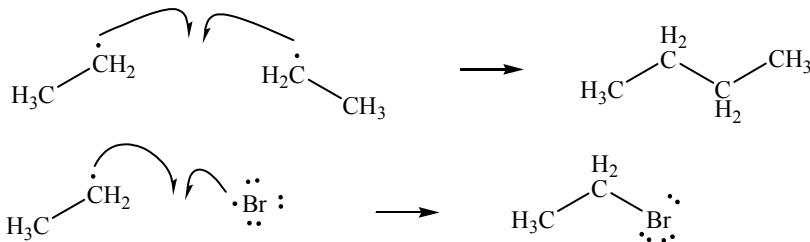
2a. propagation (step 1) - bromine atom abstracts H from weakest C-H bond and makes an H-Br bond



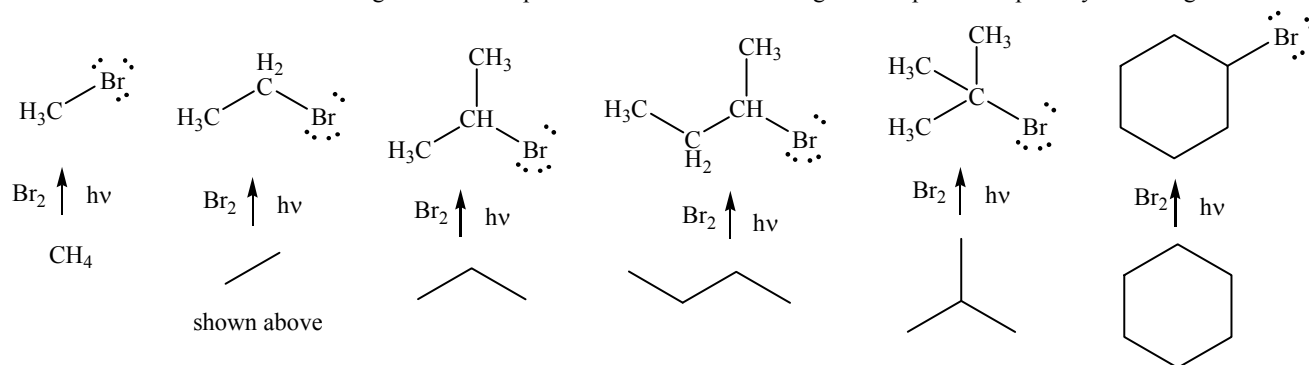
2b. propagation (step 2) - carbon free radical abstracts Br atom from bromine molecule and makes a C-Br bond



3. termination - two reactive free radicals find one another and combine

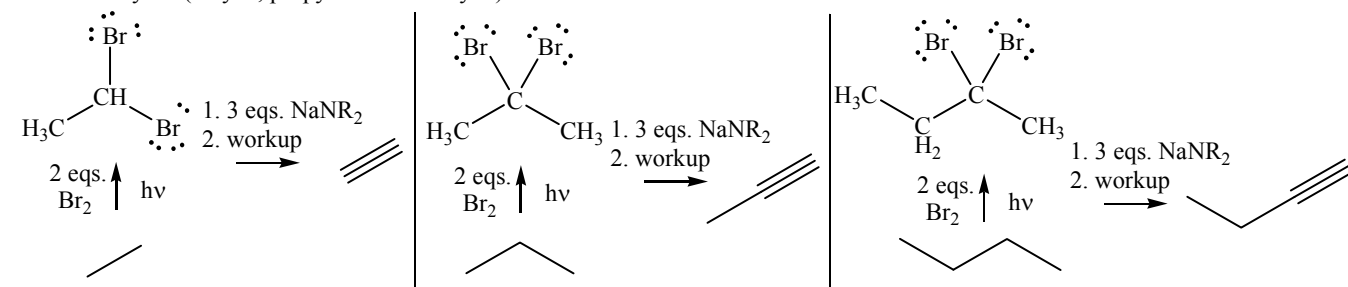


Other R-Br to make from our starting alkanes. Six possible RBr from our starting alkanes plus three primary RBr are given = 9 total.



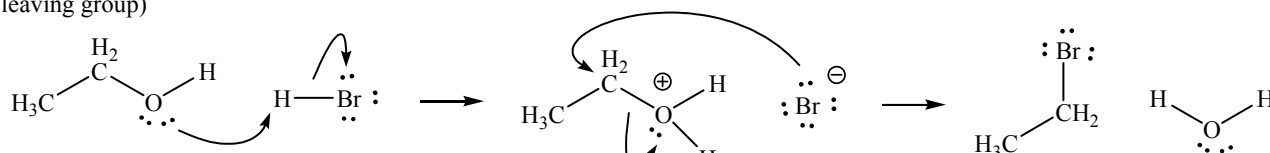
There is no easy way to make a primary R-Br compound in our course yet (from our given starting structures). Three examples are provided above until we can do this. (Not in 201)

In our course we will propose dibromoalkanes from ethane, propane and butane by using 2 equivalents of  $\text{Br}_2/\text{h}\nu$ . We will use these to make alkynes (ethyne, propyne and but-1-yne)

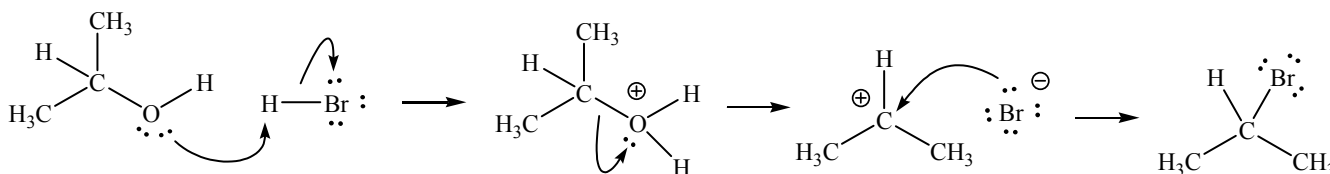


- b. Make R-Br from alcohols (reaction with HBr,  $\text{S}_{\text{N}}2$  at methyl and primary ROH,  $\text{S}_{\text{N}}1$  at secondary and tertiary ROH)

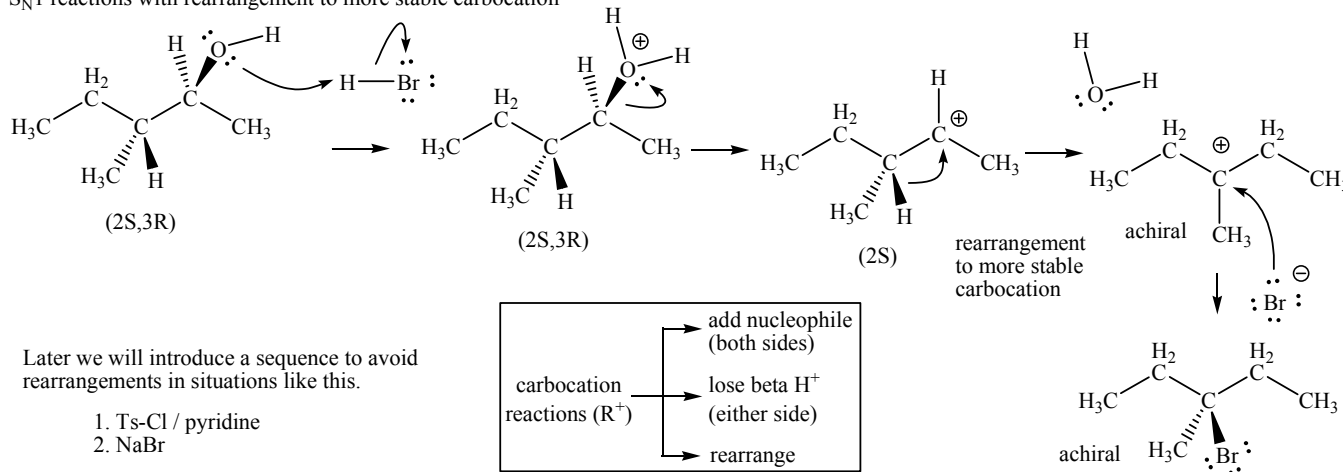
$\text{S}_{\text{N}}2$  reactions with methyl and primary alcohols and H-Br (steps = 1. protonation 2.  $\text{S}_{\text{N}}2$  reaction with bromide, with water leaving group)



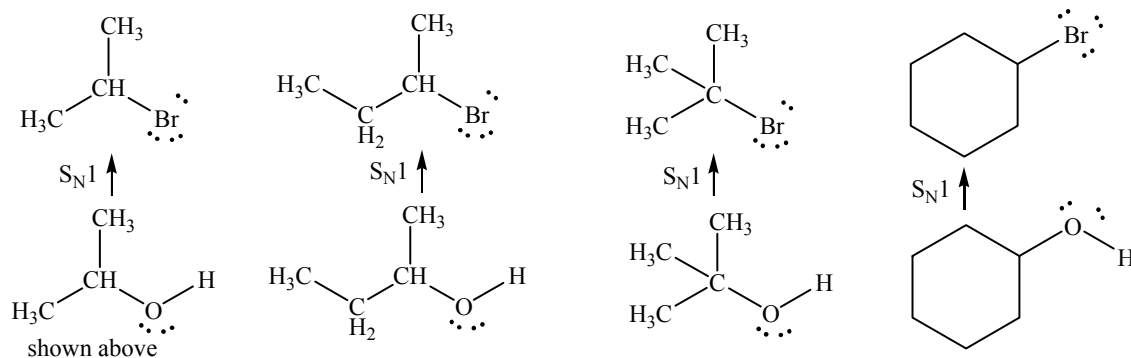
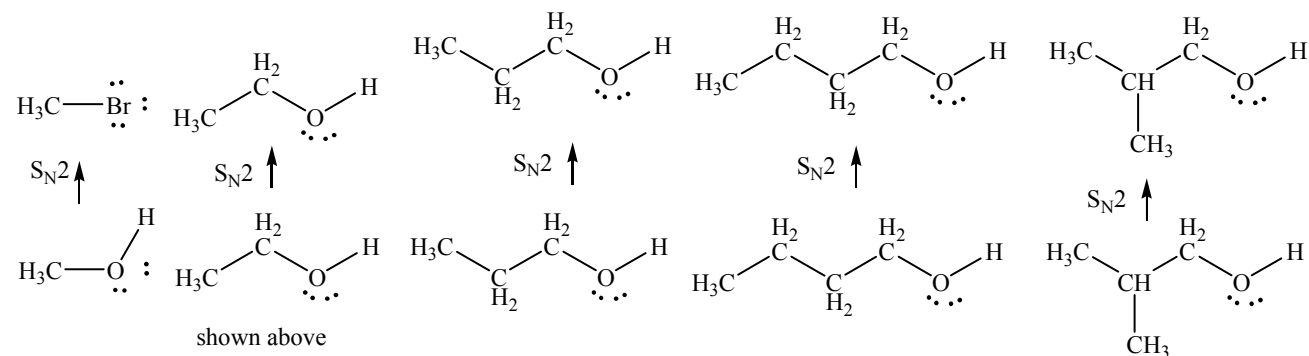
$\text{S}_{\text{N}}1$  reactions with secondary and tertiary alcohols and H-Br (steps = 1. protonation 2. water leaving group forms carbocation 3. bromide adds)



$\text{S}_{\text{N}}1$  reactions with rearrangement to more stable carbocation

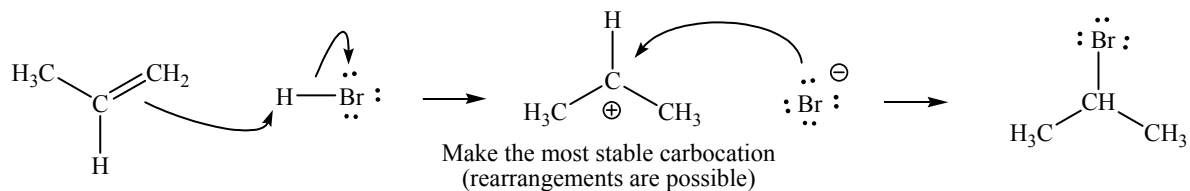


Examples of other R-Br to make from alcohols. There will be more possibilities as we progress through organic chemistry.

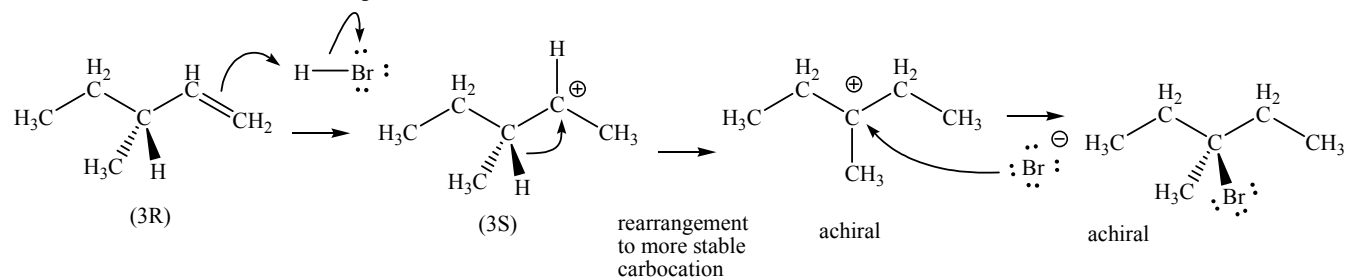


c. Make R-Br from alkenes and H-Br (addition reactions – Markovnikov addition = form most stable carbocation)

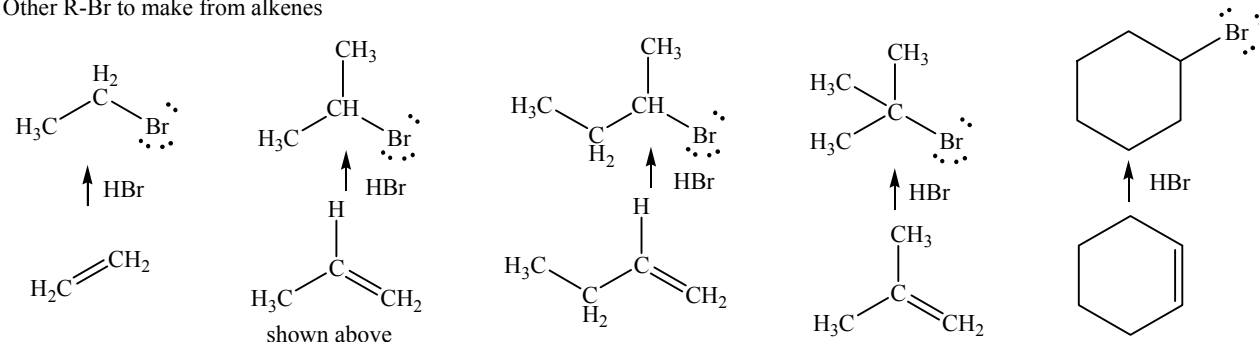
Addition reaction of H-Br to alkene - 1. form the most stable carbocation 2. add bromide (possible rearrangements)



Alkene addition reactions with rearrangement to more stable carbocation.

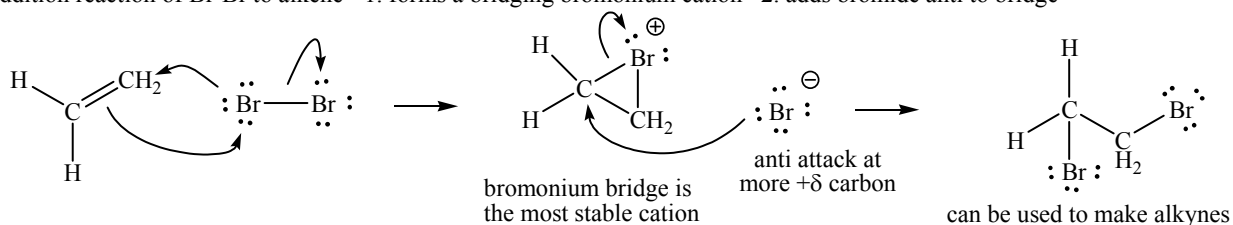


Other R-Br to make from alkenes

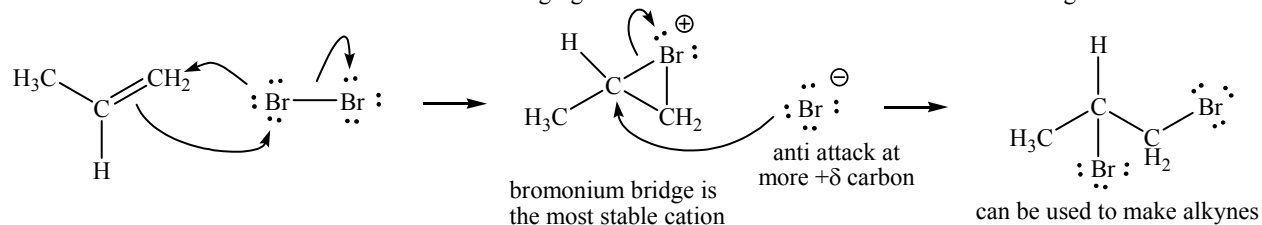


- d. Make  $\text{RBr}_2$  from alkanes +  $\text{Br}_2/h\nu$  (2x free radical substitution) or use  $\text{Br}_2$  + alkenes (addition reactions with  $\text{Br}_2$ , forms bromonium bridge followed by anti attack of bromide at more  $\delta^+$  carbon).

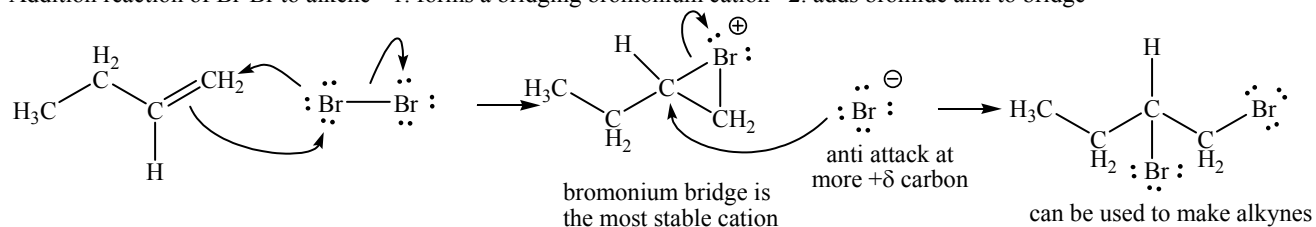
Addition reaction of Br-Br to alkene - 1. forms a bridging bromonium cation 2. adds bromide anti to bridge



Addition reaction of Br-Br to alkene - 1. forms a bridging bromonium cation 2. adds bromide anti to bridge

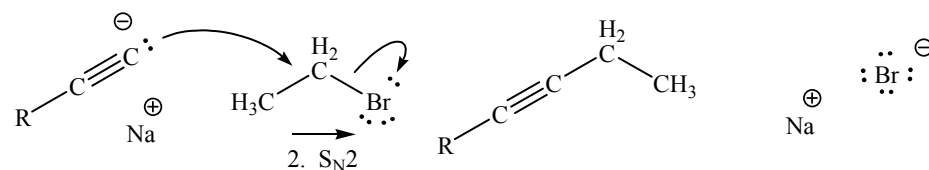
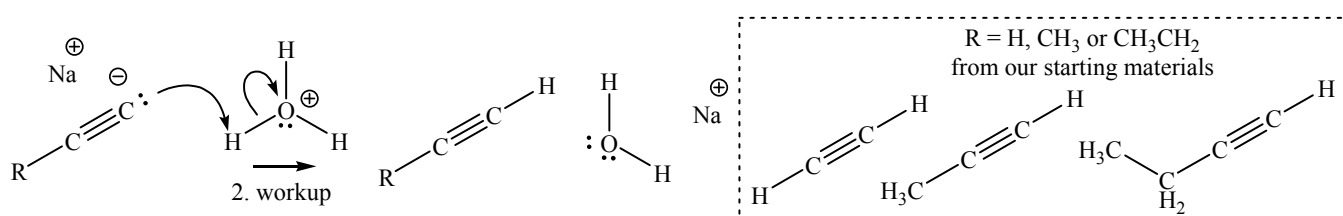
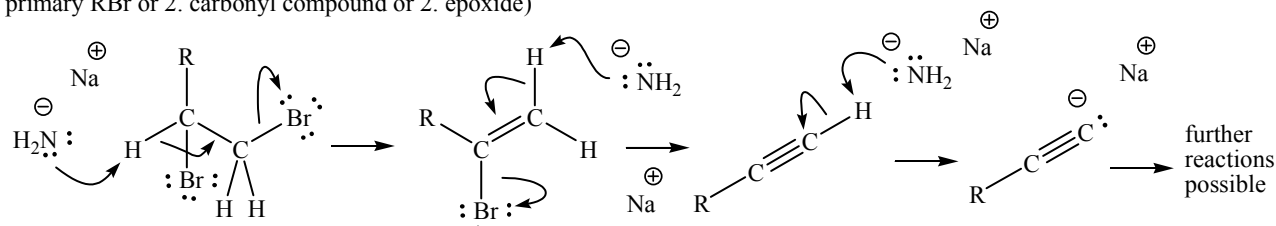


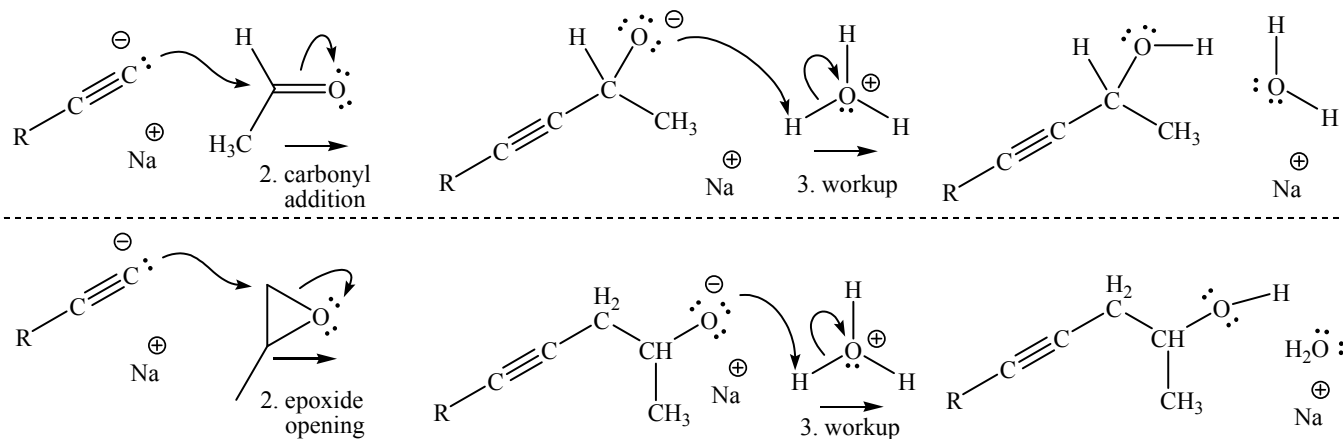
Addition reaction of Br-Br to alkene - 1. forms a bridging bromonium cation 2. adds bromide anti to bridge



Double E2 reaction to make alkynes: Use  $\text{RBr}_2$  + 3 equivalents  $\text{NaNR}_2$

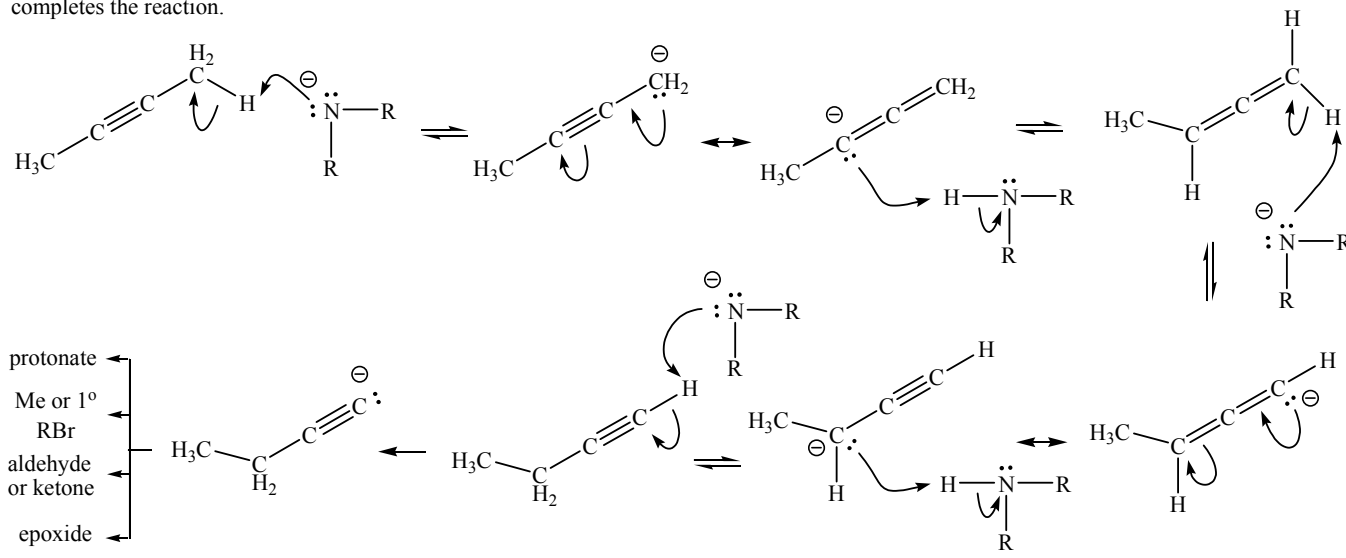
Double elimination reaction (E2) forms alkynes using  $\text{NaNR}_2$  as the base. The acidity of  $\text{sp}$  C-H uses a third equivalent of the base and can form a terminal acetylide which is either protonated in a workup step or reacted further with an electrophile (2. methyl or primary  $\text{RBr}$  or 2. carbonyl compound or 2. epoxide)





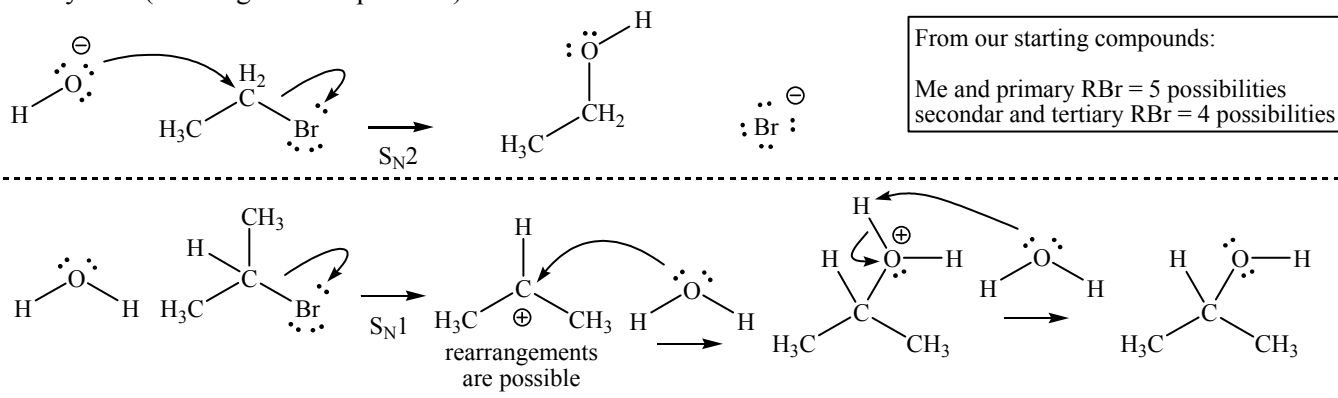
### Zipper reaction – moves internal alkynes to a terminal position, forming terminal acetylide

The zipper reaction changes a linear internal alkyne into a terminal acetylide that can be made into a terminal alkyne (2. simple workup) or reacted with one of our three common electrophiles (2. methyl or primary RBr) or (2. aldehyde or ketone 3. workup) or (2. epoxide 3. workup). The steps of the zipper reaction are similar to the steps of tautomers in base: 1. proton off, 2. resonance, 3. proton on. This continues until the terminal alkyne is formed. Loss of the  $sp$  C-H forms the most stable anion and the reaction stops there until one of the workup possibilities completes the reaction.

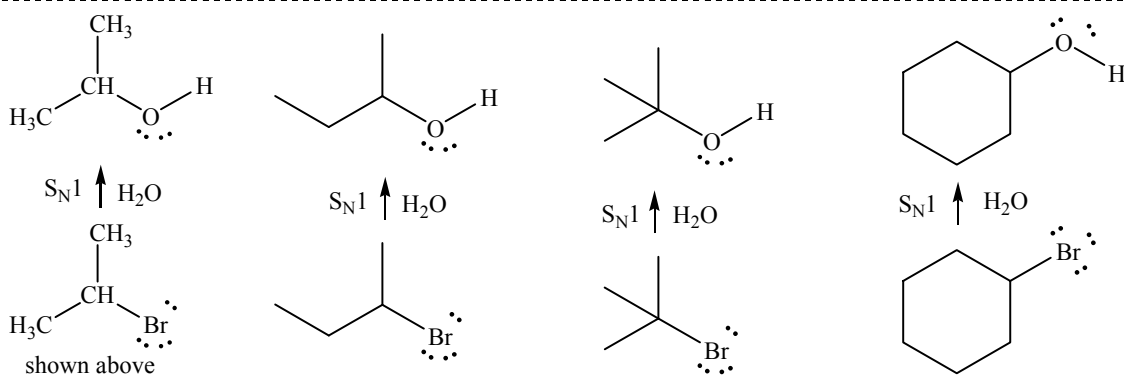
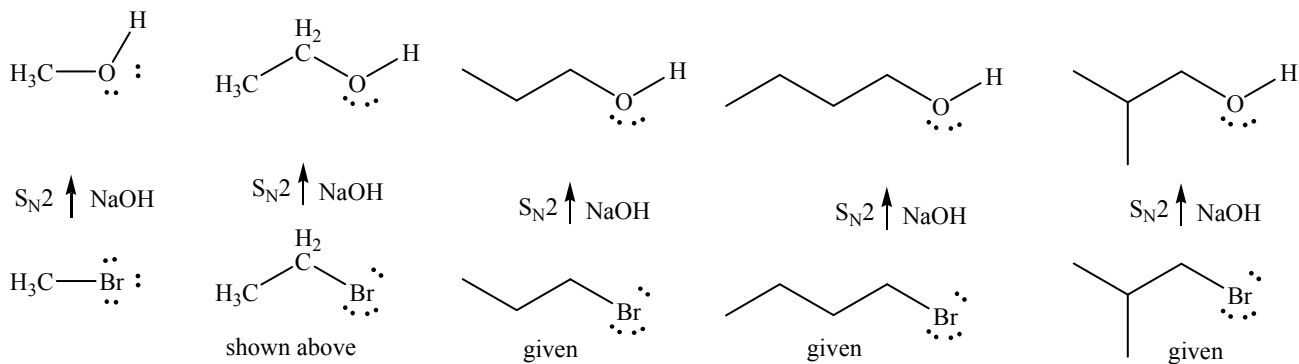


## 2. Make other functional groups from R-Br

a. Make alcohols using  $S_N2$  reaction with NaOH at methyl and primary RBr. Use  $S_N1$  with  $H_2O$  at secondary and tertiary RBr (rearrangement is possible).

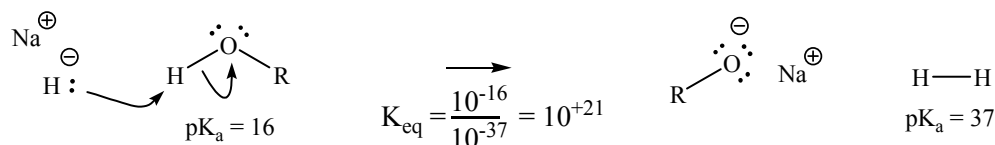


Other alcohols from R-Br (nine possible in our course)

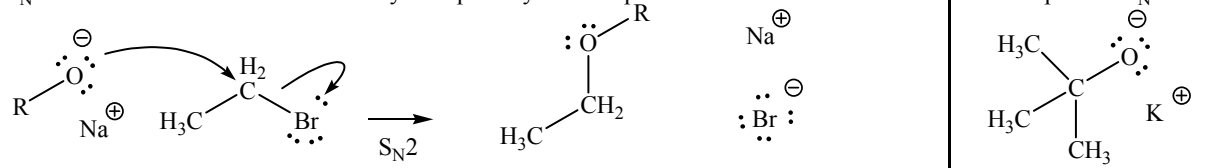


b. Make ethers using  $\text{S}_{\text{N}}2$  reaction with NaOR at methyl and primary RBr;  $\text{S}_{\text{N}}1$  with ROH at secondary and tertiary RBr

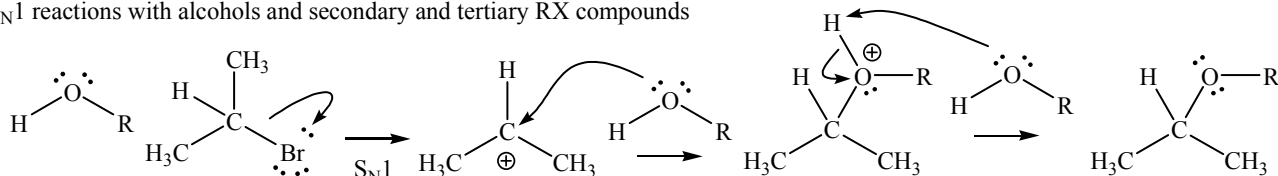
Make alkoxide from alcohol and NaH (acid/base reaction) to use in  $\text{S}_{\text{N}}2$  reaction



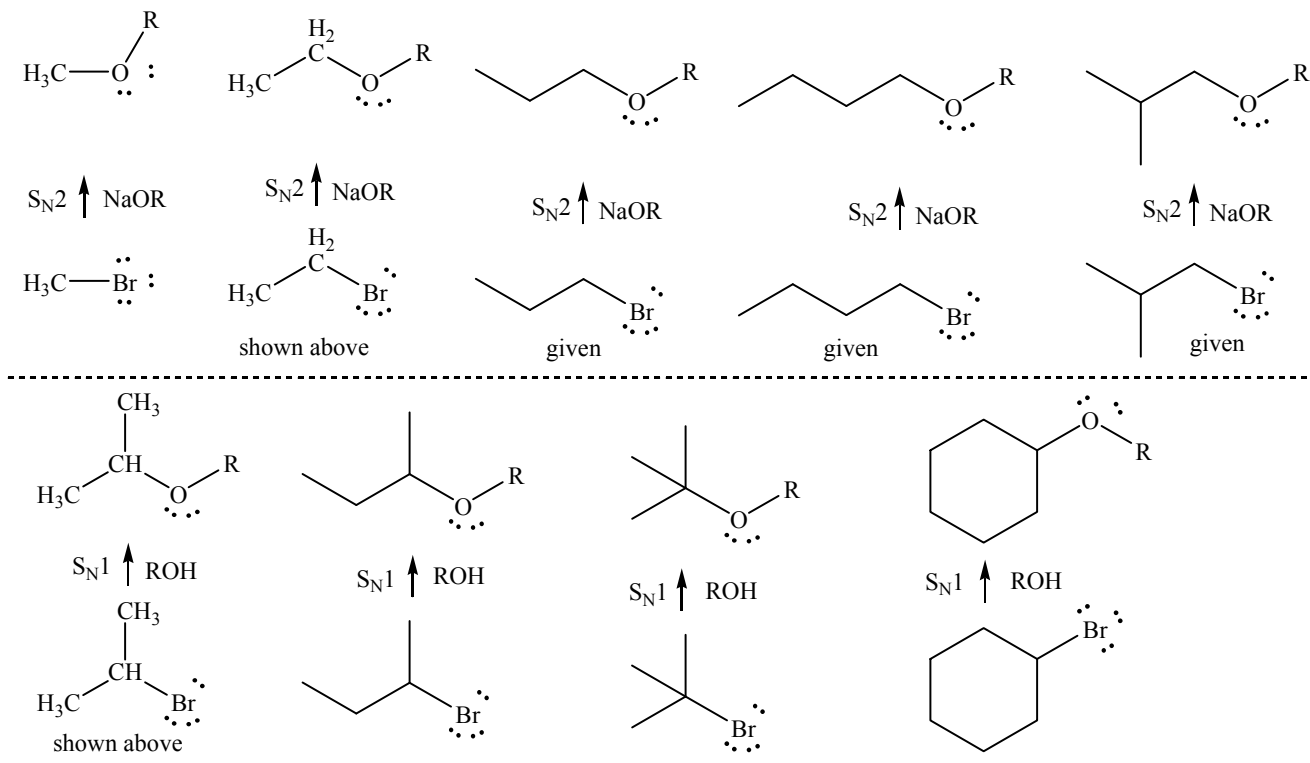
$\text{S}_{\text{N}}2$  reactions with alkoxides and methyl and primary RX compounds



$\text{S}_{\text{N}}1$  reactions with alcohols and secondary and tertiary RX compounds

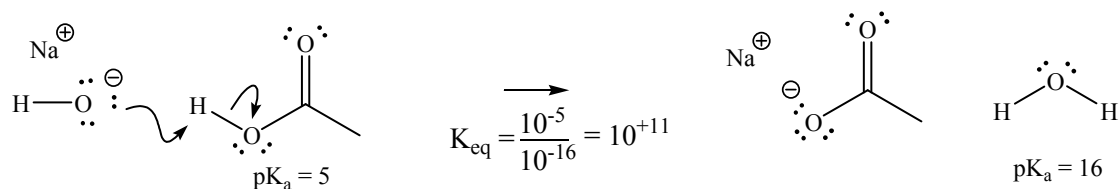


Other ethers from R-Br (9 ROH x 9 RBr = 81 possibilities in our course, some duplicates)

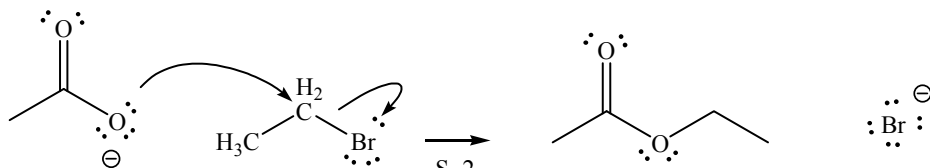


c. Make esters using  $\text{S}_{\text{N}}2$  reaction with  $\text{CH}_3\text{CO}_2\text{Na}$  (example carboxylate, more possible later) at methyl, primary and secondary RBr; and  $\text{S}_{\text{N}}1$  with  $\text{CH}_3\text{CO}_2\text{H}$  (example acid, other acids are possible later) at tertiary RBr

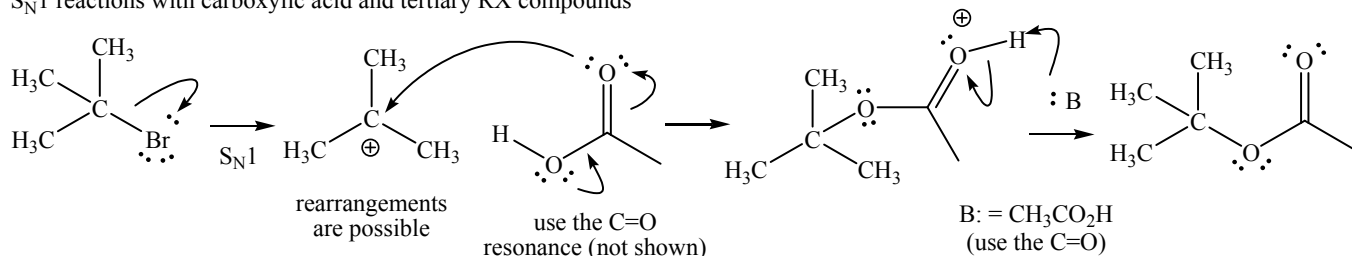
Make carboxylate from carboxylic acid and NaOH (acid/base reaction) to use in  $\text{S}_{\text{N}}2$  reactions with methyl,  $1^\circ$ ,  $2^\circ$  RX compounds



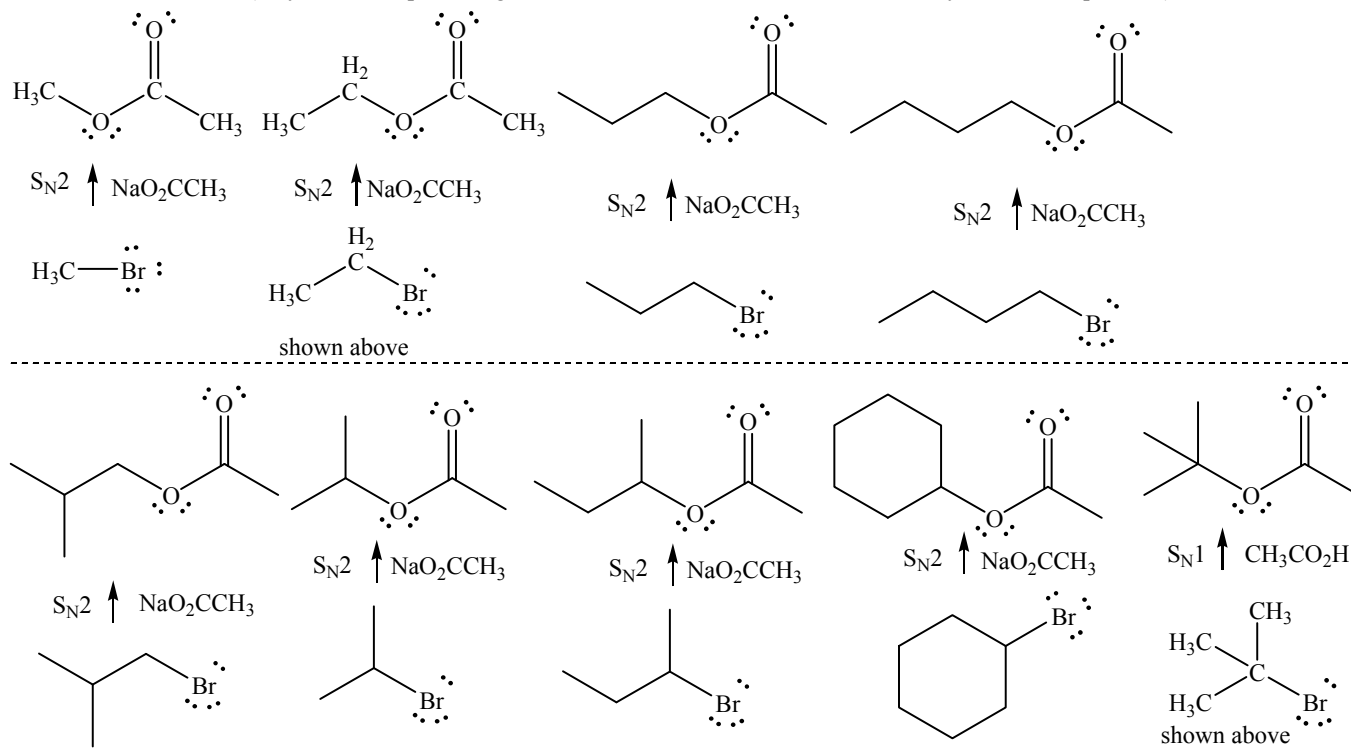
$\text{S}_{\text{N}}2$  reactions with carboxylates and methyl, primary and secondary RX compounds



$\text{S}_{\text{N}}1$  reactions with carboxylic acid and tertiary RX compounds

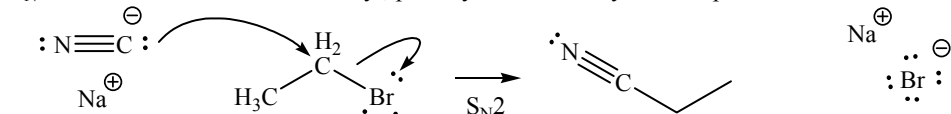


Other esters from R-Br (only nine examples using ethanoic acid, later more when other carboxylic acids are possible)

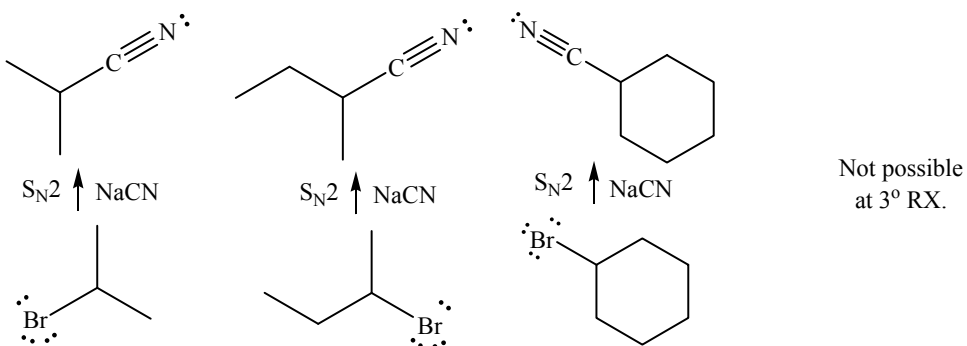
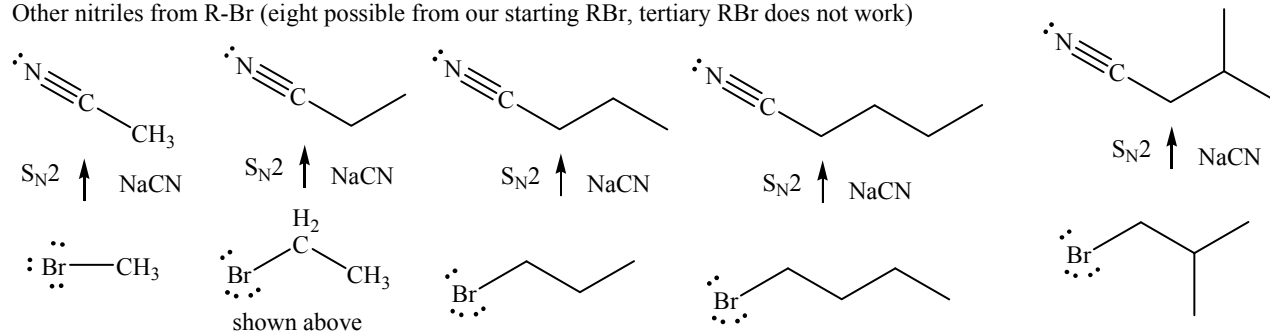


d. Make nitriles using  $S_N2$  reaction with NaCN at methyl, primary and secondary RBr

$S_N2$  reactions with NaCN and methyl, primary and secondary RX compounds



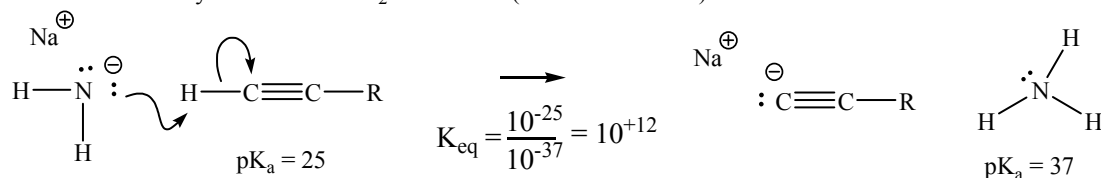
Other nitriles from R-Br (eight possible from our starting RBr, tertiary RBr does not work)



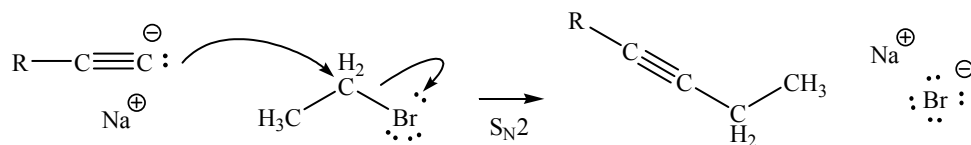


e. Make larger alkynes using  $S_N2$  reaction with  $\text{NaCCR}$  ( $R = \text{H}, \text{CH}_3, \text{CH}_2\text{CH}_3$ ) at methyl and primary  $\text{RBr}$ .

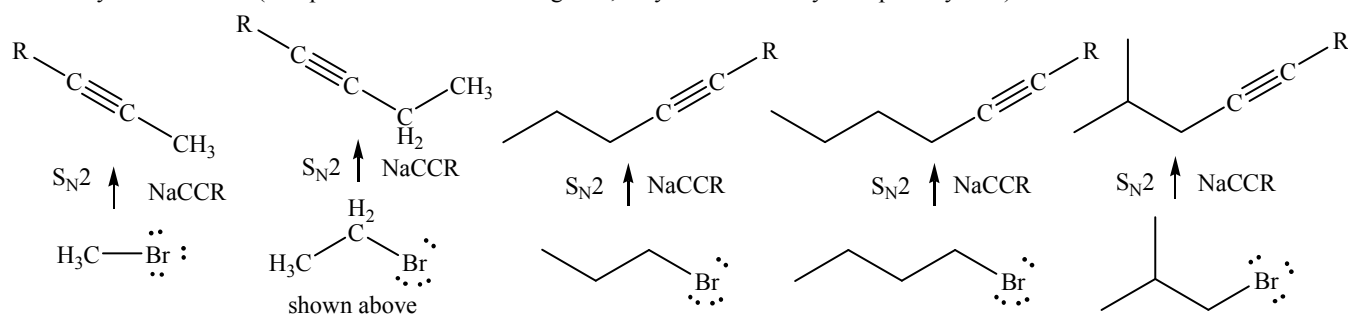
Make terminal acetylides from  $\text{NaNR}_2$  and  $\text{HCCH}$  (acid/base reaction)



$S_N2$  reactions with  $\text{NaCCH}$  and methyl and primary  $\text{RX}$  compounds (too basic to use at secondary  $\text{RX} = \text{E}2 > S_N2$ )

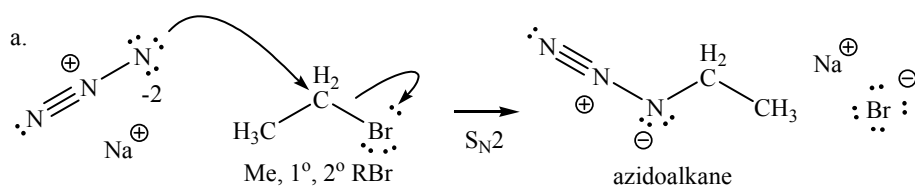


Other alkynes from  $\text{R-Br}$  (five possible from our starting  $\text{RBr}$ , only works at methyl and primary  $\text{RBr}$ )

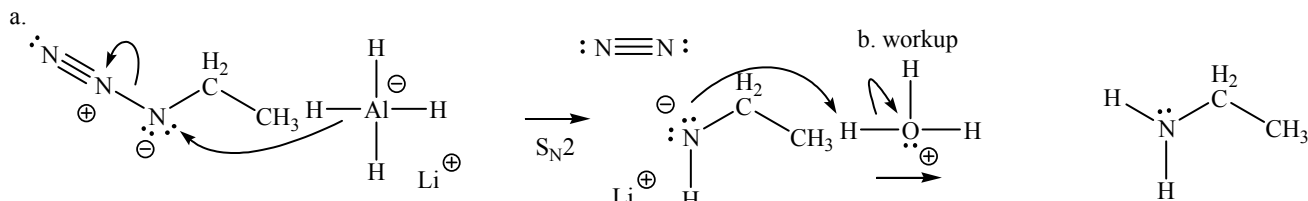


f. Make azides, then primary amines using: Reaction 1:  $S_N2$  reaction with  $\text{NaN}_3$  at methyl, primary and secondary  $\text{RBr}$  Reaction 2:  $S_N2$  with  $\text{LiAlH}_4$  at the azide nitrogen 3. Workup  $\rightarrow \text{RNH}_2$

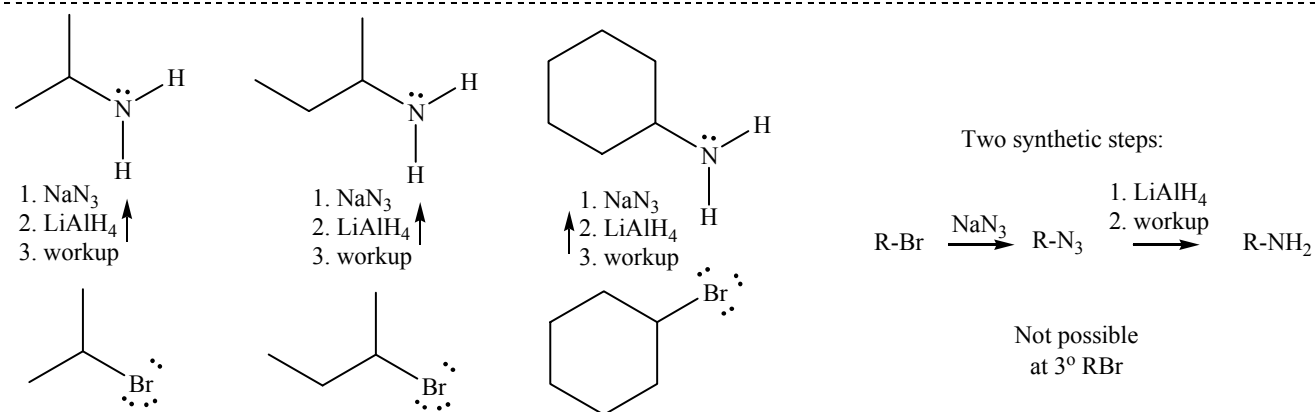
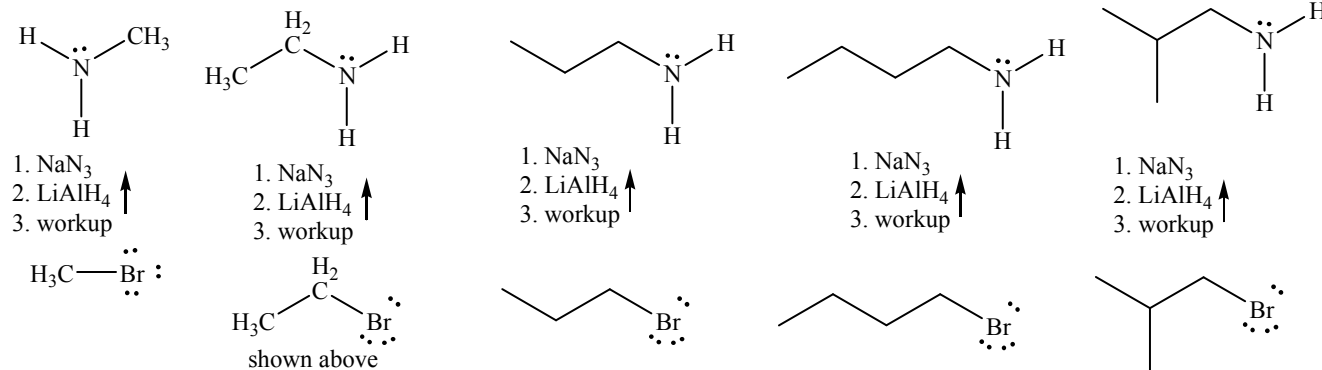
Reaction 1:  $S_N2$  reactions with  $\text{NaN}_3$  and methyl, primary and secondary  $\text{RX}$  compounds makes azides



Reaction 2: a. reduce azide with lithium aluminium hydride with  $S_N2$  reaction at nitrogen b. workup

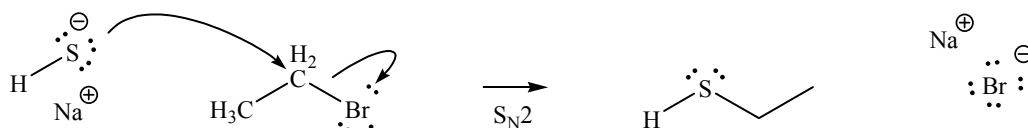


Other amines from R-Br (eight possible from our starting RBr, does not work at tertiary RBr)

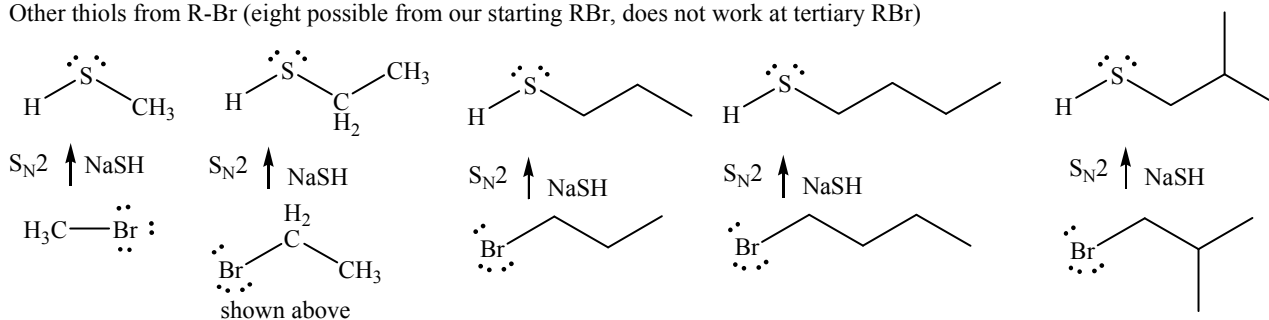


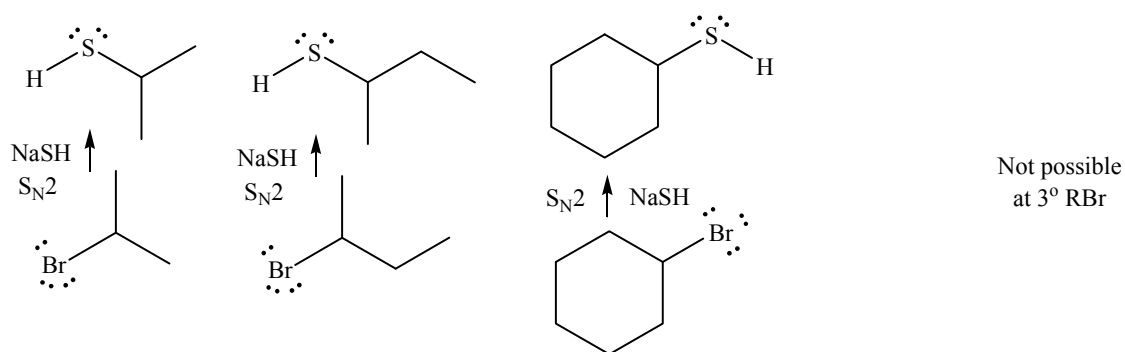
g. Make thiols using S<sub>N</sub>2 reaction with NaSH at methyl, primary and secondary RBr

S<sub>N</sub>2 reactions to make thiols with NaSH and methyl, primary and secondary RX compounds

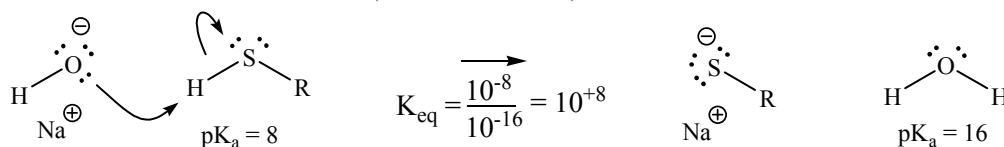
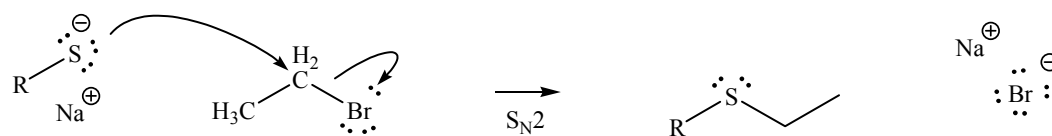


Other thiols from R-Br (eight possible from our starting RBr, does not work at tertiary RBr)

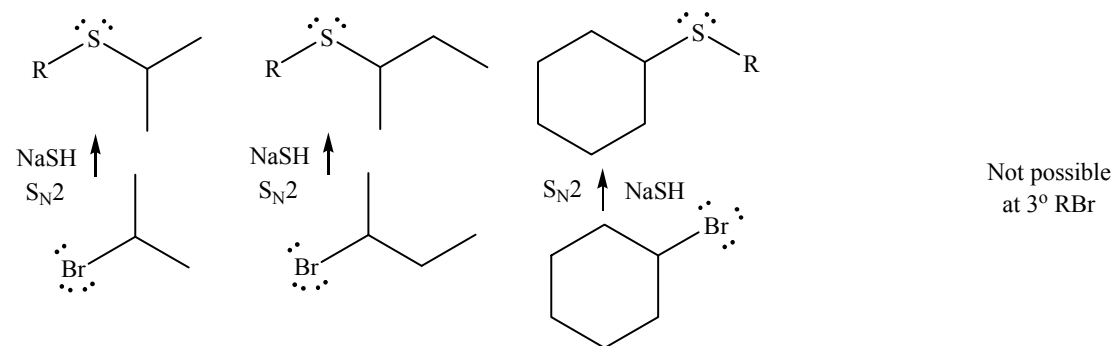
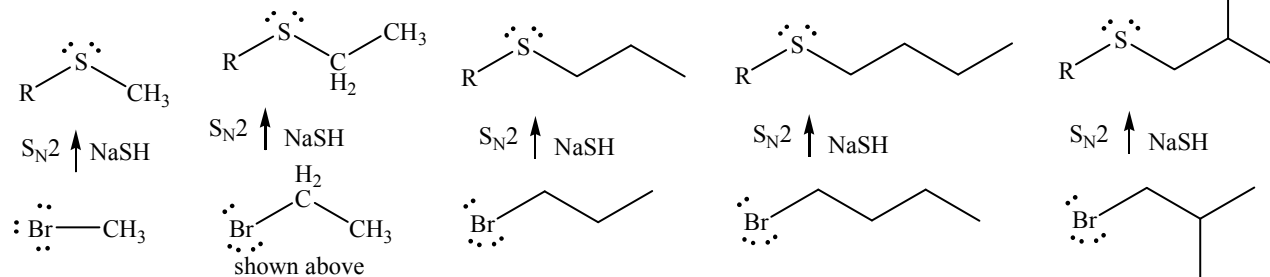


h. Make sulfides using  $\text{S}_{\text{N}}2$  reaction with NaSR at methyl, primary and secondary RBr

Make thiolates with NaOH and thiols (acid / base reaction)

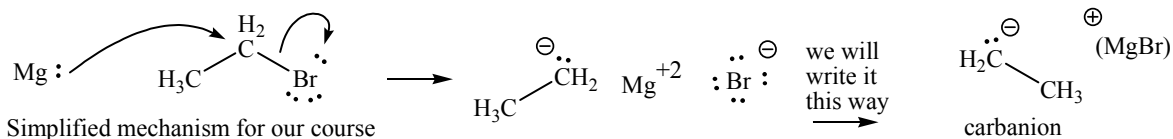
 $\text{S}_{\text{N}}2$  reactions to make sulfides with NaSR and methyl, primary and secondary RX compounds

Other sulfides from R-Br (8 RSH x 8 RBr = 64 RSR in our course, does not work at tertiary RBr)

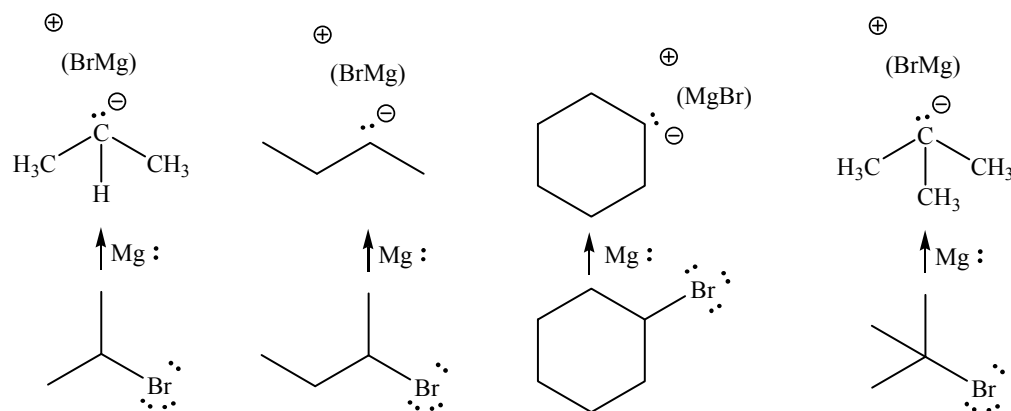
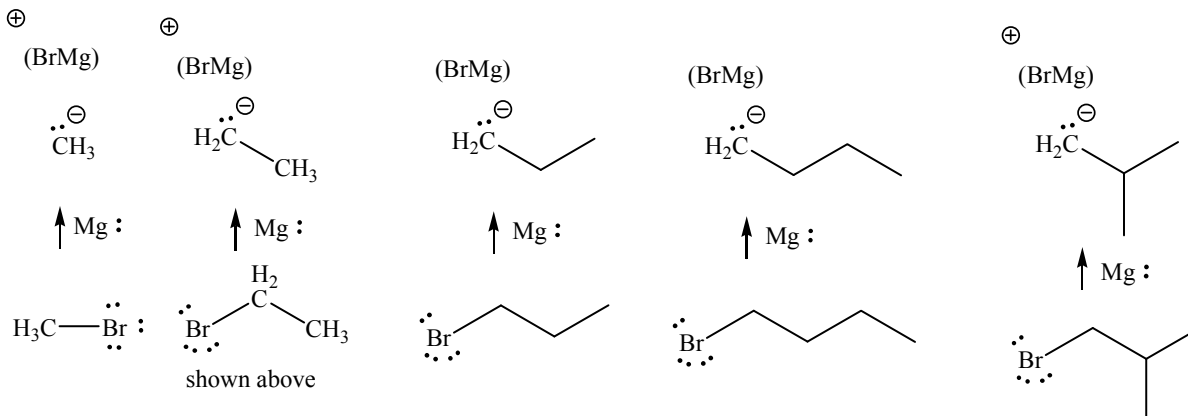


i. Make Grignard carbanions using 1. Mg with R-Br 2. react Grignard reagents with a. carbonyl (aldehydes and ketones), b. epoxides and c. carbon dioxide electrophiles 3. Workup

Make Grignard carbanions and bromide anion with Mg metal and RX compounds (oxidation / reduction reaction),  $Mg^{+2}$  inserts itself between carbanion and bromide

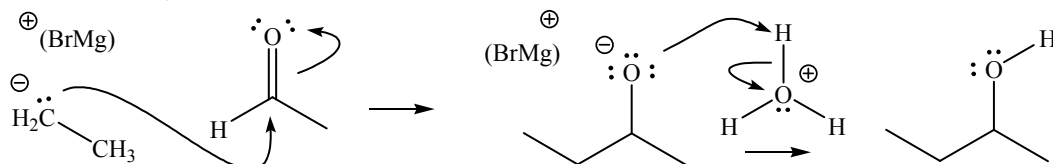


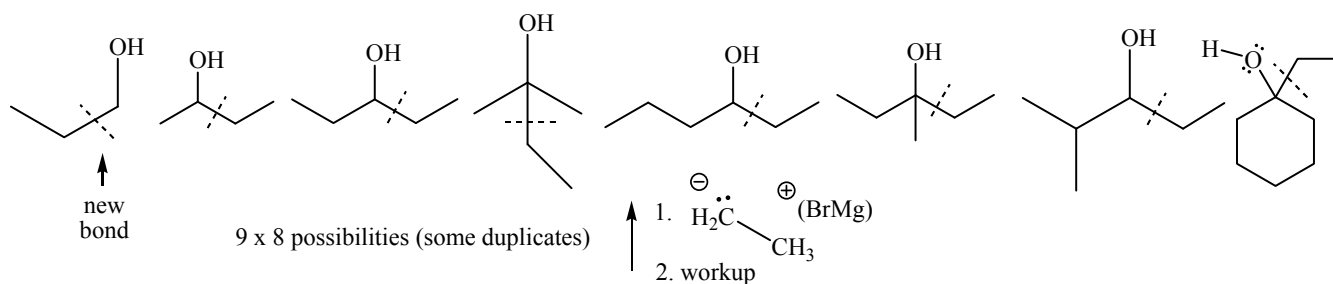
Other Grignard reagents (nine possible from our starting R-Br, tertiary does work on this reaction)



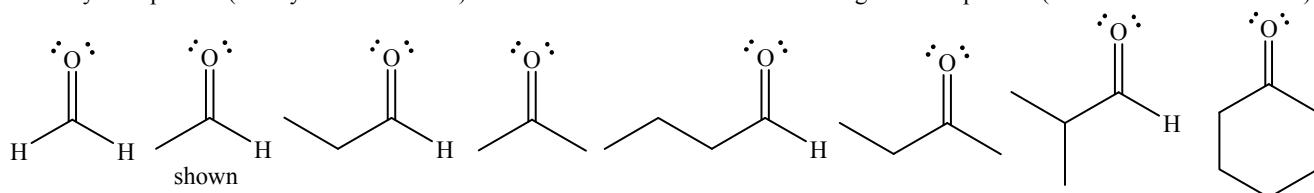
Currently 9 possibilities from our starting structures, but there will be more possibilities later.

1. React Grignard reagents with aldehydes and ketones 2. workup : makes alcohols (Various carbonyl compounds will become available when E2 reactions are discussed via oxidation reactions with  $CrO_3$ . For now we will just list the carbonyl compounds that will be made later.)

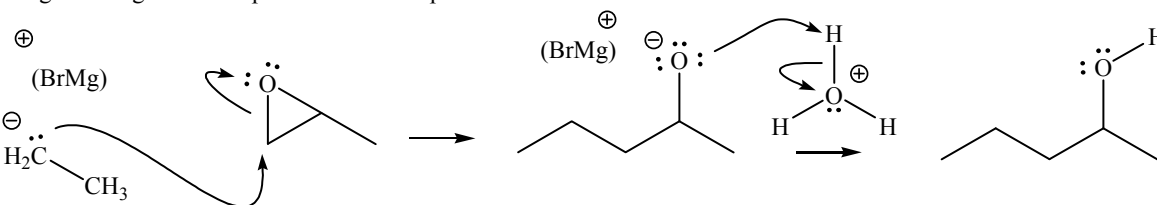




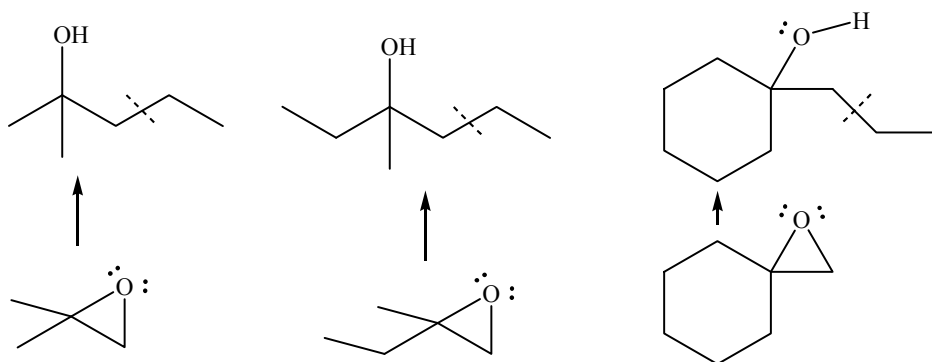
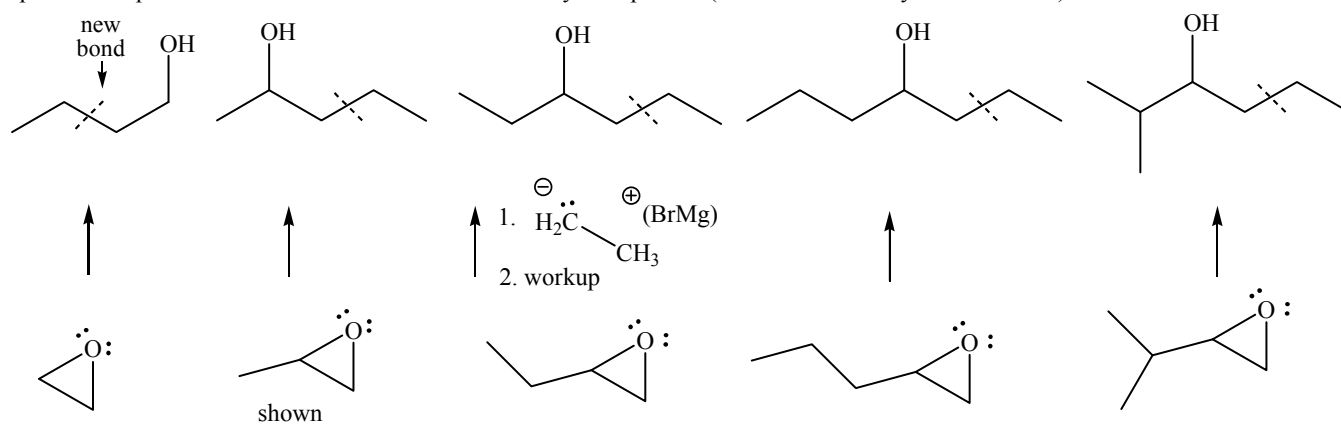
Carbonyl compounds (aldehydes and ketones) that will be made later from our starting RBr compounds (available to use until then).



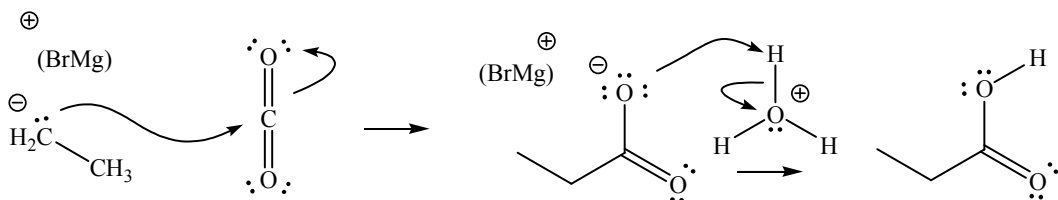
1. Grignard reagents with epoxides 2. workup : makes alcohols



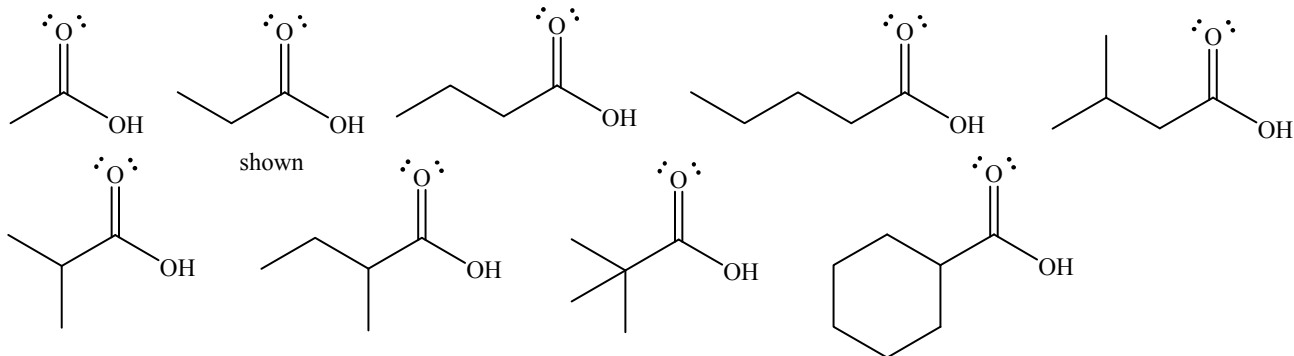
Epoxide compounds that will be made later from carbonyl compounds (available to use anytime until then).



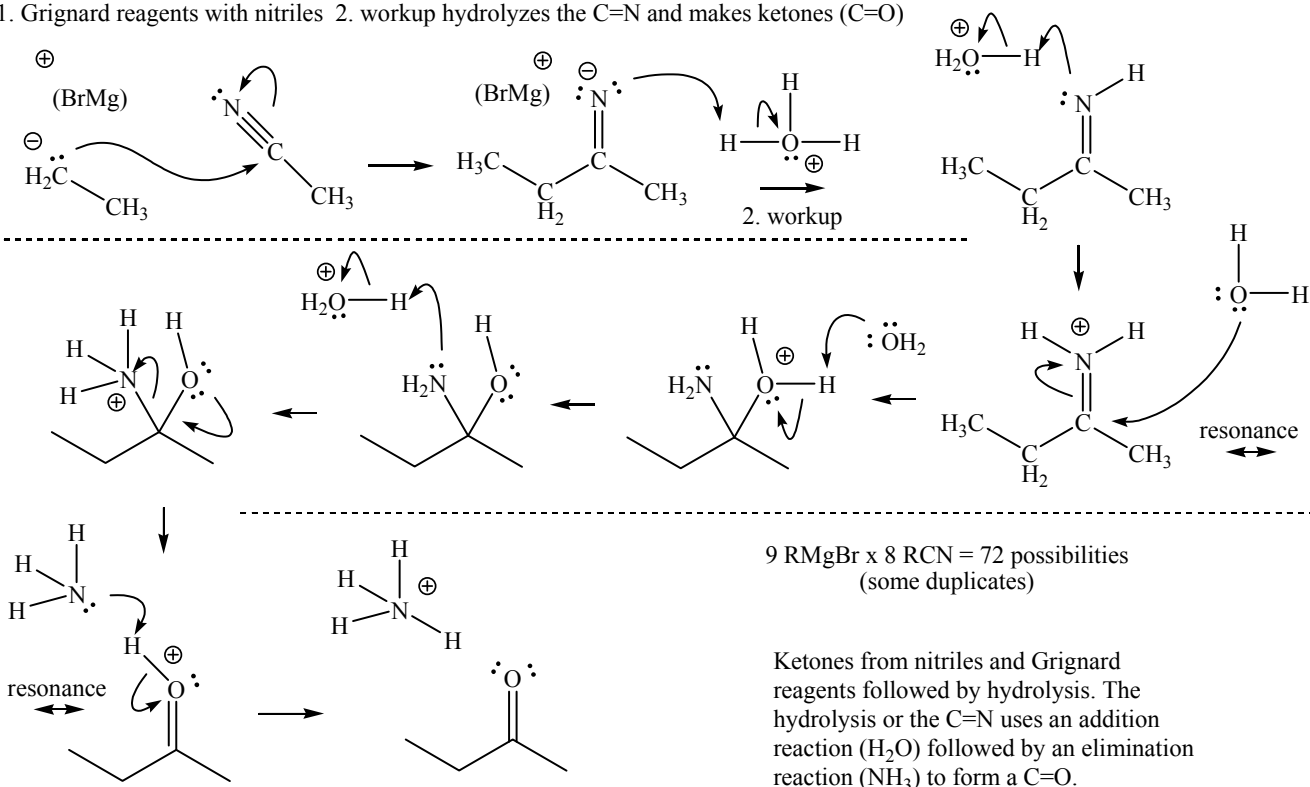
1. Grignard reagents with carbon dioxide 2. workup : makes carboxylic acids



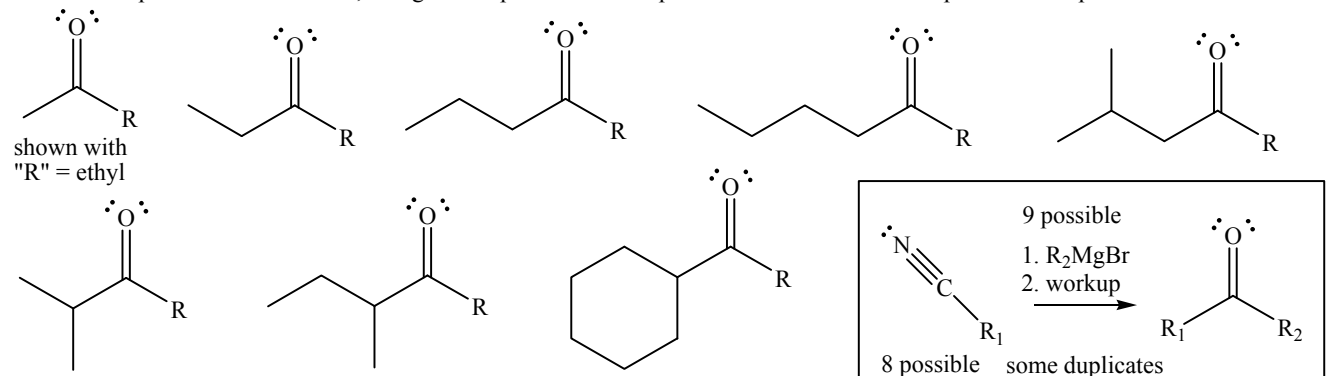
Carboxylic acids that can be made from our starting RBr compounds using the Grignard reagents with carbon dioxide.



1. Grignard reagents with nitriles 2. workup hydrolyzes the C=N and makes ketones (C=O)

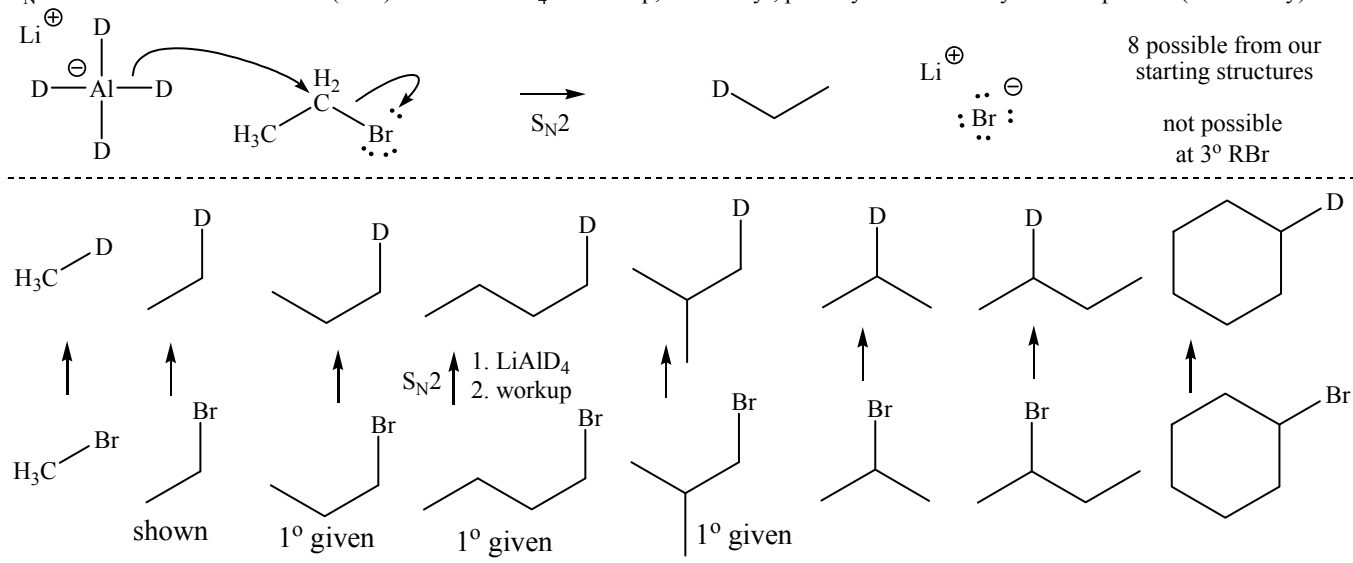


Nine Grignard reagents can be made from our starting RBr compounds and reacted with eight possible nitriles from our RBr compounds make for 72 possible combinations, though some produce similar products. Each "R" below represents nine possibilities.

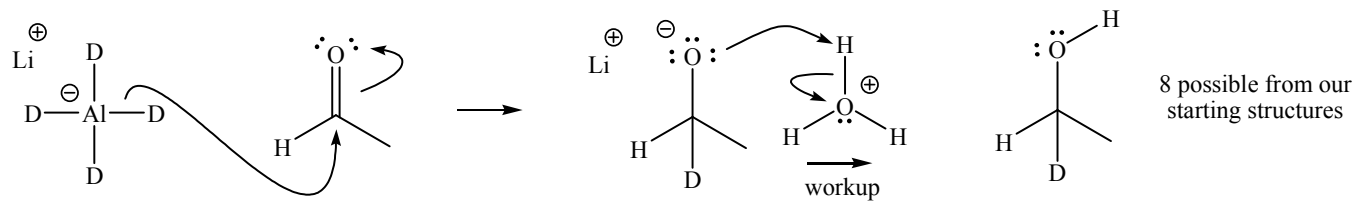


j. Lithium aluminum hydride ( $LiAlH_4$ ) = nucleophilic hydride with methyl, primary and secondary R-Br compounds (reduces Br to H, we will use  $LiAlD_4$  to show where hydride reaction occurs, D = deuteride / deuterium). Also reacts at carbonyl and epoxide electrophiles, followed by a workup step (similar to Grignard reaction above, except using nucleophilic hydride or deuteride reagents =  $LiAlH_4$  or  $LiAlD_4$  for us). For now we will consider lithium aluminium hydride ( $LiAlH_4$ ) as equivalent to sodium borohydride ( $NaBH_4$ ) and only use LAH or LAD ( $LiAlD_4$ ).

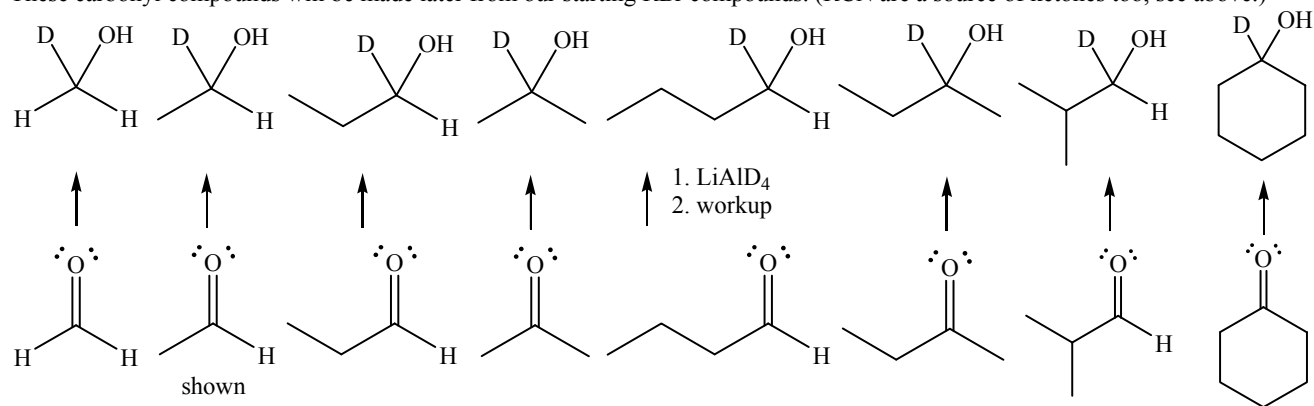
$S_N2$  reactions to reduce Br to H (or D) with 1.  $LiAlH_4$  2. workup, at methyl, primary and secondary RX compounds (not tertiary)



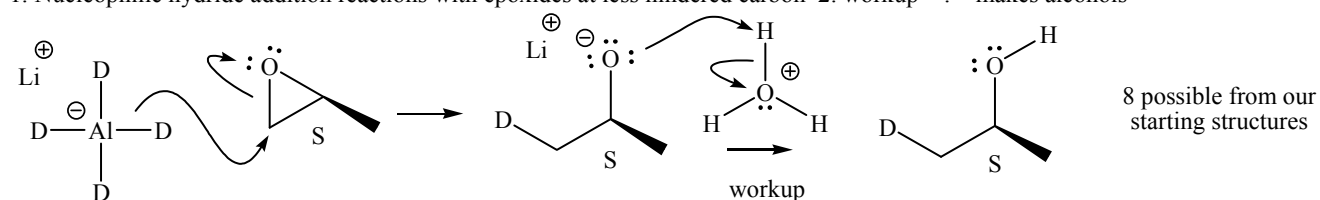
1. Nucleophilic hydride addition reactions with aldehydes and ketones 2. workup : makes alcohols



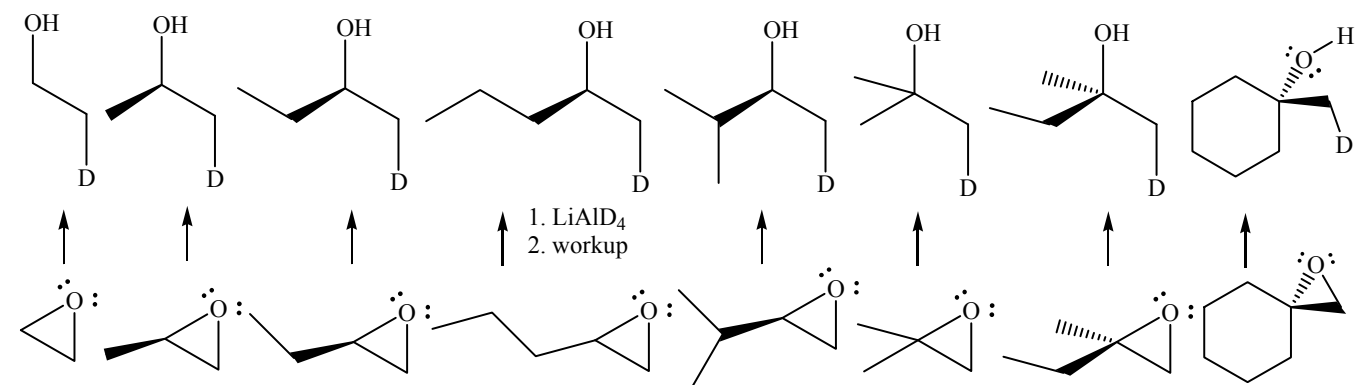
Carbonyl compounds (aldehydes and ketones) that will react with  $\text{LiAlD}_4$  / workup to form alcohols (carbonyl addition reactions). These carbonyl compounds will be made later from our starting RBr compounds. (RCN are a source of ketones too, see above.)



1. Nucleophilic hydride addition reactions with epoxides at less hindered carbon 2. workup : makes alcohols

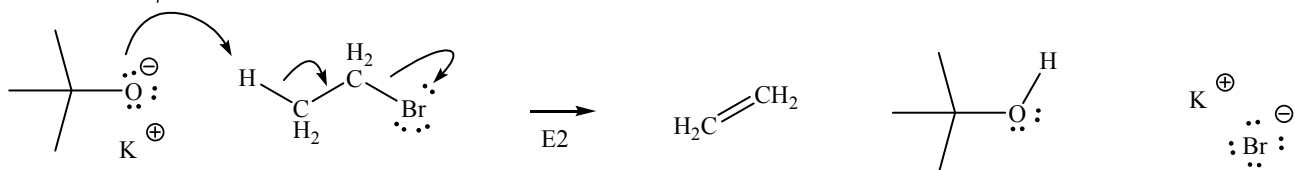


Epoxide compounds will be made later from the above carbonyl compounds and trimethylsulfonium iodide / n-butyl lithium. The first step is  $\text{S}_{\text{N}}2$  attack by hydride or deuteride on the least hindered carbon atom, followed by workup to neutralize the alkoxide.



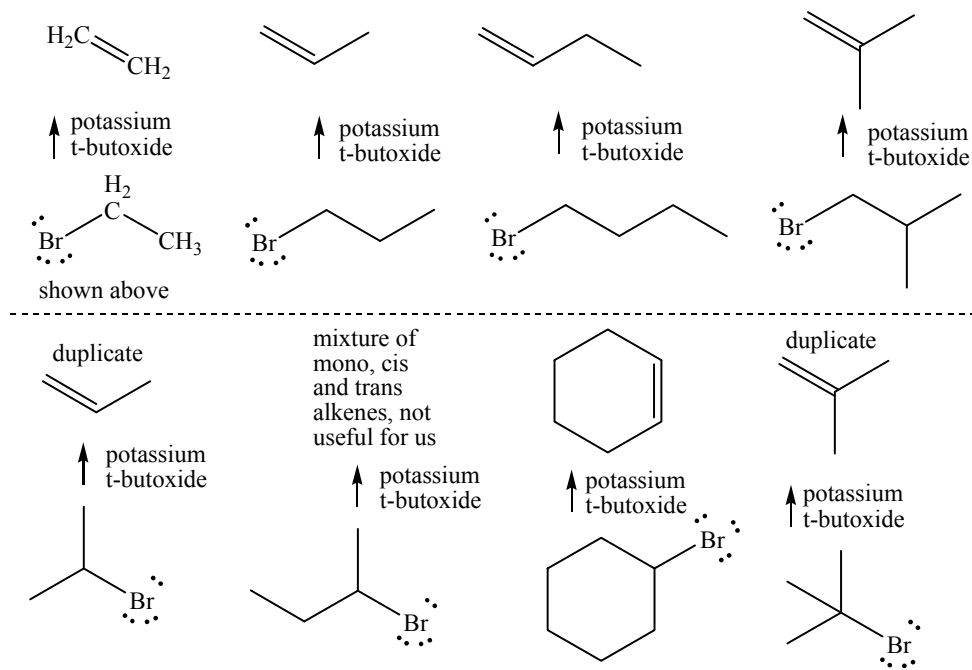
3. a. E2 elimination reactions can make alkenes from R-Br compounds (E2 reactions using bulky, basic potassium t-butoxide in our course).

E2 reactions using potassium t-butoxide and primary, secondary or tertiary RBr (eight possible from our starting RBr compounds), requires anti  $\text{C}_{\beta}\text{-H}$  and  $\text{C}_{\alpha}\text{-Br}$  to be able to start forming pi bond in transition state.



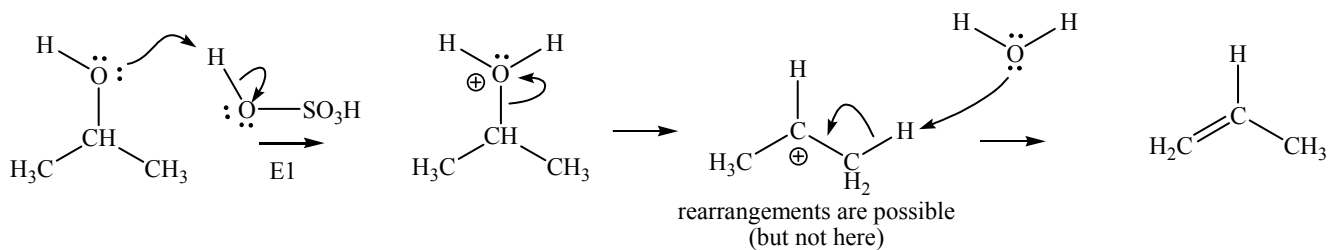


Other E2 reactions (eight possible from our starting R-Br, two are duplicates and one produces a mixture of alkene products)

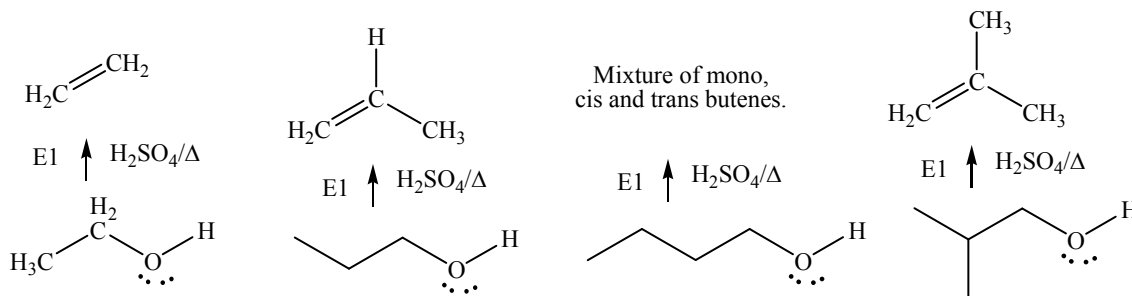


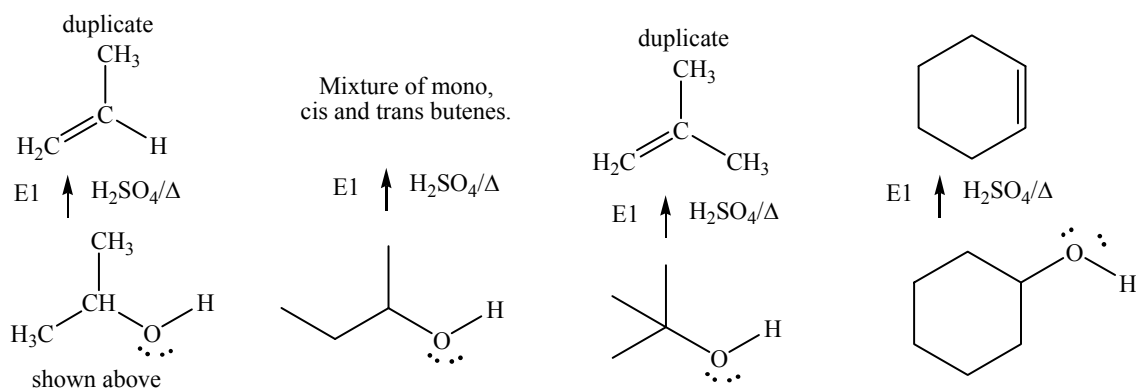
b. E1 elimination reactions can make alkenes from alcohols. ROH and concentrated sulfuric acid and heat forms alkenes and alkenes distill away from the mixture. Rearrangements are possible due to carbocation intermediates.

E1 reactions using concentrated  $\text{H}_2\text{SO}_4/\Delta$  and ROH, rearrangements are possible



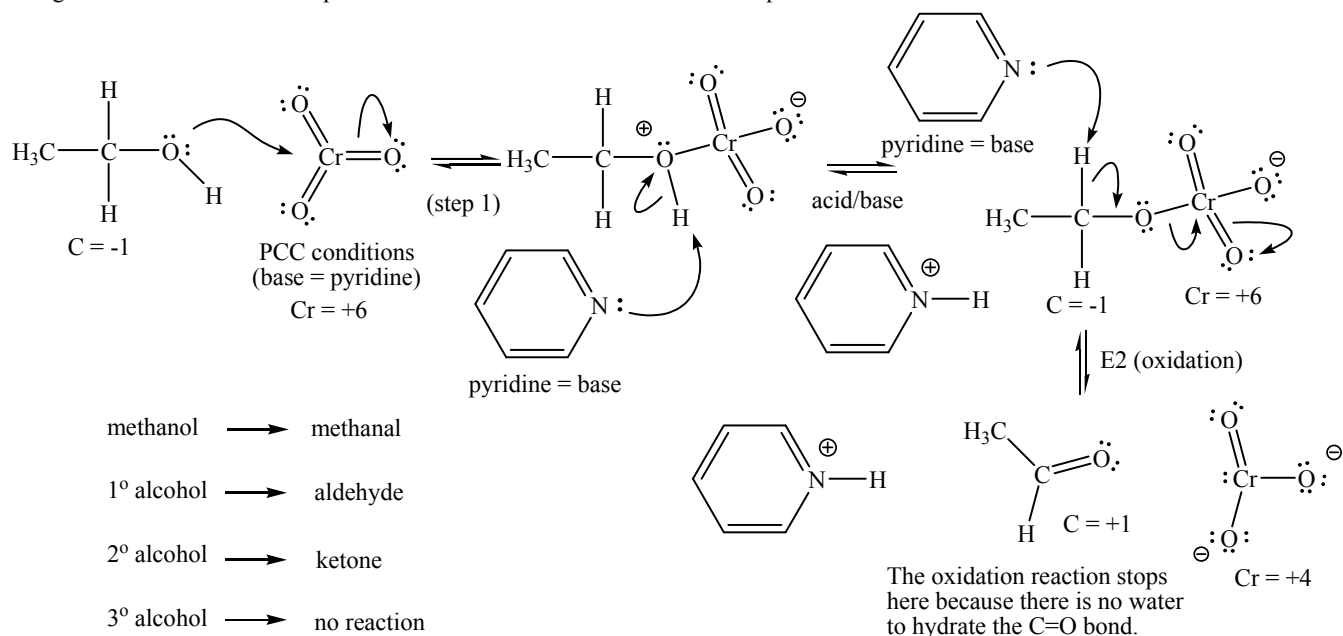
Other alcohol dehydrations to alkenes (eight ROH possible from our starting R-Br, methyl won't work because we need at least two carbons, the two straight chain, 4C alcohols won't be useful because they will produce a mixture of mono, cis and trans butenes, the other 4C skeleton produce duplicate alkenes, as do the two 3C skeletons, so only four different alkenes are produced in this E1 reaction.)



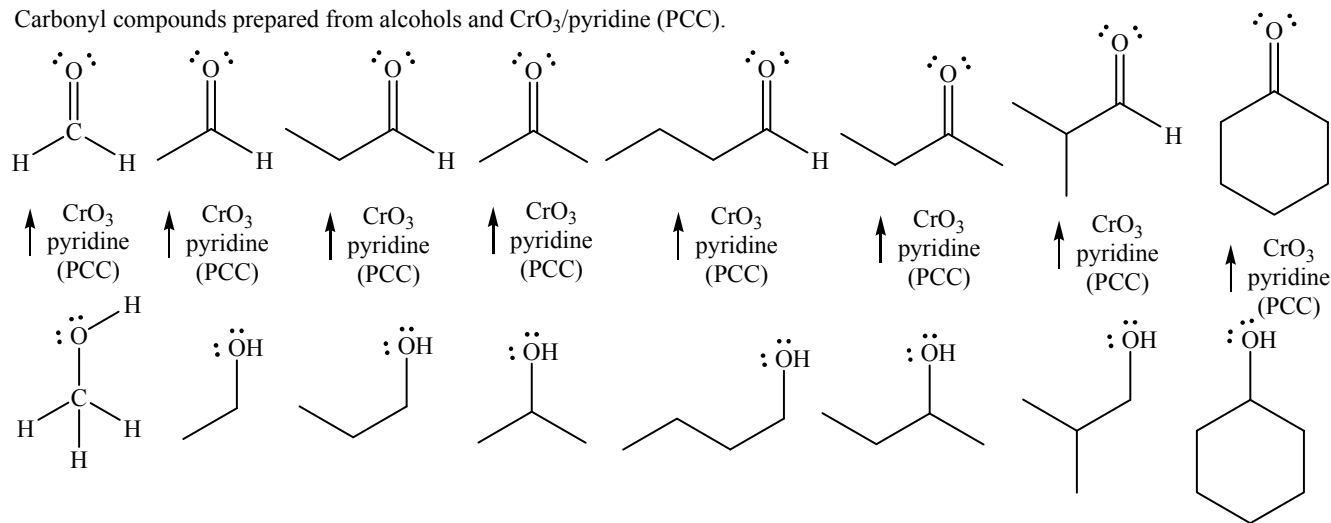


c. A very important E2 elimination reaction involves methyl, primary and secondary alcohols and highly oxidized chromium +6 (we will write it as  $\text{CrO}_3$ ). There are many variations of this overall transformation but for now we will only present one simplified version, pyridinium chlorochromate (PCC =  $\text{CrO}_3/\text{pyridine}$ ). A preliminary step forms an inorganic ester and uses pyridine as a base to pick off protons. A second step is our familiar E2 reaction, though it occurs across C and O with a Cr leaving group taking electrons with it, instead of C and C and a bromide leaving group. The details of all the steps are written out for you below. This reaction allows us to make aldehydes and ketones from methyl, primary and secondary alcohols, a very valuable functional group interconversion (FGI).

The oxidation sequence uses a methyl, primary or secondary alcohol to form a carbonyl group (aldehyde or ketone). In the first step an inorganic ester is formed and a proton is lost from the OH. In the second step an E2 elimination reaction occurs across the C-O bond.



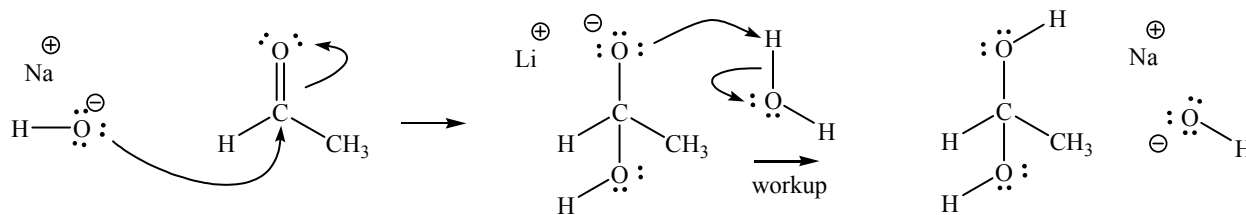
Carbonyl compounds prepared from alcohols and  $\text{CrO}_3/\text{pyridine}$  (PCC).



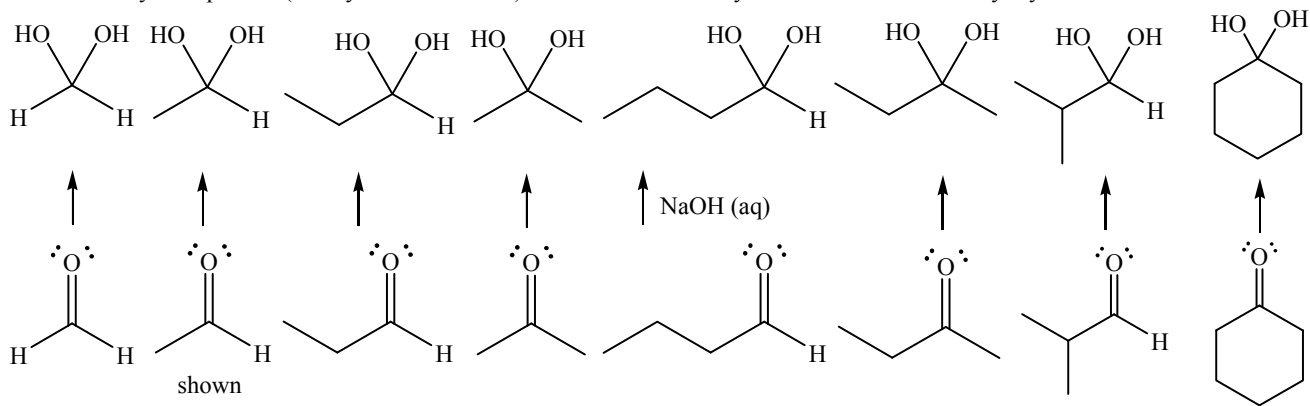
#### 4. Carbonyl addition reactions at aldehydes and ketones with strong nucleophiles (negatively charged, for us).

a. Hydration of carbonyl groups with aqueous hydroxide to make carbonyl hydrates.

1. Nucleophilic hydroxide addition reactions with aldehydes and ketones forms carbonyl hydrates, reversible reaction reforms carbonyl

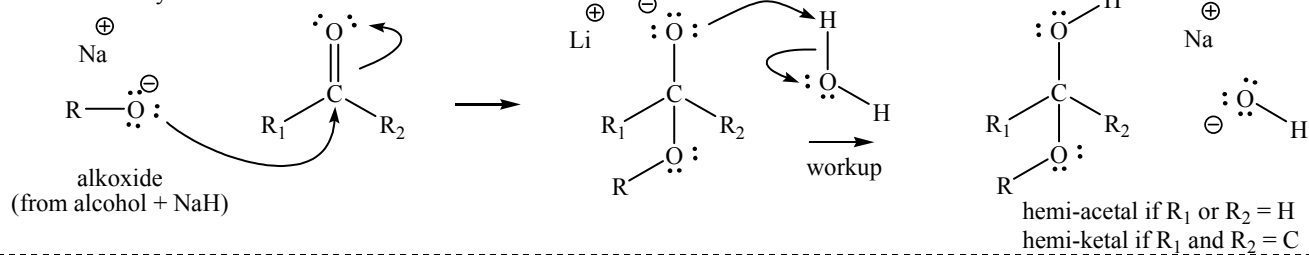


Other carbonyl compounds (aldehydes and ketones) that will react with hydroxide to form a carbonyl hydrate.

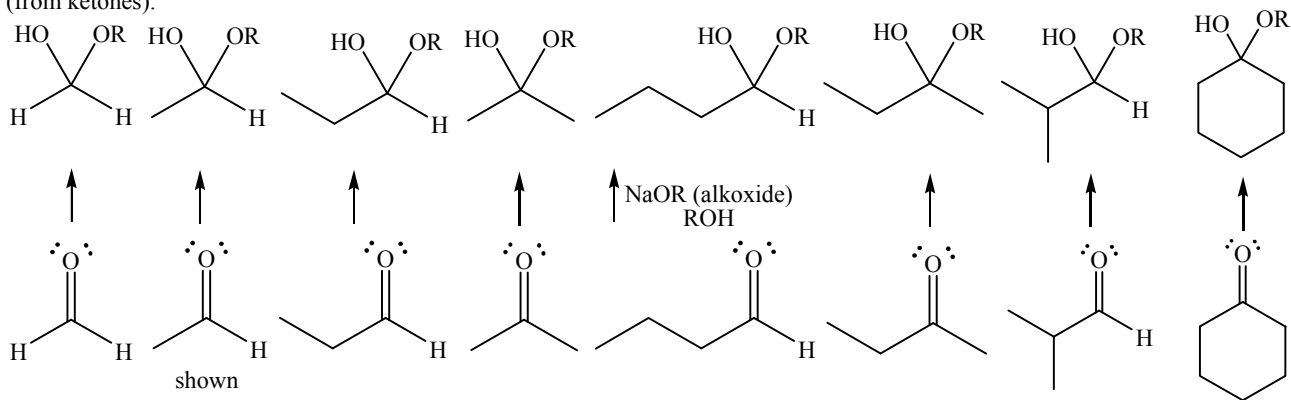


b. Carbonyl groups reacting with alcoholic alkoxides form hemi-acetals and hemi-ketals. (Similar to hydration, above.)

1. Nucleophilic alkoxide addition reactions with aldehydes and ketones forms hemi-acetals and hemi-ketals, reversible reaction reforms carbonyl

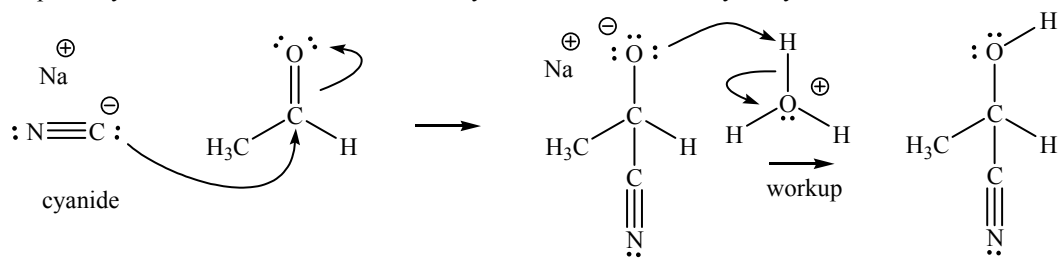


Other carbonyl compounds (aldehydes and ketones) that will react with hydroxide to form hemi-acetals (from aldehydes) and hemi-ketals (from ketones).

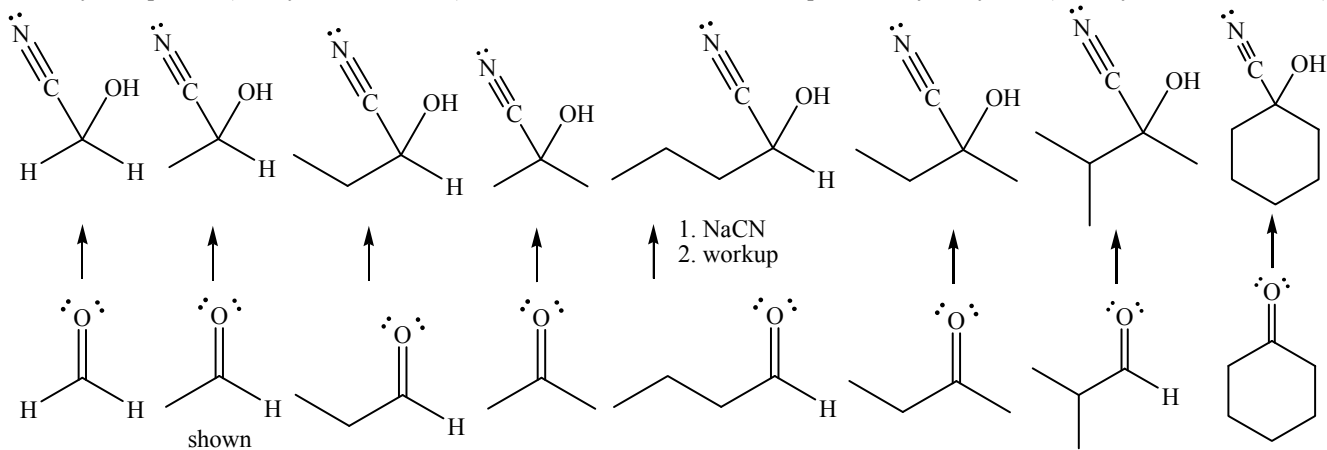


c. Carbonyl groups reacting with cyanide (C=O addition reaction) to form cyanohydrins.

Nucleophilic cyanide addition reactions with aldehydes and ketones forms cyanohydrins.

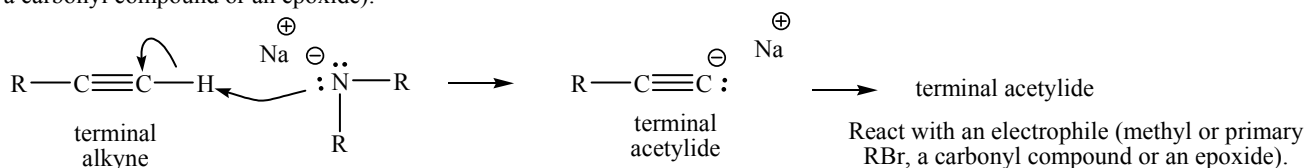


Carbonyl compounds (aldehydes and ketones) that will react with NaCN / workup to form cyanohydrins (carbonyl addition reactions).

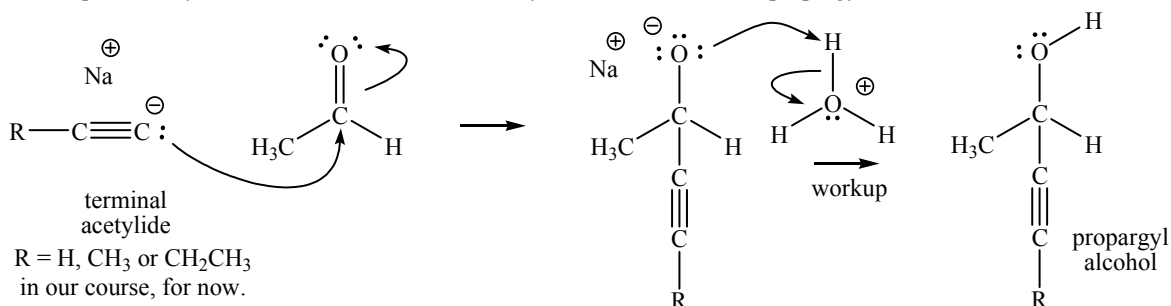


d. Carbonyl groups reacting with terminal acetylides ( $C=O$  addition reaction) to form propargylic alcohols, after workup.

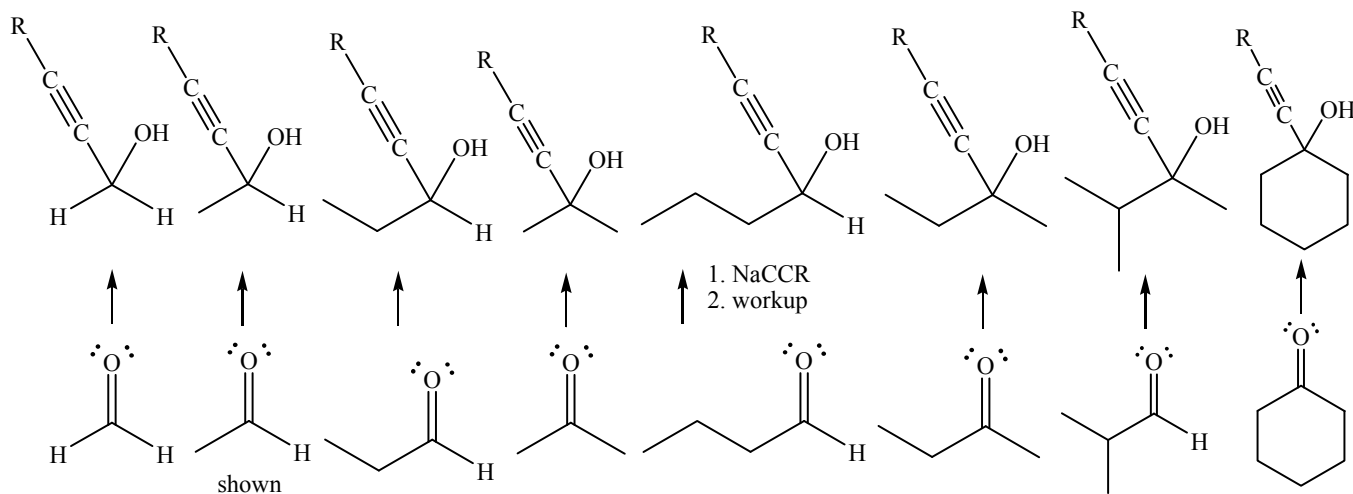
Make terminal acetylide nucleophiles from terminal alkynes and sodium amide,  $NaNR_2$ , then add electrophile (methyl or primary  $RBr$ , a carbonyl compound or an epoxide).



Nucleophilic acetylide addition reactions with aldehydes and ketones forms propargyl alcohols.

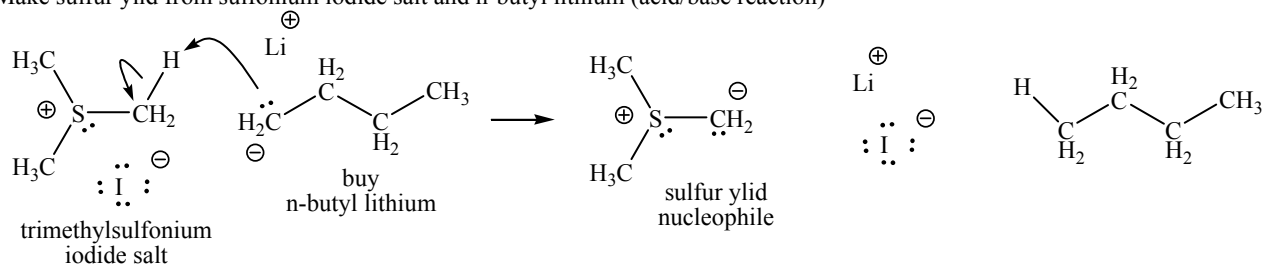


Carbonyl compounds (aldehydes and ketones) that will react with  $NaCCR$  / workup to form propargyl alcohols (carbonyl addition reactions).

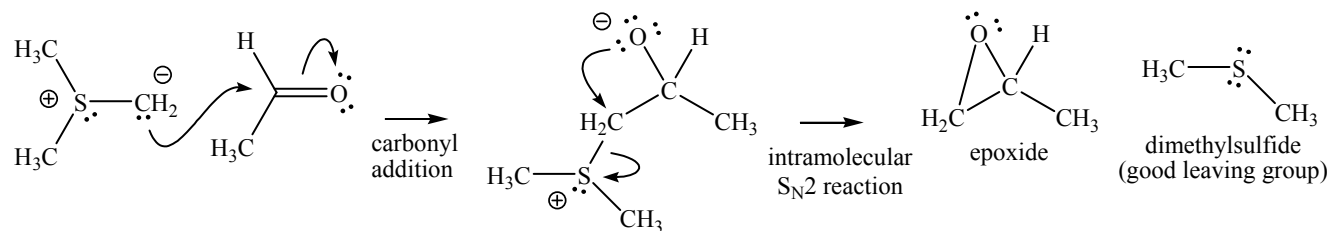


## d. Sulfur ylid additions to aldehydes and ketones – epoxide syntheses

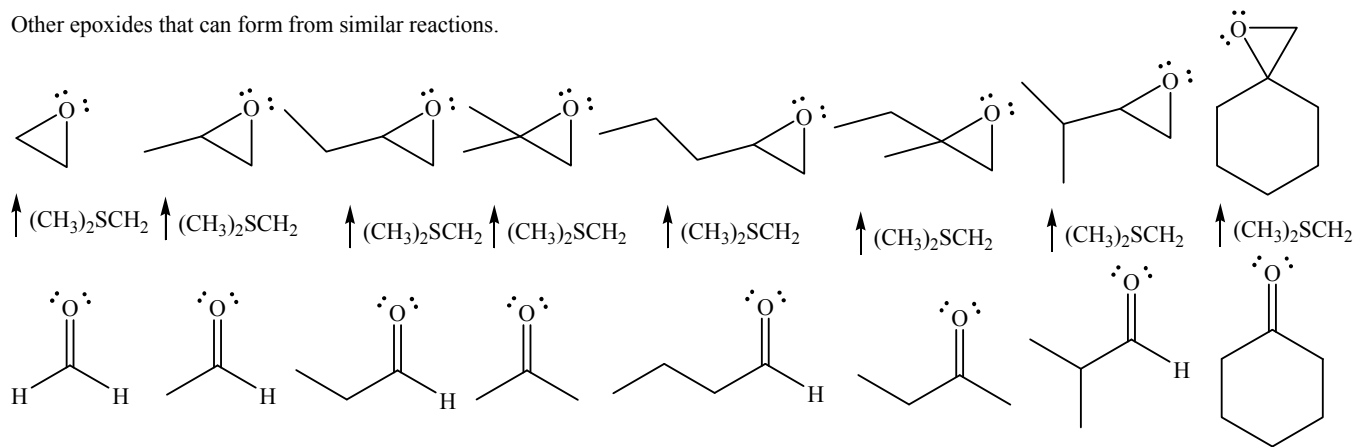
Make sulfur ylid from sulfonium iodide salt and n-butyl lithium (acid/base reaction)



Sulfur ylid reactions with carbonyl compounds makes epoxides

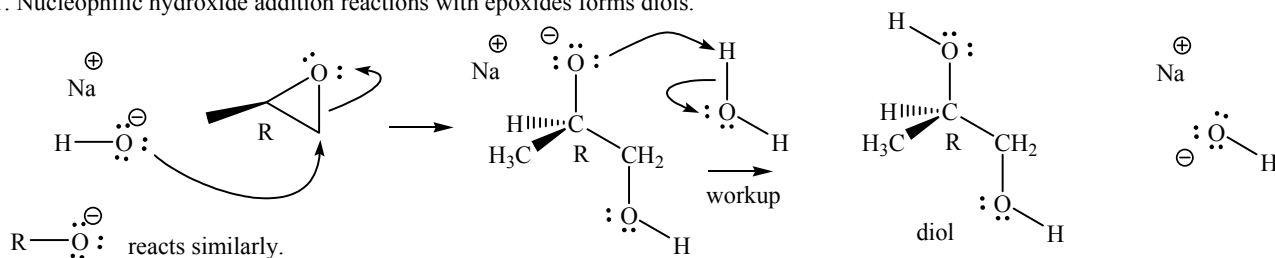


Other epoxides that can form from similar reactions.

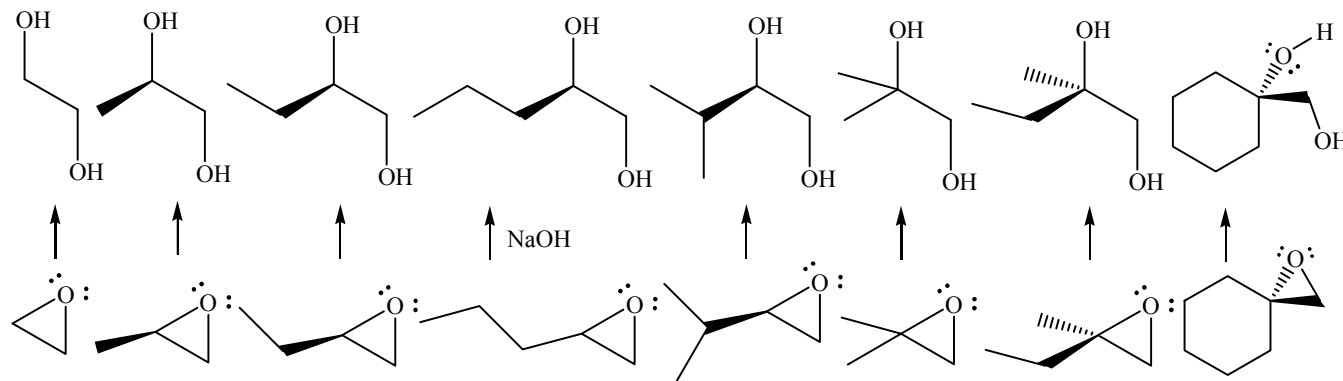


## e. Hydration of epoxide groups with aqueous hydroxide.

1. Nucleophilic hydroxide addition reactions with epoxides forms diols.

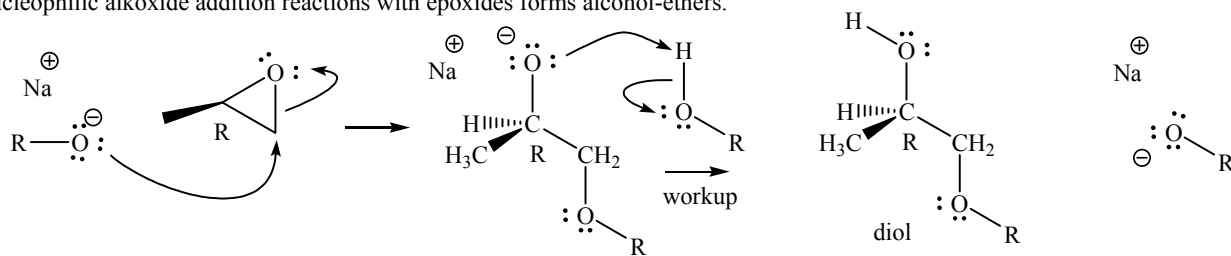


Other epoxide examples also form diols.

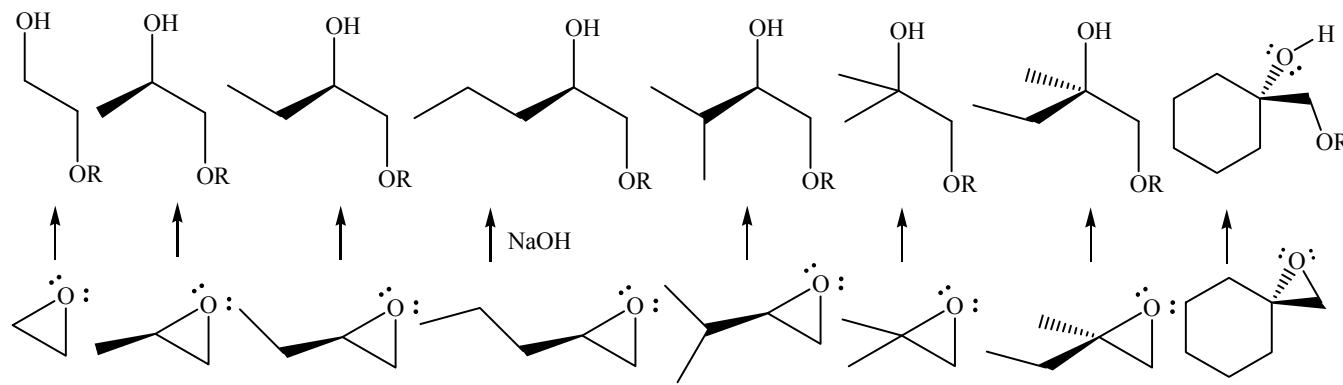


## f. Alkoxide addition to epoxide groups.

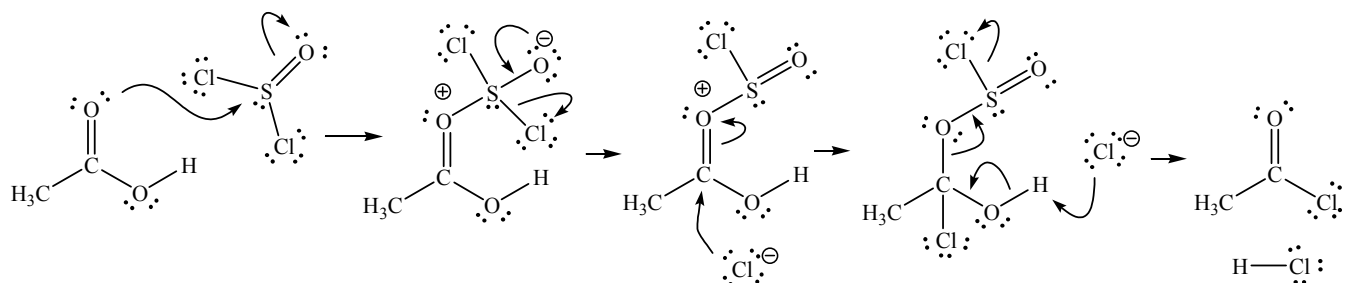
1. Nucleophilic alkoxide addition reactions with epoxides forms alcohol-ethers.



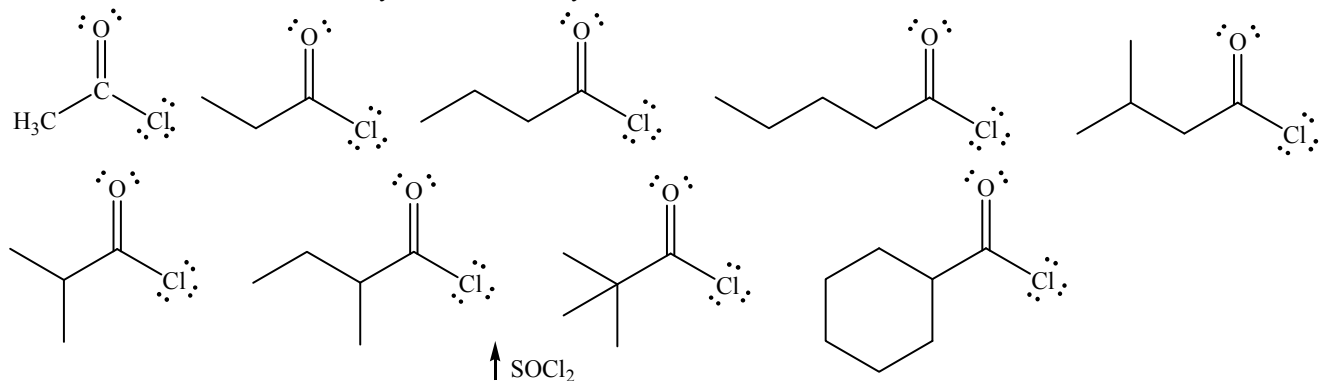
Other epoxide examples also form diols.



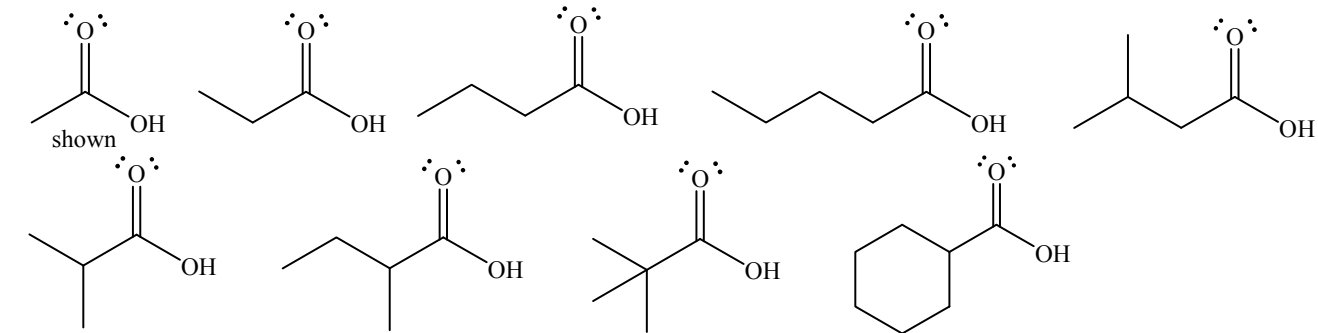
## 5. Substitution reactions at carboxyl functional groups (examples: acid chlorides and esters)

a. Carboxylic acids reacted with thionyl chloride ( $\text{SOCl}_2$ )Make acid chlorides from carboxylic acids and thionyl chloride ( $\text{SOCl}_2$ )

Nine acid chlorides made from carboxylic acids and thionyl chloride.



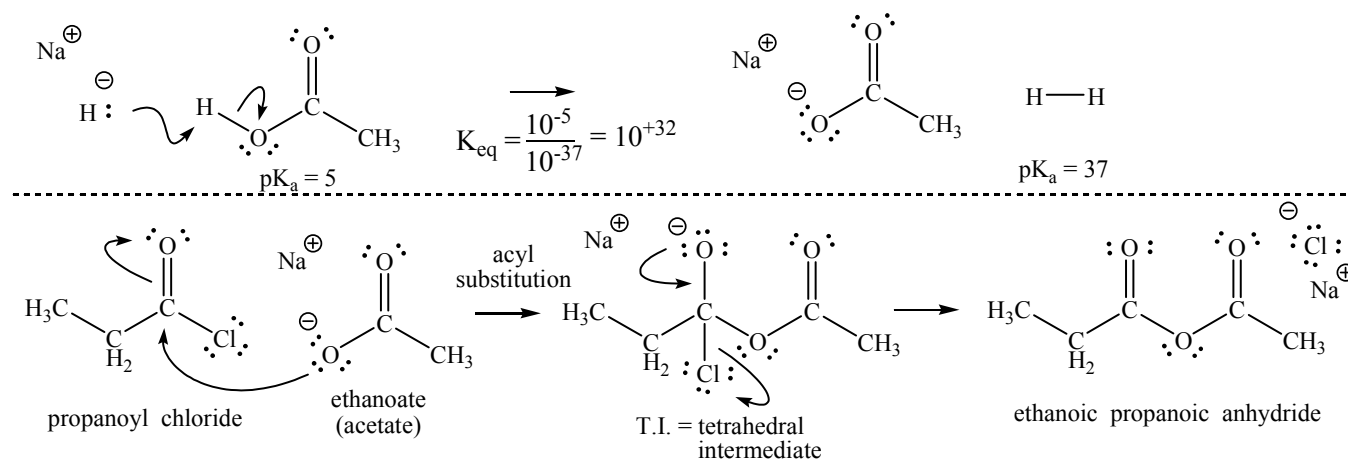
Nine carboxylic acids made from our starting RBr compounds using the Grignard reagents with carbon dioxide.



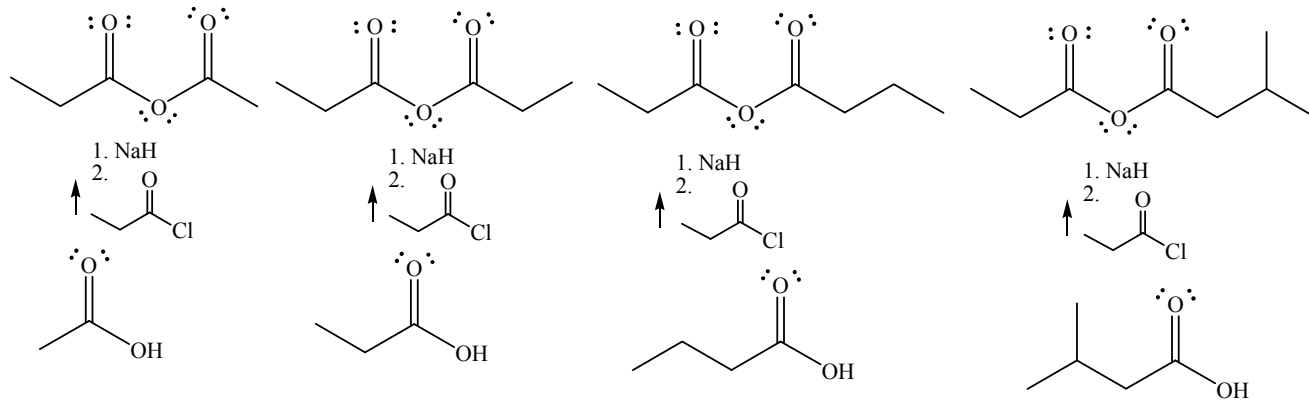


## 6. b. Anhydrides from acid chlorides (nine possible above) reacted with carboxylates (nine possible from above)

Make carboxylate from carboxylic acid and NaH (acid/base reaction) to use in reactions with acid chlorides.

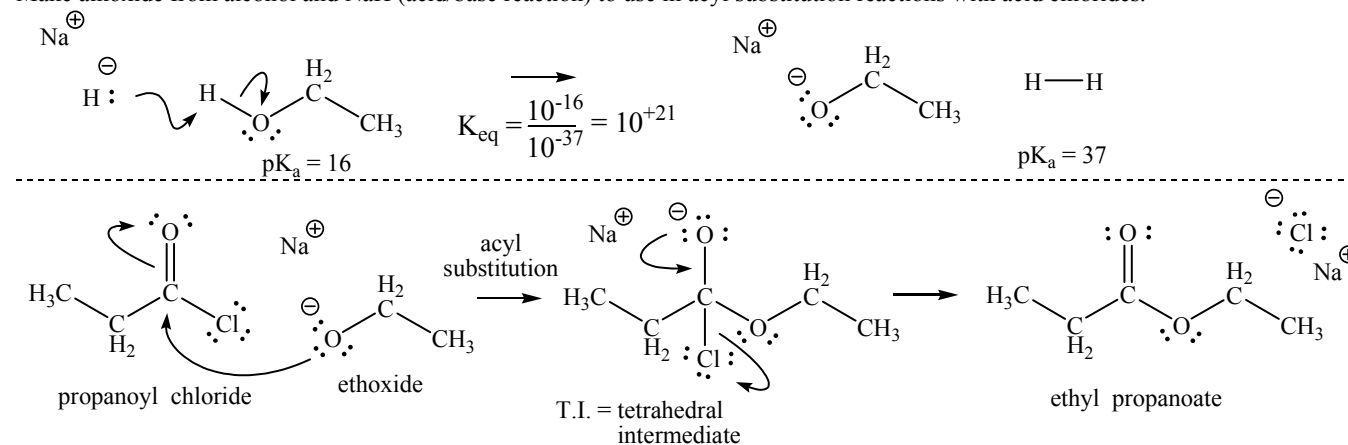


Nine acid chlorides x nine carboxylic acids = 81 possible anhydrides (with some duplicates). Only a few examples shown.

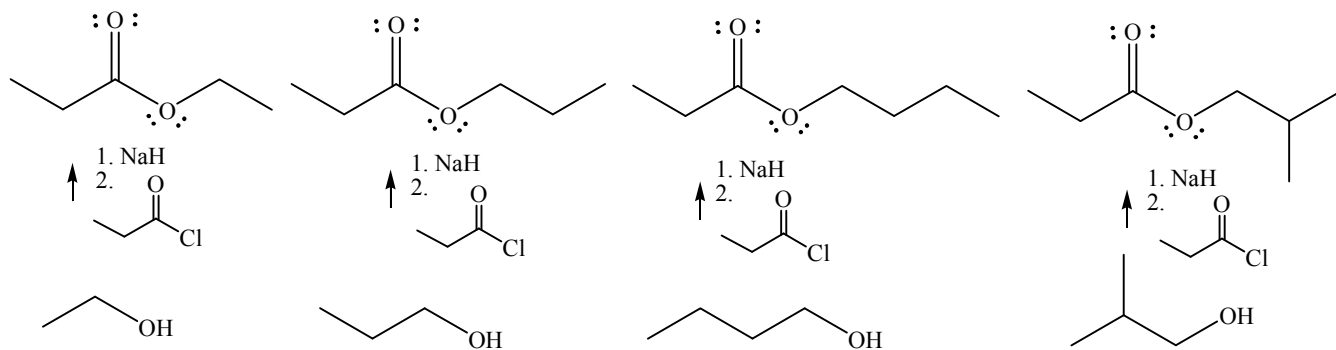


c. Nine acid chlorides reacted with nine alkoxides makes a lot of esters. This is a second way from the  $\text{S}_{\text{N}}2$  approach. Using the  $\text{S}_{\text{N}}2$  approach the carboxylate was the nucleophile reacting with the electrophilic RBr compound and in this approach the acid chloride is the electrophile reacting with the nucleophilic alkoxide.

Make alkoxide from alcohol and NaH (acid/base reaction) to use in acyl substitution reactions with acid chlorides.

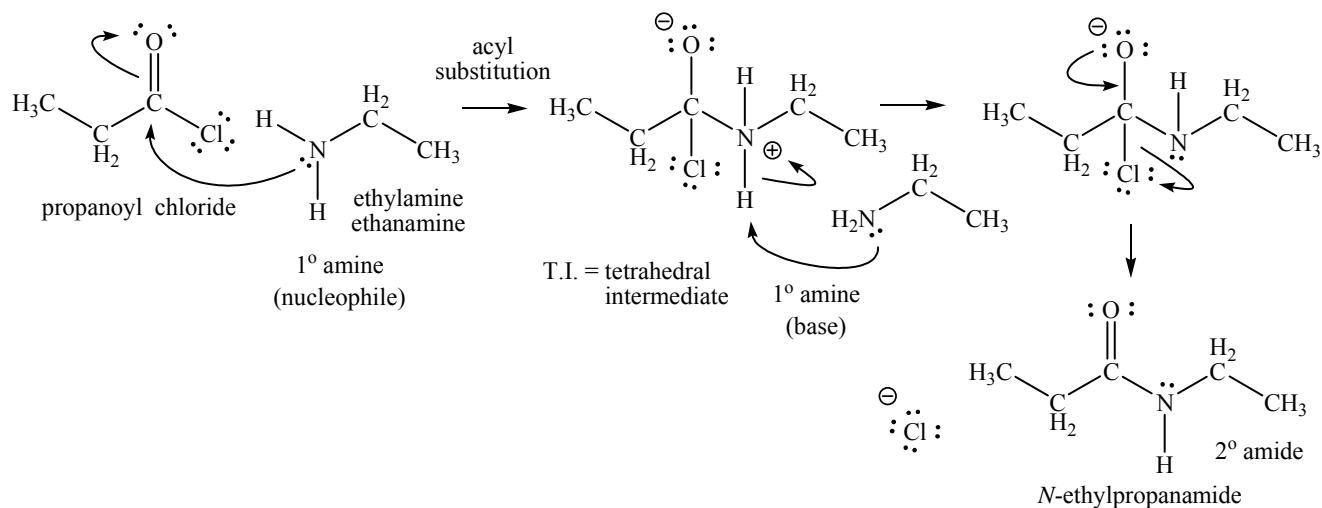


Nine acid chlorides x nine alcohols = 81 possible esters. Only a few examples shown.

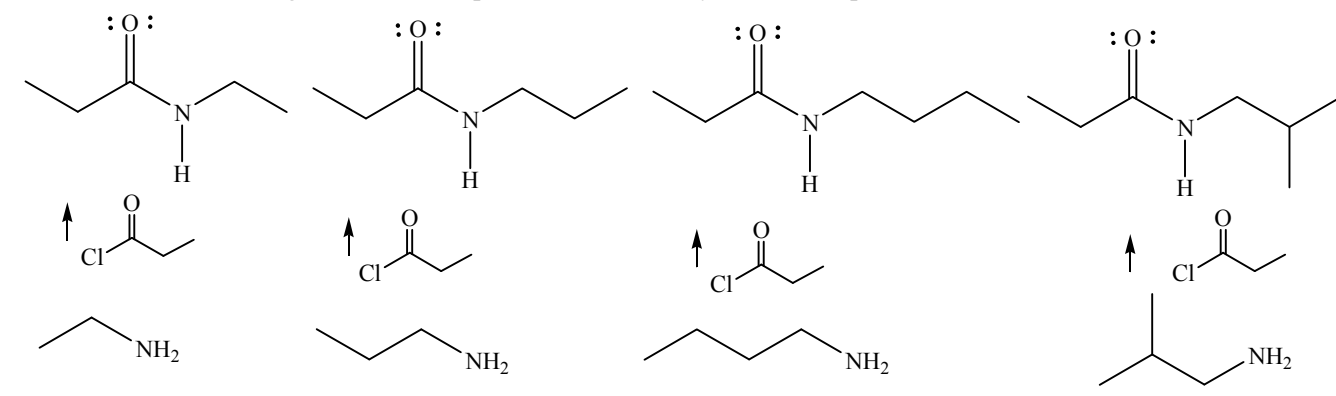


d. Nine acid chlorides reacted with eight amines makes a lot of amides. In this reaction the amine is both a nucleophile and a base.

Make amides from amines and acid chlorides using acyl substitution reactions.

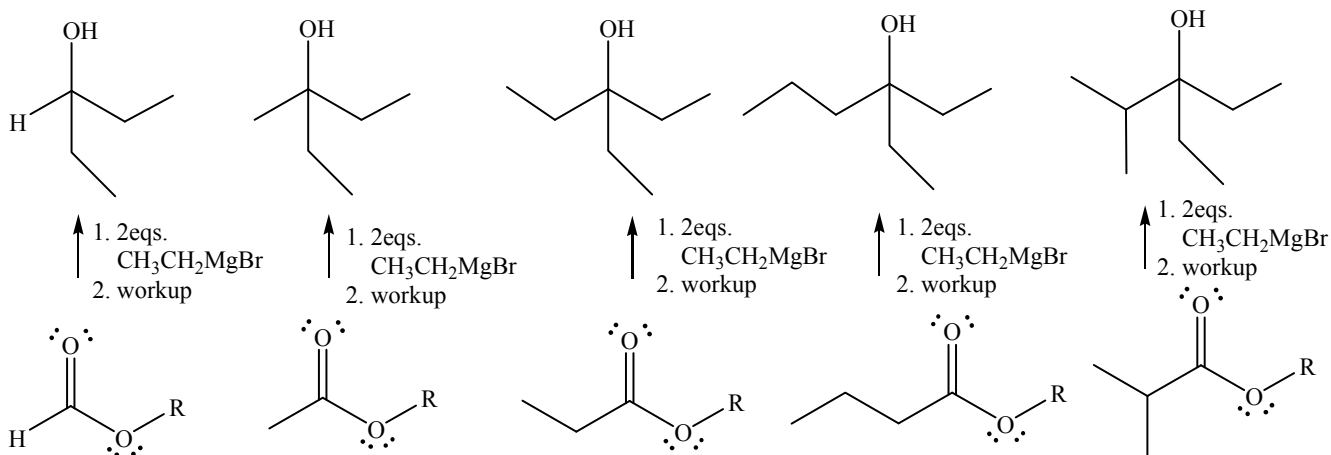
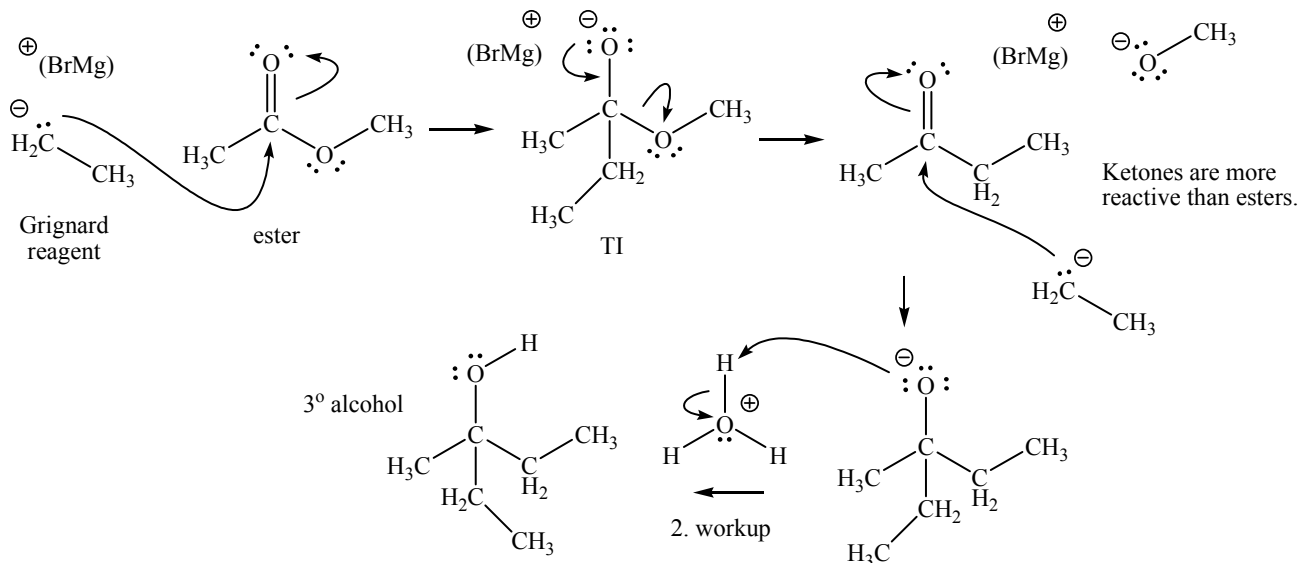


Nine acid chlorides x eight amines = 72 possible esters. Only a few examples shown.



## e. Esters reacted with Grignard reagents, followed by workup.

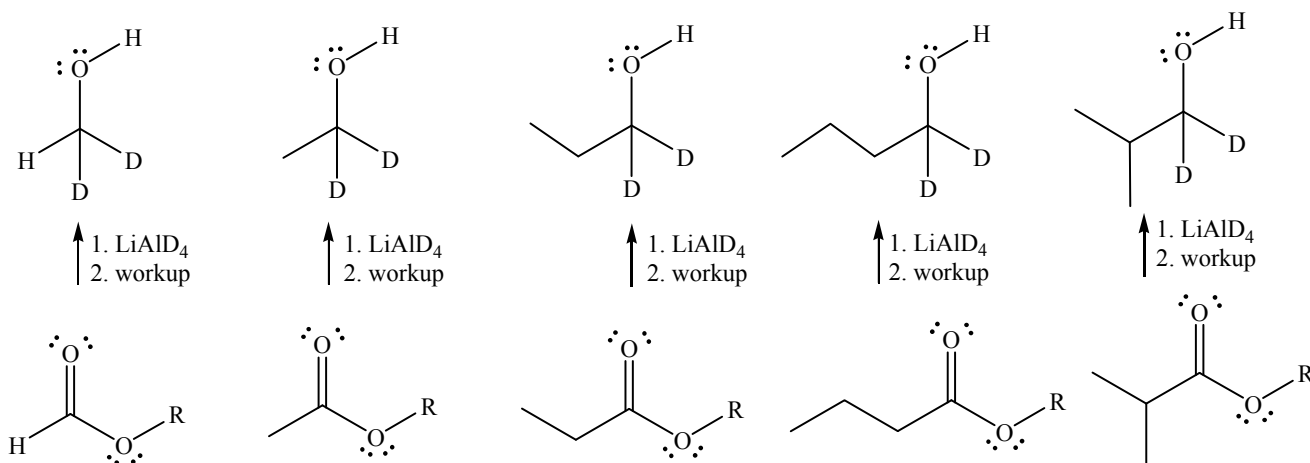
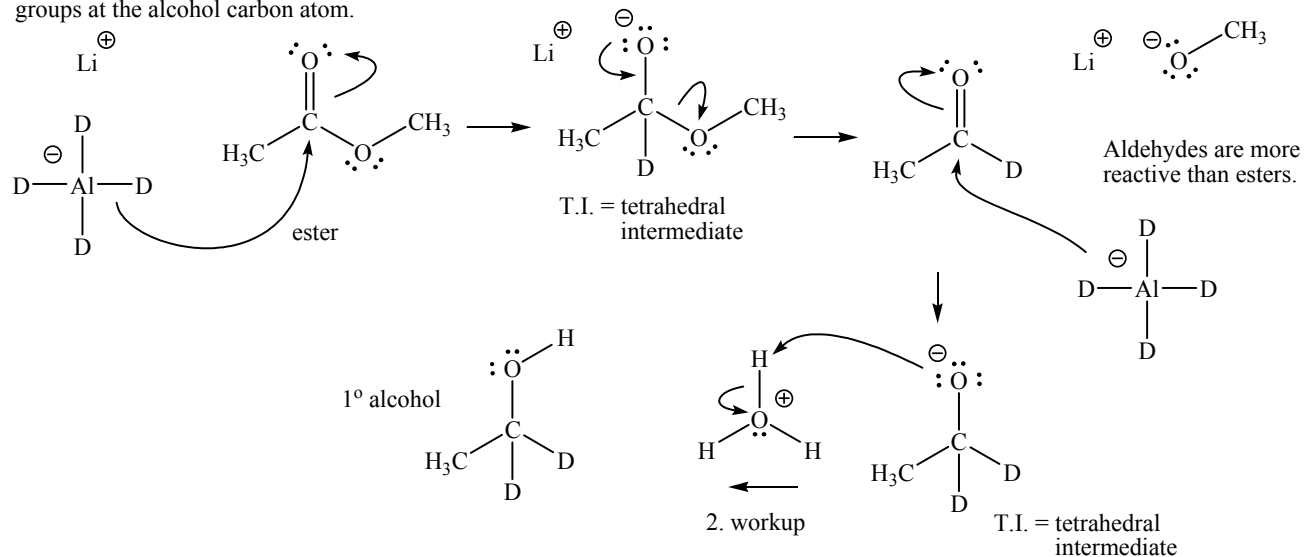
1. React 2 equivalents of Grignard reagent with esters. This occurs in 2 steps. The Grignard reagent adds to the ester carbonyl forming a tetrahedral intermediate (TI), which collapses back to a carbonyl group with the extrusion of the alkoxide anion. The newly formed ketone is more reactive than an ester so it immediately reacts with another equivalent of Grignard reagent forming a tertiary alkoxide.
2. The final workup step protonates the alkoxide oxygen forming a tertiary alcohol with 2 identical groups at the alcohol carbon atom.



Carbonyl compounds (aldehydes and ketones) that will be made later from our starting RBr compounds (available to use until then).

## f. Reactions of esters reacted with lithium aluminum hydride (deuteride), followed by workup.

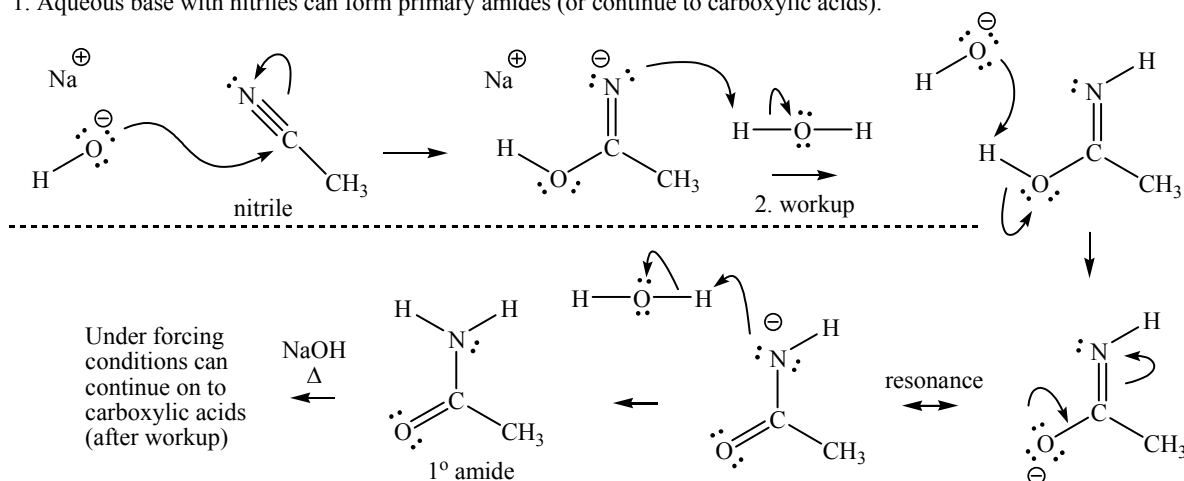
1. React 2 equivalents of hydride (deuteride) from LAH (LAD) with esters. This occurs in 2 steps. The hydride (deuteride) reagent adds to the ester carbonyl forming a tetrahedral intermediate (TI), which collapses back to a carbonyl group with the extrusion of the alkoxide anion. The newly formed aldehyde is more reactive than an ester so it immediately reacts with another equivalent of Grignard reagent forming a primary alkoxide. 2. The final workup step protonates the alkoxide oxygen forming a primary alcohol with 2 identical groups at the alcohol carbon atom.



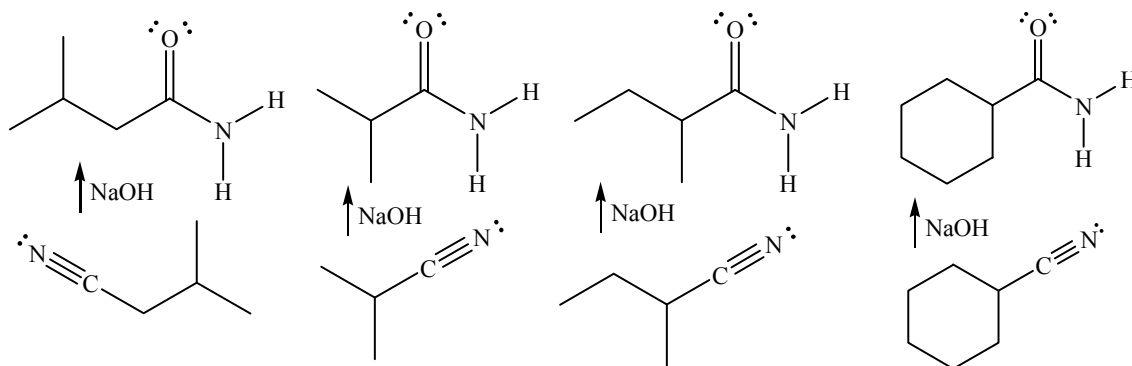
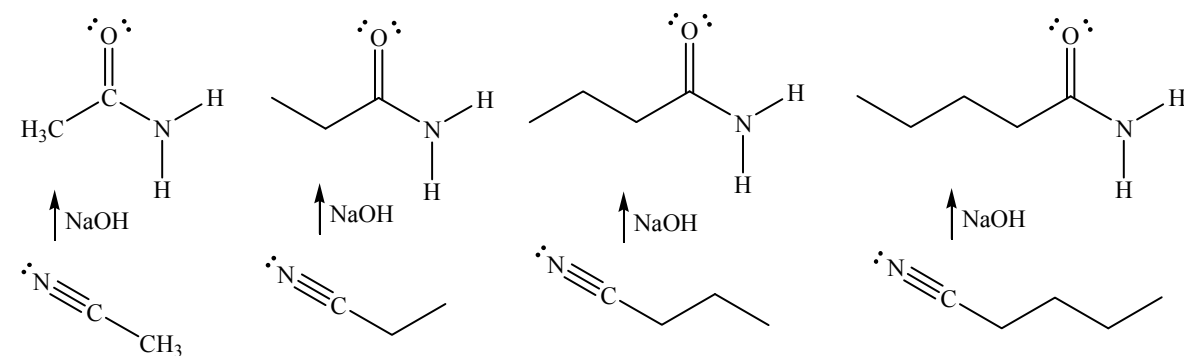
Carbonyl compounds (aldehydes and ketones) that will be made later from our starting RBr compounds (available to use until then).

g. Nitriles reacted with aqueous sodium hydroxide, followed by workup.

1. Aqueous base with nitriles can form primary amides (or continue to carboxylic acids).

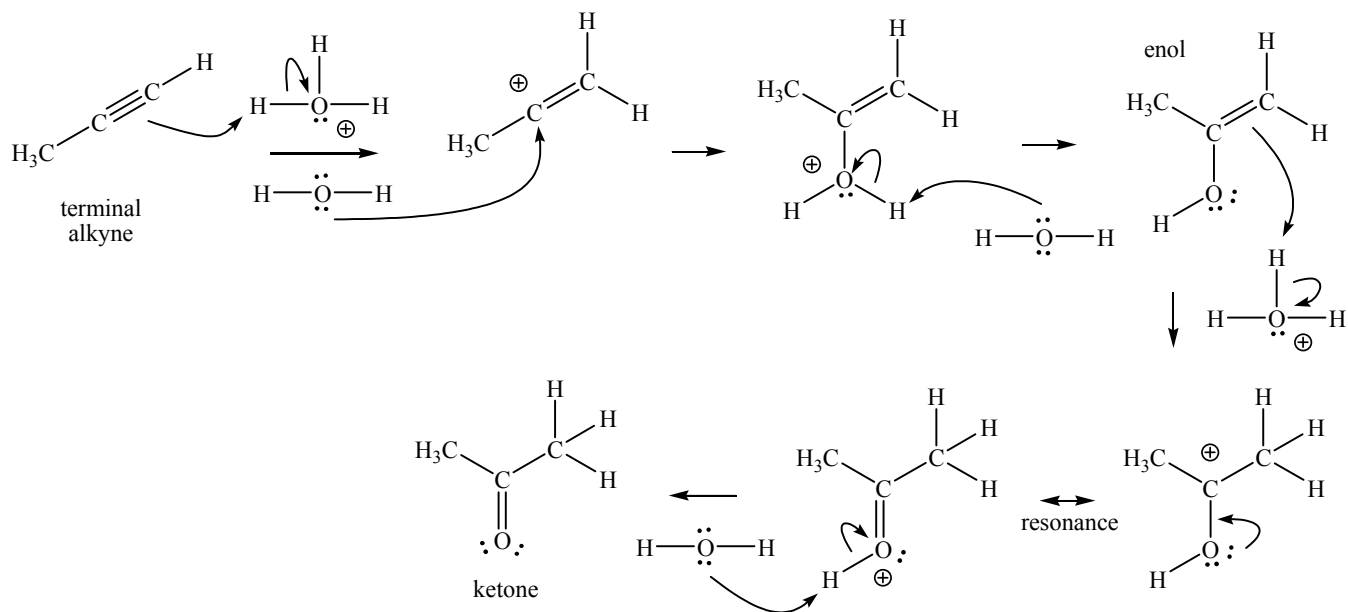


Other nitriles to consider.

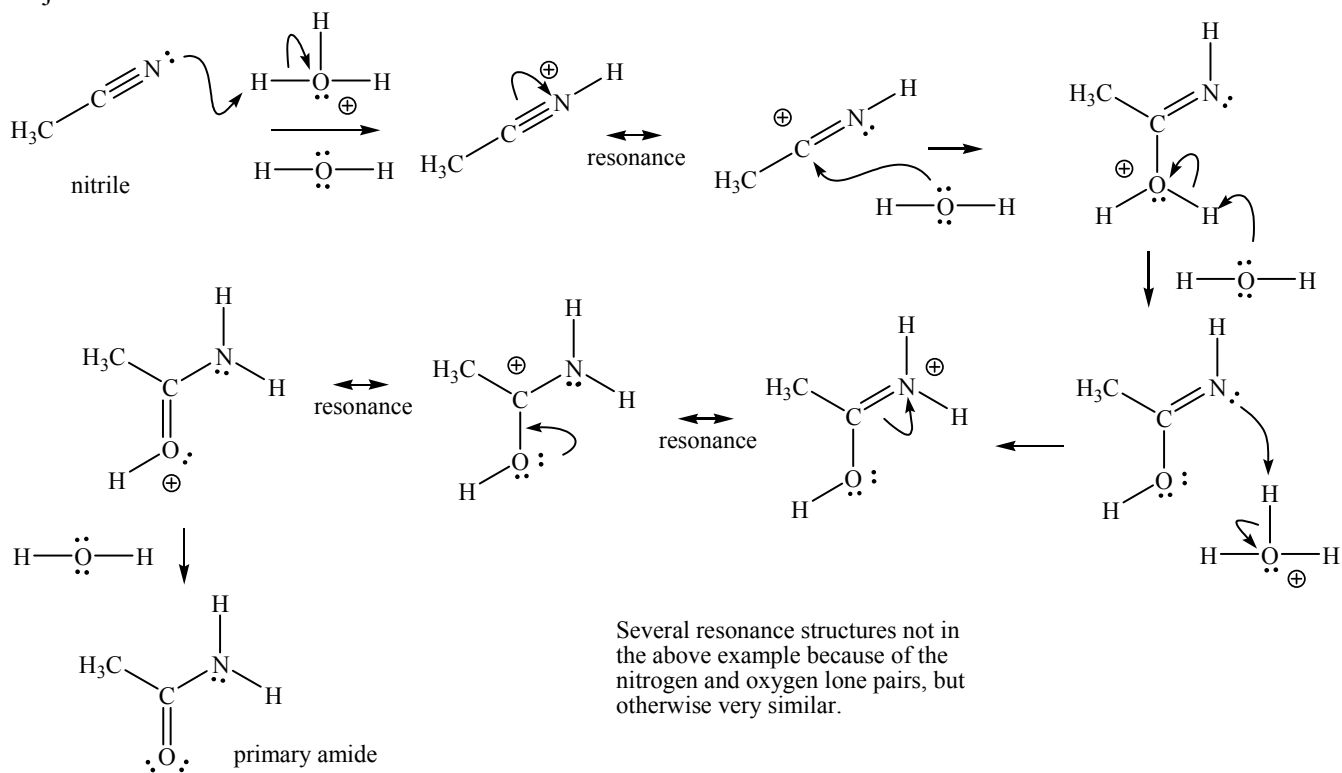


## 7. Hydrolysis of nitriles and terminal alkynes in aqueous sulfuric acid.

## a. Synthesis of ketones from aqueous acid hydrolysis of alkynes.

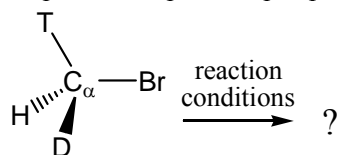
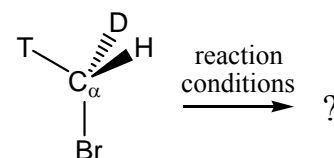


## b. Synthesis of primary amides from aqueous acid hydrolysis of nitriles. Notice the similarities to the reaction, just above.

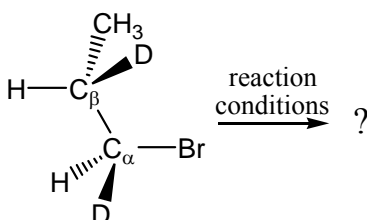
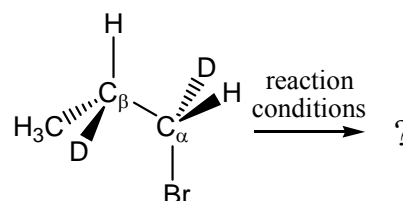


**Basic RX patterns to know, with isotope substitutions to show mechanism details**(horizontal and vertical perspectives, templates for studying S<sub>N</sub> and E mechanisms)

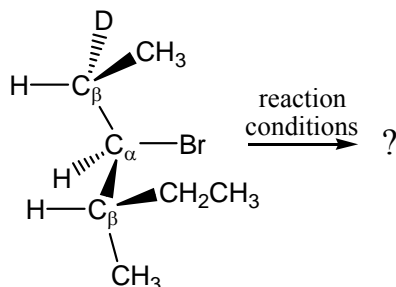
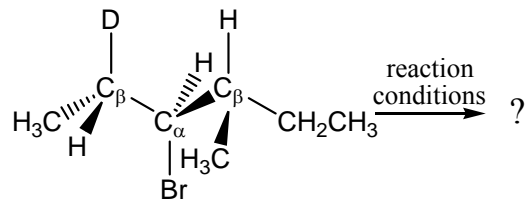
Example 1 - two possible perspectives (deuterium and tritium are isotopes of hydrogen that can be distinguished)

**S-bromoderteriotritiomethane**  
R-bromoderteriotritiomethane**methyl RX example****Bold = actual structure**  
others = possible structures**S-bromoderteriotritiomethane**  
R-bromoderteriotritiomethane

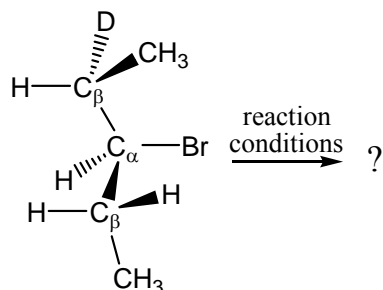
Example 2 - two possible perspectives (deuterium is an isotope of hydrogen that can be distinguished)

**(1S,2S)- 1,2-dideuterio-1-bromopropane**  
(1R,2R)- 1,2-dideuterio-1-bromopropane  
(1R,2S)- 1,2-dideuterio-1-bromopropane  
(1S,2R)- 1,2-dideuterio-1-bromopropane**primary RX example****Bold = actual structure**  
others = possible structures**(1S,2R)- 1,2-dideuterio-1-bromopropane**  
(1S,2S)- 1,2-dideuterio-1-bromopropane  
(1R,2R)- 1,2-dideuterio-1-bromopropane  
(1R,2S)- 1,2-dideuterio-1-bromopropane

Example 4 - two possible perspectives (deuterium is an isotope of hydrogen that can be distinguished)

**(2S,3R,4S)-2-deuterio-4-methyl-3-bromohexane**  
(2R,3S,4R)-2-deuterio-4-methyl-3-bromohexane  
(2S,3S,4S)-2-deuterio-4-methyl-3-bromohexane  
(2R,3R,4R)-2-deuterio-4-methyl-3-bromohexane  
(2S,3S,4R)-2-deuterio-4-methyl-3-bromohexane  
(2R,3R,4S)-2-deuterio-4-methyl-3-bromohexane  
(2S,3R,4R)-2-deuterio-4-methyl-3-bromohexane  
(2R,3S,4S)-2-deuterio-4-methyl-3-bromohexane**secondary RX example****(2S,3S,4S)-2-deuterio-4-methyl-3-bromohexane**  
(2R,3R,4R)-2-deuterio-4-methyl-3-bromohexane  
(2S,3R,4S)-2-deuterio-4-methyl-3-bromohexane  
(2R,3S,4R)-2-deuterio-4-methyl-3-bromohexane  
(2S,3S,4R)-2-deuterio-4-methyl-3-bromohexane  
(2R,3R,4S)-2-deuterio-4-methyl-3-bromohexane  
(2S,3R,4R)-2-deuterio-4-methyl-3-bromohexane  
(2R,3S,4S)-2-deuterio-4-methyl-3-bromohexane

Example 3 - two possible perspectives (deuterium is an isotope of hydrogen that can be distinguished)



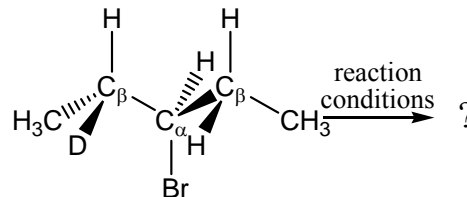
**(2S,3R)-3-deuterio-2-bromobutane**

(2R,3S)-3-deuterio-2-bromobutane

(2S,3S)-3-deuterio-2-bromobutane

(2R,3R)-3-deuterio-2-bromobutane

**secondary RX example**



**(2R,3R)-3-deuterio-2-bromobutane**

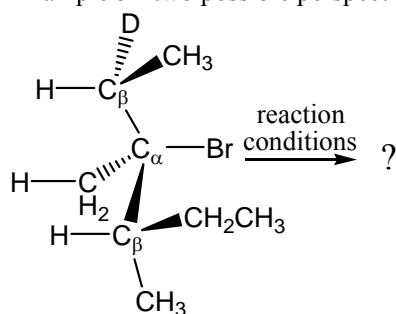
(2S,3S)-3-deuterio-2-bromobutane

(2S,3R)-3-deuterio-2-bromobutane

(2R,3S)-3-deuterio-2-bromobutane

**Bold = actual structure**  
others = possible structures

Example 5 - two possible perspectives (deuterium is an isotope of hydrogen that can be distinguished)



**(2S,3R,4S)-2-deuterio-4-methyl-3-bromohexane**

(2R,3S,4R)-2-deuterio-4-methyl-3-bromohexane

(2S,3S,4S)-2-deuterio-4-methyl-3-bromohexane

(2R,3R,4R)-2-deuterio-4-methyl-3-bromohexane

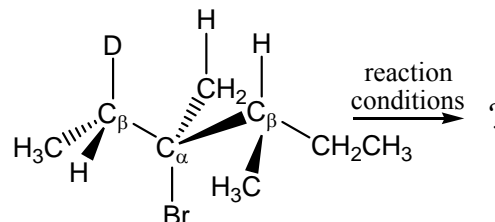
(2S,3S,4R)-2-deuterio-4-methyl-3-bromohexane

(2R,3R,4S)-2-deuterio-4-methyl-3-bromohexane

(2R,3S,4S)-2-deuterio-4-methyl-3-bromohexane

(2S,3R,4R)-2-deuterio-4-methyl-3-bromohexane

**tertiary RX example**



**(2S,3S,4S)-2-deuterio-4-methyl-3-bromohexane**

(2R,3R,4R)-2-deuterio-4-methyl-3-bromohexane

(2S,3R,4S)-2-deuterio-4-methyl-3-bromohexane

(2R,3S,4R)-2-deuterio-4-methyl-3-bromohexane

(2S,3S,4R)-2-deuterio-4-methyl-3-bromohexane

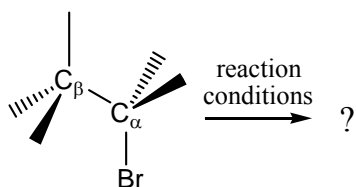
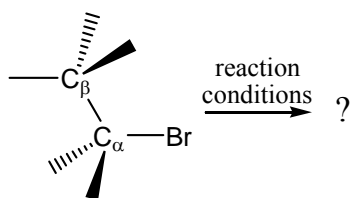
(2R,3R,4S)-2-deuterio-4-methyl-3-bromohexane

(2R,3S,4S)-2-deuterio-4-methyl-3-bromohexane

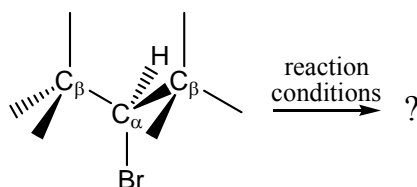
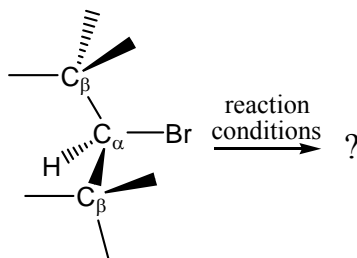
(2S,3R,4R)-2-deuterio-4-methyl-3-bromohexane

### Blank Templates

**primary RX examples**



**secondary RX examples**



**tertiary RX examples**

