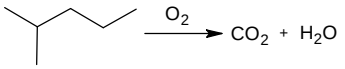
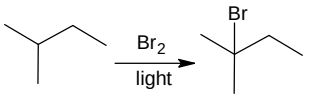
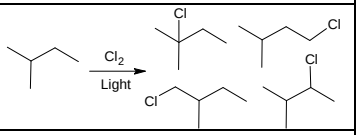
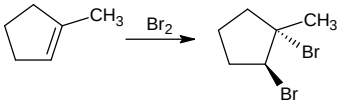
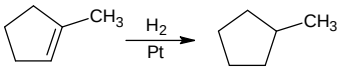
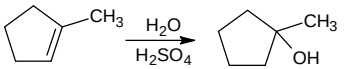
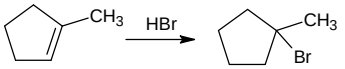
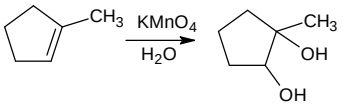
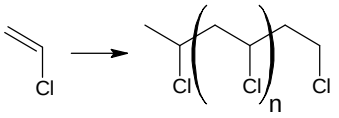
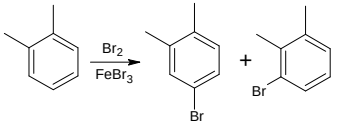
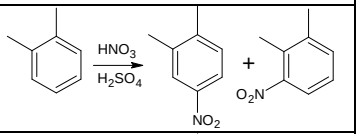
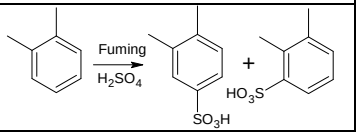
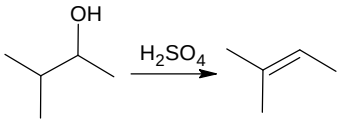
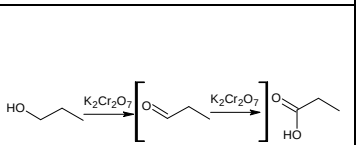
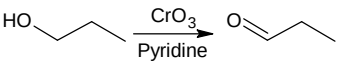
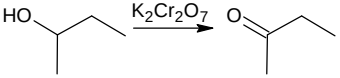
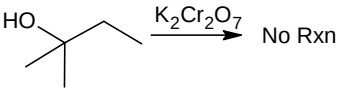
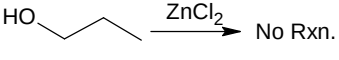
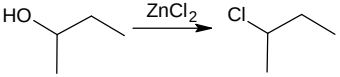
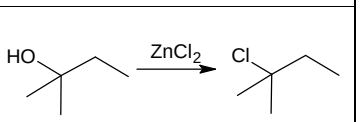
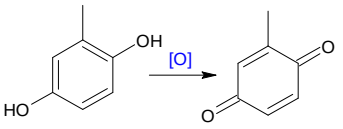
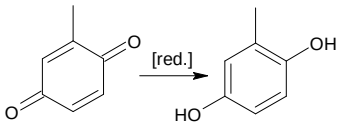
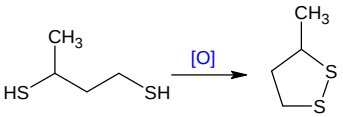
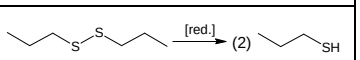
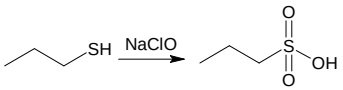
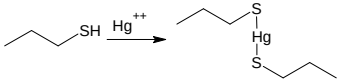
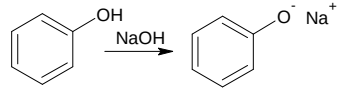
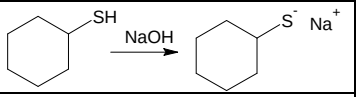
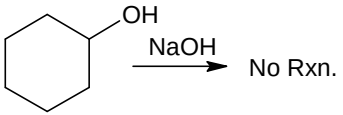
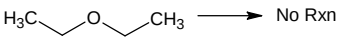
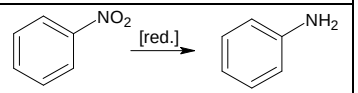
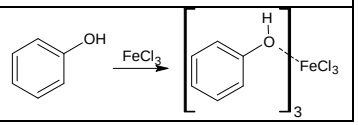
Reactions Study Guide

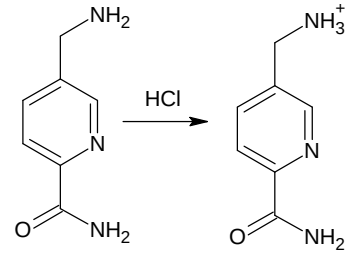
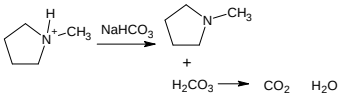
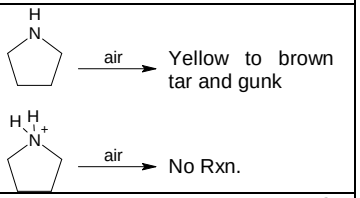
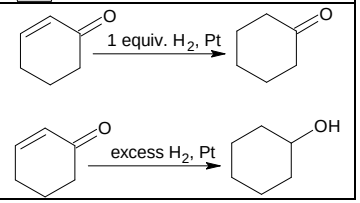
Functional group	Reagent	Name	Description of reaction	Notes	Application or Biochemical relevance	Example
Alkane (and all functional groups)	O_2	Combustion	All C becomes CO_2, all H and O become H_2O	A spark is required to start the rxn, but is not listed as a reagent. ALL functional groups combust, but rxn is incomplete with aromatic rings (giving a very sooty flame) unless excess O_2 added.	The reaction releases energy, and the biochemical version is the source of energy for almost all non-photosynthetic life. Photosynthesis is the reverse reaction.	
Alkane	Br_2, light	Bromination of alkane	Remove one H from alkane and replace with Br.	HBr is also produced. Br selectively goes onto most substituted carbon if there is a choice, otherwise several products form.	*Similar reaction may produce organic haze on Saturn's moon Titan. Another moon has water. Water + organics + energy = life?*	
Alkane	Cl_2, light	Chlorination of alkane	Remove one H from alkane and replace with Cl. HCl is also produced	HCl is also produced. Cl is NOT selective. If there are several sets of equivalent H's, several products form.		
Alkene	Br_2	Bromination of alkene	Add one Br to each side of C=C, convert C=C to single bond	The disappearance of Br_2 color (reddish-brown) is evidence for an alkene. *Br atoms add trans to each other in rings.*	Brominated vegetable oil, used in orange soda and other foods, is produced using this reaction.	
Alkene	Cl_2	Chlorination of alkene	(same as Br_2)	(same as Br_2)		(see above)
Alkene	H_2, Pt	Hydrogen-ation of alkene	Add one H to each side of C=C, convert C=C to single bond	Pt is catalyst.	Partial hydrogenation of a cis alkene results in some trans. Trans fats in the diet are implicated in increased risk for heart disease	
Alkene	H_2O, H_2SO_4 or H_2O, H^+	Hydration of alkene	Add OH to more substituted side of C=C, add H to less substituted side, convert C=C to single bond	H_2SO_4 is catalyst, or any strong acid, which can be represented as "H^+"		
Alkene	HBr	Hydro-bromination of alkene	Add Br to more substituted side of C=C, add H to less substituted side, convert C=C to single bond			

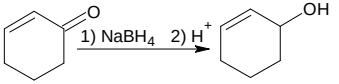
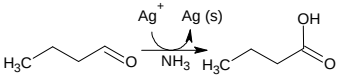
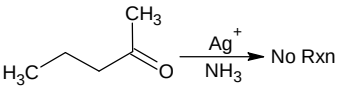
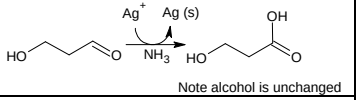
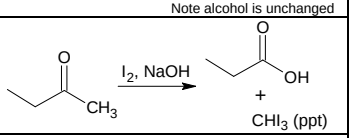
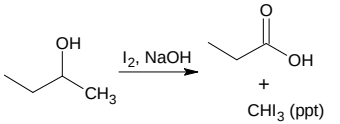
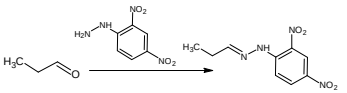
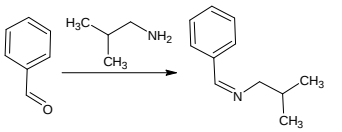
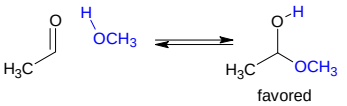
Alkene	HCl	Hydro-chlorination of alkene	(same as HBr)			(see above)
Alkene	$KMnO_4$, H_2O	Dihydroxyl-ation or oxidation of alkene	Add one OH to each side of C=C.	Purple, soluble permanganate is reduced to insoluble brown MnO_2, a positive test for alkenes.	$KMnO_4$ can preserve vegetables in the refrigerator by destroying the plant ripening hormone ethylene. (KeepFresh)	
Alkene	[Polymer-ization]	Poly-merization	Attach one end of one C=C to one end of another C=C, convert C=C to single bond, repeat many times	Name of product is usually "poly" + name of ORIGINAL alkene, i.e. polyethylene	Chemists can only create polymers with repeating units of the same monomer, and can not fully control the length of the polymer; biopolymers have specific sequences of different monomers and exact length (i.e. terpenes, DNA and proteins)	
Aromatic	Br_2, $FeBr_3$ or Br_2, $AlCl_3$	Aromatic bromination	Remove one H from aromatic ring, replace with Br.	HBr is also produced. Multiple products if there are non-equivalent H's on aromatic ring. If Br_2 color does not disappear initially, but does after addition of $AlCl_3$, an aromatic ring is present.		
Aromatic	Cl_2, $AlCl_3$	Aromatic chlorination	(Same as Br_2)	(Same as Br_2, but Cl_2 is unsuitable for a chemical test because it is a gas and harder to handle.)		(see above)
Aromatic	HNO_3, H_2SO_4	Aromatic nitration	Remove one H from aromatic ring, replace with NO_2	H_2O also produced; to remember "NO_2", note H from ring, OH from HNO_3. H_2SO_4 is catalyst		
Aromatic	Fuming H_2SO_4	Aromatic sulfonation	Remove one H from aromatic ring, replace with SO_3H	H_2O also produced; to remember "SO_3H", note H from ring, OH from H_2SO_4	Sulfonic acids were important antibiotics ("Sulfa drugs") before penicillin.	

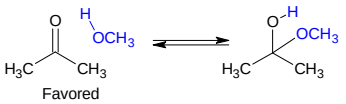
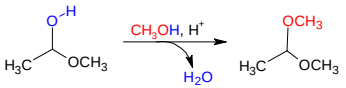
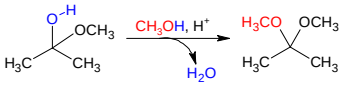
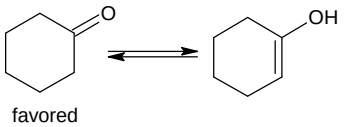
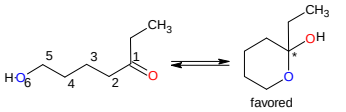
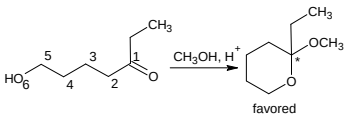
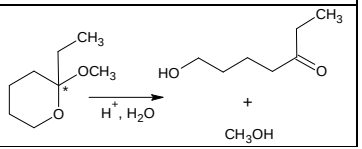
Alcohol (any)	H_2SO_4, heat or H^+, heat	Dehydration	Remove OH, and remove an H on a carbon next to the one with the OH, make a new C=C	The most substituted C=C is produced if there is a choice of more or less substituted.	Important reaction in the conversion of glucose to energy	
Primary alcohol	$K_2Cr_2O_7$ or $Na_2Cr_2O_7$	Oxidation	Remove H from O and H from C, make new C=O. Initial product is aldehyde, which reacts with $K_2Cr_2O_7$ to make carboxylic acid	Orange $K_2Cr_2O_7$ is converted to green Cr^{3+}, a positive test for primary or secondary alcohol	Breathalizer test uses color change to measure level of ethanol in breath. *A liver enzyme, alcohol dehydrogenase, catalyzes this reaction*	
Primary alcohol	CrO_3 in pyridine	Oxidation	Remove H from O and H from C, make new C=O. Stop at aldehyde.	This reaction will be covered in the chapter on aldehydes.		
Secondary alcohol	$K_2Cr_2O_7$ or $Na_2Cr_2O_7$ or *CrO_3 in pyridine*	Oxidation	Remove H from O and H from C, make new C=O (stop there, ketone is final product)	Orange $K_2Cr_2O_7$ is converted to green Cr^{3+}, a positive test for primary or secondary alcohol		
Tertiary alcohol	$K_2Cr_2O_7$ or $Na_2Cr_2O_7$ or *CrO_3 in pyridine*	-	NO REACTION because there is no H on the carbon attached to the OH.	Orange $K_2Cr_2O_7$ is NOT converted to green Cr^{3+}, a negative test	Martian police CAN NOT use this to test Martians for drunk space-ship piloting, since Martians get drunk on 2-methyl-2-propanol ;-)	
Primary alcohol	$ZnCl_2$	Lucas test	NO REACTION because the reaction is too slow.			
Secondary alcohol	$ZnCl_2$	Lucas test, or Chloro-dehydroxyl-ation	Remove OH, replace with Cl	Slow reaction, faster with heating. side product $Zn(OH)_2$ is insoluble in water, giving cloudy solution, a positive test for primary or secondary alcohol		
Tertiary alcohol	$ZnCl_2$	Lucas test, or Chloro-dehydroxyl-ation	Remove OH, replace with Cl	Fast reaction, side product $Zn(OH)_2$ is insoluble in water, giving cloudy solution, a positive test for primary or secondary alcohol	Martian police CAN use this to test Martians for drunk space-ship piloting, since Martians get drunk on 2-methyl-2-propanol ;-)	

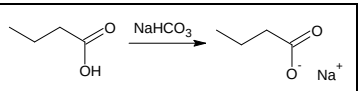
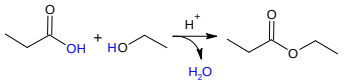
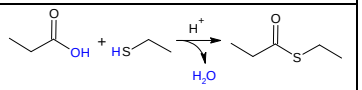
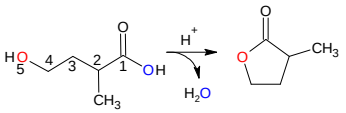
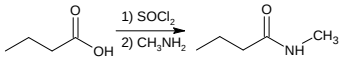
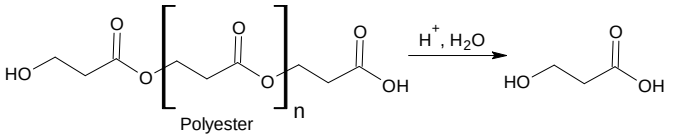
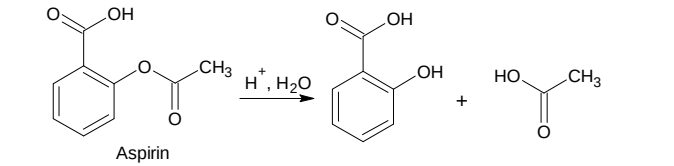
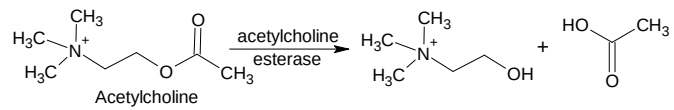
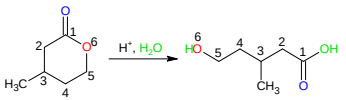
Phenol	[Oxidation] or [O] or O_2	Oxidation or Auto-oxidation	Remove H from each O on aromatic ring, make two C=O, rearrange other double bonds so no octet is violated.	*Reaction is faster with the anion of phenol.*	Phenol-Quinone reaction is important for transport of electrons and hydrogen atoms. *(Phenol has two more electrons and two more H^+ than quinone)*	
Quinone	[Reduction] or Ascorbic acid (Vitamin C)	Reduction	Add H to each O on ring, make each C=O into single bond, rearrange double bonds to make aromatic ring		Quinones can react to form brown pigment in apples, pears, bananas, avocadoes, etc. Reducing these quinones with vitamin C prevents browning	
Thiol (sulfide)	[Oxidation] or O_2	Oxidation to disulfide	Remove H from each of two S, make a bond between two S's (i.e. makes a disulfide)	Reaction can couple two molecules of thiol or make a ring from one molecule of a dithiol.	Sulfide-disulfide reaction is important for transport of electrons and H atoms, and for connecting parts of proteins together. Two thiols have two more electrons and two more H's than one disulfide.	
Disulfide	[Reduction]	Reduction	Add H to each S, remove single bond between S's	Reaction can cut one molecule into two, or make a chain from a ring	(see above)	
Thiol (sulfide)	NaClO, sodium hypochlorite (bleach), or hydrogen peroxide	Oxidation to sulfonic acid	Remove H from S, add two =O and one –OH to S.	Bleach or peroxide cause this reaction, oxygen and other oxidants produce disulfides.	This is the best method for destroying the thiols present in skunk odor. (Tomato juice does not work!)	
Thiol (sulfide)	Hg^{2+}, other heavy metal ions	Complexation with mercury or heavy metal	Remove H from two S, form bonds between each S and Hg^{2+}	Thiols are also called "mercaptans" because they capture mercury. Get it?	Treatment for mercury poisoning: ingest egg white (protein thiols), pump stomach. Also basis for heavy metal protein denaturation.	
Phenol	NaOH (or other base)	Deproton-ation	Remove H from O, put negative charge on O	Product is more soluble in water, and more reactive to oxidation, than starting material	The phenolic skin irritant in poision ivy is easier to dissolve with basic solution, phenol oxidation faster at high pH (basic)	
Thiol (sulfide)	NaOH (or other base)	Deproton-ation	Remove H from S, put negative charge on S	Product is more soluble in water and more reactive to oxidation	High pH (basic) speeds oxidation to sulfonic acid or disulfide.	
Alcohol (any)	NaOH	-	NO REACTION because alcohols are not as acidic as phenols	Compare to reaction of phenols and thiols.		

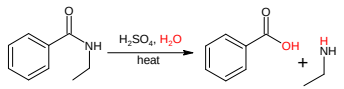
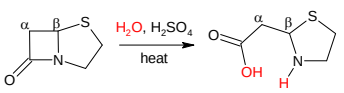
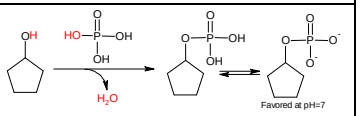
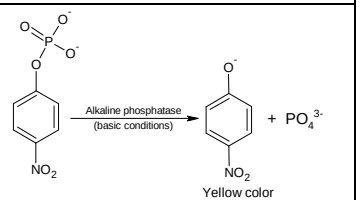
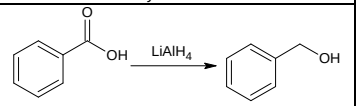
Ether	(any of the above)	-	NO REACTION	Ethers are inert to most reagents; in Chem 212 we will not study any reactions of ethers		
Aromatic nitro group	H_2, Pt or [reduction]	Reduction	Remove both O from N, attach two H to N	This reaction is used along with the nitration of an aromatic ring to add an NH_2 group.		
Phenols	$FeCl_3$	Ferric chloride test	-	Positive test for phenols if a precipitate forms		

Acids and Bases	HCl, HBr, HI, HNO_3, H_2CO_3, H_2SO_4 H_3PO_4, $HClO_4$, RCOOH(weak); $Ca(OH)_2$, NaOH, KOH, LiOH, RNH_2 (weak), $NaHCO_3$ (weak)	Acid base reaction	Remove H from acid, attach H to base. Adjust charges: subtract 1 where H was removed, add 1 where H was added.	Position at equilibrium (for a weak acid plus a weak base) is determined by the strength of the acid on the reactant side vs. the conjugate acid on the product side. Equilibrium favors the weaker acid side. If H_2CO_3 forms it decomposes to give CO_2 gas and H_2O	$CH_3NH_2 + CH_3COOH \rightleftharpoons CH_3NH_3^+ + CH_3COO^-$ pKa = 4.75 pKa = 9.0 This side favored $K_{eq} = 10^{+4.25}$	
					Buffers act by reacting with added acid or base to prevent change in pH. The total charge on a protein, and the charge of individual amino acids, is pH dependent. HCO_3^-/H_2CO_3 is an important blood buffer.	
Amines (primary, secondary, or tertiary)	HCl or H_2SO_4 or any carboxylic acid	Protonation	Attach H to N, put + on N. May write counterion nearby to N	Aliphatic amines are more basic than aromatic, which are much more basic than amides. Quaternary amines do not react with acid because no lone pair is available on N.	Ammonium salts are much more soluble than amines in water, and the protonated N is less reactive to oxygen.	
Ammonium salts	$NaHCO_3$ or NaOH or any base	De-protonation	Remove H from N, erase + charge	Quaternary amines do not react with base because no H's are attached. When H_2CO_3 forms it decomposes to give CO_2 gas.	The uncharged free base is less soluble in water and more volatile than the charged ammonium salt	
Amines	Air or O_2	Oxidation of amines	(Many products form)	Quaternary amines and protonated amines do not react.	Drugs with amine groups are susceptible to oxidation.	
Aldehydes or Ketones	one equiv. H_2, Pt OR excess H_2, Pt	Reduction of aldehyde or ketone	Put one H on each end of C=O, convert to single bond	This reagent will reduce an alkene before it reduces an aldehyde or ketone. If only "one equivalent" of H_2 is present, only the alkene is reduced	Converts aldose or ketose sugars to alditols	

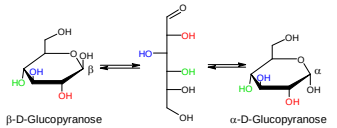
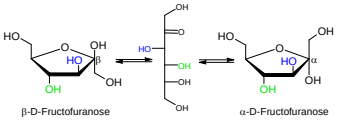
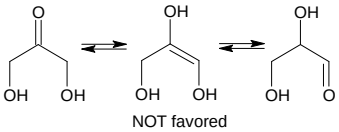
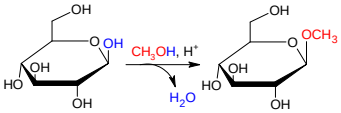
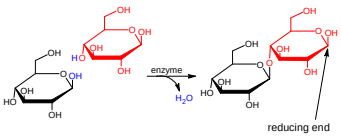
Aldehydes or Ketones	1)$NaBH_4$ 2)H^+	Reduction of aldehyde or ketone	Put one H on each end of C=O, convert to single bond	Reduces aldehyde or ketone in the presence of an alkene. Alkenes do not react with this reagent	Converts aldose and ketose sugars to alditols	
Aldehydes	Ag^+ and NH_3 or Tollens Reagent	Tollens Test	Remove H from aldehyde, add OH	Ag^+ is a mild oxidant and will not react with alcohols. The Ag^+ is reduced to metallic Ag^0, a positive test for aldehyde.	Converts aldose sugars to aldonic acids, because this oxidant is selective for aldehydes	
Ketones	Ag^+ and NH_3 or Tollens Reagent	Tollens Test	NO REACTION	Only aldehydes give positive test	Ketose sugars give only a very slow positive test due to keto-enol equilibrium	
Alcohols (primary)	Ag+ and NH_3 or Tollens Reagent	Tollens Test	NO REACTION	Other oxidants convert primary alcohols to aldehydes and ketones, but not Ag+		
Methyl ketone	NaOH, I_2	Iodoform test	Remove CH_3, replace with OH	CH_3 group becomes precipitate of solid brown CHI_3 for a positive test		
Methyl secondary alcohol CH_3-CH(OH)-	NaOH, I_2	Iodoform test	Oxidize OH to ketone, then remove CH_3, replace with OH	The iodoform reagent oxidizes secondary alcohols to ketones. CH_3 group becomes precipitate of solid brown CHI_3 for a positive test.		
Aldehyde or Ketone	2,4-Dinitro-phenyl hydrazine (2,4-DNP)	DNP test	Draw N near O of ketone, remove two H from N and O from keton (i.e. remove H_2O), make N=C	The products are yellow or orange solids insoluble in organic solvents. Formation of a ppt is positive test		
Aldehyde or Ketone	Primary amine	Condensation or Imine Formation or Schiff Base formation	Draw N near O of ketone, remove two H from N and O from keton (i.e. remove H_2O), make N=C	Called condensation because water is produced. Does not occur with carboxylic acids.	*Browning of toast is rxn of an aldose with a protein amine. Advanced Glycosylation End products (AGEs) and opsin + protein, are other examples*	
Aldehydes	CH_3OH or any primary or secondary alcohol	Hemiacetal equilibrium	Add the ROH across the C=O: the H attaches to O, the RO attaches to C, the C=O becomes single bond	For aldehydes, the reaction equilibrium favors the products	This reaction is responsible for the formation of pyranose and furanose rings in carbohydrates	

Ketones	CH_3OH or any primary or secondary alcohol	Hemiacetal equilibrium	Add the ROH across the C=O: the H attaches to O, the RO attaches to C, the C=O becomes single bond	For ketones, the reaction equilibrium favors the reactants, except in cyclic systems (see Hydroxy ketones below)	This reaction is responsible for the formation of pyranose and furanose rings in carbohydrates	
Aldehydes	CH_3OH, H^+ or any primary or secondary alcohol with acid.	Acetal formation	Start same as hemiacetal, then add ROH across the C-O: the H attaches to O, the RO attaches to C, the C-O is erased	Acid is required to drive the reaction to the products. If two OH groups are in the reacting alcohol, a cyclic acetal can form	This reaction is responsible for the formation of glycosidic bonds in carbohydrates	See above for first half 
Ketones	CH_3OH, H^+ or any primary or secondary alcohol with acid.	Acetal formation (Ketal formation)	Start same as hemiacetal, then add ROH across the C-O: the H attaches to O, the RO attaches to C, the C-O is erased	Acid is required to drive the reaction to the products. If two OH groups are in the reacting alcohol, a cyclic acetal can form	This reaction is responsible for the formation of glycosidic bonds in carbohydrates	See above for first half 
Aldehydes and Ketones	H^+ or OH^- or enzyme (isomerase), or no reagent	Keto-enol equilibrium or Tautomer-ization	Remove H from C adjacent to C=O, make C=C between that C and C of ketone. Convert C=O to single bond, add H to O	The ketone or aldehyde is favored over the enol. A tautomer is a consti-tutional isomer that differs in the position of the double bond – either between two C or between a C and O.	Converts aldose sugars to ketose sugars and vice versa. The enzyme triose phosphate isomerase catalyzes this reaction in glycolysis	
Hydroxy-ketone or hydroxy-aldehyde	No reagent required	Cyclic hemiacetal equilibrium	Same as hemiacetal, but a ring forms connecting the OH to the aldehyde C	Count the number of atoms that will be in the ring, starting with the carbon of the C=O and ending with the OH	The C=O becomes a new stereocenter, called the anomeric carbon in carbohydrates	
Hydroxy-ketone or hydroxy-aldehyde	H^+ or enzyme (synthase)	Cyclic acetal formation	Same as acetal, but a ring forms connecting the OH to the ketone C	Count the number of atoms that will be in the ring, starting with the carbon of the C=O and ending with the OH. Cyclic acetals have one O as part of the ring, and the other from the added alcohol.	The C=O becomes a new stereocenter, called the anomeric carbon in carbohydrates	
Cyclic acetal	H^+, H_2O or enzyme (hydrolase, amylase)	Hydrolysis of cyclic acetal	Reverse of formation of acetal.	Enzymes are specific for the stereochemistry of the anomeric carbon	Different enzymes are required to hydrolyze starch vs. cellulose, which differ at the anomeric carbon.	

Carboxylic acid	$NaHCO_3$ or NH_3 or any amine or base.	De-protonation	Remove H from COOH, give O negative charge	Lower pKa is stronger acid. Electronegative groups close to the COOH increase acidity.	Anion is less volatile and more soluble in water.	
Carboxylic acid	CH_3OH, H^+ or Any alcohol and H+	Ester formation	Remove OH from acid, H from alcohol, and bond together	This is a different reaction than for aldehydes and ketones, which produce acetals using the same reagent.	Ester bonds are important in lipids. Esters are not acidic, so they are neutral at physiological pH.	
Carboxylic acid	Any primary thiol	Thioester formation	Remove OH from acid, H from thiol, and bond together	Similar to the reaction of alcohols and amines with carboxylic acids	Acetyl-coenzyme A is important metabolic intermediate with a thioester bond	
Hydroxy acid	H^+	Lactone (cyclic ester) formation	Count the number of atoms in the ring. Remove OH from acid, H from alcohol, and bond together	Size of ring is indicated by a Greek letter representing position of OH relative to COOH. Thus, 3=α(alpha) 4=β(beta), 5=γ(gamma), 6=δ(delta)	δ-Gluconolactone, used in the manufacture of tofu, is an example.	
Carboxylic acid	1)$SOCl_2$ 2)Primary amine or enzyme (ribosome et.al.)	Amide formation	Remove OH from acid, remove H from amine, and bond together	Acid must be activated by $SOCl_2$ in order to form amide. Nylon synthesis demonstration	Amide bonds are important in proteins. Amides are much less basic than amines, so they are neutral at physiological pH.	
Ester	H^+, H_2O or enzyme (esterase)	Ester hydrolysis	Add OH to C=O of ester, H to O of ester, break C-O bond	Reverse of ester formation. Reaction can occur slowly at room temperature.		
				Lactomer® stitches are polyesters and slowly dissolve. Aspirin decomposes to acetic acid (vinegar) and salicylic acid. Acetylcholine is an ester neurotransmitter, catabolized by acetylcholine esterase, soap is made by hydrolysis of fatty acid triester	 	
Lactone (cyclic ester)	H^+, H_2O	Lactone hydrolysis (ring opening)	Add OH to C=O of ester, H to O of ester, break C-O bond (which opens the ring)	Same as ester hydrolysis, but opens a cyclic ester.		

Amide or peptide	H_2SO_4, H_2O, heat or enzyme (protease, peptidase)	Amide or Peptide hydrolysis	Add OH to C=O of amide, H to N of amide, break C-N bond	Similar to ester hydrolysis, but amide/peptide bonds are much harder to hydrolyze than esters.	Peptide bonds link amino acid in proteins and are more stable than esters.	
Lactam (cyclic amide)	H_2SO_4, H_2O, heat or enzyme (lactamase))	Lactam hydrolysis (ring opening)	Add OH to C=O of amide, H to N of amide, break C-N bond (which opens the ring)	Similar to ester and lactone hydrolysis. As with lactones, the size of ring is indicated by a Greek letter representing position of OH relative to COOH.	β-Lactam antibiotics (e.g. penicillin) have very strained ring. β-lactamase gene in bacteria confers penicillin resistance	
Alcohol and PO_4^{3-} or SO_4^{2-} acid	Enzyme (Phosphatase or sulfatase)	Phosphoryl-ation or Sulfonation	Remove OH from inorganic acid, remove H from alcohol, form bond.	Similar to formation of ester of carboxylic acid	Alcohols are neutral at physiological pH, but the phosphate or sulfate esters are negatively charged	
Phosphate or sulfate ester	Enzyme (Phosphatase or sulfatase)	Dephosphoryl -ation or Desulfon-ation	Erase O-P or O-S bond, add OH to inorganic acid, add H to alcohol	Similar to hydrolysis of carboxylic acid ester	Phosphorylation and sulfonation are important mechanisms of enzyme control; change in charge of protein side chain can result in protein conformational change.	 Yellow color (phenol is deprotonated under alkaline conditions) A chemical test for the enzyme alkaline phosphat-ase (ALP), elevated in many diseases
Carboxylic acid	$LiAlH_4$	Reduction	Erase =O, add two H's to carbon.	This is the reverse reaction to chromic acid oxidation of primary alcohols		
Anhydride	*Primary amine*	*Formation of amide*		*Anhydride is an activated form of a carboxylic acid. Carboxylic acids do not form amides when combined with amines unless they are activated (by $SOCl_2$ above, or by using the anhydride form here)*	*Formation of amide bonds in biochemical systems requires activation of the acid, often by formation of an anhydride with phosphate from ATP*	
Anhydride	*Alcohol*	*Formation of ester*		*Anhydrides are activated and ester formation does not require acid catalysis as it did with carboxylic acids.*		
Anhydride	*Water*	*Hydrolysis of anhydride*				
Ester	*Primary amine*	*Formation of amide*		*Esters are somewhat activated and will react to form amides, in contrast to carboxylic acids (see above)*		

Phosphoric acid anhydride	*Water*	*Hydrolysis*		*At physiological pH, phosphate OH groups are all deprotonated and energy is stored in the repulsion of adjacent negative charges*	*Hydrolysis of phosphate anhydrides in ATP is basis for energy storage of this molecule.*	
Phosphoric acid amide	*-*	*-*	*(no reaction)*	*Like amides made from carboxylic acids, these compounds are resistant to hydrolysis but are structurally similar to anhydrides*	*Phosphoric acid amides are used as biochemical tools. AMPPNP is an analog of ATP which binds to the same enzymes but does not undergo hydrolysis.*	

Aldo-hexose	*(no reagent)*	*Pyranose equilibrium*	*Count six atoms, from aldehyde C to OH. Use that OH to make hemiacetal. For stereochemistry, rotate Fisher projection clockwise.*	*Aldohexoses exist in equilibrium between the open and cyclic forms in solution, but are 100% cyclic in solid form. Both α and β cyclic isomers exist in solution, but only one (β usually) in solid form.*	*This equilibrium is responsible for mutarotation, the slow conversion of β-D-glucose to a mixture of α- and β- in solution, which changes the optical rotation.*	
Keto-hexose	*(no reagent)*	*Furanose formation*	*Count five atoms, from ketone C to OH. Use that OH to make hemiacetal. For stereo-chemistry, rotate Fisher projection clockwise.*	*Ketohexoses exist in equilibrium between open and cyclic forms.*		
Ketose or Aldose	*Isomerase enzyme or H^+*	*Keto-Enol equilibrium*	*Remove H from C adjacent to C=O, make C=C between that C and C of ketone. Convert C=O to single bond, add H to O. Reverse for second OH.*	*Reaction is very slow without enzyme, but fast enough that ketoses give slow positive Fehlings test. Ketone or aldehyde is favored, but not enediol*	*Converts ketose to aldose and vice-versa. Important reaction in glycolysis*	
Monosaccharide	*Alcohol, H^+*	*Glycosidic bond formation*	*Remove OH from acetal C, remove H from primary alcohol, bond O of alcohol to acetal C*	*Carbohydrate acetals are unreactive Tollens or Fehling's solution, and are called "nonreducing sugars" because they do not reduce Ag^+ or Cu^+*		
Two carbo-hydrates	*Enzyme (synthase)*	*Glycosidic bond formation*	*Remove OH from acetal C, remove H from an OH of second carbohydrate, bond O to acetal C.*	*See above regarding nonreducing sugars. The enzyme controls the stereochemistry (α or β) at anomeric C, and also which OH group of the second carbohydrate bonds to the acetal carbon – there are many possibilities!*	*This reaction constructs disaccharides, oligosaccharides, and polysaccharides. The hemiacetal is called the reducing end of the sugar.*	
Poly-saccharide	*Enzyme, or H^+*	*Glycosidic bond cleavage or hydrolysis*	*Break glycosidic (acetal) bond, add OH to acetal C, H to oxygen*	*Enzyme can be very specific for α or β and the saccharide. Product has a reducing end.*	*Humans have α-glucosidase, but not β-. This is why cellulose is indigestible but starch is digestible*	
Glycerol + fatty acid	*Enzyme*	*Triglyceride formation*	*(see formation of ester above)*			
Alcohol or	*Enzyme,*	*Formation of*		*Addition of glucouronic*	*Examples: anesthetic*	

phenol	*glucouronic acid*	*Glucouronate*		*acid groups is important catabolic pathway for making molecules more soluble in water and excretable in urine.*	*propofol is metabolized to the glucouronate, bilirubin is conjugated to glucouronic acid to make it soluble in the urine. (Unconjugated bilirubin is not soluble in urine)*	
Tri-glyceride	*Enzyme (lipase)*	*Hydrolysis*				
Two amino acids		*Amide (peptide) bond formation*			*Penicillin inhibits an enzyme that uses this reaction to build bacterial cell walls (or similar reaction..)*	
Protein	*Enzyme (peptidase)*	*Peptide bond hydrolysis*				
Arachi-donic acid	*Cyclo-oxygenaze (COX-1 and COX-2)*	*Prosta-glandin formation*				
Phenylalanine	*Enzyme*			*Addition of OH groups is important catabolic pathway for making molecules more soluble in water and excretable in urine.*	*Enzyme absent or deficient in genetic disorder phenylketonuria.*	
Benzo[a]anthracene	*Cytochrome P450*			*Cytochrome P450 is the most important liver enzyme for detoxifying molecules; in this case it backfires and makes the molecule more toxic.*		
Lipid	*H_2, Pt*	*Partial hydrogen-ation or partial reduction*	*Erase some of the C=C, add H to each carbon. Change some C=C from cis to trans.*	*Partial hydrogenation does not reduce all of the C=C to single bonds, but some of the C=C that are not reduced can be changed from cis to trans.*	*Trans fats are implicated in heart disease. The FDA recently required inclusion of the amount of trans fats on nutrition labels.*	
Protein + carbohydrate		*Browning reaction*				
		Advanced Glycosylation End products				

The Chemical Basis for Regulation in Biological Systems: Examples of reactions and other things that can alter protein structure.

Change the pKa of a side chain

Formation/Hydrolysis of amide ($R\text{-}NH_2$ -> $R\text{-}NHCOCH_3$ or $RCOOH$ -> $RCOONH_2$)

Formation/Hydrolysis of ester ($RCOOH$ -> $RCOOCH_3$)

Formation/Hydrolysis of sulfate or phosphate ester ($R\text{-}OH$ -> $R\text{-}OSO_3^-$)

Quaternization of amine

Surround the group with other groups to change pKa
Change the pH of the solvent
Protonate/deprotonate amine
Protonate/deprotonate acid
Change the concentration of ions in the solvent
Add or remove coordination of Mg2+ or Ca2+ or other ions
Add Hg2+ to coordinate with cystine SH groups
Change the polarity of the solvent
Nonpolar amino acids are normally inside the protein, but are on the surface of transmembrane portions
Detergents solubilize nonpolar regions of proteins
High ion concentration can disrupt hydrogen bonding and salt bridges
6M urea disrupts hydrogen bonds
Alcohol disrupts water molecules surrounding protein, makes solvent less polar
Change the temperature
Heat disrupts hydrogen bonds
Change the covalent bonding
Oxidation/Reduction of sulfide/disulfide