SYNTHETIC TOOLBOX

Some of the reactions in this handout may not have been covered in your course. Some of the reactions covered in your course may not be included in this handout. You should come up with your own synthetic toolbox that matches the reactions covered in your course; as your course proceeds and new reactions are introduced, keep updating your toolbox.

functionalize—i.e., replace a H with a functional group defunctionalize—i.e., replace a functional group with a H or D add C's—i.e., create a C-C bond Grignard reagent + carbonyl Grignard reagent + carbonyl Grignard reagent + carbonyl Grignard reagent + epoxide alkene + H ₂ SO ₄ (cationic polymerization) ozonolysis: R1 C=C R ₄ + H ₂ Pd/C R2 R4 H2 Pd/C R4 H2 Pd/C R4 R2 C=C R4 H H H H R1 R2 C=C R4 H H H H H H R1 R2 C=C R4 H H H H R1 R2 C=C R4 H H H H R1 R2 C=C R4 H H H H R1 R2 C=C R4 H H H H R1 R2 C=C R4 H H H H R1 R2 C=C R4 H H H H R1 R2 C=C R4 H H H R1 R2 C=C R4 H H H H H R1 R2 C=C R4 H H H H H H H H H H H H H H H H H H H	goals	reactions
replace a H with a functional group $\begin{array}{l} 1 \\ -C \\ -H \\ +X \\ -X \\ -K \\ -K \\ -K \\ -K \\ -K \\ -K \\ -$		
functional group $\begin{array}{c} -C - H + X - X \xrightarrow{arrev} - C - X + H - X \\ 1 \\ \end{array}$ $\begin{array}{c} -C - H + X - X \xrightarrow{arrev} - C - X + H - X \\ 1 \\ \end{array}$ $\begin{array}{c} -R_{1} + R_{2} O^{*} \Rightarrow R - H + H_{2}O + {}^{*}MgX \\ \text{hydrogenation:} \\ R_{2} & C = C \\ R_{4} + H_{2} \end{array}$ $\begin{array}{c} R_{1} & Pd/C \\ R_{2} & C = C \\ R_{4} + H_{2} \end{array}$ $\begin{array}{c} R_{1} & Pd/C \\ R_{2} & C = C \\ R_{4} + H_{2} \end{array}$ $\begin{array}{c} R_{1} & Pd/C \\ R_{1} & R_{2} \\ R_{2} & R_{4} \\ R_{3} \end{array}$ $\begin{array}{c} R_{1} & R_{1} \\ R_{2} & R_{4} \\ R_{3} \end{array}$ $\begin{array}{c} R_{1} & R_{2} \\ R_{2} & R_{4} \\ R_{3} \\ R_{2} & C \\ R_{4} \\ R_{3} \end{array}$ $\begin{array}{c} R_{1} & R_{1} \\ R_{2} & R_{4} \\ R_{3} \\ R_{2} \\ R_{4} \\ R_{3} \end{array}$ $\begin{array}{c} R_{1} & R_{1} \\ R_{2} & R_{4} \\ R_{3} \\ R_{2} \\ R_{4} \\ R_{3} \end{array}$ $\begin{array}{c} R_{1} & R_{1} \\ R_{2} \\ R_{4} \\ R_{3} \\ R_{2} \\ R_{4} \\ R_{3} \end{array}$ $\begin{array}{c} R_{1} \\ R_{2} \\ R_{4} \\ R_{3} \\ R_{2} \\ R_{4} \\ R_{3} \end{array}$ $\begin{array}{c} R_{1} \\ R_{1} \\ R_{2} \\ R_{4} \\ R_{3} \\ R_{2} \\ R_{4} \\ R_{3} \end{array}$ $\begin{array}{c} R_{1} \\ R_{1} \\ R_{2} \\ R_{4} \\ R_{3} \\ R_{4} \\ R_{1} \\ R_{2} \\ R_{4} \\ R_{3} \\ R_{4} \\ R_{1} \\ R_{2} \\ R_{4} \\ R_{3} \\ R_{4} \\ R_{1} \\ R_{2} \\ R_{4} \\ R_{3} \\ R_{4} \\ R_{1} \\ R_{2} \\ R_{4} \\ R$		
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	_	$-C - H + X - X \xrightarrow{Aortu} - C - X + H - X$
replace a functional group with a H or D hydrogenation: $R_1 = C = C = R_3 + H_2 \xrightarrow{Pd/C} R_2 = R_1 + R_3 = R_4 + R_3$ add C's—i.e., create a C-C bond Grignard reagent + carbonyl Grignard reagent + epoxide alkene + H ₂ SO ₄ (cationic polymerization) remove C's—i.e., cleave a C-C bond radical halogenation: $R_1 = C = C = R_3 + R_3 - R_4 + R_2 = C = 0 + 0 = C = R_3 + R_4$ synthesize an alkyl halide $R_1 = C = C = R_3 + R_3 - R_4 + R_4 = R_4 + R$		
group with a H or D $R_1 = C = C = R_3 + H_2$ $Pd/C = Pd/C + R_3 = R_4$ $R_2 = R_4$ $R_1 = R_2 = R_4$ $R_1 = R_2 = R_4$ add C's—i.e., create a C-C bondGrignard reagent + carbonyl Grignard reagent + epoxide alkene + H_2SO4 (cationic polymerization)Grignard reagent + epoxide alkene + H_2SO4 (cationic polymerization) $R_1 = R_2 = R_4 = R_3$ remove C's—i.e., cleave a C-C bondozonolysis: $R_1 = C = C = R_3$ $R_1 = C = C = C = R_3$ $R_2 = C = 0 + 0 = C = C = R_4$ synthesize an alkyl halideradical halogenation: $-C = -H + X - X = \frac{4 \omega \pi \omega}{L} = \frac{1}{C} - X + H - X$ $R_1 = C = C = R_4$ alkyl bromide from a methyl, 1°, or 2° alcohol: $R = OH + PBr_3 \Rightarrow R - Br + HOPBr_2$ alkyl choride, bromide, or iodide from a 3° alcohol (S_N1): $R - OH + HX \Rightarrow R - X + H_2O$ hydrohalogenation of an alkene (X on less substituted C): $C = C + H - X \rightarrow H - C - C - X$ synthesize a 1,2-dihalide (X's on adjacent C's) $R_1 = C = C = R_3 + X_2 \rightarrow R_2 = R_1 - X - R_4 = R_3 + R_4 - R_4 = R_4 + R_3 = R_4 + R_4 - R_4 = R_4 + R_3 = R_4 + R_4 + R_4 = R_4 + $		$RMgX + H_3O^+ \rightarrow RH + H_2O + {}^+MgX$
$\begin{array}{c} \begin{array}{c} R_{1}\\ R_{2} & = C \\ R_{4} \\ R_{2} \end{array} + H_{2} \end{array} \xrightarrow{Pd/C} C - C \\ H \\ H \\ R_{1} \\ R_{2} \end{array} \xrightarrow{R_{4} \\ R_{3}} add C's \\ \hline R_{1} \\ R_{2} \\ R_{2} \\ R_{4} \\ R_{3} \end{array} + H_{2} \\ \begin{array}{c} Pd/C \\ R_{4} \\ R_{3} \\ R_{3} \\ R_{2} \\ C - C \\ R_{4} \\ R_{3} \\ R_{3} \\ R_{4} \\ R_{4} \\ R_{4} \\ R_{4} \\ R_{3} \\ R_{4} \\ $	-	hydrogenation:
add C's—i.e., create a C-C bond Grignard reagent + carbonyl Grignard reagent + epoxide alkene + H ₂ SO ₄ (cationic polymerization) remove C's—i.e., cleave a C-C bond R ₁ C=C R ₃ 1.03 R ₂ $\xrightarrow{R_4}$ R ₁ C=O + O=C R ₃ R ₂ $\xrightarrow{R_4}$ R ₃ radical halogenation: $-C - H + X - X \xrightarrow{4 \text{ series}} -C - X + H - X$ alkyl bromide from a methyl, 1°, or 2° alcohol: R-OH + PBr ₃ \Rightarrow R-Br + HOPBr ₂ alkyl chloride, bromide, or iodide from a 3° alcohol (S _N 1): R-OH + HX \Rightarrow R-X + H ₂ O hydrohalogenation of an alkene (X on less substituted C): $C=C + H - X \rightarrow H - C - C - X$ synthesize a 1,2-dihalide (X's on adjacent C's) R ¹ C=C R ₃ $+ X_2 \rightarrow R_2$ R ₁ $\xrightarrow{R_1}$ C=C R ₃ R ₂ $\xrightarrow{R_2}$ R ₄ $\xrightarrow{R_1}$ C=C R ₃ R ₂ $\xrightarrow{R_2}$ R ₁ $\xrightarrow{R_1}$ C=C R ₃ R ₂ $\xrightarrow{R_1}$ C=C R ₃ $\xrightarrow{R_1}$ $\xrightarrow{R_2}$ C=O + O =C R ₃ R ₂ $\xrightarrow{R_4}$ synthesize a Grignard RX + Mg \Rightarrow RMgX, X = Cl, Br, or I	group with a H or D	\mathbf{P} \mathbf{P} $\mathbf{R}_2 \mathbf{K}_1 \mathbf{K}_3 \mathbf{R}_4 \mathbf{H}$
add C's—i.e., create a C-C bond Grignard reagent + carbonyl Grignard reagent + epoxide alkene + H ₂ SO ₄ (cationic polymerization) remove C's—i.e., cleave a C-C bond R ₁ C=C R ₃ 1.03 R ₂ $\xrightarrow{R_4}$ R ₁ C=O + O=C R ₃ R ₂ $\xrightarrow{R_4}$ R ₃ radical halogenation: $-C - H + X - X \xrightarrow{4 \text{ series}} -C - X + H - X$ alkyl bromide from a methyl, 1°, or 2° alcohol: R-OH + PBr ₃ \Rightarrow R-Br + HOPBr ₂ alkyl chloride, bromide, or iodide from a 3° alcohol (S _N 1): R-OH + HX \Rightarrow R-X + H ₂ O hydrohalogenation of an alkene (X on less substituted C): $C=C + H - X \rightarrow H - C - C - X$ synthesize a 1,2-dihalide (X's on adjacent C's) R ¹ C=C R ₃ $+ X_2 \rightarrow R_2$ R ₁ $\xrightarrow{R_1}$ C=C R ₃ R ₂ $\xrightarrow{R_2}$ R ₄ $\xrightarrow{R_1}$ C=C R ₃ R ₂ $\xrightarrow{R_2}$ R ₁ $\xrightarrow{R_1}$ C=C R ₃ R ₂ $\xrightarrow{R_1}$ C=C R ₃ $\xrightarrow{R_1}$ $\xrightarrow{R_2}$ C=O + O =C R ₃ R ₂ $\xrightarrow{R_4}$ synthesize a Grignard RX + Mg \Rightarrow RMgX, X = Cl, Br, or I		Γ^{1} $C = C^{-\Gamma_{3}} + H_{a} \xrightarrow{Pd/C} \sum_{C = C} \int_{C} \int_{$
add C's—i.e., create a C-C bond Grignard reagent + carbonyl Grignard reagent + epoxide alkene + H ₂ SO ₄ (cationic polymerization) remove C's—i.e., cleave a C-C bond R ₁ C=C R ₃ 1.03 R ₂ $\xrightarrow{R_4}$ R ₁ C=O + O=C R ₃ R ₂ $\xrightarrow{R_4}$ R ₃ radical halogenation: $-C - H + X - X \xrightarrow{4 \text{ series}} -C - X + H - X$ alkyl bromide from a methyl, 1°, or 2° alcohol: R-OH + PBr ₃ \Rightarrow R-Br + HOPBr ₂ alkyl chloride, bromide, or iodide from a 3° alcohol (S _N 1): R-OH + HX \Rightarrow R-X + H ₂ O hydrohalogenation of an alkene (X on less substituted C): $C=C + H - X \rightarrow H - C - C - X$ synthesize a 1,2-dihalide (X's on adjacent C's) R ¹ C=C R ₃ $+ X_2 \rightarrow R_2$ R ₁ $\xrightarrow{R_1}$ C=C R ₃ R ₂ $\xrightarrow{R_2}$ R ₄ $\xrightarrow{R_1}$ C=C R ₃ R ₂ $\xrightarrow{R_2}$ R ₁ $\xrightarrow{R_1}$ C=C R ₃ R ₂ $\xrightarrow{R_1}$ C=C R ₃ $\xrightarrow{R_1}$ $\xrightarrow{R_2}$ C=O + O =C R ₃ R ₂ $\xrightarrow{R_4}$ synthesize a Grignard RX + Mg \Rightarrow RMgX, X = Cl, Br, or I		
C-C bondGrignard reagent + epoxide alkene + H2SO4 (cationic polymerization)remove C's—i.e., cleave a C-C bondozonolysis: $R_1 \subseteq C = C_{R_4} = \frac{1.0_3}{2.Me_2S \text{ or } Zn}$ $R_1 \subseteq C = 0 + 0 = C_{R_4} = \frac{R_3}{R_4}$ synthesize an alkyl halideradical halogenation: $-C = H + X - X \xrightarrow{dosted} - \frac{1}{C} - X + H - X$ alkyl bromide from a methyl, 1°, or 2° alcohol: $R - OH + PBr_3 \Rightarrow R - Br + HOPBr_2$ alkyl chloride, bromide, or iodide from a 3° alcohol (S _N 1): $R - OH + HX \Rightarrow R - X + H_2O$ hydrohalogenation of an alkene (X on less substituted C): $-C = C + H - X \rightarrow H - \frac{1}{C} - \frac{1}{C} - X$ synthesize a 1,2-dihalide (X's on adjacent C's) $R_1 - C = C_{R_4} + X_2 \rightarrow R_2 + R_2 R_1$ $R_2 - C - C_{R_4} + X_2 \rightarrow R_2 + R_2 R_1$ $R_2 - C - R_4 + R_3 - R_2 - R_4$ synthesize a carbonyl (aldehyde or ketone)methyl, 1°, or 2° alcohol + PCC, no H2O ozonolysis: $R_1 - C = C_{R_4} + R_3 - R_1 - C - C_{R_4} - R_3 - R_2 - R_4 - R_3 - R_4 - R_4 - R_3 - R_4 - R_$		\square
$\begin{array}{c} alkene + H_2SO_4 (cationic polymerization) \\ \hline remove C's-i.e., \\ cleave a C-C bond \\ \hline R_2 = C = C = R_4 1 = O_3 \\ \hline R_2 = C = C = R_4 1 = O_3 \\ \hline R_2 = C = C = R_4 1 = O_3 \\ \hline R_2 = C = C = R_4 1 = O_3 \\ \hline R_2 = C = C = R_4 1 = O_4 \\ \hline R_2 = C = C = R_4 1 = O_4 \\ \hline R_2 = C = C = R_4 1 = O_4 \\ \hline R_2 = C = C = R_4 1 = O_4 \\ \hline R_2 = C = C = R_4 1 = O_4 \\ \hline R_4 = C = C \\ \hline R_4 \\ \hline R_5 \\$		
remove C's—i.e., cleave a C-C bondozonolysis:R1 Q = CR3 R41. 03 2. Me2S or ZnR1 R2C=O + O=CR3 R4synthesize an alkyl halideradical halogenation: - C - H + X - Xiiii- C - H + X - Xiiiii- C - H + Y- Xiiii- C - H + Y- Xiiii- C - H + PBr3 → R-Br + HOPBr2 alkyl bromide from a methyl, 1°, or 2° alcohol: R-OH + PBr3 → R-Ar + H2O hydrohalogenation of an alkene (X on less substituted C): C=C + H - X → H - C - C - Xiisynthesize a 1,2-dihalide (X's on adjacent C's)R1 R2C - C R3 R4R2 R4R2 R4R3 R4 R1 R2R3 R4 <br< td=""><td>C-C bond</td><td></td></br<>	C-C bond	
cleave a C-C bond $R_{1} = C = C \xrightarrow{R_{3}} \frac{1 \cdot O_{3}}{2 \cdot Me_{2}S \text{ or } Zn} \xrightarrow{R_{1}} C = O + O = C \xrightarrow{R_{3}} \frac{R_{3}}{R_{4}}$ synthesize an alkyl halide $R_{2} = C = C \xrightarrow{R_{4}} \frac{1 \cdot O_{3}}{2 \cdot Me_{2}S \text{ or } Zn} \xrightarrow{R_{1}} C = O + O = C \xrightarrow{R_{3}} \frac{R_{4}}{R_{4}}$ radical halogenation: $-C = H + X - X \xrightarrow{Aorliv} -C = X + H - X$ alkyl bromide from a methyl, 1°, or 2° alcohol: R-OH + PBr_{3} \Rightarrow R-Br + HOPBr_{2} alkyl chloride, bromide, or iodide from a 3° alcohol (S_{N}1): R-OH + HX \Rightarrow R-X + H ₂ O hydrohalogenation of an alkene (X on less substituted C): $C = C + H - X \xrightarrow{H} - C - C - X$ synthesize a 1,2-dihalide (X's on adjacent C's) synthesize a carbonyl (aldehyde or ketone) $R_{1} = C = C \xrightarrow{R_{3}} \frac{1 \cdot O_{3}}{R_{2}} \xrightarrow{R_{1}} C = O + O = C \xrightarrow{R_{3}} R_{4}$ synthesize a Grignard RX + Mg \Rightarrow RMgX, X = Cl, Br, or I		
synthesize an alkyl halide ha		ozonolysis:
synthesize an alkyl halide ha	cleave a C-C bond	$ \begin{array}{cccccccccccccccccccccccccccccccccccc$
synthesize an alkyl halide ha		$C=C$ $\sim R_4 2$. Me ₂ S or Zn R_2 $\sim R_4$
halide halid	synthesize an alkyl	radical halogenation:
$\begin{array}{c} -\dot{C} - H + X - X \xrightarrow{Assub} - C - X + H - X \\ 1 \\ alkyl bromide from a methyl, 1^{\circ}, or 2^{\circ} alcohol: \\ R - OH + PBr_3 \rightarrow R - Br + HOPBr_2 \\ alkyl chloride, bromide, or iodide from a 3^{\circ} alcohol (S_N1): \\ R - OH + HX \rightarrow R - X + H_2O \\ hydrohalogenation of an alkene (X on less substituted C): \\ \hline C = C + H - X \rightarrow H - \stackrel{i}{C} - \stackrel{i}{C} - X \\ \hline C = C + H - X \rightarrow H - \stackrel{i}{C} - \stackrel{i}{C} - X \\ \hline R_2 - C = C + H - X \rightarrow H - \stackrel{i}{C} - \stackrel{i}{C} - X \\ R_4 + X_2 \rightarrow R_4 + X_2 \rightarrow R_4 + R_3 \\ \hline R_1 - R_2 - C = C + R_4 + R_3 \\ \hline R_1 - R_2 - C = C + R_4 + R_4 - R_1 + R_2 \\ \hline R_1 - R_2 - C = C + R_4 + R_4 - R_1 + R_4 \\ \hline R_1 - R_2 - C = C + R_4 + R_4 - R_4 \\ \hline R_1 - R_2 - C = C + R_4 + R_4 \\ \hline R_1 - R_4 - R_4 + R_4 - R_4 + R_4 \\ \hline R_1 - R_4 - R_4 + R_4 + R_4 + R_4 \\ \hline R_1 - R_4 + R_4 + R_4 + R_4 + R_4 \\ \hline R_1 - R_4 + R_4 + R_4 + R_4 + R_4 \\ \hline R_1 - R_4 + R_4 + R_4 + R_4 + R_4 \\ \hline R_1 - R_4 + R_4 + R_4 + R_4 + R_4 \\ \hline R_1 - R_4 + R_4 + R_4 + R_4 + R_4 \\ \hline R_1 - R_4 + R_4 + R_4 + R_4 + R_4 \\ \hline R_1 - R_4 + R_4 + R_4 + R_4 + R_4 \\ \hline R_1 - R_4 + R_4 + R_4 + R_4 + R_4 \\ \hline R_1 - R_4 + R_4 + R_4 + R_4 + R_4 \\ \hline R_1 - R_4 + R_4 + R_4 + R_4 + R_4 \\ \hline R_1 - R_4 + R_4 + R_4 + R_4 + R_4 \\ \hline R_1 - R_4 + R_4 + R_4 + R_4 + R_4 \\ \hline R_1 - R_4 + R_4 + R_4 + R_4 + R_4 \\ \hline R_1 - R_4 + R_4 + R_4 + R_4 + R_4 + R_4 \\ \hline R_1 - R_4 + R_4 + R_4 + R_4 + R_4 + R_4 \\ \hline R_1 - R_4 + R_4 \\ \hline R_1 - R_4 + R_4 \\ \hline R_1 - R_4 + R_4$	5	
$\begin{array}{c} \begin{array}{c} \begin{array}{c} \begin{array}{c} \begin{array}{c} 1\\ alkyl \ bromide \ from \ a \ methyl, 1^{\circ}, \ or \ 2^{\circ} \ alcohol: \\ R-OH + PBr_{3} \rightarrow R-Br + HOPBr_{2} \\ alkyl \ chloride, \ bromide, \ or \ iodide \ from \ a \ 3^{\circ} \ alcohol \ (S_{N}1): \\ R-OH + HX \rightarrow R-X + H_{2}O \\ hydrohalogenation \ of \ an \ alkene \ (X \ on \ less \ substituted \ C): \\ \hline C=C + H-X \rightarrow H- \begin{array}{c} \\ - \\ - \\ - \\ - \\ - \\ - \\ - \\ - \\ $	hunde	$-\dot{C}$ $-H + X - X \xrightarrow{\Delta \alpha \pi \psi} - \dot{C} - X + H - X$
$\begin{array}{c} R-OH+PBr_{3} \rightarrow R-Br+HOPBr_{2} \\ alkyl chloride, bromide, or iodide from a 3° alcohol (S_{N}1): \\ R-OH+HX \rightarrow R-X+H_{2}O \\ hydrohalogenation of an alkene (X on less substituted C): \\ \bigcirc C=C-C+H-X \rightarrow H-\overset{C}{C}-\overset{C}{C}-X \\ Synthesize a \\ 1,2-\text{dihalide} \\ (X's on adjacent C's) \\ \begin{array}{c} R_{1} \\ R_{2}-C=C\overset{R_{3}}{R_{4}}+X_{2} \rightarrow \overset{R_{2}}{\overset{R_{1}}{C}-\overset{X}{C}-\overset{R_{3}}{R_{4}}R_{3} \\ R_{1} \\ R_{2}-C=C\overset{R_{3}}{R_{4}}+X_{2} \rightarrow \overset{R_{2}}{\overset{R_{1}}{C}-\overset{X}{C}-\overset{A}{R_{4}}R_{3} \\ R_{1} \\ R_{2}-C=C\overset{R_{3}}{R_{4}}+\overset{X_{2}}{\overset{Z}{C}-C} \\ R_{4} \\ R_{3} \\ R_{1} \\ R_{2}-C=C\overset{R_{3}}{R_{4}}, \overset{I}{C}=O+O=C\overset{R_{3}}{R_{4}} \\ R_{1} \\ R_{2}-C=C\overset{R_{3}}{R_{4}}, \overset{I}{C}=O+O=C\overset{R_{3}}{R_{4}} \\ R_{1} \\ R_{2}-C=O+R_{4} \\ R_{2}-R_{4}-R_{3} \\ R_{1}-R_{2}-C=O+O=C\overset{R_{3}}{R_{4}} \\ R_{1} \\ R_{2}-C=O+R_{3} \\ R_{4}-$		
$\begin{array}{c} R-OH+PBr_{3} \rightarrow R-Br+HOPBr_{2} \\ alkyl chloride, bromide, or iodide from a 3° alcohol (S_{N}1): \\ R-OH+HX \rightarrow R-X+H_{2}O \\ hydrohalogenation of an alkene (X on less substituted C): \\ \bigcirc C=C-C+H-X \rightarrow H-\overset{C}{C}-\overset{C}{C}-X \\ Synthesize a \\ 1,2-\text{dihalide} \\ (X's on adjacent C's) \\ \begin{array}{c} R_{1} \\ R_{2}-C=C\overset{R_{3}}{R_{4}}+X_{2} \rightarrow \overset{R_{2}}{\overset{R_{1}}{C}-\overset{X}{C}-\overset{R_{3}}{R_{4}}R_{3} \\ R_{1} \\ R_{2}-C=C\overset{R_{3}}{R_{4}}+X_{2} \rightarrow \overset{R_{2}}{\overset{R_{1}}{C}-\overset{X}{C}-\overset{A}{R_{4}}R_{3} \\ R_{1} \\ R_{2}-C=C\overset{R_{3}}{R_{4}}+\overset{X_{2}}{\overset{Z}{C}-C} \\ R_{4} \\ R_{3} \\ R_{1} \\ R_{2}-C=C\overset{R_{3}}{R_{4}}, \overset{I}{C}=O+O=C\overset{R_{3}}{R_{4}} \\ R_{1} \\ R_{2}-C=C\overset{R_{3}}{R_{4}}, \overset{I}{C}=O+O=C\overset{R_{3}}{R_{4}} \\ R_{1} \\ R_{2}-C=O+R_{4} \\ R_{2}-R_{4}-R_{3} \\ R_{1}-R_{2}-C=O+O=C\overset{R_{3}}{R_{4}} \\ R_{1} \\ R_{2}-C=O+R_{3} \\ R_{4}-$		alkyl bromide from a methyl, 1°, or 2° alcohol:
$\begin{array}{c} \text{alkyl chloride, bromide, or iodide from a 3° alcohol (S_N1):} \\ R-OH + HX \rightarrow R-X + H_2O \\ \text{hydrohalogenation of an alkene (X on less substituted C):} \\ \bigcirc C = C \begin{pmatrix} + H - X \end{pmatrix} \rightarrow H - C - C - X \\ \downarrow - I \end{pmatrix} \\ \stackrel{R_1}{\subseteq} C = C \begin{pmatrix} R_3 \\ R_4 \end{pmatrix} + X_2 \end{pmatrix} \xrightarrow{R_2R_1} \begin{pmatrix} X \\ R_4 R_3 \end{pmatrix} \\ \stackrel{R_1}{\subseteq} R_4 R_3 \end{pmatrix} \\ \stackrel{R_1R_2}{\subseteq} R_4 + X_2 \longrightarrow R_4R_3 \\ \stackrel{R_1R_2}{\subseteq} R_4 R_3 \end{pmatrix} \\ \begin{array}{c} R_1R_2 \\ R_1R_2 \end{pmatrix} \\ \stackrel{R_1R_2}{\subseteq} R_4 \end{pmatrix} \\ \stackrel{R_1R_2}{\subseteq} R_4 + R_2 \\ \stackrel{R_1R_2}{\cong} R_4 R_3 \end{pmatrix} \\ \stackrel{R_1R_2}{\cong} R_1 R_2 \\ \stackrel{R_1R_2}{\cong} R_1 \\ \stackrel{R_2}{\cong} R_1 \\ \stackrel{R_2}{\cong} R_2 \\ \stackrel{R_1R_2}{\cong} R_1 \\ \stackrel{R_2}{\cong} R_2 \\ \stackrel{R_2}{\cong} R_1 \\ \stackrel{R_2}{\cong} R_2 \\ \stackrel{R_2}{\cong} R_2 \\ \stackrel{R_2}{\cong} R_1 \\ \stackrel{R_2}{\cong} R_2 \\ \stackrel{R_2}{\cong} $		
$\begin{array}{c} \text{R-OH} + \text{HX} \rightarrow \text{R-X} + \text{H}_2\text{O} \\ \text{hydrohalogenation of an alkene (X on less substituted C):} \\ \hline C = C + H - X \rightarrow H - \stackrel{!}{C} - \stackrel{!}{C} - X \\ \hline \text{synthesize a} \\ 1,2-\text{dihalide} \\ (X's \text{ on adjacent C's)} \\ \begin{array}{c} \text{R}_1 \\ \text{R}_2 - \text{C} - C \\ \text{R}_4 + X_2 \end{array} \rightarrow \begin{array}{c} \text{R}_2 \\ \text{R}_1 \\ \text{R}_2 - \text{C} - C \\ \text{R}_4 + X_2 \end{array} \rightarrow \begin{array}{c} \text{R}_2 \\ \text{R}_1 \\ \text{R}_2 - \text{C} - C \\ \text{R}_4 \\ \text{R}_3 \end{array} \xrightarrow{\text{R}_4} \begin{array}{c} \text{R}_3 \\ \text{R}_4 \\ \text{R}_1 \\ \text{R}_2 \end{array} \rightarrow \begin{array}{c} \text{R}_2 \\ \text{R}_1 \\ \text{R}_2 \\ \text{R}_4 \end{array} \xrightarrow{\text{R}_3} \begin{array}{c} \text{R}_4 \\ \text{R}_1 \\ \text{R}_2 \\ \text{C} - C \\ \text{R}_4 \end{array} \xrightarrow{\text{R}_4} \begin{array}{c} \text{R}_3 \\ \text{R}_1 \\ \text{R}_2 \\ \text{C} - C \\ \text{R}_4 \end{array} \xrightarrow{\text{R}_3} \begin{array}{c} \text{R}_4 \\ \text{R}_1 \\ \text{R}_2 \\ \text{R}_2 \\ \text{C} - C \\ \text{R}_4 \end{array} \xrightarrow{\text{R}_4} \begin{array}{c} \text{R}_3 \\ \text{R}_1 \\ \text{R}_2 \\ \text{C} - C \\ \text{R}_4 \end{array} \xrightarrow{\text{R}_4} \begin{array}{c} \text{R}_3 \\ \text{R}_1 \\ \text{R}_2 \\ \text{C} - C \\ \text{R}_4 \end{array} \xrightarrow{\text{R}_4} \begin{array}{c} \text{R}_3 \\ \text{R}_1 \\ \text{R}_2 \\ \text{C} - C \\ \text{R}_4 \end{array} \xrightarrow{\text{R}_4} \begin{array}{c} \text{R}_3 \\ \text{R}_1 \\ \text{R}_2 \\ \text{C} - C \\ \text{R}_4 \end{array} \xrightarrow{\text{R}_4} \begin{array}{c} \text{R}_3 \\ \text{R}_2 \\ \text{R}_4 \\ \text{R}_5 \\ \text{R}_4 \\ \text{R}_5 \\ \text{R}_4 \\ \text{R}_5 \\ \text{R}_4 \\ \text{R}_5 \\ \text{R}_5 \\ \text{R}_4 \\ \text{R}_5 \\ $		alkyl chloride, bromide, or iodide from a 3° alcohol ($S_{N}1$):
$\begin{array}{c} \begin{array}{c} \begin{array}{c} C=C + H-X \rightarrow H- \stackrel{1}{C}-\stackrel{1}{C}-X \\ \end{array} \end{array}$ synthesize a 1,2-dihalide (X's on adjacent C's) $\begin{array}{c} R_{1} \\ R_{2} \end{array} = \begin{array}{c} R_{3} \\ R_{2} \end{array} + X_{2} \end{array} \xrightarrow{\begin{array}{c} R_{2} \\ R_{4} \end{array}} \xrightarrow{\begin{array}{c} R_{2} \\ R_{4} \end{array} \xrightarrow{\begin{array}{c} R_{3} \\ R_{4} \end{array}} \xrightarrow{\begin{array}{c} R_{3} \\ R_{4} \end{array} \xrightarrow{\begin{array}{c} R_{3} \\ R_{4} \end{array}} \xrightarrow{\begin{array}{c} R_{3} \\ R_{4} \end{array} \xrightarrow{\begin{array}{c} R_{3} \\ R_{4} \end{array} \xrightarrow{\begin{array}{c} R_{3} \\ R_{4} \end{array}} \xrightarrow{\begin{array}{c} R_{3} \\ R_{4} \end{array} \xrightarrow{\begin{array}{c} R_{3} \\ R_{2} \end{array} \xrightarrow{\begin{array}{c} R_{3} \\ R_{4} \end{array} \xrightarrow{\begin{array}{c} R_{3} \\ R_{2} \end{array} \xrightarrow{\begin{array}{c} R_{3} \\ R_{4} \end{array} \xrightarrow{\begin{array}{c} R_{4} \\ R_{4} \end{array} \xrightarrow{\begin{array}{c} R_{3} \\ R_{4} \end{array} \xrightarrow{\begin{array}{c} R_{4} \\ R_{4} \end{array} \xrightarrow{\begin{array}{c} R_{3} \\ R_{4} \end{array} \xrightarrow{\begin{array}{c} R_{4} \\ R_{4} \end{array} \xrightarrow{\begin{array}{c} R_{3} \\ R_{4} \end{array} \xrightarrow{\begin{array}{c} R_{4} \\ R_{4} \end{array} \xrightarrow{\begin{array}{c} R_{4} \\ \end{array} \xrightarrow{\begin{array}{c} R_{4} \\ R_{4} \end{array} \xrightarrow{\begin{array}{c} R_{4} \\ \end{array} \xrightarrow{\begin{array}{c} R_{4} \\ R_{4} \end{array} \xrightarrow{\begin{array}{c} R_{4} \\ R_{4} \end{array} \xrightarrow{\begin{array}{c} R_{4} \\ \end{array} \xrightarrow{\begin{array}{c} R_{4} \end{array} \xrightarrow{\begin{array}{c} R_{4} \\ \end{array} \xrightarrow{\begin{array}{c} R_{4} } \end{array} \xrightarrow{\begin{array}{c} R_{4} \\ \end{array} \xrightarrow{\begin{array}{c} R_{4} } \end{array} \xrightarrow{\begin{array}{c} R_{4} } \end{array} \xrightarrow{\begin{array}{c} R_{4} } \end{array} \xrightarrow{\begin{array}{c} R_{4} } \end{array} \xrightarrow{\begin{array}{c} R_{4} }$		
synthesize a 1,2-dihalide (X's on adjacent C's) $ \begin{array}{c} R_{1} \\ R_{2} \\ \end{array} \\ R_{2} \\ \end{array} \\ R_{4} \\ R_{3} \\ \end{array} \\ R_{2} \\ R_{4} \\ R_{3} \\ R_{1} \\ R_{2} \\ \end{array} $ $ \begin{array}{c} R_{1} \\ R_{2} \\ R_{4} \\ R_{3} \\ R_{1} \\ R_{2} \\ \end{array} \\ R_{1} \\ R_{2} \\ \end{array} $ $ \begin{array}{c} R_{1} \\ R_{2} \\ R_{4} \\ R_{3} \\ R_{1} \\ R_{2} \\ \end{array} $ $ \begin{array}{c} R_{1} \\ R_{2} \\ R_{4} \\ R_{3} \\ R_{1} \\ R_{2} \\ \end{array} $ $ \begin{array}{c} R_{1} \\ R_{2} \\ R_{4} \\ R_{3} \\ R_{1} \\ R_{2} \\ \end{array} $ $ \begin{array}{c} R_{1} \\ R_{2} \\ R_{4} \\ R_{3} \\ R_{1} \\ R_{2} \\ R_{4} \\ R_{3} \\ R_{1} \\ R_{2} \\ \end{array} $ $ \begin{array}{c} R_{3} \\ R_{1} \\ R_{2} \\ R_{4} \\ R_$		hydrohalogenation of an alkene (X on less substituted C):
synthesize a 1,2-dihalide (X's on adjacent C's) $ \begin{array}{c} R_{1} \\ R_{2} \\ \end{array} \\ R_{2} \\ \end{array} \\ R_{4} \\ R_{3} \\ \end{array} \\ R_{2} \\ R_{4} \\ R_{3} \\ R_{1} \\ R_{2} \\ \end{array} $ $ \begin{array}{c} R_{1} \\ R_{2} \\ R_{4} \\ R_{3} \\ R_{1} \\ R_{2} \\ \end{array} \\ R_{1} \\ R_{2} \\ \end{array} $ $ \begin{array}{c} R_{1} \\ R_{2} \\ R_{4} \\ R_{3} \\ R_{1} \\ R_{2} \\ \end{array} $ $ \begin{array}{c} R_{1} \\ R_{2} \\ R_{4} \\ R_{3} \\ R_{1} \\ R_{2} \\ \end{array} $ $ \begin{array}{c} R_{1} \\ R_{2} \\ R_{4} \\ R_{3} \\ R_{1} \\ R_{2} \\ \end{array} $ $ \begin{array}{c} R_{1} \\ R_{2} \\ R_{4} \\ R_{3} \\ R_{1} \\ R_{2} \\ R_{4} \\ R_{3} \\ R_{1} \\ R_{2} \\ \end{array} $ $ \begin{array}{c} R_{3} \\ R_{1} \\ R_{2} \\ R_{4} \\ R_$		$c - c' + H - \chi \rightarrow H - c - c - \chi$
1,2-dihalide (X's on adjacent C's) $R_1 \ C=C \ R_3 \ R_4 + X_2 \longrightarrow C-C \ R_4 \ R_3 \ R_1 \ R_2$ and C-C \ R_1 \ R_2 \ R_1 \ R_2 \ R_1 \ R_2synthesize a carbonyl (aldehyde or ketone)methyl, 1°, or 2° alcohol + PCC, no H ₂ O ozonolysis:methyl, 1°, or 2° alcohol + PCC, no H ₂ O ozonolysis:R_1 \ R_2 \ R_3 \ R_2 \ R_4 \ R_3 \ R_2 \ R_4 \ R_2 \ R_4 \ R_2 \ R_4 \ R_2 \ R_4		
$\begin{array}{c} \text{(X's on adjacent C's)} \\ \text{(X's on adjacent C's)} \\ \text{synthesize a carbonyl} \\ \text{(aldehyde or ketone)} \\ \text{synthesize a Grignard} \\ \text{synthesize a Grignard} \\ \text{Rt} + \text{Mg} \rightarrow \text{RMgX}, \\ \text{Rt} = \text{Cl}, \text{Rt} + \text{Mg}, \text{Cl} + \text{Cl}, \text{Rt} + \text{Rt} + \text{Cl}, \text{Rt} + \text{Cl} +$	•	$R_2R_1 \rightarrow X R_3R_4$
$\begin{array}{c} R_{2} \\ R_{4} \\ R_{4} \\ R_{3} \\ R_{1} \\ R_{2} \\ R_{4} \\ R_{3} \\ R_{1} \\ R_{2} \\ R_{2} \\ R_{1} \\ R_{2} \\ R_{2} \\ R_{2} \\ R_{3} \\ R_{1} \\ R_{2} \\ R_{2} \\ R_{3} \\ R_{1} \\ R_{2} \\ R_{1} \\ R_{2} \\ R_{1} \\ R_{2} \\ R_{2} \\ R_{2} \\ R_{3} \\ R_{1} \\ R_{2} \\ R_{2} \\ R_{3} \\ R_{1} \\ R_{1} \\ R_{1} \\ R_{2} \\ R_{3} \\ R_{1} \\ R_{2} \\ R_{1} \\ R_{2} \\ R_{3} \\ R_{1} \\ R_{2} \\ R_{1} \\ R_{2} \\ R_{1} \\ R_{2} \\ R_{1} \\ R_{2} \\ R_{2} \\ R_{1} \\ R_{1} \\ R_{2} \\ R_{1} \\ R_{1} \\ R_{2} \\ R_{1} \\ R_{2} \\ R_{1} \\ R_{1} \\ R_{2} \\ R_{1} \\ R_{1} \\ R_{2} \\ R_{1} \\ R_{1} \\$		$ R_1 \rangle \langle R_3 \rangle \rangle \langle N_1 \rangle \langle N_2 \rangle \langle N_1 \rangle \rangle \langle N_2 \rangle \langle N_1 \rangle \langle N_2 \rangle \langle N_1 \rangle \langle N_1 \rangle \langle N_2 \rangle \langle N_1 \rangle \langle$
$\begin{array}{c} & & & & & & & \\ \text{synthesize a carbonyl} \\ (aldehyde or ketone) & & & & \\ & & & & \\ R_1 & & & \\ & & & \\ R_2 & & \\ & & & \\ \end{array} \\ \begin{array}{c} \text{methyl, 1^\circ, or 2^\circ alcohol} \ + \ \text{PCC, no H_2O} \\ \text{ozonolysis:} \\ & & \\ R_1 & & \\ R_2 & \\ \hline \\ & & \\ R_2 & \\ \end{array} \\ \begin{array}{c} \text{R_1} & & \\ R_1 & \\ R_2 & \\ \hline \\ & & \\ R_2 & \\ \end{array} \\ \begin{array}{c} \text{R_1} & & \\ R_1 & \\ R_2 & \\ \hline \\ & & \\ R_2 & \\ \hline \\ & & \\ R_2 & \\ \end{array} \\ \begin{array}{c} \text{R_1} & & \\ R_1 & \\ R_2 & \\ \hline \\ & & \\ R_2 & \\ \hline \\ & & \\ R_2 & \\ \end{array} \\ \begin{array}{c} \text{R_1} & & \\ R_1 & \\ R_2 & \\ \hline \\ & & \\ R_2 & \\ \hline \\ & & \\ R_2 & \\ \end{array} \\ \begin{array}{c} \text{R_1} & & \\ R_1 & \\ R_2 & \\ \hline \\ & & \\ R_2 & \\ \hline \\ & & \\ R_2 & \\ \end{array} \\ \begin{array}{c} \text{R_1} & & \\ R_1 & \\ R_2 & \\ \hline \\ & & \\ R_2 & \\ \hline \\ & & \\ R_2 & \\ \end{array} \\ \begin{array}{c} \text{R_1} & & \\ R_2 & \\ \hline \\ & & \\ R_2 & \\ \hline \\ & & \\ \end{array} \\ \begin{array}{c} \text{R_2} & & \\ R_1 & \\ R_2 & \\ \hline \\ & & \\ \end{array} \\ \begin{array}{c} \text{R_2} & & \\ R_1 & \\ \hline \\ & & \\ R_2 & \\ \end{array} \\ \begin{array}{c} \text{R_2} & & \\ R_1 & \\ \hline \\ & & \\ \end{array} \\ \begin{array}{c} \text{R_2} & & \\ R_2 & \\ \end{array} \\ \begin{array}{c} \text{R_1} & & \\ R_2 & \\ \end{array} \\ \begin{array}{c} \text{R_2} & & \\ R_1 & \\ \hline \\ & & \\ \end{array} \\ \begin{array}{c} \text{R_2} & & \\ R_1 & \\ \end{array} \\ \begin{array}{c} \text{R_2} & & \\ \end{array} \\ \begin{array}{c} \text{R_1} & & \\ R_2 & \\ \end{array} \\ \begin{array}{c} \text{R_2} & & \\ \end{array} $	(X's on adjacent C's)	
(aldehyde or ketone) (aldehyde or ketone) $R_1 \sim C = C \xrightarrow{R_3} \frac{1. O_3}{2. Me_2 S \text{ or } Zn} \xrightarrow{R_1} C = O + O = C \xrightarrow{R_3} R_4$ synthesize a Grignard RX + Mg \rightarrow RMgX, X = CI, Br, or I		
(aldehyde or ketone) (aldehyde or ketone) $R_1 \sim C = C \xrightarrow{R_3} \frac{1. O_3}{2. Me_2 S \text{ or } Zn} \xrightarrow{R_1} C = O + O = C \xrightarrow{R_3} R_4$ synthesize a Grignard RX + Mg \rightarrow RMgX, X = CI, Br, or I	synthesize a carbonyl	methyl, 1°, or 2° alcohol + PCC, no H_2O
$\begin{array}{c} R_{1} \\ R_{2} \\ R_{2} \\ \end{array} \xrightarrow{R_{4}} C = C \xrightarrow{R_{3}} \frac{1 \cdot O_{3}}{2 \cdot Me_{2}S \text{ or } Zn} \xrightarrow{R_{1}} C = O + O = C \xrightarrow{R_{3}} R_{4} \\ R_{2} \\ R_{4} \\ $	(aldehyde or ketone)	ozonolysis:
$\begin{array}{c} C = C \\ R_2 & R_4 \end{array} \xrightarrow{\begin{subarray}{c} C = 0 \\ R_2 & R_4 \end{array} \xrightarrow{\begin{subarray}{c} R_4 \end{array} \xrightarrow{\begin{subarray}{c} R_4 \\ R_4 & R_4 \end{array} \xrightarrow{\begin{subarray}{c} R_4 & R_4 \end{array} \xrightarrow{\begin{subarray}{c} R_4 & R_4 \\ R_4 & R_4 & R_4 \end{array} \xrightarrow{\begin{subarray}{c} R_4 & R_4 \\ R_4 & R_4 & R_4 & R_4 \end{array} \xrightarrow{\begin{subarray}{c} R_4 & R_4 & R_4 \\ R_4 & R_4$		$R_1 R_3 I.O_3 R_1 R_3$
synthesize a Grignard $RX + Mg \rightarrow RMgX$, $X = CI, Br, or I$		R_2 R_4 $\overline{2.Me_2S \text{ or } Zn}$ R_2 $C=0+0=C$ R_4
reagant	synthesize a Grignard	$\bar{RX} + Mg \rightarrow RMgX$, $X = Cl, Br, or l$
	reagant	

goals	reactions
synthesize an	reduction of carbonyl (OH on attacked C):
alcohol	$C=0 \xrightarrow{\text{NaBH}_4, \text{HOR}} H - C - 0 - H$
	aldehyde alcohol
	$ \begin{array}{c} \begin{array}{c} \oplus & \oplus \\ & \oplus \\ & H \\ & H \\ & -C \\ -C \\ & -C \\ $
	reduction of epoxide with LiAlH ₄ or Grignard (OH on C adjacent to attacked C):
	$ \begin{array}{c} \bigcirc & \bigoplus \\ \bigcirc & & H \\ - \bigcirc & H \\ - \bigcirc & - & -$
	hydration of an alkene (OH on more substituted C):
	$C=C + H_2O \xrightarrow{HA} H - C - C - OH$
	hydroboration-oxidation (OH on less substituted C):
	$ \begin{array}{c} R_1 \\ C = C \end{array} \xrightarrow{R_3} \begin{array}{c} 1. BH_3 \end{array} \xrightarrow{R_2 R_1} \\ C = C \end{array} \xrightarrow{R_3 R_4} \begin{array}{c} H \\ C = C \end{array} \xrightarrow{R_1 R_2 R_1} \\ C = C \end{array} \xrightarrow{R_3 R_4} \begin{array}{c} H \\ C = C \end{array} \xrightarrow{R_1 R_2 R_1} \\ C = C \end{array} \xrightarrow{R_2 R_1} \\ C = C \end{array} \xrightarrow{R_3 R_4} \begin{array}{c} H \\ C = C \end{array} \xrightarrow{R_3 R_4} \\ C = C \end{array} \xrightarrow{R_3 R_4} \begin{array}{c} H \\ C = C \end{array} \xrightarrow{R_3 R_4} \\ C = C \end{array} \xrightarrow{R_3 R_4} \begin{array}{c} H \\ C = C \end{array} \xrightarrow{R_3 R_4} \\ C = C \end{array} \xrightarrow{R_3 R_4} \begin{array}{c} H \\ C = C \end{array} \xrightarrow{R_3 R_4} \\ C = C \end{array} \xrightarrow{R_3 R_4} \begin{array}{c} H \\ C = C \end{array} \xrightarrow{R_3 R_4} \\ C = C \end{array} \xrightarrow{R_3 R_4} \begin{array}{c} H \\ C = C \end{array} \xrightarrow{R_3 R_4} \\ C = C \end{array} \xrightarrow{R_3 R_4} \\ C = C \end{array} \xrightarrow{R_3 R_4} \\ C = C \xrightarrow{R_3 R_4} \\ C \xrightarrow{R_3 R_4} \\ C = C \xrightarrow{R_3 R_4} \\ C \xrightarrow{R_3 R_4} $
	$ \begin{array}{c} R_1 \\ R_2 \\ \hline \\ R_2 \\ \hline \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ $
synthesize a 1,2-haloalcohol (X and OH on adjacent C's)	$ \begin{array}{c} R_{1} \\ R_{2} \\ \end{array} \\ C = C \\ R_{4} \\ \end{array} \\ R_{2} \\ \end{array} \\ R_{4} \\ R_{2} \\ \end{array} \\ \begin{array}{c} R_{2} \\ R_{4} \\ R_{3} \\ R_{4} \\ R_{3} \\ R_{1} \\ R_{2} \\ \end{array} \\ \begin{array}{c} R_{3} \\ R_{4} \\ R_{3} \\ R_{1} \\ R_{2} \\ \end{array} \\ \begin{array}{c} R_{3} \\ R_{4} \\ R_{3} \\ R_{1} \\ R_{2} \\ \end{array} \\ \begin{array}{c} R_{3} \\ R_{4} \\ R_{4} \\ R_{3} \\ R_{1} \\ R_{2} \\ \end{array} \\ \begin{array}{c} R_{3} \\ R_{4} \\ R_{4} \\ R_{3} \\ R_{1} \\ R_{2} \\ \end{array} \\ \begin{array}{c} R_{3} \\ R_{4} \\ R_{4} \\ R_{3} \\ R_{1} \\ R_{2} \\ \end{array} \\ \begin{array}{c} R_{3} \\ R_{4} \\ R_{4} \\ R_{3} \\ R_{1} \\ R_{2} \\ \end{array} \\ \begin{array}{c} R_{3} \\ R_{4} \\ R_{4} \\ R_{3} \\ R_{1} \\ R_{2} \\ \end{array} \\ \begin{array}{c} R_{3} \\ R_{4} \\ R_{4} \\ R_{3} \\ R_{1} \\ R_{2} \\ \end{array} \\ \begin{array}{c} R_{3} \\ R_{4} \\ R_{4} \\ R_{3} \\ R_{1} \\ R_{2} \\ \end{array} \\ \begin{array}{c} R_{3} \\ R_{4} \\ R_{4} \\ R_{3} \\ R_{1} \\ R_{2} \\ \end{array} \\ \begin{array}{c} R_{3} \\ R_{4} \\ R_{4} \\ R_{3} \\ R_{1} \\ R_{2} \\ \end{array} \\ \begin{array}{c} R_{3} \\ R_{4} \\ R_{4} \\ R_{1} \\ R_{2} \\ \end{array} \\ \begin{array}{c} R_{3} \\ R_{4} \\ R_{1} \\ R_{2} \\ \end{array} \\ \begin{array}{c} R_{3} \\ R_{4} \\ R_{1} \\ R_{2} \\ \end{array} \\ \begin{array}{c} R_{3} \\ R_{4} \\ R_{1} \\ R_{2} \\ \end{array} \\ \begin{array}{c} R_{3} \\ R_{4} \\ R_{1} \\ R_{2} \\ \end{array} \\ \begin{array}{c} R_{3} \\ R_{4} \\ R_{1} \\ R_{2} \\ \end{array} \\ \begin{array}{c} R_{3} \\ R_{4} \\ R_{1} \\ \end{array} \\ \begin{array}{c} R_{3} \\ R_{4} \\ R_{1} \\ R_{2} \\ \end{array} \\ \begin{array}{c} R_{3} \\ R_{4} \\ R_{1} \\ R_{2} \\ \end{array} \\ \begin{array}{c} R_{3} \\ R_{1} \\ R_{2} \\ \end{array} \\ \begin{array}{c} R_{3} \\ R_{1} \\ R_{2} \\ \end{array} \\ \begin{array}{c} R_{3} \\ R_{1} \\ R_{2} \\ \end{array} \\ \begin{array}{c} R_{1} \\ R_{2} \\ R_{1} \\ R_{2} \\ \end{array} \\ \begin{array}{c} R_{1} \\ R_{2} \\ R_{1} \\ \end{array} \\ \begin{array}{c} R_{1} \\ R_{2} \\ R_{1} \\ \end{array} \\ \begin{array}{c} R_{1} \\ R_{2} \\ R_{1} \\ R_{2} \\ \end{array} \\ \begin{array}{c} R_{1} \\ R_{2} \\ R_{1} \\ \end{array} \\ \begin{array}{c} R_{1} \\ R_{2} \\ R_{1} \\ \end{array} \\ \begin{array}{c} R_{1} \\ R_{2} \\ R_{1} \\ \end{array} \\ \begin{array}{c} R_{1} \\ R_{2} \\ R_{1} \\ R_{2} \\ \end{array} \\ \begin{array}{c} R_{1} \\ R_{1} \\ \end{array} \\ \begin{array}{c} R_{1} \\ R_{1} \\ R_{2} \\ \end{array} \\ \begin{array}{c} R_{1} \\ R_{1} \\ R_{1} \\ \end{array} \\ \begin{array}{c} R_{1} \\ \end{array} \\ \begin{array}{c} R_{1} \\ R_{1} \\ \end{array} \\ \end{array} \\ \begin{array}{c} R_{1} \\ R_{1} \\ \end{array} \\ \end{array} \\ \begin{array}{c} R_{1} \\ R_{1} \\ \end{array} \\ \end{array} \\ \begin{array}{c} R_{1} \\ \end{array} \\ \begin{array}{c} R_{1} \\ R_{1} \\ \end{array} \\ \end{array} \\ \begin{array}{c} R_{1} \\ \end{array} \\ \begin{array}{c} R_{1} \\ \end{array} \\ \end{array} \\ \begin{array}{c} R_{1} \\ \end{array} \\ \end{array} \\ \begin{array}{c} R_{1} \\ \end{array} \\ \end{array} \\ \begin{array}{c} R_{1} \\ $
synthesize a 1,2-diol (OH's on	trans dihydroxylation: epoxide plus HO^{-} in H_2O (S _N 2), or epoxide plus H_2O with H_2SO_4 (S _N 1) osmium catalyzed dihydroxylation is cis:
adjacent C's)	$ \begin{array}{c} R_1 \\ R_2 \\ R_2 \\ \end{array} \xrightarrow{R_4} \\ R_4 \\ \end{array} \xrightarrow{OsO_4, H_2O_2} \\ R_2 \\ \end{array} R_2 \\ C-C \\ C-C \\ and \\ C-C $
	HO OH $R_1 R_2 R_4 R_3$

goals	reactions
synthesize an alkene	E2: $R-L + LDA$ (major product: less substituted alkene) E2: $R-L$ (3°, 2°, or hindered 1°) + NaOH (major: more-substituted alkene) E1: $R-L$ (2° or 3°) + H_2SO_4 + heat (major: more-substituted alkene) reduction of carbonyl, followed by E1 dehydration:
	reduction of carbonyl, followed by E1 denydration: $ \begin{array}{c} \bigcirc & H \\ - \bigcirc -$
	$ \begin{array}{c} 0 \\ H \\ -C - C - C - \end{array} \xrightarrow{H} 1. RMgX \xrightarrow{XMg} O \\ R \\$
	reduction of epoxide, followed by E1 dehydration: $1 \stackrel{\text{LiAlH}_4}{\circ r} 2 \stackrel{\text{H}_2\text{SO}_4}{\rightarrow} \stackrel{\text{C}_2\text{-C}_2\text{-C}_2}{\longrightarrow} \xrightarrow{\text{RMgX}} \stackrel{\Delta}{\longrightarrow}$
synthesize an epoxide	deprotonation followed by intramolecular S_N^2 : $R_2 \stackrel{R_1}{\longrightarrow} C - C \xrightarrow{OH} + NaH \xrightarrow{R_2 \stackrel{R_1}{\longrightarrow} C - C} \xrightarrow{O} \xrightarrow{O} \xrightarrow{C - C} \xrightarrow{O} \xrightarrow{C - C} \xrightarrow{C - C} \xrightarrow{R_4 \stackrel{R_3}{\longrightarrow} R_1 \stackrel{R_2}{\longrightarrow} \stackrel{R_2}{\longrightarrow} \xrightarrow{R_1 \stackrel{R_2}{\longrightarrow} R_2 \stackrel{R_3}{\longrightarrow} \xrightarrow{R_1 \stackrel{R_2}{\longrightarrow} R_1 \stackrel{R_2}{\longrightarrow} \xrightarrow{R_2 \stackrel{R_3}{\longrightarrow} R_1 \stackrel{R_2}{\longrightarrow} \xrightarrow{R_2 \stackrel{R_3}{\longrightarrow} R_1 \stackrel{R_3}{\longrightarrow} \xrightarrow{R_2 \stackrel{R_3}{\longrightarrow} R_1 \stackrel{R_3}{\longrightarrow} \xrightarrow{R_1 \stackrel{R_2}{\longrightarrow} R_2 \stackrel{R_3}{\longrightarrow} \xrightarrow{R_1 \stackrel{R_2}{\longrightarrow} R_1 \stackrel{R_3}{\longrightarrow} \xrightarrow{R_1 \stackrel{R_2}{\longrightarrow} R_1 \stackrel{R_3}{\longrightarrow} \xrightarrow{R_1 \stackrel{R_3}{\longrightarrow} R_1 \stackrel{R_3}{\longrightarrow} \xrightarrow{R_1 \stackrel{R_3}{\longrightarrow} R_1 \stackrel{R_3}{\longrightarrow} \xrightarrow{R_1 \stackrel{R_3}{\longrightarrow} R_1 \stackrel{R_3}{\longrightarrow} \xrightarrow{R_1 \stackrel{R_3}{\longrightarrow} \xrightarrow{R_1 \stackrel{R_3}{\longrightarrow} R_1 \stackrel{R_3}{\longrightarrow} \xrightarrow{R_1 \stackrel{R_3}{\xrightarrow} R_1 \stackrel{$
	MCPBA oxidation of an alkene: $\begin{array}{c} R_{1} \\ R_{2} \end{array} \xrightarrow{C=C} \begin{array}{c} R_{3} \\ R_{4} \end{array} \xrightarrow{MCPBA} \end{array} \xrightarrow{R_{2} \begin{array}{c} R_{1} \\ C-C \end{array} \xrightarrow{R_{3} \begin{array}{c} R_{4} \\ C-C \end{array}} \xrightarrow{R_{4} \begin{array}{c} R_{3} \\ R_{1} \end{array} \xrightarrow{R_{2} \begin{array}{c} R_{4} \end{array} \xrightarrow{R_{4} \begin{array}{c} R_{3} \\ R_{4} \end{array}} \xrightarrow{R_{4} \begin{array}{c} R_{3} \\ R_{4} \end{array} \xrightarrow{R_{4} \begin{array}{c} R_{3} \\ R_{4} \end{array} \xrightarrow{R_{4} \begin{array}{c} R_{3} \\ R_{4} \end{array} \xrightarrow{R_{4} \begin{array}{c} R_{3} \\ R_{4} \end{array}} \xrightarrow{R_{4} \begin{array}{c} R_{3} \\ R_{4} \end{array} \xrightarrow{R_{4} \begin{array}{c} R_{4} \\ R_{3} \end{array}} \xrightarrow{R_{4} \begin{array}{c} R_{4} \\ R_{4} \end{array} \xrightarrow{R_{4} \end{array} \xrightarrow{R_{4} \begin{array}{c} R_{4} \\ R_{4} \end{array} \xrightarrow{R_{4} } \end{array} \xrightarrow{R_{4} \begin{array}{c} R_{4} \\ R_{4} \end{array} \xrightarrow{R_{4} \begin{array}{c} R_{4} \\ R_{4} \end{array} \xrightarrow{R_{4} } \end{array} \xrightarrow{R_{4} \begin{array}{c} R_{4} \\ R_{4} \end{array} \xrightarrow{R_{4} } \end{array} \xrightarrow{R_{4} \begin{array}{c} R_{4} \\ R_{4} \end{array} \xrightarrow{R_{4} } \end{array} \xrightarrow{R_{4} \begin{array}{c} R_{4} \\ R_{4} \end{array} \xrightarrow{R_{4} } \end{array} \xrightarrow{R_{4} } \end{array} \xrightarrow{R_{4} \begin{array}{c} R_{4} \\ R_{4} \end{array} \xrightarrow{R_{4} } \end{array} \xrightarrow{R_{4} \begin{array}{c} R_{4} \\ R_{4} \end{array} \xrightarrow{R_{4} } \end{array} \xrightarrow{R_{4} \begin{array}{c} R_{4} \\ \end{array} \xrightarrow{R_{4} } \end{array} \xrightarrow{R_{4} } \end{array} \xrightarrow{R_{4} } \end{array} \xrightarrow{R_{4} } \begin{array}{c} R_{4} \\ \xrightarrow{R_{4} } \end{array} \xrightarrow{R_{4} } \end{array} \xrightarrow{R_{4} } \begin{array}{c} R_{4} \\ \xrightarrow{R_{4} } \end{array} R_{$