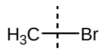
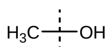
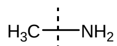
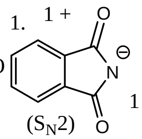
Propose synthetic reactions for the indicated target structures from the given starting materials. Show the starting material (methane, ethane and propane), a reaction arrow with the reagent and a product for each synthetic step of your synthesis. If a compound has been prepared earlier you do not need to remake it (just refer to the part where you made it). Common organic reagents may be used as needed. Additional "carbon" compounds available include bromobenzene, cyclohexane, carbon dioxide and sodium cyanide.

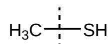
1. Given starting material = methane,(CH_4)

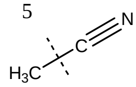
Target molecules (the part from methane has the "C" written out).

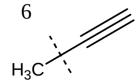
1

methane + Br_2/hν
2 + HBr
2 + PBr_3
2 + $SOBr_2$
2 + a. TsCl/py
b. NaBr

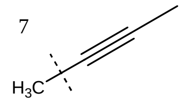
2

a. 1 + ester (S_N2)
b. ester + NaOH
31 + H_3O^+, H_2O
a. 31+HgX_2/H_2O
b. $NaBH_4$
a. 13 + $NaBH_4$
b. WK

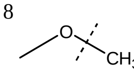
3

1. 1 +

(S_N2)
2. NaOH

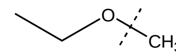
4

1 + NaSH (S_N2)

5

1 + NaCN (S_N2)

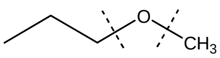
6

a. 40 + $NaNR_2$
b. bromomethane

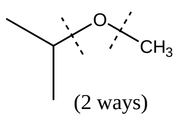
7

a. propyne + $NaNR_2$
b. bromomethane

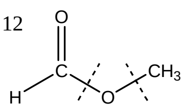
8

(2 ways)

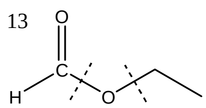
9

(2 ways)

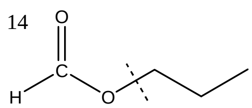
$RO^{\ominus}$ + RBr (S_N2)

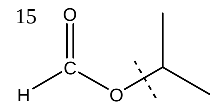
10

(2 ways)
$RO^{\ominus}$ + RBr (S_N2)

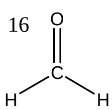
11

(2 ways)
RO + RBr (S_N2)
ROH + RBr (S_N1)

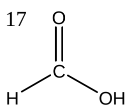
12

(2 ways)
$RCO_2^{\ominus}$ + RBr (S_N2)
RCOCl + ROH (acyl substitution)

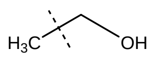
13

(2 ways)
$RCO_2^{\ominus}$ + RBr (S_N2)
RCOCl + ROH (acyl substitution)

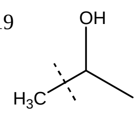
14

(2 ways)
$RCO_2^{\ominus}$ + RBr (S_N2)
RCOCl + ROH (acyl substitution)

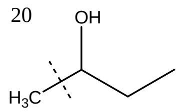
15

(2 ways)
$RCO_2^{\ominus}$ + RBr (S_N2)
RCOCl + ROH (acyl substitution)

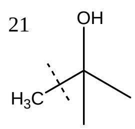
16

2 + CrO_3/py
(PCC)

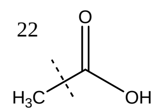
17

2 + CrO_3/H_2O
(Jones)

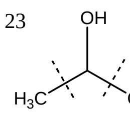
18

a. 1 + Mg (or Li)
b. methanal
c. WK

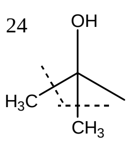
19

a. 1 + Mg (or Li)
b. ethanal
c. WK

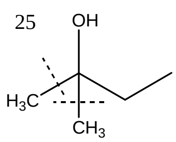
20

a. 1 + Mg (or Li)
b. propanal
c. WK

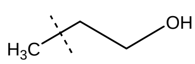
21

a. 1 + Mg (or Li)
b. propanone
c. WK

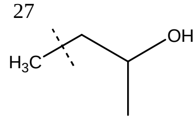
22

a. 1 + Mg (or Li)
b. CO_2
c. WK

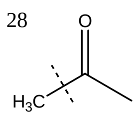
23

a. 1 + Mg (or Li)
b. alkyl methanoate
c. WK

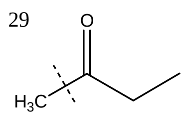
24

a. 1 + Mg (or Li)
b. alkyl ethanoate
c. WK

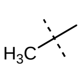
25

a. 1 + Mg (or Li)
b. alkyl propanoate
c. WK

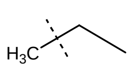
26

a. 1 + Mg (or Li)
b. 2C epoxide
c. WK

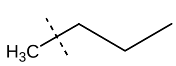
27

a. 1 + Mg (or Li)
b.3C epoxide
c. WK

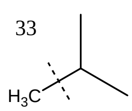
28

acid chloride + cuprate
a. 1 + Mg (or Li)
b. ethanenitrile
ethanoic acid +
2 eqs methyl lithium

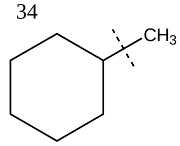
29

acid chloride + cuprate
a. 1 + Mg (or Li)
b. propanenitrile
propanoic acid +
2 eqs methyl lithium

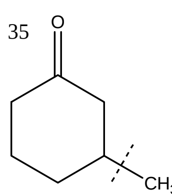
30

(2 ways)
cuprate + RBr

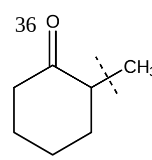
31

(2 ways)
cuprate + RBr

32

(2 ways)
cuprate + RBr

33

(2 ways)
cuprate + RBr

34

(2 ways)
cuprate + RBr

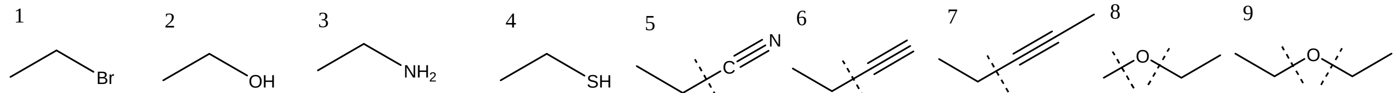
35

cuprate + enone
(conjugate addition)

36

1. ketone + LDA
2. RBr (compound 1)

a. enamine + 1
b. H_2O (hydrolysis)

2. Given starting material = ethane,(CH_3CH_3)

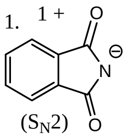
1 2 3 4 5 6 7 8 9



1
ethane + Br_2/hv
2 + HBr
2 + PBr_3
2 + $SOBr_2$
2 + a. TsCl/py
b. NaBr

2
a. 1 + ester (S_N2)
b. ester + NaOH
31 + H_3O^+, H_2O
a. 31+HgX_2/H_2O
b. $NaBH_4$
a. 13 + $NaBH_4$
b. WK

3
1. 1 +



(S_N2)
2. NaOH

4
1 + NaSH (S_N2)

5
1 + NaCN (S_N2)

6
a. 40 + $NaNR_2$
b. bromoethane

7
a. propyne + $NaNR_2$
b. bromoethane

8
(2 ways)

9
(2 ways)

$RO^{\ominus}$ + RBr (S_N2)

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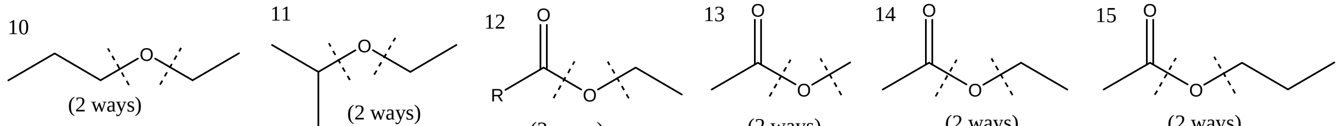
10 11 12 13 14 15



10
(2 ways)
$RO^{\ominus}$ + RBr (S_N2)

11
(2 ways)
RO + RBr (S_N2)
ROH + RBr (S_N1)

12
(2 ways)
$RCO_2^{\ominus}$ + RBr (S_N2)
RCOCl + ROH (acyl substitution)

13
(2 ways)
$RCO_2^{\ominus}$ + RBr (S_N2)
RCOCl + ROH (acyl substitution)

14
(2 ways)
$RCO_2^{\ominus}$ + RBr (S_N2)
RCOCl + ROH (acyl substitution)

15
(2 ways)
$RCO_2^{\ominus}$ + RBr (S_N2)
RCOCl + ROH (acyl substitution)

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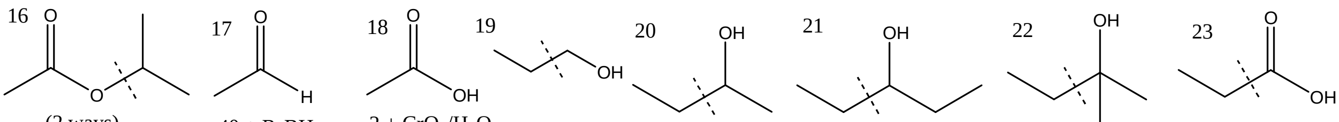
16 17 18 19 20 21 22 23



16
(2 ways)
$RCO_2^{\ominus}$ + RBr (S_N2)
RCOCl + ROH (acyl substitution)

17
a. 40 + R_2BH
b. H_2O_2 / $HO^{\ominus}$

40 + H_3O^+/H_2O

2 + CrO_3/py (PCC)

18
2 + CrO_3/H_2O (Jones)
a. CH_3Br/Mg
b. CO_2
c. WK

ethanenitrile + $H_2SO_4/H_2O/\Delta$

19
a. 1 + Mg (or Li)
b. methanal
c. WK

20
a. 1 + Mg (or Li)
b. ethanal
c. WK

21
a. 1 + Mg (or Li)
b. propanal
c. WK

22
a. 1 + Mg (or Li)
b. propanone
c. WK

23
a. 1 + Mg (or Li)
b. CO_2
c. WK

5 + H_2SO_4/H_2O

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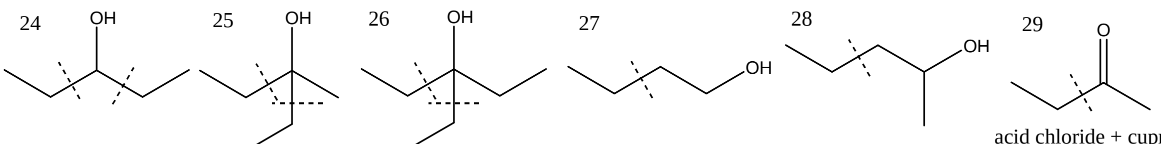
24 25 26 27 28 29



24
a. 1 + Mg (or Li)
b. alkyl methanoate
c. WK

25
a. 1 + Mg (or Li)
b. alkyl ethanoate
c. WK

26
a. 1 + Mg (or Li)
b. alkyl propanoate
c. WK

27
a. 1 + Mg (or Li)
b. 2C epoxide
c. WK

28
a. 1 + Mg (or Li)
b.3C epoxide
c. WK

29
acid chloride + cuprate
a. 1 + Mg (or Li)
b. ethanenitrile
ethanoic acid +
2 eqs ethyl lithium

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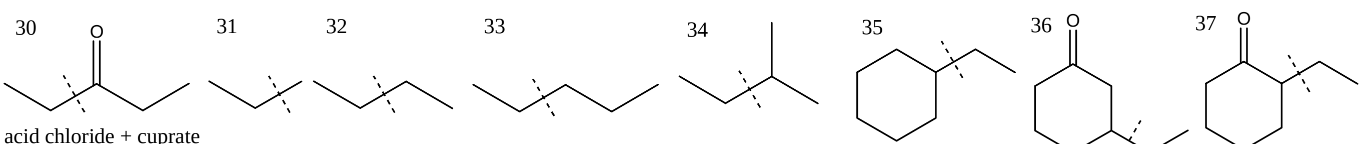
30 31 32 33 34 35 36 37



30
acid chloride + cuprate
a. 1 + Mg (or Li)
b. propanenitrile
ethanoic acid +
2 eqs propyl lithium

31
(2 ways)
cuprate + RBr

32
(2 ways)
cuprate + RBr

33
(2 ways)
cuprate + RBr

34
(2 ways)
cuprate + RBr

35
(2 ways)
cuprate + RBr

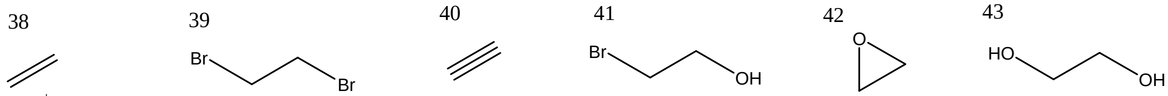
36
cuprate + enone
(conjugate addition)

37
1. ketone + LDA
2. RBr (compound 1)

a. enamine + 1
b. H_2O (hydrolysis)

---

38 39 40 41 42 43



38
1 + K^+ t-butoxide

2 + H_2SO_4/Δ

Wittig =
methanal + ylid

39
Br_2

40
a. 39 + $NaNR_2$
b. WK

41
Br_2 / H_2O

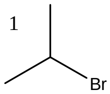
42
38 + mCPBA

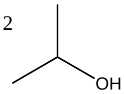
41 + NaOH

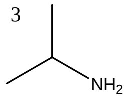
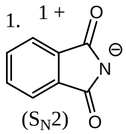
43
38 + OsO_4
(or $KMnO_4$)

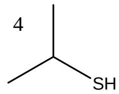
3. Given starting material = propane,($CH_3CH_2CH_3$)

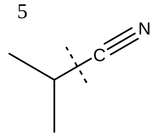
a.

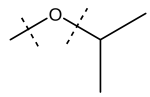
1

propane + Br_2/hv
2 + HBr
2 + PBr_3
2 + $SOBr_2$
2 + a. TsCl/py
b. NaBr

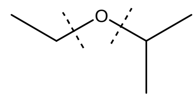
2

a. 1 + ester (S_N2)
b. ester + NaOH
31 + H_3O^+, H_2O
a. 31+HgX_2/H_2O
b. $NaBH_4$
a. 13 + $NaBH_4$
b. WK

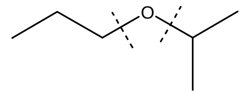
3

1. 1 +

(S_N2)
2. NaOH

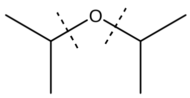
4

1 + NaSH (S_N2)

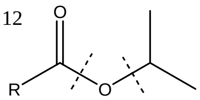
5

1 + NaCN (S_N2)

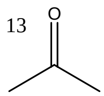
8

(2 ways)
$RO^{\ominus}$ + RBr (S_N2)
ROH + RBr (S_N1)

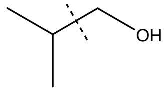
9

(2 ways)
RO + RBr (S_N2)
ROH + RBr (S_N1)

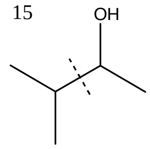
10

(2 ways)
RO + RBr (S_N2)
ROH + RBr (S_N1)

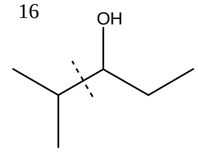
11

ROH + RBr (S_N1)

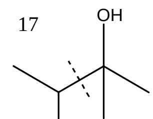
12

(2 ways)
$RCO_2^{\ominus}$ + RBr
(S_N2)
RCOCl + ROH
(acyl substitution)

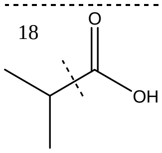
13

(lots of ways)
2 + CrO_3/H_2O
(Jones)
2 + CrO_3/py
(PCC)
33 + H_3O^+/H_2O
...and more

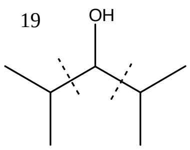
14

a. 1 + Mg (or Li)
b. methanal
c. WK

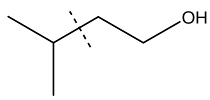
15

a. 1 + Mg (or Li)
b. ethanal
c. WK

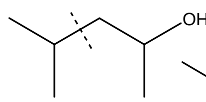
16

a. 1 + Mg (or Li)
b. propanal
c. WK

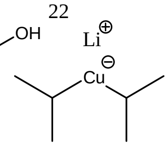
17

a. 1 + Mg (or Li)
b. propanone
c. WK

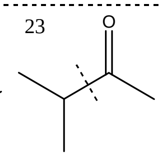
18

a. 1 + Mg (or Li)
b. CO_2
c. WK
5 + H_2SO_4/H_2O

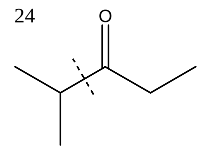
19

a. 1 + Mg (or Li)
b. alkyl methanoate
c. WK

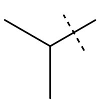
20

a. 1 + Mg (or Li)
b. 2C epoxide
c. WK

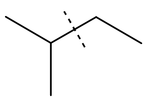
21

a. 1 + Mg (or Li)
b.3C epoxide
c. WK

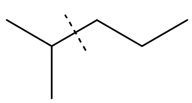
22

cuprate
2RLi + CuBr

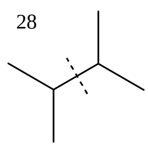
23

acid chloride + cuprate
a. 1 + Mg (or Li)
b. ethanenitrile
ethanoic acid +
2 eqs propyl lithium

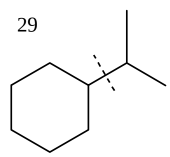
24

acid chloride + cuprate
a. 1 + Mg (or Li)
b. propanenitrile
ethanoic acid +
2 eqs propyl lithium

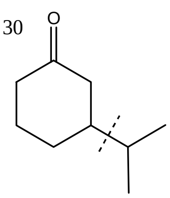
25

(2 ways)
cuprate + RBr

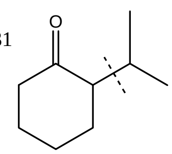
26

(2 ways)
cuprate + RBr

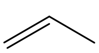
27

(2 ways)
cuprate + RBr

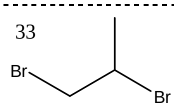
28

(2 ways)
cuprate + RBr

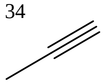
29

(2 ways)
cuprate + RBr

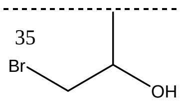
30

cuprate + enone
(conjugate addition)

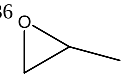
31

1. ketone + LDA
2. RBr (compound 1)
a. enamine + 1
b. H_2O (hydrolysis)

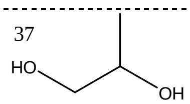
32

1 + K^+ t-butoxide

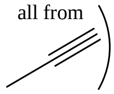
33

31 + Br_2

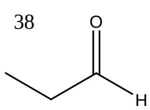
34

a. 32 + $NaNR_2$
b. WK

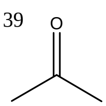
35

31 + Br_2/H_2O

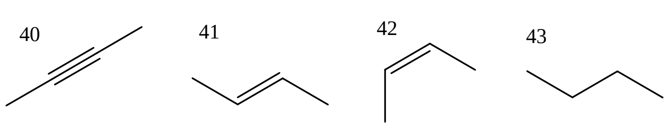
36

31 + mCPBA
34 + NaOH

37

31 + H_2O_2 / $HO^{\ominus}$

(all from

)

38

1. R_2BH
b. H_2O_2 / $HO^{\ominus}$

39

(lots of ways)
2 + CrO_3/H_2O
(Jones)
2 + CrO_3/py
(PCC)
33 + H_3O^+/H_2O
...and more



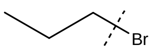
40
a. $NaNR_2$
b. CH_3-Br

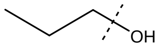
41
39 + Na / NH_3

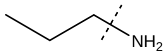
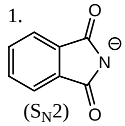
42
39 + Pd / H_2
quinoline

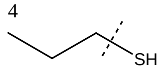
43
39 + Pd / H_2

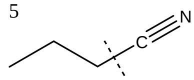
b.

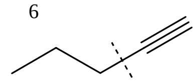
1

2 + HBr
2 + PBr_3
2 + $SOBr_2$
2 + a. TsCl/py
b. NaBr

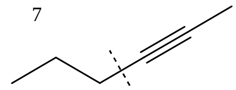
2

1 + NaOH (S_N2)
31 + a. BH_3
b. H_2O_2, $HO^{\ominus}$

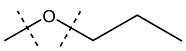
3

1.

(S_N2)
2. NaOH

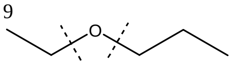
4

1 + NaSH (S_N2)

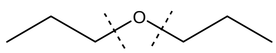
5

1 + NaCN (S_N2)

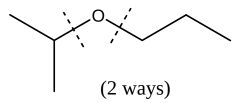
6

1 + NaCCH (S_N2)

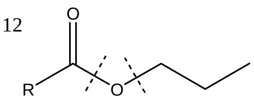
7

1 + $NaCCCH_3$ (S_N2)

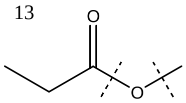
8

(2 ways)
$RO^{\ominus}$ + RBr
(both S_N2)

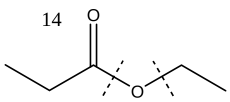
9

(2 ways)
$RO^{\ominus}$ + RBr
(both S_N2)

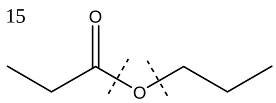
10

(2 ways)
$RO^{\ominus}$ + RBr
(both S_N2)

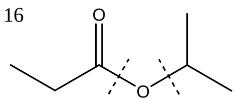
11

(2 ways)
$RO^{\ominus}$ + RBr
(both S_N2)

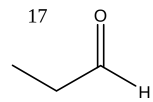
12

(2 ways)
$RCO_2^{\ominus}$ + RBr
(S_N2)
RCOCl + ROH
(acyl substitution)

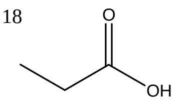
13

(2 ways)
$RCO_2^{\ominus}$ + RBr
(S_N2)
RCOCl + ROH
(acyl substitution)

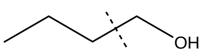
14

(2 ways)
$RCO_2^{\ominus}$ + RBr
(S_N2)
RCOCl + ROH
(acyl substitution)

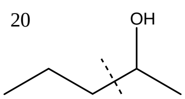
15

(2 ways)
$RCO_2^{\ominus}$ + RBr
(S_N2)
RCOCl + ROH
(acyl substitution)

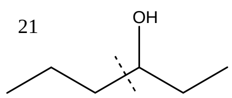
16

(2 ways)
$RCO_2^{\ominus}$ + RBr
(S_N2)
RCOCl + ROH
(acyl substitution)

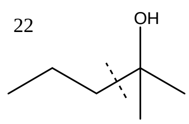
17

(2 ways)
2 + CrO_3/py
(PCC)
33 + a. R_2BH
b. H_2O_2, $HO^{\ominus}$

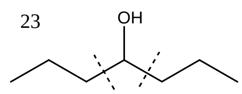
18

(2 ways)
2 + CrO_3/H_2O
(Jones)
nitrile + H_2SO_4/H_2O

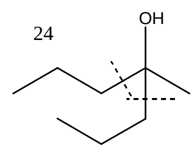
19

a. 1 + Mg (or Li)
b. methanal
c. WK

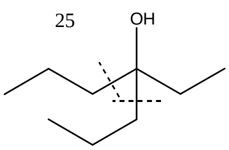
20

a. 1 + Mg (or Li)
b. ethanal
c. WK

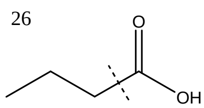
21

a. 1 + Mg (or Li)
b. propanal
c. WK

22

a. 1 + Mg (or Li)
b. propanone
c. WK

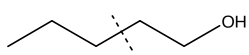
23

a. 1 + Mg (or Li)
b. alkyl methanoate
c. WK

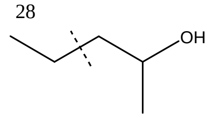
24

a. 1 + Mg (or Li)
b. alkyl ethanoate
c. WK

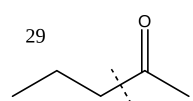
25

a. 1 + Mg (or Li)
b. alkyl propanoate
c. WK

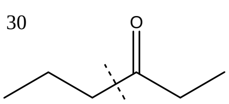
26

(2 ways)
a. 1 + Mg (or Li)
b. CO_2
c. WK

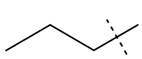
5 + H_2SO_4/H_2O

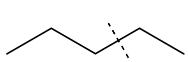
27

a. 1 + Mg (or Li)
b. 2C epoxide
c. WK

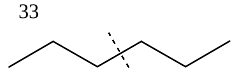
28

a. 1 + Mg (or Li)
b.3C epoxide
c. WK

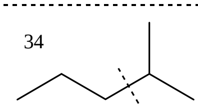
29

acid chloride + cuprate
a. 1 + Mg (or Li) b. ethanenitrile
ethanoic acid + 2 eqs propyl lithium

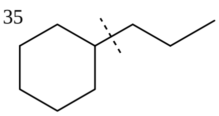
30

acid chloride + cuprate
a. 1 + Mg (or Li) b. propanenitrile
ethanoic acid + 2 eqs propyl lithium

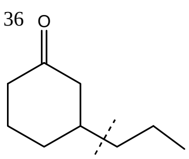
31

(2 ways)
cuprate + RBr

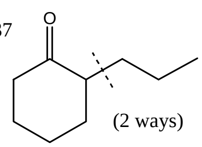
32

(2 ways)
cuprate + RBr

33

(2 ways)
cuprate + RBr

34

(2 ways)
cuprate + RBr

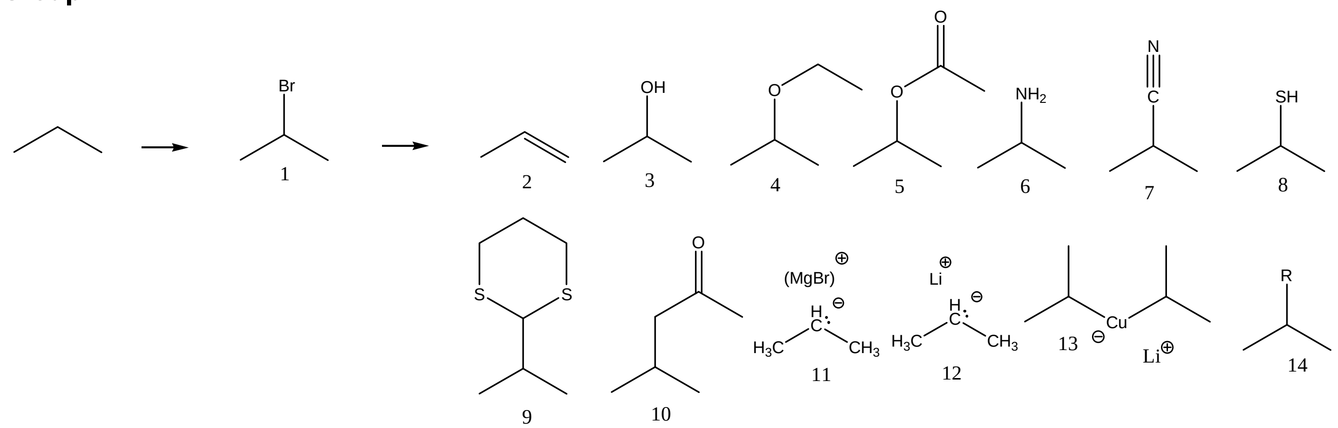
35

(2 ways)
cuprate + RBr

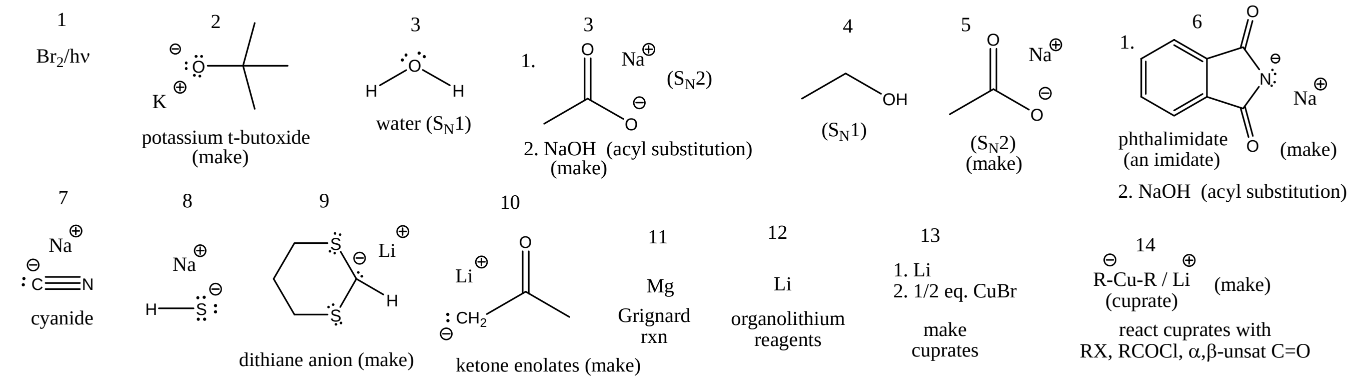
36

cuprate + enone
(conjugate addition)

37

(2 ways)
1. ketone + LDA
2. RBr (compound 1)

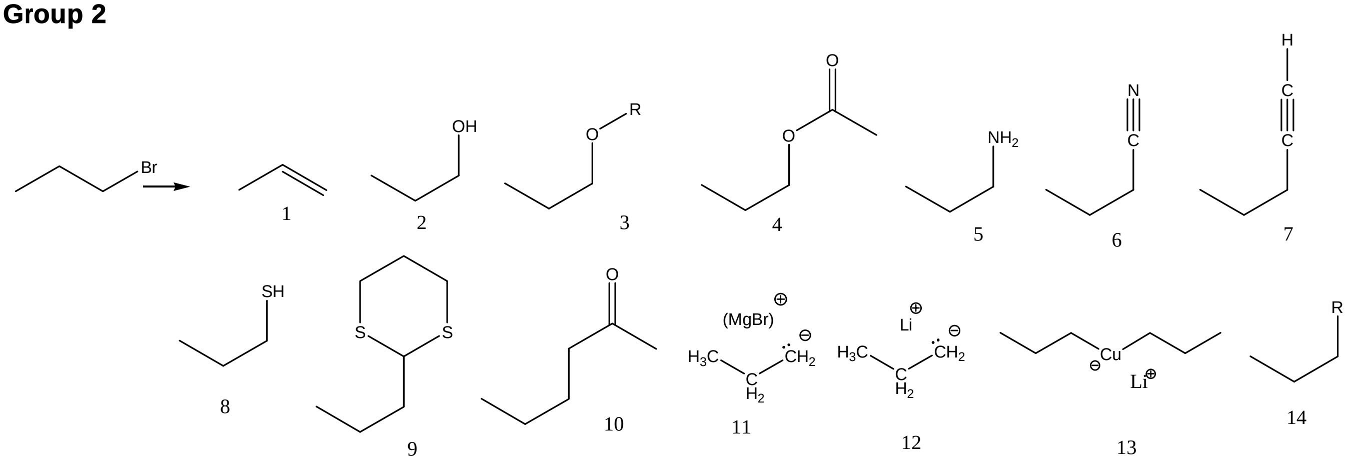
a. enamine + 1
b. H_2O (hydrolysis)

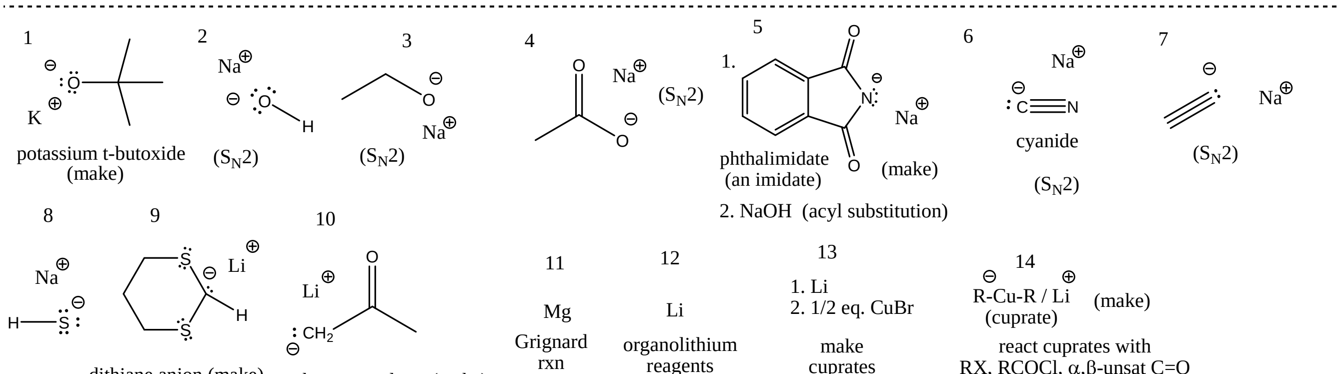
Group 1



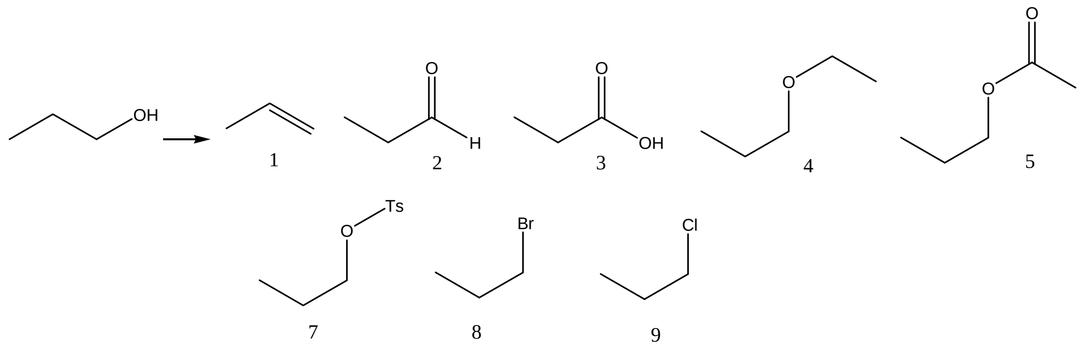


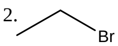
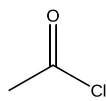
1. **Group 2**





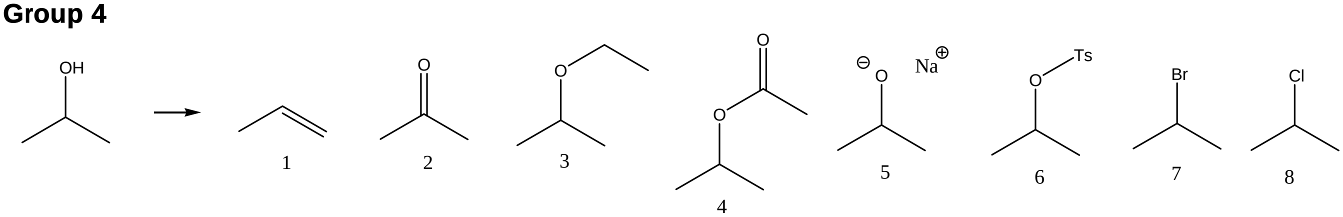
Group 3

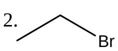
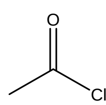


1	2	3	4	5	6	9	7 (four ways)	8 (four ways)
H_2SO_4/Δ ($-H_2O$) rearrangement possible (E1)	CrO_3 / H_2O (Jones) (E2)	CrO_3 / H_2O (Jones) (E2)	1. $Na^{\oplus}$ $H^{\ominus}$ sodium hydride 2.  (S_N2)	 (acyl substitution)	$Na^{\oplus}$ $H^{\ominus}$ sodium hydride (acid/base)	Ts-Cl / py (acyl substitution)	HBr PBr_3 $SOBr_2$ a. TsCl/py b.NaBr (S_N2 & S_N1)	HCl PCl_3 $SOCl_2$ a. TsCl/py b.NaCl (S_N2 & S_N1)

last approach avoids S_N1 (& rearrangements)

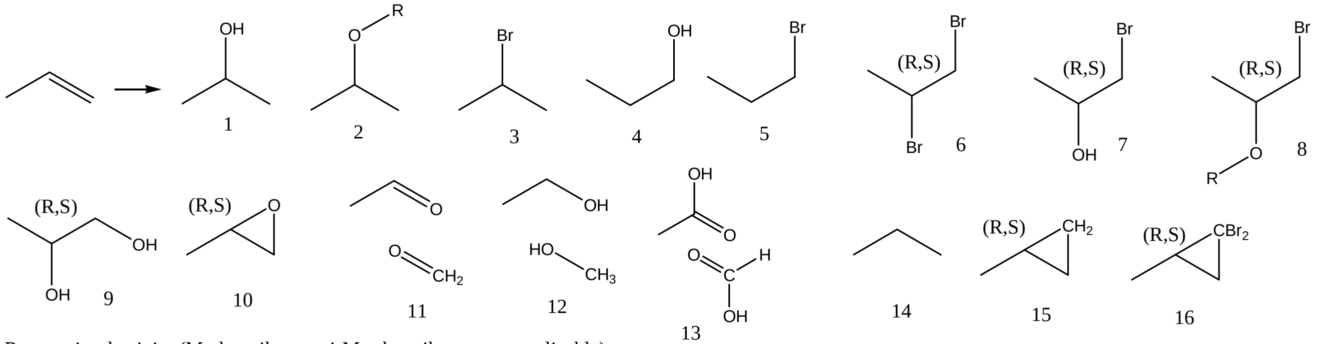
2. Group 4



1	2	2	3	4	5	6	7 (four ways)	8 (four ways)
H_2SO_4/Δ ($-H_2O$) rearrangement possible (E1)	CrO_3 / H_2O (Jones) (E2)	CrO_3 / H_2O (Jones) (E2)	1. $Na^{\oplus}$ $H^{\ominus}$ sodium hydride 2.  (S_N2)	 (acyl substitution)	$Na^{\oplus}$ $H^{\ominus}$ sodium hydride (acid/base)	Ts-Cl / py (acyl substitution)	HBr PBr_3 $SOBr_2$ a. TsCl/py b.NaBr (S_N2 & S_N1)	HCl PCl_3 $SOCl_2$ a. TsCl/py b.NaCl (S_N2 & S_N1)

last approach avoids S_N1 (& rearrangements)

3. Group 5



Rg = regioselectivity (Markovnikov, anti-Marrkovnikov or not applicable)
St = stereoselectivity (syn, anti or random addition)

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1 (two ways)
- H_3O^+, H_2O rearrangements possible — Rg = Y, St = N
- 1. HgX_2 / H_2O 2. $NaBH_4$ no rearrangements — Rg = Y, St = N

2 (two ways)
- ROH_2^+, ROH rearrangements possible — Rg = Y, St = N
- 1. HgX_2 / ROH 2. $NaBH_4$ no rearrangements — Rg = Y, St = N

3 HBr rearrangements possible — Rg = Y, St = N

4 1. BH_3 2. H_2O_2, $HO^{\ominus}$ anti-Markovnikov — Rg = Y, St = Y, syn

5 1. BH_3 2. Br_2, $CH_3O^{\ominus}$ anti-Markovnikov — Rg = Y, St = Y, syn

1. hydroboration 2. oxidation

6 Br_2 — Rg = NA, St = Y, anti

7 Br_2 / H_2O — Rg = Y, St = Y, anti (convert to epoxide in NaOH)

8 Br_2 / ROH — Rg = Y, St = Y, anti

9 OsO_4 or $KMnO_4$ — Rg = NA, St = Y, syn (dihydroxylation)

10 mCPBA or 1. Br_2/H_2O 2. NaOH — Rg = NA, St = Y, syn (epoxidation)

11 1. O_3, -78°C 2. CH_3SCH_3 — Rg = NA, St = NA

12 1. O_3, -78°C 2. $NaBH_4$ — Rg = NA, St = NA

13 1. O_3, -78°C 2. H_2O_2 / $HO^{\ominus}$ — Rg = NA, St = NA

(11–13: ozonolysis)

14 Pd / H_2 — Rg = NA, St = Y, syn (catylic reduction)

15 CH_2I_2 Zn (Cu) — Rg = NA, St = Y, syn

16 $CHBr_3$ K^+ t-butoxide — Rg = NA, St = Y, syn

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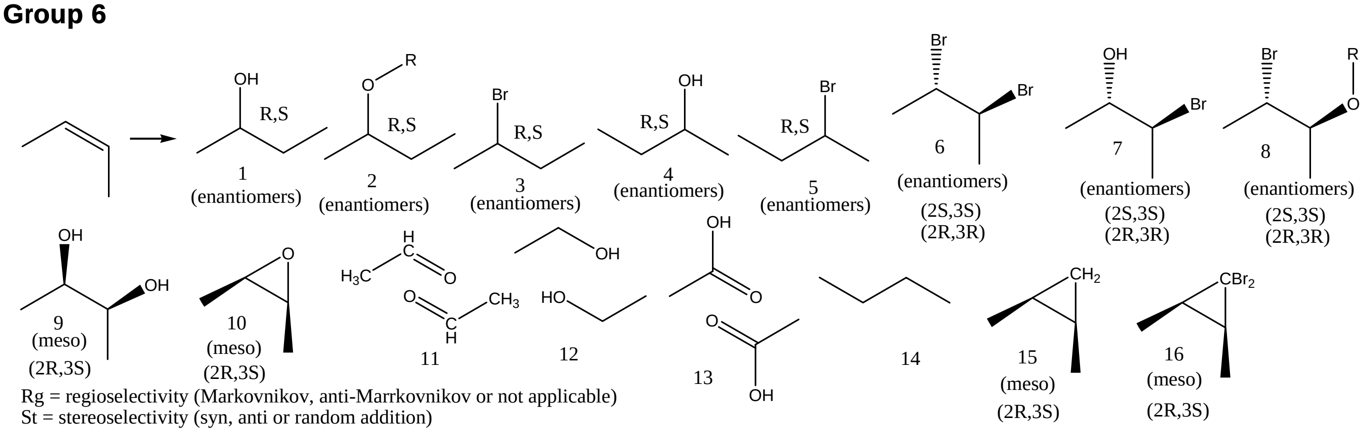
4. Group 6



Rg = regioselectivity (Markovnikov, anti-Marrkovnikov or not applicable)
St = stereoselectivity (syn, anti or random addition)

---

1 (two ways)
- H_3O^+, H_2O rearrangements possible — Rg = Y, St = N
- 1. HgX_2 / H_2O 2. $NaBH_4$ no rearrangements — Rg = Y, St = N

2 (two ways)
- ROH_2^+, ROH rearrangements possible — Rg = Y, St = N
- 1. HgX_2 / ROH 2. $NaBH_4$ no rearrangements — Rg = Y, St = N

3 HBr rearrangements possible — Rg = Y, St = N

4 1. BH_3 2. H_2O_2, $HO^{\ominus}$ anti-Markovnikov — Rg = Y, St = Y, syn

5 1. BH_3 2. Br_2, $CH_3O^{\ominus}$ anti-Markovnikov — Rg = Y, St = Y, syn

1. hydroboration 2. oxidation

6 Br_2 — Rg = NA, St = Y, anti

7 Br_2 / H_2O — Rg = Y, St = Y, anti (convert to epoxide in NaOH)

8 Br_2 / ROH — Rg = Y, St = Y, anti

9 OsO_4 or $KMnO_4$ — Rg = NA, St = Y, syn (dihydroxylation)

10 mCPBA or 1. Br_2/H_2O 2. NaOH — Rg = NA, St = Y, syn (epoxidation)

11 1. O_3, -78°C 2. CH_3SCH_3 — Rg = NA, St = NA

12 1. O_3, -78°C 2. $NaBH_4$ — Rg = NA, St = NA

13 1. O_3, -78°C 2. H_2O_2 / $HO^{\ominus}$ — Rg = NA, St = NA

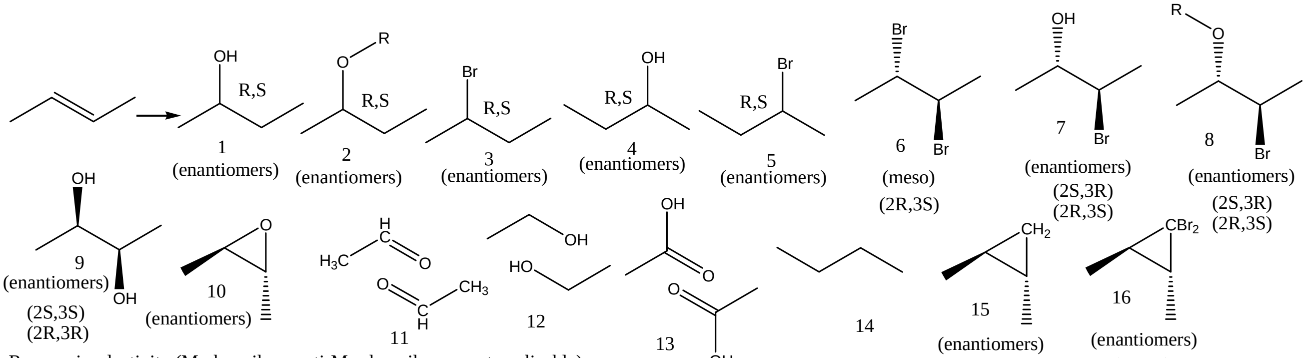
(11–13: ozonolysis)

14 Pd / H_2 — Rg = NA, St = Y, syn (catylic reduction)

15 CH_2I_2 Zn (Cu) — Rg = NA, St = Y, syn

16 $CHBr_3$ K^+ t-butoxide — Rg = NA, St = Y, syn

5. Group 7



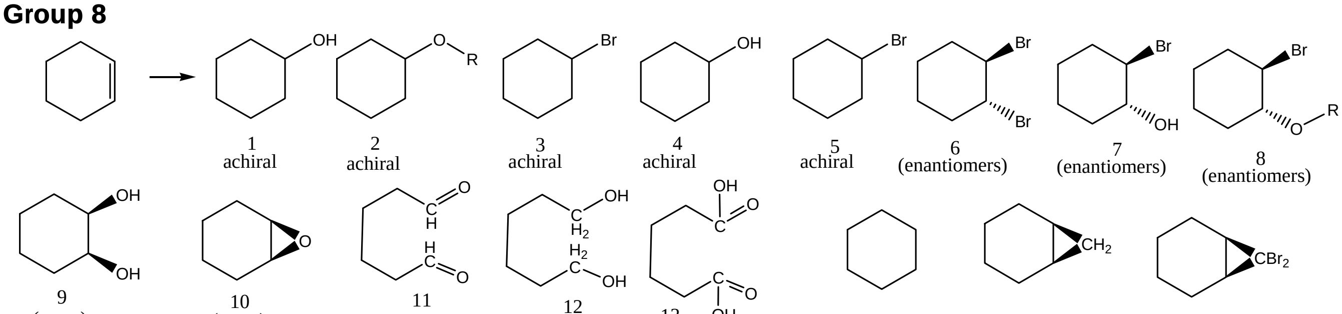
1 (enantiomers); 2 (enantiomers); 3 (enantiomers); 4 (enantiomers); 5 (enantiomers); 6 (meso) (2R,3S); 7 (enantiomers) (2S,3R) (2R,3S); 8 (enantiomers) (2S,3R) (2R,3S); 9 (enantiomers) (2S,3S) (2R,3R); 10 (enantiomers); 11; 12; 13; 14; 15 (enantiomers) (2S,3S) (2R,3R); 16 (enantiomers) (2S,3S) (2R,3R)

Rg = regioselectivity (Markovnikov, anti-Marrkovnikov or not applicable)
St = stereoselectivity (syn, anti or random addition)

	1 (two ways)		2 (two ways)		3	4	5	6	7
Reagents	H_3O^+, H_2O rearrangements possible	1. HgX_2 / H_2O 2. $NaBH_4$ no rearrangements	ROH_2^+, ROH rearrangements possible	1. HgX_2 / ROH 2. $NaBH_4$ no rearrangements	HBr rearrangements possible	1. BH_3 2. H_2O_2, $HO^\ominus$ anti-Markovnikov	1. BH_3 2. Br_2, $CH_3O^\ominus$ anti-Markovnikov	Br_2	Br_2 / H_2O
Rg	Y	Y	Y	Y	Y	Y	Y	NA	Y
St	N	N	N	N	N	Y, syn	Y, syn	Y, anti	Y, anti

	8	9	10	11	12	13	14	15	16
Reagents	Br_2 / ROH	OsO_4 or $KMnO_4$	mCPBA or 1. Br_2/H_2O 2. NaOH	1. O_3, -78^oC 2. CH_3SCH_3	1. O_3, -78^oC 2. $NaBH_4$	1. O_3, -78^oC 2.H_2O_2 / $HO^\ominus$	Pd / H_2	CH_2I_2 Zn (Cu)	$CHBr_3$ K^+ t-butoxide
Rg	Y	NA	NA	NA	NA	NA	NA	NA	NA
St	Y, anti	Y, syn	Y, syn	NA	NA	NA	Y, syn	Y, syn	Y, syn

6. Group 8



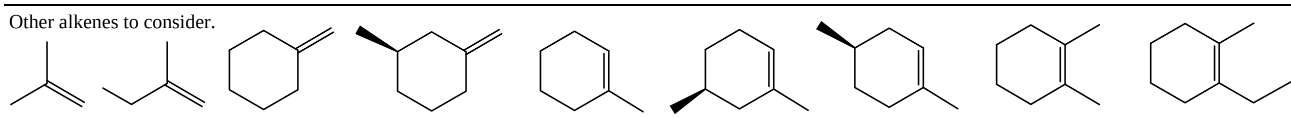
1 achiral; 2 achiral; 3 achiral; 4 achiral; 5 achiral; 6 (enantiomers); 7 (enantiomers); 8 (enantiomers); 9 (meso); 10 (meso); 11 achiral; 12 achiral; 13 achiral; 14 achiral; 15 (meso); 16 (meso)

Rg = regioselectivity (Markovnikov, anti-Marrkovnikov or not applicable)
St = stereoselectivity (syn, anti or random addition)

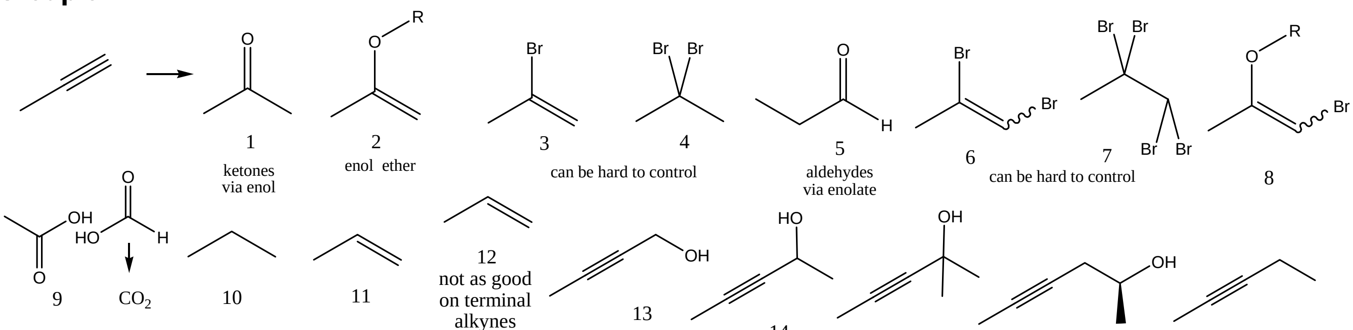
	1 (two ways)		2 (two ways)		3	4	5	6	7
Reagents	H_3O^+, H_2O rearrangements possible	1. HgX_2 / H_2O 2. $NaBH_4$ no rearrangements	ROH_2^+, ROH rearrangements possible	1. HgX_2 / ROH 2. $NaBH_4$ no rearrangements	HBr rearrangements possible	1. BH_3 2. H_2O_2, $HO^\ominus$ anti-Markovnikov	1. BH_3 2. Br_2, $CH_3O^\ominus$ anti-Markovnikov	Br_2	Br_2 / H_2O
Rg	Y	Y	Y	Y	Y	Y	Y	NA	Y
St	N	N	N	N	N	Y, syn	Y, syn	Y, anti	Y, anti

	8	9	10	11	12	13	14	15	16
Reagents	Br_2 / ROH	OsO_4 or $KMnO_4$	mCPBA or 1. Br_2/H_2O 2. NaOH	1. O_3, -78^oC 2. CH_3SCH_3	1. O_3, -78^oC 2. $NaBH_4$	1. O_3, -78^oC 2.H_2O_2 / $HO^\ominus$	Pd / H_2	CH_2I_2 Zn (Cu)	$CHBr_3$ K^+ t-butoxide
Rg	Y	NA	NA	NA	NA	NA	NA	NA	NA
St	Y, anti	Y, syn	Y, syn	NA	NA	NA	Y, syn	Y, syn	Y, syn

Other alkenes to consider.

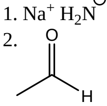
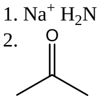
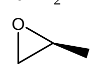
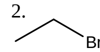


7. Group 9

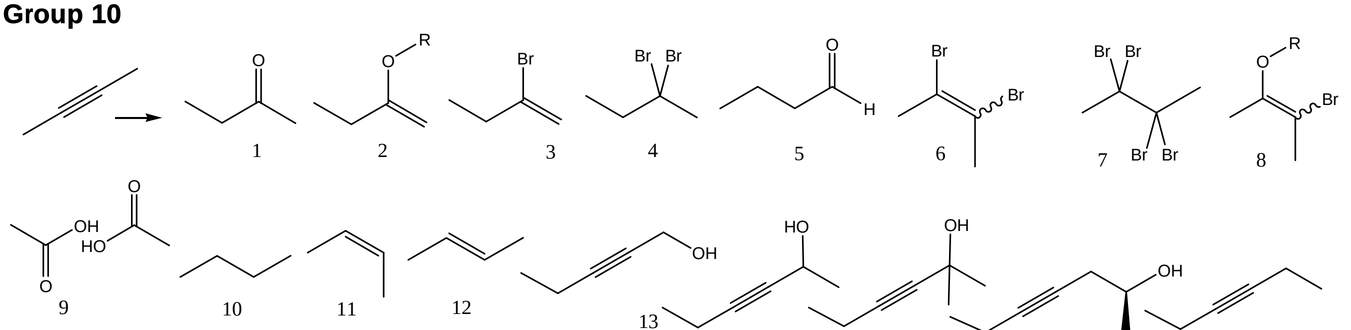


Rg = regioselectivity (Markovnikov, anti-Marrkovnikov or not applicable)
St = stereoselectivity (syn, anti or random addition)

1	2	3	4	5	6	7	8	9
H_3O^+, H_2O (Hg^{+2} cat.)	ROH_2^+, ROH (Hg^{+2} cat.)	HBr (1 eq)	HBr (2 eqs)	1. R_2BH 2. H_2O_2, $HO^{\ominus}$ anti-Markovnikov	Br_2 (1 eq)	Br_2 (2 eqs)	Br_2 / ROH	$KMnO_4$ (hot)
Rg = Y St = N	Rg = Y St = N	Rg = Y St = N	Rg = Y St = N	Rg = Y St = Y, syn	Rg = NA St = mixed	Rg = NA St = mixed	Rg = Y St = mixed	Rg = NA St = Y, syn harsh conditions

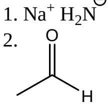
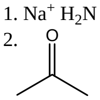
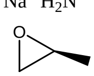
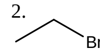
10	11	12	13	14	15	16	17	18
Pd / H_2	Pd / H_2 quinoline Lindlar's Cat.	Na / NH_3 (Birch)	1. Na^+ $H_2N^{\ominus}$ 2. $H_2C{=}O$ 3. WK	1. Na^+ $H_2N^{\ominus}$ 2.  3. WK	1. Na^+ H_2N 2.  3. WK	1. Na^+ $H_2N^{\ominus}$ 2.  3. WK	1. Na^+ $H_2N^{\ominus}$ 2.  3. WK	→ can continue using zipper reaction
Rg = NA St = Y, syn complete reduction	Rg = NA St = Y, syn (makes Z)	(makes E, not good with terminal alkynes)						

8. Group 10



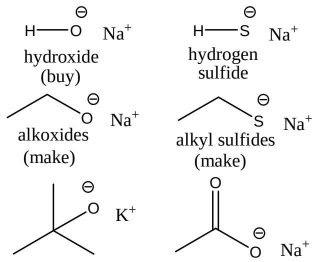
Rg = regioselectivity (Markovnikov, anti-Marrkovnikov or not applicable)
St = stereoselectivity (syn, anti or random addition)

1	2	3	4	5	6	7	8	9
H_3O^+, H_2O (Hg^{+2} cat.)	ROH_2^+, ROH (Hg^{+2} cat.)	HBr (1 eq)	HBr (2 eqs)	1. R_2BH 2. H_2O_2, $HO^{\ominus}$ anti-Markovnikov	Br_2 (1 eq)	Br_2 (2 eqs)	Br_2 / ROH	$KMnO_4$ (hot)
Rg = Y St = N	Rg = Y St = N	Rg = Y St = N	Rg = Y St = N	Rg = Y St = Y, syn	Rg = NA St = mixed	Rg = NA St = mixed	Rg = Y St = mixed	Rg = NA St = Y, syn harsh conditions

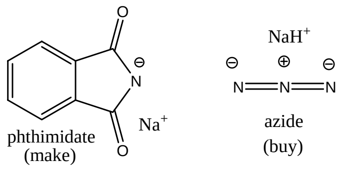
10	11	12	13	14	15	16	17	18
Pd / H_2	Pd / H_2 quinoline Lindlar's Cat.	Na / NH_3 (Birch)	1. Na^+ $H_2N^{\ominus}$ 2. $H_2C{=}O$ 3. WK	1. Na^+ $H_2N^{\ominus}$ 2.  3. WK	1. Na^+ H_2N 2.  3. WK	1. Na^+ $H_2N^{\ominus}$ 2.  3. WK	1. Na^+ $H_2N^{\ominus}$ 2.  3. WK	→ can continue using zipper reaction
Rg = NA St = Y, syn complete reduction	Rg = NA St = Y, syn (makes Z)	(makes E, not good with terminal alkynes)						

Chemical Catalog of Reagents

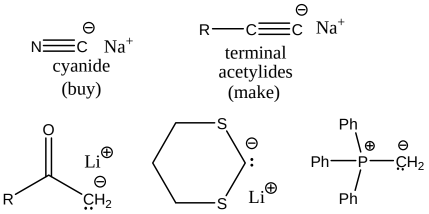
Nucleophiles / Bases - electron pair donors



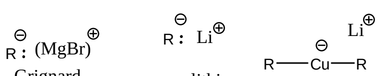
hydroxide (buy); hydrogen sulfide; alkoxides (make); alkyl sulfides (make); t-butoxide (make); carboxylates (make)



phthimidate (make); NaH^+ azide (buy)



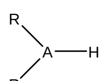
cyanide (buy); terminal acetylides (make); enolates (make); dithiane carbanions (make); Wittig ylid (make)



Grignard reagents (make); organolithium reagents (make); lithium dialkyl cuprates (make)

$LiAlH_4$ LAH (buy) lithium aluminium hydride

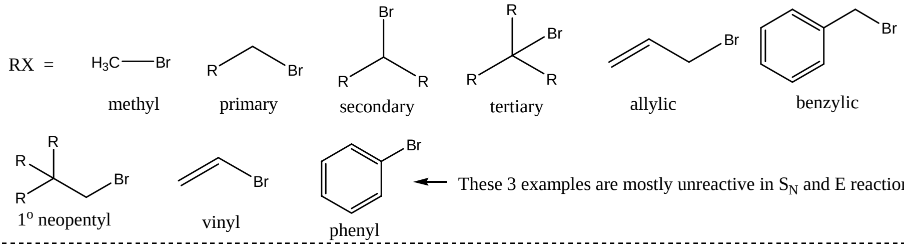
$NaBH_4$ sodium borohydride (buy)



DIBAH diisobutyl aluminium hydride (buy)

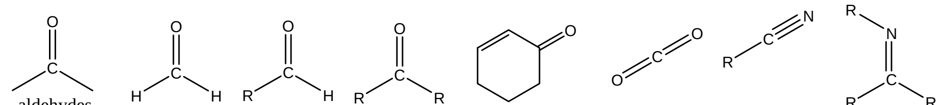
$(RO)_3AlH^{\ominus}$ $Li^{\oplus}$ lithium trialkoxy aluminium hydride (buy)

Electrophiles / Lewis Acids - electron pair acceptors

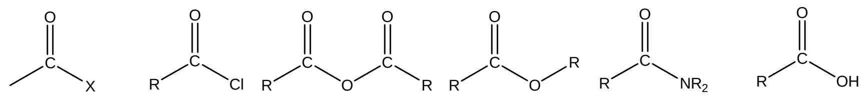


RX = methyl; primary; secondary; tertiary; allylic; benzylic

1° neopentyl; vinyl; phenyl ← These 3 examples are mostly unreactive in S_N and E reactions.

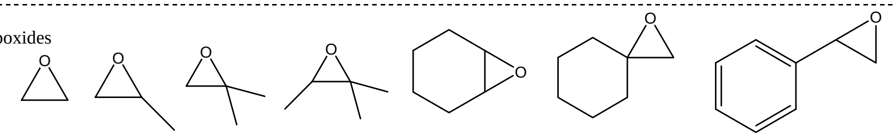


aldehydes & ketones; methanal; aldehydes; ketones; α,β-unsaturated C=O; carbon dioxide; nitriles; imines



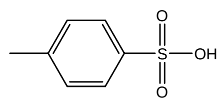
carboxylic acids & derivatives (X = leaving group); acid chloride; anhydrides; esters; amides (1°,2°,3°); carboxylic acid

epoxides



Strong Mineral Acids

H_2SO_4 sulfuric acid; H—Cl hydrochloric acid; H—Br hydrobromic acid; H—I hydroiodic acid



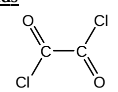
toluenesulfonic acid

HNO_3 nitric acid; $H_3O^{\oplus}$; $ROH_2^{\oplus}$

Other Lewis Acids

$SOCl_2$ thionyl chloride

$SOBr_2$ thionyl bromide



oxalyl chloride

PCl_3 phosphorous trichloride

PBr_3 phosphorous tribromide

FeX_3 feric trihalide

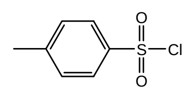
AlX_3 aluminium trihalide

BH_3 borane

R_2BH dialkylborane

HgX_2 mecuric ion

BF_3 boron trifluoride



toluenesulfonyl chloride

Reducing Reagents

Na / NH_3 Birch Conditions

H_2 / Pd catalytic hydrogenation

H_2 / Pd / quinoline (Lindlar's Cat.)

Oxidizing Reagents

1. O_3, -78°C 2. CH_3SCH_3

1. O_3, -78°C 2. $NaBH_4$

1. O_3, -78°C 2. H_2O_2 / $HO^{\ominus}$

OsO_4

$KMnO_4$

CrO_3 / H_2O Jones

CrO_3 / pyridine PCC

Br_2 bromine

Cl_2 chlorine

H_2O_2 peroxide

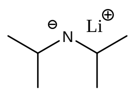
CuBr cuprous bromide

Always act as Bases

Na^+ $H:^{\ominus}$ sodium hydride (buy)

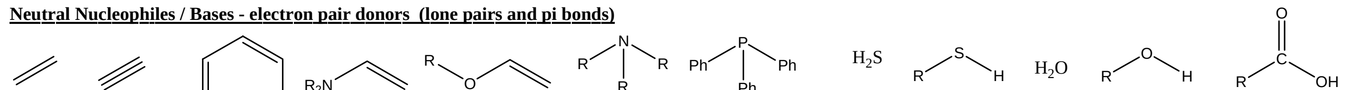
K^+ $H:^{\ominus}$ potssium hydride (buy)

1. $Na^{\oplus}$ $R_2N^{\ominus}$ 2. workup sodium amide (buy)



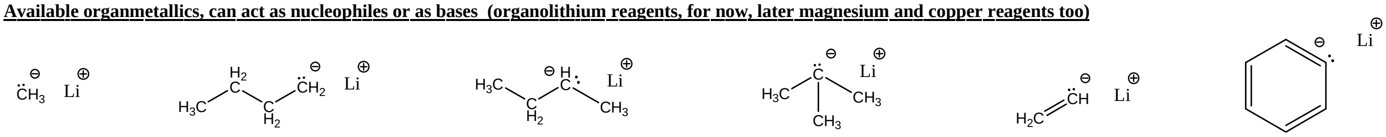
LDA lithium diisopropylamide (make)

Neutral Nucleophiles / Bases - electron pair donors (lone pairs and pi bonds)

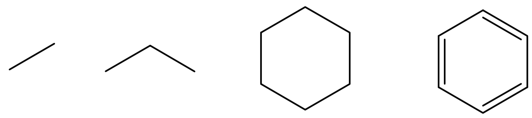


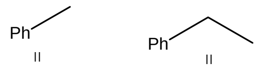
alkenes; alkynes; aromatics; enamines; enol ethers; amines (1°,2°,3°); phosphines; H_2S hydrogen sulfide; thiols; H_2O water; alcohols; carboxylic acids

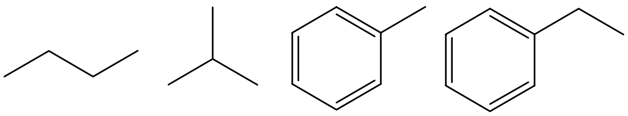
Available organmetallics, can act as nucleophiles or as bases (organolithium reagents, for now, later magnesium and copper reagents too)

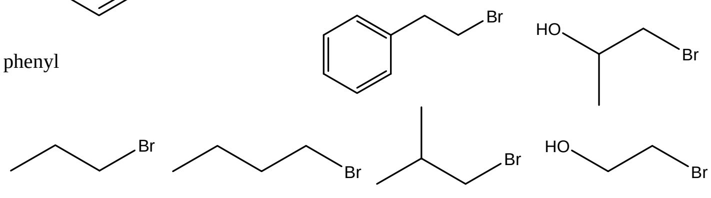


methyl lithium; n-butyl lithium; sec-butyl lithium; t-butyl lithium; vinyl lithium; phenyl lithium

Always available: CH_4 

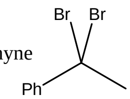
Provided for now:  Ph = phenyl

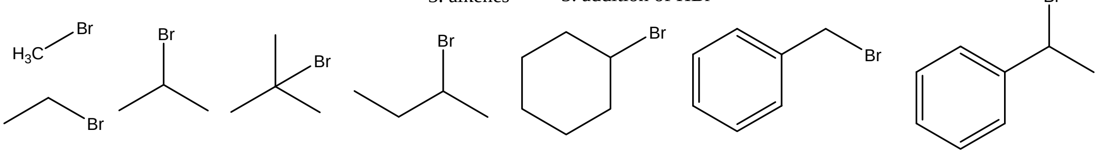


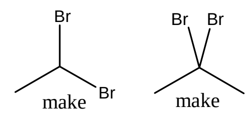


Make (propose a synthesis for RBr - possible from 1. R-H, 2. R-OH, 3. alkenes

1. Br_2/hν, free radicals
2. many ways (see below)
3. addition of HBr

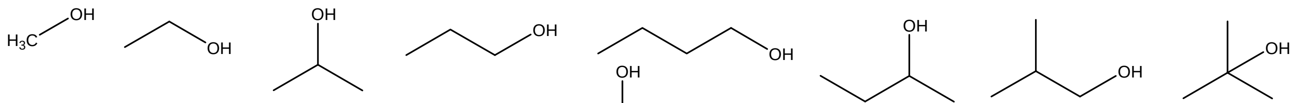
make phenylethyne 

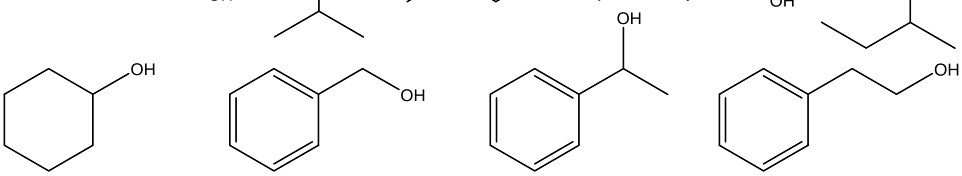




make ethyne make propyne

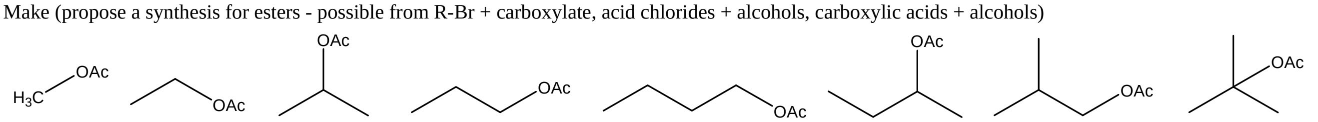
Make (propose a synthesis for ROH - possible from R-Br, alkenes, esters, C=O, epoxides)

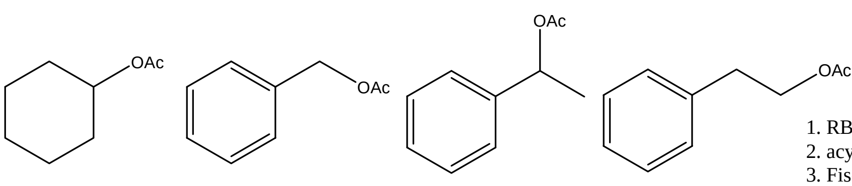


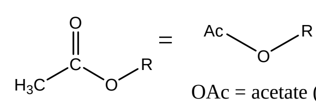


1. S_N2 or S_N1
2. ester hydrolysis
3. carbonyl reduction
4. open epoxides

Make (propose a synthesis for esters - possible from R-Br + carboxylate, acid chlorides + alcohols, carboxylic acids + alcohols)



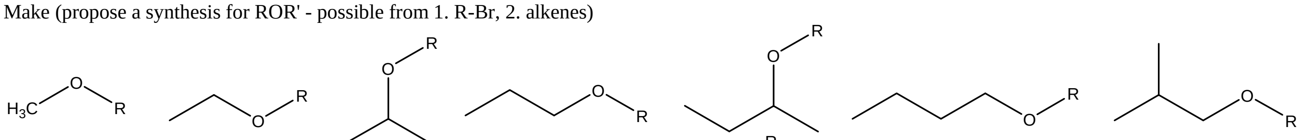


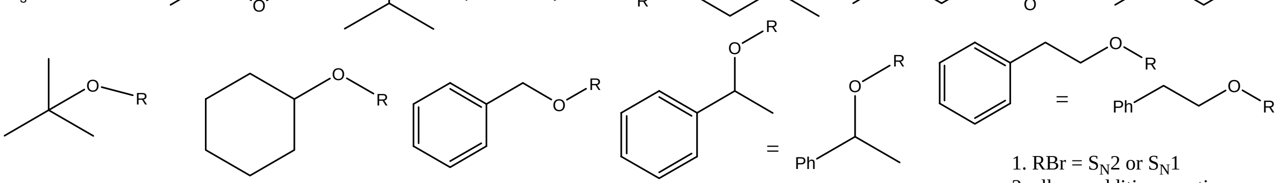


1. RBr = S_N2 or S_N1
2. acyl substitution
3. Fischer ester synthesis

OAc = acetate (ester)

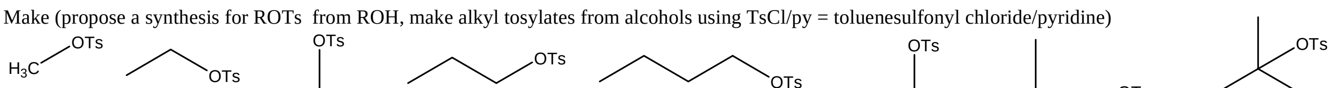
Make (propose a synthesis for ROR' - possible from 1. R-Br, 2. alkenes)



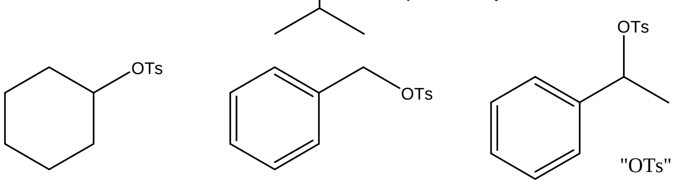


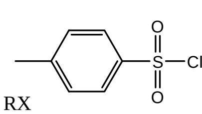
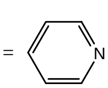
1. RBr = S_N2 or S_N1
2. alkene addition reactions

Make (propose a synthesis for ROTs from ROH, make alkyl tosylates from alcohols using TsCl/py = toluenesulfonyl chloride/pyridine)



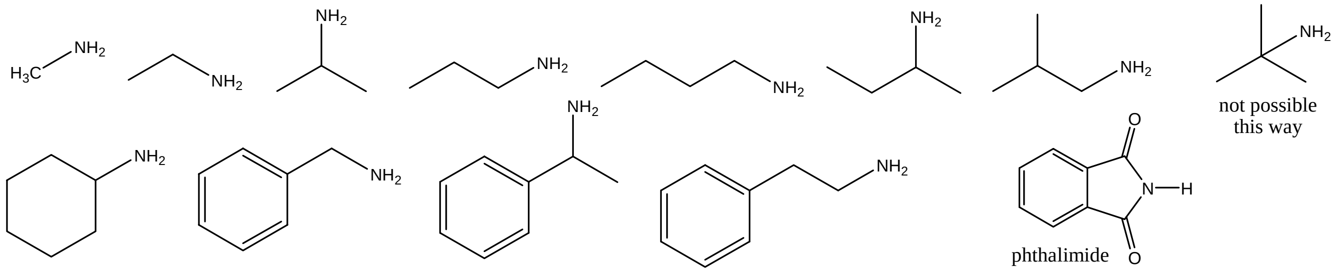
elimination is a common side rxn



Ts-Cl =  pyridine = 

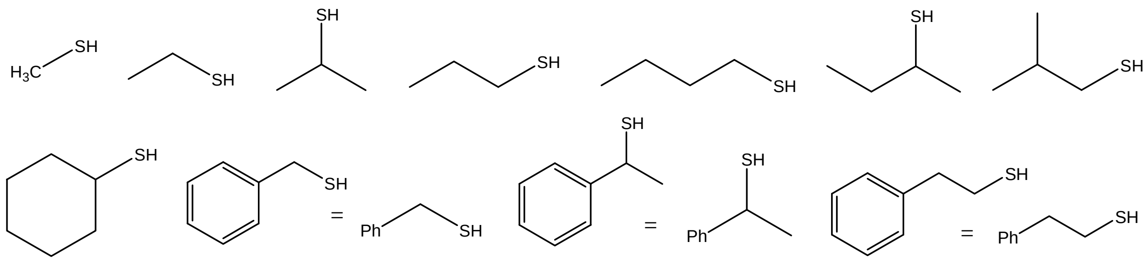
"OTs" ≈ "I" as a leaving group from RX

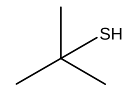
Make (propose a synthesis for RNH_2 - possible from R-Br + phthalimide,= S_N2 at methyl, 1°, 2° RX, but not 3° RX)



not possible this way

Make (propose a synthesis for thiol - possible from R-Br + NaSH = S_N2 at methyl, 1°, 2° RX, but not 3° RX)

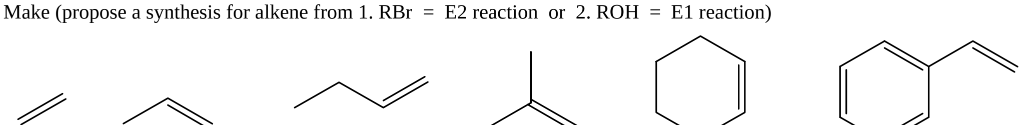




not possible this way

Thiols are very stinky compounds, and often biologically active.

Make (propose a synthesis for alkene from 1. RBr = E2 reaction or 2. ROH = E1 reaction)



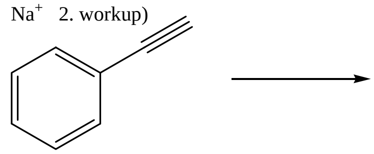
E2: from 1-bromobutane

1. RBr + K^+ t-butoxide
2. ROH + H_2SO_4/Δ

Make (propose a synthesis for alkyne from RBr_2, 1. double E2 reaction using $R_2N^{\ominus}$ Na^+ 2. workup)

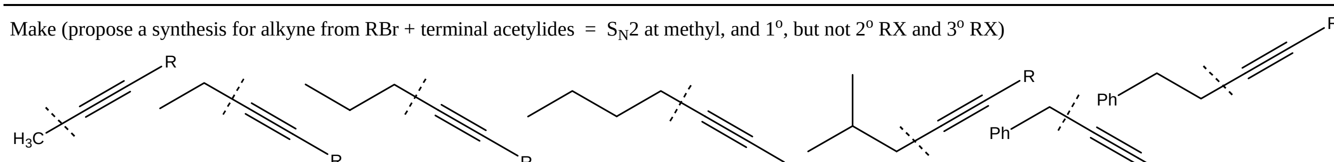
from:
1,1-dibromoethane
1,2-dibromoethane

from:
1,1-dibrompropane
1,2-dibromopropane
2,2-dibromopropane



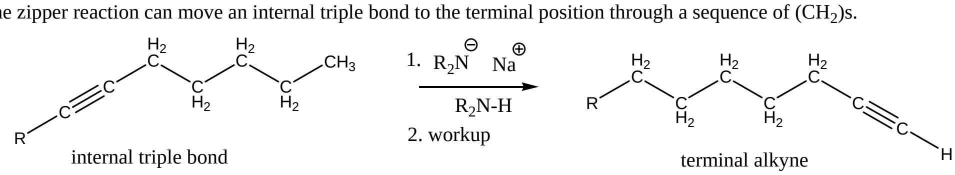
aldehyde
ketone
alkene (E/Z)
alkane
other rxns possible

Make (propose a synthesis for alkyne from RBr + terminal acetylides = S_N2 at methyl, and 1°, but not 2° RX and 3° RX)

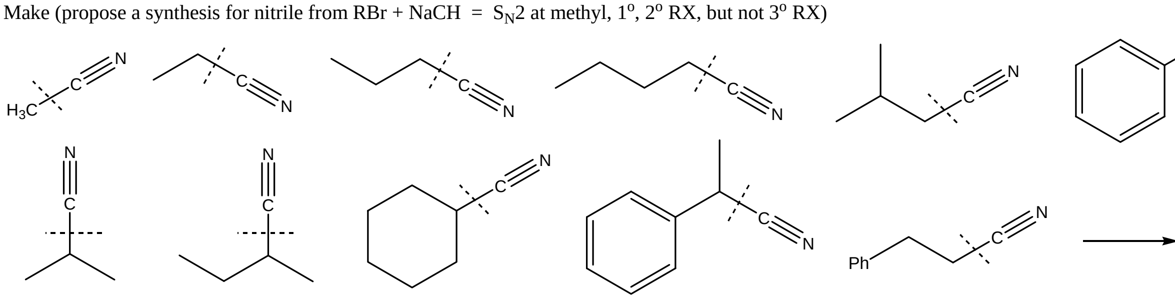


R = H from ethyne or CH_3 from propyne

The zipper reaction can move an internal triple bond to the terminal position through a sequence of (CH_2)s.



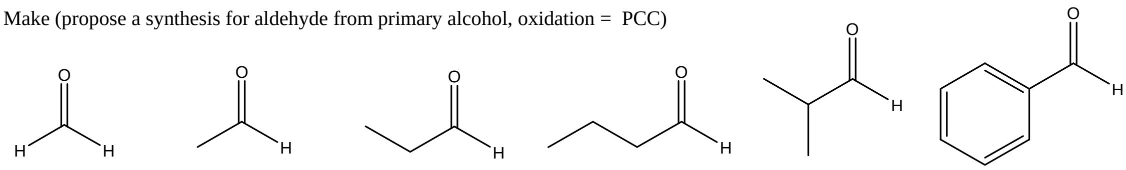
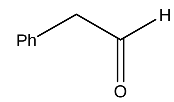
Make (propose a synthesis for nitrile from RBr + NaCH = S_N2 at methyl, 1°, 2° RX, but not 3° RX)



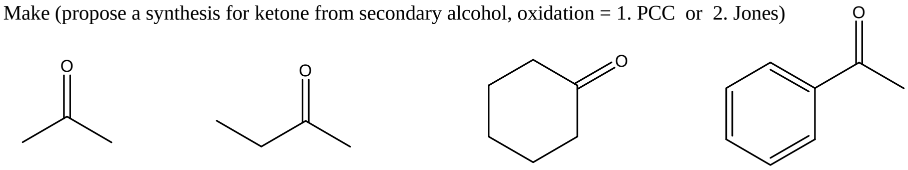
amides
carboxylic acids
aldehydes
ketones
1° amines

Make (propose a synthesis for aldehyde from primary alcohol, oxidation = PCC)

PCC = CrO_3/pyridine
(no water)

Make (propose a synthesis for ketone from secondary alcohol, oxidation = 1. PCC or 2. Jones)

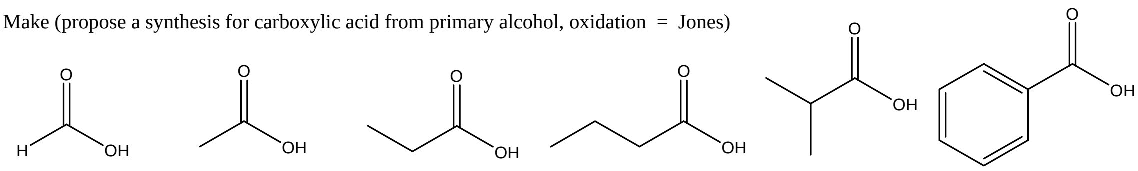
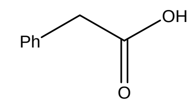


1. PCC = CrO_3/pyridine
(no water)

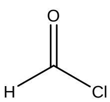
2. Jones = CrO_3/acid
(with water)

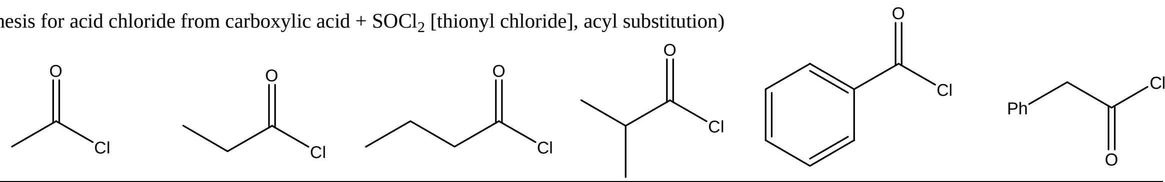
Make (propose a synthesis for carboxylic acid from primary alcohol, oxidation = Jones)

Jones = CrO_3/acid
(with water)

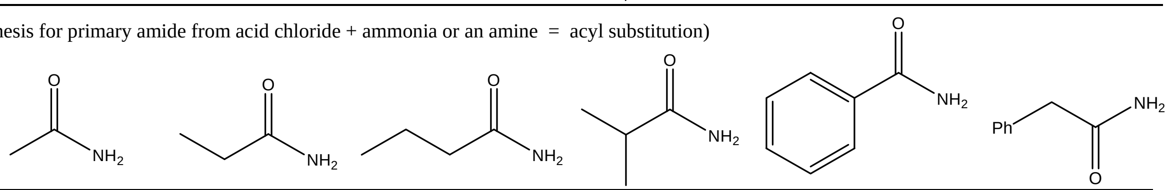



Make (propose a synthesis for acid chloride from carboxylic acid + $SOCl_2$ [thionyl chloride], acyl substitution)

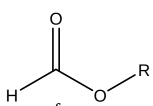

(not stable)

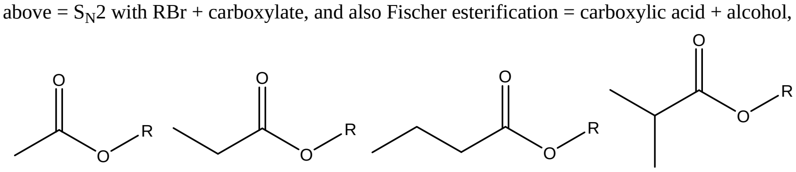
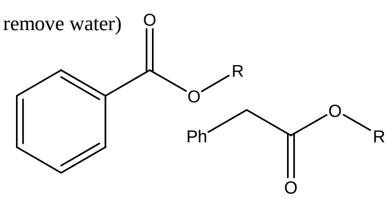


Make (propose a synthesis for primary amide from acid chloride + ammonia or an amine = acyl substitution)

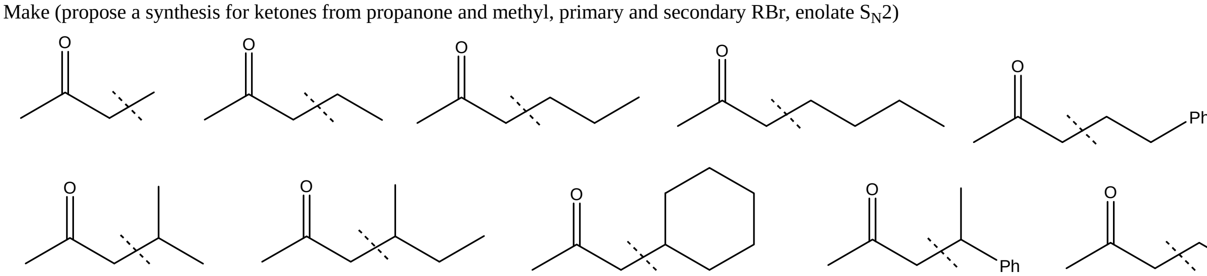


Make (propose a synthesis for alkyl ester from acid chloride and alcohol, ROH, acyl substitution,
or also see above = S_N2 with RBr + carboxylate, and also Fischer esterification = carboxylic acid + alcohol, remove water)


not from
acid chloride

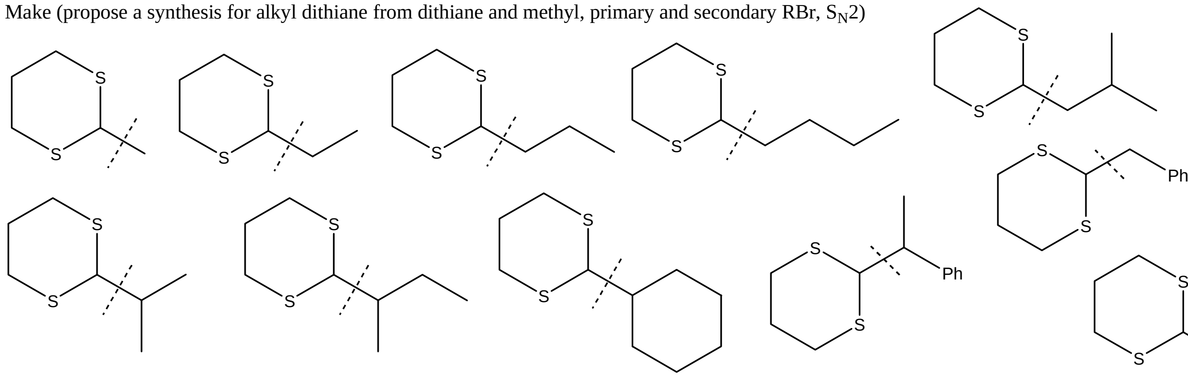



Make (propose a synthesis for ketones from propanone and methyl, primary and secondary RBr, enolate S_N2)

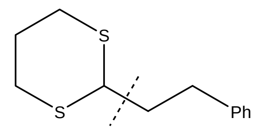


1. ketone
2. LDA / -78^oC
3. RBr
4. workup

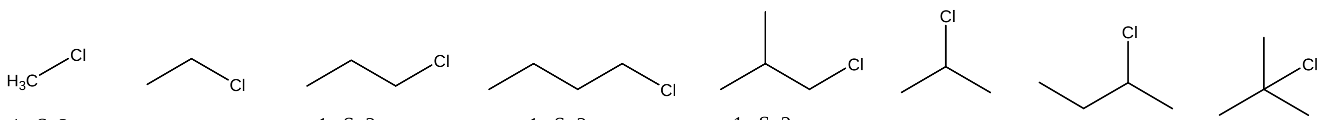
Make (propose a synthesis for alkyl dithiane from dithiane and methyl, primary and secondary RBr, S_N2)



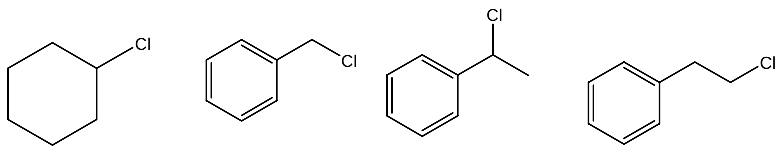
1. dithiane
2. n-BuLi
3. RBr
4. workup



Make (propose a synthesis for RCl from ROH - four ways: 1. HCl, 2. PCl_3, 3. $SOCl_2$, 4. a. TsCl/pyridine, b. NaCl, also possibilities for "Br" and "I" below)



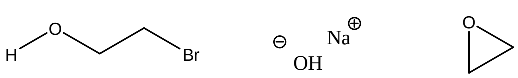
1. S_N2	1. S_N2	1. S_N2	1. S_N2	1. S_N2	1. S_N1	1. S_N1	1. S_N1
2.. S_N2	2.. S_N2	2.. S_N2	2.. S_N2	2.. S_N2	2.. S_N1	2.. S_N1	2.. S_N1
3.. S_N2	3.. S_N2	3.. S_N2	3.. S_N2	3.. S_N2	3.. S_N1	3.. S_N1	3.. S_N1
4a. acyl subst.	4a. acyl subst.	4a. acyl subst.	4a. acyl subst.	4a. acyl subst.	4a. acyl subst.	4a. acyl subst.	4a. acyl subst.
b. S_N2	b. S_N2	b. S_N2	b. S_N2	b. S_N2	b. S_N2	b. S_N2	b. S_N1



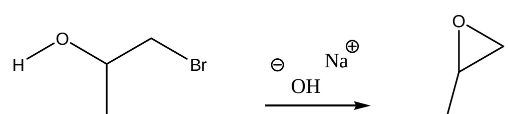
1. S_N1	1. S_N1	1. S_N1	1. S_N2
2.. S_N1	2.. S_N1	2.. S_N1	2.. S_N2
3.. S_N1	3.. S_N1	3.. S_N1	3.. S_N2
4a. acyl subst.	4a. acyl subst.	4a. acyl subst.	4a. acyl subst.
b. S_N2	b. S_N2	b. S_N2	b. S_N2

1. ROH + HCl also HBr, HI S_N2 or S_N1	1. ROH + $SOCl_2$ also $SOBr_2$ S_N2 or S_N1
1. ROH + PCl_3 also PBr_3 S_N2 or S_N1	1. ROH + TsCl/pyridine (acyl substitution) 2. NaCl (S_N2) also 2. NaBr or 2. NaI

Special Reaction: form epoxide from bromohydrin in NaOH

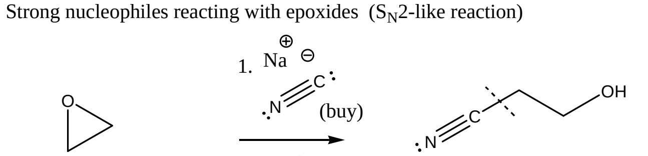


given for now epoxide

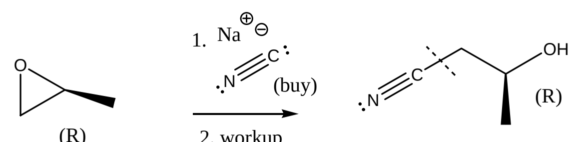


given for now epoxide

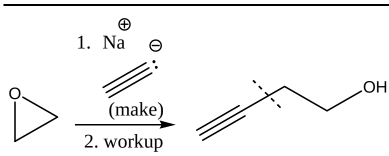
Strong nucleophiles reacting with epoxides (S_N2-like reaction)



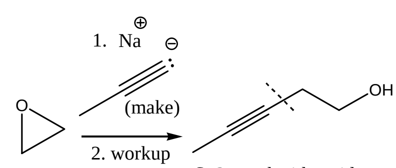
S_N2 attack either side



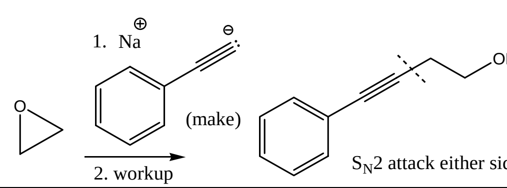
S_N2 attack less hindered side



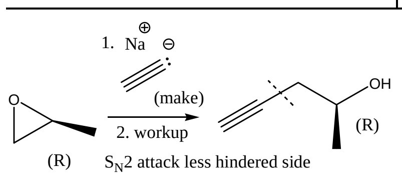
S_N2 attack either side



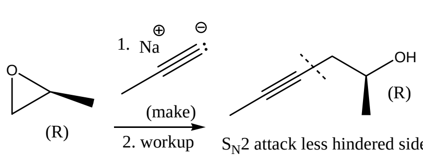
S_N2 attack either side



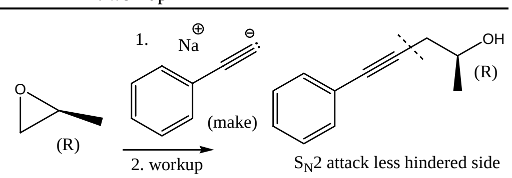
S_N2 attack either side



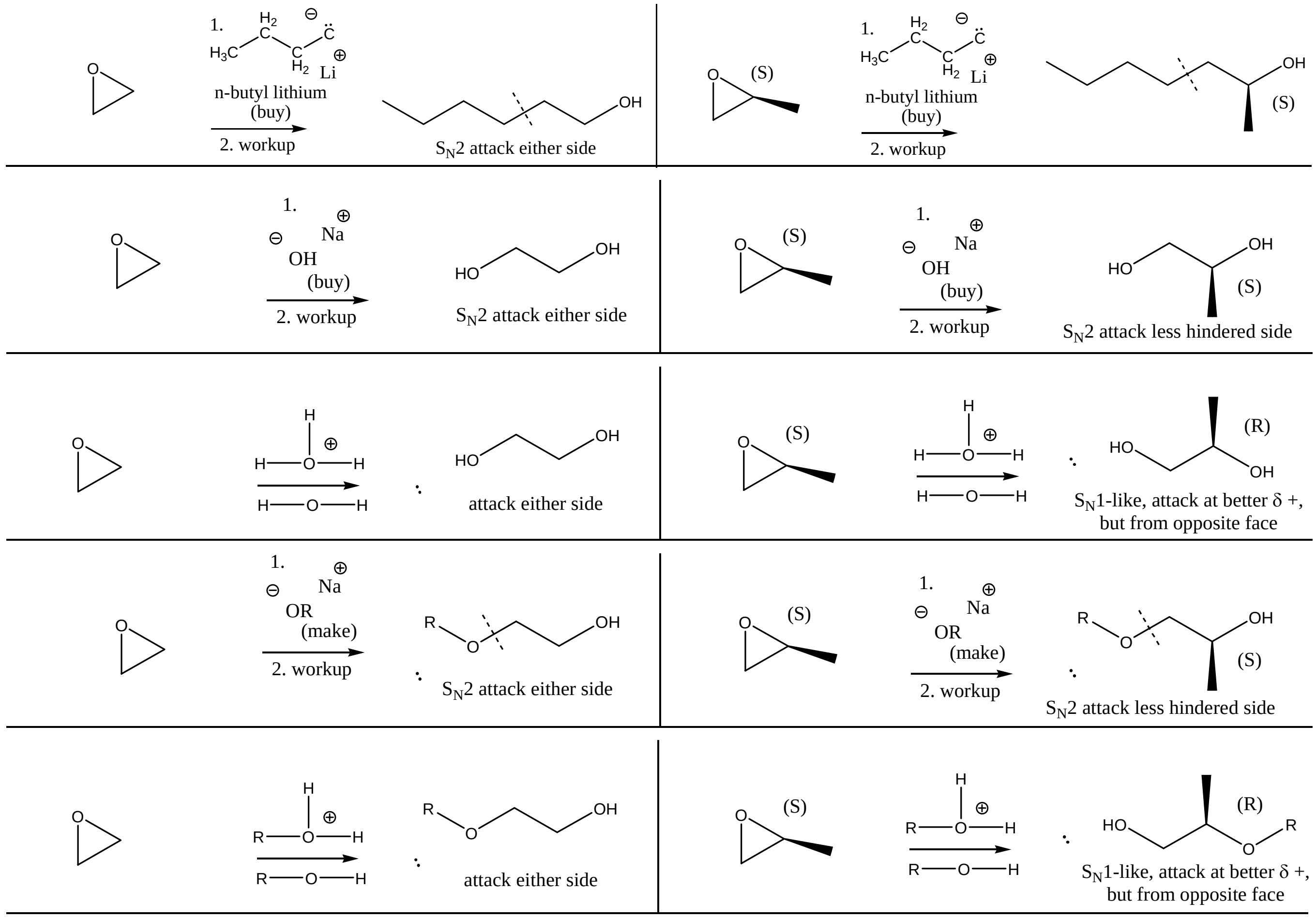
S_N2 attack less hindered side



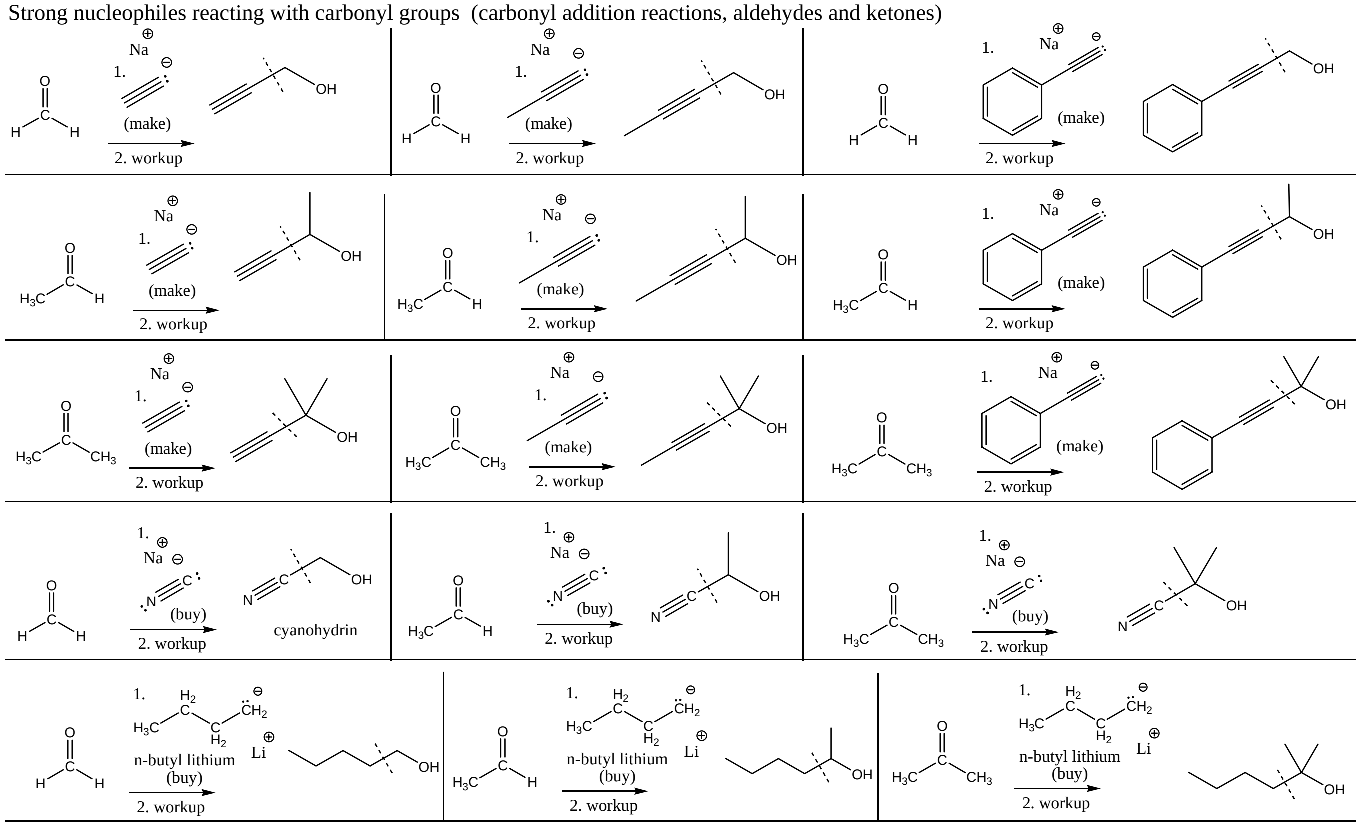
S_N2 attack less hindered side

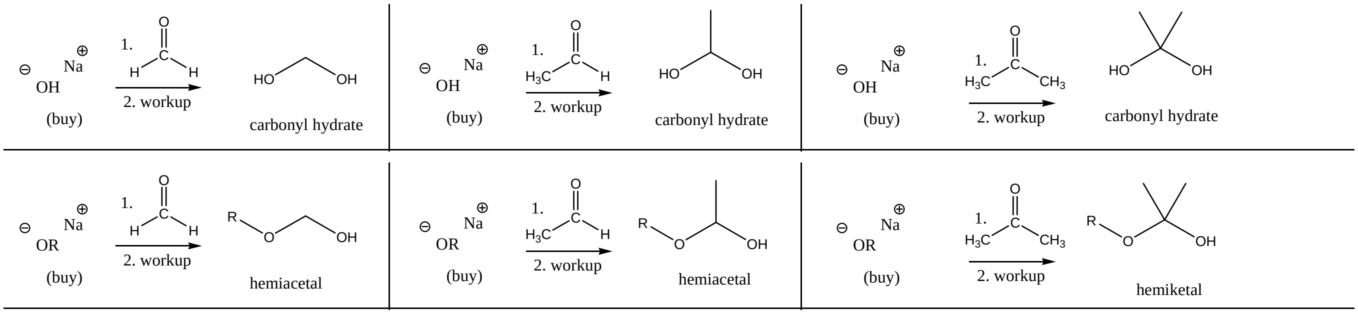


S_N2 attack less hindered side



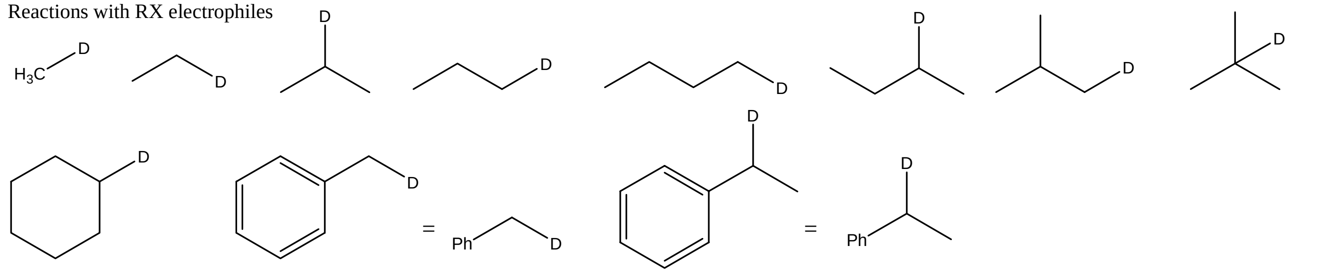
Strong nucleophiles reacting with carbonyl groups (carbonyl addition reactions, aldehydes and ketones)

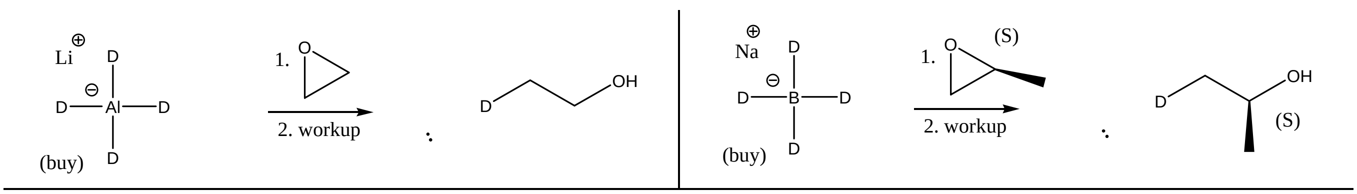


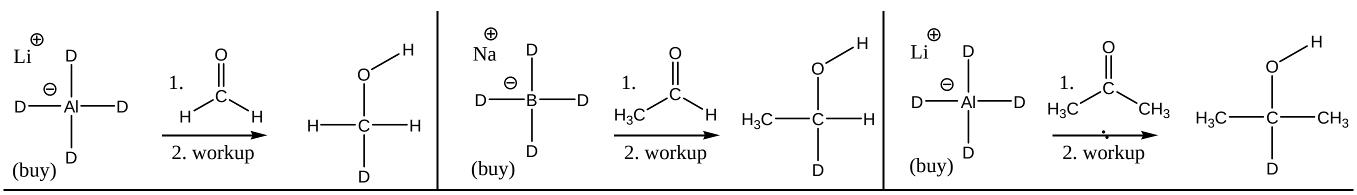


Lithium aluminium hydride ($LiAlH_4$ = LAH) and sodium borohydride ($NaBH_4$) nucleophiles reacting with various electrophiles ($LiAlD_4$ and $NaBD_4$ used in examples below so you can see where the hydride went.)

Reactions with RX electrophiles

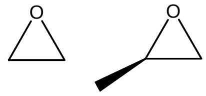
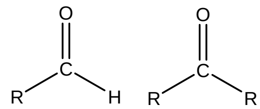
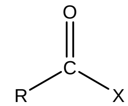
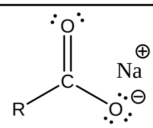
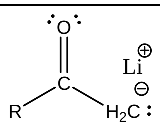






More reactions will be added.

Commonly encountered nucleophiles and electrophiles thus far

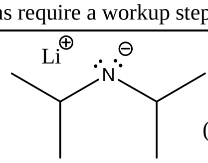
Important electrophiles / **Important nucleophiles (can also be bases)**	R—X Me, 1°, 2°, 3°, allylic, benzylic (C vs. H competition)	 epoxides (C vs. H competition)	 aldehydes, ketones = C=O addition reactions (C vs. H competition)	 X = leaving group esters, acid chlorides, anhydrides, amides, carboxylic acids = acyl substitution reactions (C vs. H competition)
$H-\ddot{\underset{..}{O}}:^{\ominus}$ $Na^{\oplus}$ hydroxide (buy)	methyl, S_N2 only 1° RX, S_N2 > E2 (except) 2° RX, S_N2/E2 depends 3° RX, E2 only	(S_N > E)	(Both Nu:$^{\ominus}$/B:$^{\ominus}$ reactions are possible)	
$R-\ddot{\underset{..}{O}}:^{\ominus}$ $Na^{\oplus}$ alkoxides (make)	(S_N vs E depends on RX and Nu:$^{\ominus}$/B:$^{\ominus}$)	(S_N > E)	(Both Nu:$^{\ominus}$/B:$^{\ominus}$ reactions are possible)	
 carboxylates (acetate) (make)	(S_N vs E depends on RX and Nu:$^{\ominus}$/B:$^{\ominus}$)	(S_N > E)	(No useful reactions for us)	
$:N\equiv C:^{\ominus}$ $Na^{\oplus}$ cyanide (buy)	(S_N vs E depends on RX and Nu:$^{\ominus}$/B:$^{\ominus}$)	(S_N > E)	(mainly Nu:$^{\ominus}$ reactions)	
$R-C\equiv C:^{\ominus}$ $Na^{\oplus}$ terminal acetylides (make)	(S_N vs E depends on RX and Nu:$^{\ominus}$/B:$^{\ominus}$)	(S_N > E)	(mainly Nu:$^{\ominus}$ reactions)	
 enolates (make)	(S_N vs E depends on RX and Nu:$^{\ominus}$/B:$^{\ominus}$)	(S_N > E)	(mainly Nu:$^{\ominus}$ reactions)	
$Li^{\oplus}$ $H_3Al^{\ominus}-H$ lithium aluminum hydride (buy)	(S_N vs E depends on RX and Nu:$^{\ominus}$/B:$^{\ominus}$)	(S_N > E)	(mainly Nu:$^{\ominus}$ reactions)	
$Na^{\oplus}$ $H_3B^{\ominus}-H$ sodium borohydride (buy)	(S_N vs E depends on RX and Nu:$^{\ominus}$/B:$^{\ominus}$)	(S_N > E)	(mainly Nu:$^{\ominus}$ reactions)	

Many of these reactions require a workup step to neutralize the strongly basic (nucleophilic) conditions.

Always a base in our course:

$Na^{\oplus}$ $:H^{\ominus}$
sodium hydride
(buy)

$Na^{\oplus}$ $:\ddot{N}H_2^{\ominus}$
sodium aminde
(buy)


(make)
lithium diisopropylamide
(LDA)

$Li^{\oplus}$ $:CH_2CH_2CH_2CH_3^{\ominus}$
n-butyl lithium
a very strong base and a
very strong nucleophile
(buy or make)