Ch41b Final Exam Review
Chapter 12: IR

- Using infrared light (~2000nm-20,000nm for IR spectroscopy) to excite (mostly) stretching and bending frequencies in molecules
- Hooke’s law helps predict absorbance peaks

\[ \nu = \frac{1}{2\pi c} \sqrt{\frac{\kappa (m + M)}{mM}} \]

- Strength of the bond (\(\kappa\))
- Reduced mass \(\frac{(m+M)}{mM}\)
  - If \(M \gg m\) (ie. Carbon>>hydrogen or deuterium,) then \(\frac{1}{m}\)

- Intensity
  - Concentration of bonds
  - Size of dipole moment

- Inactive in symmetrical bonds stretches ie. 2,3 dimethylbutene
# Important IR Absorbances (Appendix II)

<table>
<thead>
<tr>
<th>Bond Stretch</th>
<th>Frequency (cm(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkane C-H</td>
<td>2850-3000</td>
</tr>
<tr>
<td>C=C-H</td>
<td>3000-3100 (stretch)</td>
</tr>
<tr>
<td>C(=) C-H</td>
<td>3300</td>
</tr>
<tr>
<td>Aromatic C(=)C</td>
<td>1500 and 1600 (two peaks)</td>
</tr>
<tr>
<td>C=C</td>
<td>1640-1675</td>
</tr>
<tr>
<td>C(=)C</td>
<td>2100-2200</td>
</tr>
<tr>
<td>C=C</td>
<td>1640-1675</td>
</tr>
<tr>
<td>C=O</td>
<td>1680-1725</td>
</tr>
<tr>
<td>O-H</td>
<td>3200-3400 (very broad)</td>
</tr>
<tr>
<td>N-H</td>
<td>3200-3375 (several peaks)</td>
</tr>
</tbody>
</table>
• Election-ionization mass spectrometry
  
  - Use high energy electron beam to cause the molecule of interest to eject an electron

\[
\begin{align*}
\text{H} & : \text{C} : \text{H} + e^- \rightarrow \text{H} : \text{C}^+ : \text{H} + 2e^- \\
\text{H} & : \text{C}^+ : \text{H} \rightarrow \text{H}^* + \text{H} : \text{C}^+ : \text{H}
\end{align*}
\]

  - The radical cation will then fragment

• Fragmentation continues...
Chapter 12: Mass Spectrometry

• Only ions are detected by the mass spectrometer
  • The mass over charge (m/z) value, although in EI, z is usually 1

• The *molecular ion* (M) is the peak that corresponds to the mass before any fragmentation takes place
  • Equal to the *molecular* mass of the molecule

• The *base peak* is the peak of greatest intensity
Isotopic Peaks

- Observed when an atom in a molecule has more than one stable isotope
  - Ex. You see a $m/z$ of 17 for methane because there are molecules of $^{13}\text{CH}_4$, $^{12}\text{CDH}_3$ in the sample
  - Diagnostic for compounds with Cl or Br
  - Ratio of $^{79}\text{Br}$:$^{81}\text{Br} = 1:1$, so you'll observe two peaks of nearly equal intensity $2\ m/z$ apart in fragments with bromine
  - $^{35}\text{Cl}$:$^{37}\text{Cl} = 3:1$, so you'll observe two peaks in a 3:1 ratio $2\ m/z$ apart
Fragmentation

• Two common cases:
  • Even-electron ion: one product is a radical and a cation with no unpaired e⁻
    • More conventional
      \[
      \begin{align*}
      & \text{H} \\
      \text{H:} & \text{C}^+ \text{H} \\
      \text{H} & \rightarrow \quad \text{H}^\cdot + \text{H:} \text{C}^+ \\
      \end{align*}
      \]
  • Odd-electron ion: one product is neutral and the other is a radical cation

\[
\begin{align*}
\text{CH}_3(\text{CH}_2)\text{CH}_2\text{CH}_2&\text{CH}_2 \rightarrow \text{CH}_3(\text{CH}_2)\text{CH}_2\text{CH}_2 \quad \text{H}_2\text{O} \\
\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2&\text{CH}_2 \rightarrow \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{H}_2\text{O} \\
\text{CH}_3(\text{CH}_2)\text{CH}_2\text{CH}_2&\text{CH}_2 \rightarrow \text{CH}_3(\text{CH}_2)\text{CH}_2\text{CH}_2\text{H}_2\text{O} \\
\end{align*}
\]
α cleavage

- Cleaves the bond at the alpha position
  - Does not cleave any bonds to the charged atom
β-elimination

- A lone pair will abstract a hydrogen from the β carbon
Chemical-ionization (CI) MS

- A gentler method that generates $\text{CH}_5^+$ ions that serve as a source of protons
- These protons go on to protonate whatever the sample is
  - This generates an ion that can be detected by the MS at $\text{M}+1$
- Gives a more definite molecular ion peak while EI gives a richer picture of the structure due to more fragments
Chapter 13: NMR

• Use radio waves to excite nuclei with spin and detect magnetic differences in these nuclei
  • Nuclei with spin have an odd sum of protons + neutrons

• Each chemically distinguishable nuclei will give a different peak
  • Based on its environment and how much they are shielded (the surrounding atoms affect the local magnetic field experienced by the proton)
  • Diastereotopic hydrogens will give different shifts

• In $^1$H-NMR, can determine the number of hydrogens under each peaks
  • Can also determine the number of neighboring hydrogens by splitting patterns
  • Not applicable to $^{13}$C-NMR, IR or MS
Other Helpful Chemical Shifts to Remember

• Tert-butyl group: singlet, integrates to 9, ~1ppm
• Di-methyl: doublet, integrates to 6, 1ppm range
• Methoxy: singlet, integrates to 3, ~3ppm range
• Aromatic: ~7ppm range (depending on substituents)
• Alkene: ~5-6ppm range (depending on substituents)
Coupling constants: $J$ values

- Adjacent protons will split each other based on the $n+1$ rule
  - Number of peaks = $n + 1$; $n=$number of protons on adjacent carbon
  - Intensities of each peak can be determined using Pascal’s triangle
- The spacing between each peak is given by the coupling constant ($J$)
  - Gives information about strong their interactions are
- $J$ will be the same for protons that split each other (adjacent protons)
Useful $J$ values

- 4-10Hz
- 6-14Hz
- 0-3.5Hz
- 11-18Hz

- 0-1Hz
- 6-10Hz
- 1-3Hz
$^{13}\text{C-}\text{NMR}$

- No splitting
- No integration
- Good when molecule has many protons (discerning different hydrocarbons)
- DEPT to determine if carbon has 1, 2, or 3 hydrogens on it
Solving Structure Problems with Spectroscopy

• Using MS, determine the molecular mass
• Calculate the unsaturation number if elemental analysis is given
• Look for functional groups based on the IR and NMR
• Determine the number of non-equivalent sets of hydrogens and carbons (if spectra are given and not too complex)
• Write out partial structures
• Put them together and get full structure
Practice Problem

• $C_8H_7Br$
• IR: 1500, 1600, 1645, and 3089 cm$^{-1}$
• 6 different carbons by $^{13}$C-NMR
• $^1$HNMR: $\delta = 7.77$ (doublet, 2H, $J = 7.5$Hz)
  7.61 (doublet, 2H, $J = 7.5$Hz)
  6.72 (doublet of doublets, 1H, $J = 16.8$Hz and 10.0Hz)
  5.76 (doublet of doublets, 1H, $J = 16.8$Hz and 2.1Hz)
  5.25 (doublet of doublets, 1H, $J = 10.0$Hz and 2.1Hz)
Breakdown

• IR: Benzene ring (1500cm$^{-1}$ and 1600cm$^{-1}$), an alkene (1645cm$^{-1}$), and C(sp$^2$)-H bonds (3089cm$^{-1}$)

• 6 different carbons => two are equivalent to another

• Aromatic peaks in $^1$HNMR are ortho due to J values

• The olefin is mono-substituted (3 peaks in that region)
  • Only bonded to R on one side
  • J values confirm
Ch 14 Alkynes
The 2 pi-bonds are orthogonal to each other:

- Electron number in aromatic compound
- Benzyne
Spectra of alkyne

-C≡C-H  acetylenic protons  δ 1.7–2.5
-C≡C=H  propargylic protons  δ 1.8–2.2

C=C  vinylic protons  δ 4.5–5.5
C=CH  allylic proton  δ 1.8–2.2

propargylic carbons
δ 3.3 75.2 79.2 18.7 31.7 22.3 13.8

acetylenic carbons

H3C-C≡C-CH2-CH2-CH2-CH3

wavelength, micrometers

percent transmittance

C≡C  stretch

C-H  stretch

CH3(CH2)5C≡C-H  1-octyne

wavenumber, cm⁻¹
• Alkyl hydrogen is a little acidic, with pKa = 25
Various way to hydrogenate alkyne

- Reaction with $\text{H}_2$ and Pd/C catalyst yields an alkane.
- Reaction with $\text{H}_2$ and Lindlar catalyst yields a cis alkene.
- Reaction with Na and $\text{NH}_3$ yields a trans alkene.
Hydrobromination

Excess HBr

HBr (1 eq.) peroxide
Hydration

\[ \text{Hg}^{2+}, \text{H}_2\text{SO}_4 \]

1) disiamylborane
2) \( \text{H}_2\text{O}_2, \text{OH}^- \)
click reactions

• Copper (I) catalyzed

\[ \text{Cu(I)} \]

• Strain promoted
Diels-Alder reactions
Resonance Stabilization from Delocalization:

- Conjugated; delocalization
- Not conjugated; no delocalization
- P orbitals are perpendicular
Diels-Alder Reaction

Components: Diene and Dienophile ("diene loving")

Note: Dienes MUST be s-cis conformation to make use of transition state stabilization

Examples of Dienes:

Note: if the R groups produce too much steric clash, the s-trans conformation is favored;
Electron Donating Groups (EDG) substituted on diene to decrease energy of the pi HOMO orbitals

Examples of Dienophile

Note: want Electron Withdrawing Groups (EWG) substituted on the dienophile since this raises the energy of the dienophile's pi* LUMO orbitals
Ro = substituent on the "outside"
Ri = substituent on the "inside"

Endo product is the major product for the Diels Alder Reaction

1,2- and 1,4- addition of Hydrogen Halides
\[
\text{Product 1} \rightarrow \text{Product 2} + \text{Product 3}
\]
Provide an arrow-pushing mechanism for the transformation of the reactant to the product.
The diagram illustrates the energy changes during a reaction involving the addition of HBr to a conjugated diene. The reaction mechanism includes the formation of two addition products:

1. 1,2-addition product: \( \text{BrH} \text{C} = \text{CHCH} = \text{CH}_2 \) (labelled as \( \text{H}_2\text{C} = \text{CHCH} = \text{CH}_2 \) with an arrow pointing to the right)

2. 1,4-addition product: \( \text{BrCH}_2\text{CH} = \text{CHCH}_3 \) (labelled as \( \text{H}_2\text{C} = \text{CHCH} = \text{CH}_2 \) with an arrow pointing to the right

The reaction pathway is shown with multiple energy levels, indicating the activation energy required for each step of the reaction.
Aromatic Compounds

Requirements:

1) Contain one or more rings that have a cyclic arrangement of p orbitals (must be cyclic)
2) Every atom of an aromatic ring has a p orbital (sp² hybridized)
3) Aromatic rings must be planar (to allow for proper orbital overlap)
4) Aromatic compound must contain 4n + 2 pi electrons (n any integer). 4n pi electrons are considered anti-aromatic

How do we determine this? Frost Circles
Ch 16 – Chemistry of Benzene and Its Derivatives

• Criteria for aromaticity
  1. Uninterrupted cyclic arrangement of p orbitals
  2. Completely conjugated
     i.e. each atom in ring has a p orbital
  3. Ring must be planar
  4. π cloud must contain 4n+2 electrons (Huckel’s rule) (2, 6, 10, 14, etc.)

• Corollary: satisfy #1-3 and 4n e- (4, 8, 12, etc.) → anti-aromatic
Spectroscopic properties of aromatic compounds

- **IR**
  - $C_{sp^2}-H$ 3150-3000 cm$^{-1}$
  - C=C (arene) 1600, 1500 cm$^{-1}$

- $^1H$ NMR
  - Aryl H: 6.8-7.8 ppm
  - Benzylic H: 2-3 ppm (downfield from expected)
  - Phenolic H 5-6 ppm (rather than 2-3 ppm)
  - $J$(ortho) = 6-10 Hz
  - $J$(meta) = 1-3 Hz
  - $J$(para) = 0-1 Hz

- $^{13}C$ NMR
  - 110-160 ppm (aromatic)
  - 18-30 ppm (benzylic)
Electrophilic Aromatic Substitution

• Generation of electrophile
• Attack of aromatic π e- on electrophile
• Loss of H+ to regain aromaticity

\[
\begin{array}{c}
\text{H} \\
\text{C} \\
\text{E} \\
\text{H}
\end{array}
\quad \xrightarrow{\text{"E+"}} \quad
\begin{array}{c}
\text{C} \\
\text{E} \\
\text{H}
\end{array} + \text{H}^+
\]

• Types of EAS
  • Halogenation
  • Nitration
  • Sulfonation
  • Friedel-Crafts acylation
  • Friedel-Crafts alkylation
- **Halogenation**
  \[
  \text{C}_6\text{H}_6 + \text{Br}_2 \xrightarrow{\text{FeBr}_3} \text{C}_6\text{H}_5\text{Br}
  \]
  \[
  \text{C}_6\text{H}_6 + \text{Cl}_2/\text{FeCl}_3
  \]

- **Nitration**
  \[
  \text{C}_6\text{H}_6 + \text{HNO}_3 \xrightarrow{\text{H}_2\text{SO}_4} \text{C}_6\text{H}_5\text{NO}_2
  \]

- **Sulfonation**
  \[
  \text{C}_6\text{H}_6 + \text{SO}_3 \xrightarrow{\text{H}_2\text{SO}_4} \text{C}_6\text{H}_5\text{SO}_3\text{H}
  \]

- **Friedel-Crafts acylation**
  \[
  \text{C}_6\text{H}_6 + \text{C}_2\text{H}_5\text{COCl} \xrightarrow{\text{AlCl}_3} \text{C}_6\text{H}_5\text{COCH}_3
  \]

- **Friedel-Crafts alkylation**
  \[
  \text{C}_6\text{H}_6 + \text{CH}_3\text{CH(CH}_3\text{)}_2 \xrightarrow{\text{AlCl}_3} \text{C}_6\text{H}_5\text{CH(CH}_3\text{)}_2
  \]
Directing groups

• Alkyl group: e- donating via inductive effects

• O, N group: e- withdrawing (inductive), e- donating (resonance)
  \( \rightarrow \) net e- donation

• Halogens: e- withdrawing (inductive), e- donating (resonance)
  \( \rightarrow \) net e- withdrawing

• Aldehydes (and other carbonyls!): e- withdrawing via inductive and resonance effects
Directing groups

• Ortho, para-directing groups:
  • electron donating
    -NH2, -NR2, -OH, -OR, -NHCOR, -R, -Ph, -OCOR, -F, -Cl, -Br, -I

• Meta-directing groups:
  • electron withdrawing
    -NO2, -CN, -SO3H, -COH, -COOR
  +/δ+ adjacent to ring
Activating/Deactivating Groups

- All o,p-directing groups are activating
- All m-directing groups are deactivating
- Halogens are o,p-directing yet deactivating
- Multiple groups
  - When directing groups reinforce, the new substituent is located in the position directed by both groups
  - If directing groups oppose each other, the more powerful activator “wins”
  - No substituents between two meta-substituents due to crowding
Section 3

A further glimpse into the wonder of NMR: Chapter 14
Some useful chemical reactions to know

1. $\text{H}_2\text{O}$, $\text{Hg}^{2+}$, $\text{H}_2\text{SO}_4$ (Dilute)
2. $\text{H}_2$, Lindlar Catalyst
   Or $\text{H}_2$, Pd/C, pyridine in ethanol
3. $\text{H}_2$, Pd/C
   (no poison) in ethanol
4. $\text{Na(s)}$ in $\text{NH}_3$ (L)
   in ethanol
5. $\text{Br}$, $\text{KOH}$ at 200 °C with Cu
6. $\text{Cl}$, $\text{K NH}_2$, $\text{NH}_3$
   What kind of intermediate does this go through?
Some useful chemical reactions to know

- $\text{H}_2\text{O} \xrightarrow{\text{Hg}^{2+}, \text{H}_2\text{SO}_4 (\text{Dilute})} \text{CH}_2\text{O}$
- $1:2\text{H}_2, \text{Lindlar Catalyst}$
- $\text{Or H}_2, \text{Pd/C, pyridine}$
- $\text{ethanol}$

- $\text{H}_2, \text{Pd/C}$
- $\text{(no poison)}$
- $\text{ethanol}$

- $\text{Na(s) in NH}_3 (\text{L})$
- $\text{ethanol}$

- $\text{Br}$
- $\text{KOH}$
- $200^\circ\text{C}$

- $\text{Cu}$

- $\text{KnH}_2$
- $\text{NH}_3$

- $\text{Cl}$
Common functional groups and their associated chemical shift ranges
Practice problem 1:
Propose a structure
AND REMEMBER
Practice problem 1:
JUST KIDDING!!!!!!
Practice problem 3
Is this what we expect?
Some useful mass spec stuff
Some useful mass spec stuff

\[ \text{OH} \rightarrow \text{b-cleavage} \]

\[ \text{O} \rightarrow \text{a-cleavage} \]

\[ \rightarrow \text{inductive cleavage} \]
Summary list of rxns

Ch 14 Alkynes

Addition Rxns (HBr)

1)  

\[ \text{HBr} \quad \rightarrow \quad \text{olefin} + \text{HBr} \]

Markovnikov addition; formation of most stable C-C bond

2)  

\[ \text{HBr} + \text{peroxides} \quad \rightarrow \quad \text{olefin} + \text{HBr} \]

Anti-Markovnikov addition; process through radical mechanism

*Multiple addition of Br possible; occurs at carbon of first addition due to resonance stabilization

**Ex:**

\[ \text{HBr} + \text{olefin} \quad \rightarrow \quad \text{bromo-olefin} \]

Hydration (H_2O)

3)  

\[ \text{H}_2\text{O} \quad \rightarrow \quad \text{hydroxy-alkene} \]

Markovnikov addition; no rearrangement

Hydride (BH_3)

4)  

\[ \text{BH}_3 \quad \rightarrow \quad \text{boron-alkene} \]

Boron adds to unbranched carbon; H to more branched carbon

**Note:** To avoid multiple additions of BH_3, use the sterically bulky \( \text{OH} \) reagent
NOTE for terminal alkynes

5) \[ \text{Aldehyde} \]

6) \[ \text{Ketone} \]

Hydrogenation (H₂)

6) \[ \text{full reduction} \]

7) \[ \text{must be poisoned catalyst} \]

8) \[ \text{trans reduction} \]

C-C bond formation using alkynes

9) \[ \text{or} \]

\[ \text{or} \]
Dien-Alder Rxn

1b) \[ R_0^+ + H_2C = CH_2 \rightarrow \]  
   Endo product;  
   C-C bond forming rxn

1,2 and 1,4-additions

11)  
   \[ \text{Br} \]  
   Kinetic path  
   or  
   thermodynamic  
   path (non-substituted double bond)
Chapter 16

Electrophilic Aromatic Substitution

General Rxn

\[ \text{Ar} + E-Y \rightarrow \text{Ar}^+ + H-Y \]

Halogenation (-X)

12) \[ \text{Ar} + \text{Br}_2 (Cl) \xrightarrow{FeBr_3 (FeCl_3)} \text{Ar}^+ - \text{Br} + HBr \]

Nitration (-NO₂)

13) \[ \text{Ar} + \text{HNO}_3 \xrightarrow{H_2SO_4} \text{Ar}^+ - \text{NO}_2 \]

Sulfonation (-SO₃H)

14) \[ \text{Ar} + \text{SO}_3 \xrightarrow{H_2SO_4} \text{Ar}^+ - \text{SO}_3H \]

Friedel-Crafts Alkylation (-R)

15) \[ \text{Ar} + \text{RCl} \xrightarrow{AlCl₃ (1.1M)} \text{Ar}^+ - \text{R} \]

Friedel-Crafts Acylation (-R-CO₂⁺)

16) \[ \text{Ar} + \text{Cl} \xrightarrow{AlCl₃ (1.1M)} \text{Ar}^+ - \text{R} \xrightarrow{H₂O} \text{Ar}^+ - \text{R}-\text{CO}_₂⁻ \]

NOTE: Subject to carbocation rearrangement

\[ E^+ = R^+ \text{ or } R-\text{CO}_₂⁻ \text{ or } R-\text{Cl}^- \text{ or } R-\text{OH}^- \]

Friedel-Crafts Dealkylation

\[ \text{Ar}^+ - \text{R} \xrightarrow{} \text{Ar} \]

NOTE: Subject to no rearrangement, then can reduce to get alkyl chain
Reduction

7) \[ \text{H}_2, 	ext{Nabh}_4 \rightarrow \text{C}_8 \text{H}_{11} \text{OH} \]

Hydrogenation of Bicyclic Alinches (-H)

8) \[ \text{H}_2 \rightarrow \text{C}_8 \text{H}_{12} \text{OH} \]

9) \[ \text{Na} \rightarrow \text{C}_8 \text{H}_{12} \text{OH} \]

Ch 17 Reactions involving Allylic and Benzyllic positions

20) \[ \text{Br}_2 \rightarrow \text{H}_2 \text{O} \rightarrow \text{Br}^- \text{OH}^- \]

Radical mechanism

21) \[ \text{Br}_2 \rightarrow \text{H}_2 \text{O} \rightarrow \text{Br}^- \text{OH}^- \]

Some result

NOTE:

E2 Elimination

22) \[ \text{Br} \rightarrow \text{H}_2 \text{O} \rightarrow \text{Br}^- \text{OH}^- \]

95%

5%

Allylic and Benzyllic Oxidation

23) \[ \text{H}_2 \text{O} \rightarrow \text{Br}^- \text{OH}^- \]

Benzyllic positions, reactivity varies as eliminations favored

NOTE: forming allylic alcohol only; methylation

Secondary allylic alcohol becomes

Benzyllic Oxidation

24) \[ \text{H}_2 \text{O} \rightarrow \text{Br}^- \text{OH}^- \]

Decarboxylation
Ch18 - Aryl Halides, Vinylc Halides, Phosphorus

- Lack of reactivity of vinylc and aryl halides under SN1 conditions
- Lack of reactivity of vinylc en aryl halides under SN2 conditions

- Elimination reaction

Nucleophilic Aromatic Substitution, Rums of Aryl Halides

1) F → O

- Need electron withdrawing group (EWG) at ortho or para position
- Note: directing effect difference from electrophilic aromatic substitution

Why? Look at the intermediate

Phenols

1) ONH → X

2) OH → X

3) OH → X

4) OH → X

5) OH → X

6) OH → X

7) OH → X
25) \( \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH} \xrightarrow{\text{CuO, H}_2\text{O}} \text{CH}_3\text{CH}_2\text{CH}_2\text{CHO} \)

Note:

\( \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH} \xrightarrow{\text{Cr(VI)}} \text{CH}_3\text{CH}_2\text{CH}_2\text{CO}_2\text{H} \)

\( \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH} \xrightarrow{\text{viscous}} \text{CH}_3\text{CH}_2\text{CH}_2\text{CHO} \)

\( \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH} \xrightarrow{\text{Cr(VI)}} \text{CH}_3\text{CH}_2\text{CH}_2\text{CHO} \) (mild)

Related to reactivity of benzyllic position.
Ch 18 - Aryl Halides, Vinylc Halides, Phenols

Norr

- Lack of reactivity of vinylc and aryl halides under S_N1 conditions
- Lack of reactivity of vinylc and aryl halides under S_N2 conditions
- Elimination reacts E1

Nucleophilic Aromatic Substitution Rns of Aryl Halides

26)

\[
\begin{align*}
\text{F} & \quad \text{Nu}^+ \\
\text{Nuc} & \quad \text{Nu} \\
\text{NO}_2 &
\end{align*}
\]

- Need Electron withdrawing Group (EWG) at ortho or para position
- Note directing effect difference for electrophilic aromatic substitution
- Why? Look at the intermediate

[Diagram of intermediate]

Phenols

27)

\[
\begin{align*}
\text{ON} & \quad 1) \text{base} \\
\text{OH} & \quad 2) \text{X}
\end{align*}
\]

28)

\[
\begin{align*}
\text{OH} & \quad \text{Na}_2\text{CO}_3 \\
\text{OH} & \quad \text{H}^+
\end{align*}
\]

29)

\[
\begin{align*}
\text{O} & \quad \text{R} \\
\text{H}_2\text{O} & \quad \Delta \rightarrow \\
\text{OH} & \quad + \quad \text{RO}^-
\end{align*}
\]