Infrared Spectroscopy

- x-rays
- ultraviolet (UV)
- visible
- Infrared (IR)
- microwaves
- radiowaves

**Near IR**

<table>
<thead>
<tr>
<th>( \lambda ) (cm)</th>
<th>( \mu )</th>
<th>( \nu ) (cm(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 x 10(^{-5})</td>
<td>0.8</td>
<td>13,000</td>
</tr>
</tbody>
</table>

**Middle IR**

<table>
<thead>
<tr>
<th>( E ) (kcal/mol)</th>
<th>( \lambda ) (cm)</th>
<th>( \mu )</th>
<th>( \nu ) (cm(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5 x 10(^{-4})</td>
<td>2.5</td>
<td>25</td>
<td>4,000</td>
</tr>
<tr>
<td>2.5 x 10(^{-3})</td>
<td>25</td>
<td>400</td>
<td>40</td>
</tr>
</tbody>
</table>

**Far IR**

<table>
<thead>
<tr>
<th>( E ) (kcal/mol)</th>
<th>( \lambda ) (cm)</th>
<th>( \mu )</th>
<th>( \nu ) (cm(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5 x 10(^{-2})</td>
<td>250</td>
<td>25</td>
<td>40</td>
</tr>
</tbody>
</table>

**E = 1-10 kcal/mol**

\( \nu \) (cm\(^{-1}\)) = \frac{1}{\lambda \text{ (cm)}}

\( \nu \) (cm\(^{-1}\)) = \frac{1}{\mu \text{ (\mu m)}} \times 10,000

- **bond vibrations**
  - stretching
  - bending

- changes in bond lengths
- changes in bond angles
**Infrared Spectroscopy**

*Only* vibrations that produce a *change* in dipole moment are observed in the IR.

\[ \text{IR "invisible" if molecule is symmetric} \]

\[ \text{weak band if similar groups} \]
Infrared Spectroscopy

Fundamental Stretching & Bending Vibrations

- Symmetric stretch
  (~2853 cm⁻¹)

- Asymmetric stretch
  (~2926 cm⁻¹)

- Scissoring
  (~1450 cm⁻¹)

- Rocking
  (~720 cm⁻¹)

- Wagging
  (~1250 cm⁻¹)

- Twisting
  (~1250 cm⁻¹)

STRETCHING VIBRATIONS

BENDING VIBRATIONS
**Infrared Spectroscopy**

**Hooke’s Law**

Can approximate position (wavenumber) of spectral band using Hooke’s Law

\[ \bar{v} = \frac{1}{2\pi c} \sqrt{\frac{K}{\mu}} \]

and

\[ \mu = \frac{m_1 m_2}{m_1 + m_2} \]

so:

\[ \bar{v} = \frac{1}{2\pi c} \sqrt{K \cdot \frac{m_1 m_2}{m_1 + m_2}} \]

\( m = \text{mass of atom} \)
\( K = \text{force constant of bond} \)
\( c = \text{velocity of light} (3 \times 10^{10} \text{ cm/sec}) \)
Infrared Spectroscopy

Hooke’s Law

Can thus derive some qualitative relationships:

→ stronger bonds absorb at higher frequencies (higher $K = \text{higher } \nu$)

<table>
<thead>
<tr>
<th></th>
<th>~2159</th>
<th>~1650</th>
<th>~1200</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\nu$ (cm$^{-1}$)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Bond Strength (kcal/mol) | 230 | 168 | 90 |

→ as mass of atom increases, frequency decreases

<table>
<thead>
<tr>
<th>C–H</th>
<th>C–C</th>
<th>C–O</th>
<th>C–Br</th>
<th>C–I</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\nu$ (cm$^{-1}$)</td>
<td>3000</td>
<td>1200</td>
<td>1100</td>
<td>600</td>
</tr>
</tbody>
</table>

increasing atomic mass
Infrared Spectroscopy

Other Vibrations

Spectra include a number of other peaks. In addition to *fundamental stretching and bending absorptions*….

- **Overtones**: lower intensity vibration at an integral times the fundamental frequency
  \[ \tilde{\nu}_{\text{overtone}} = n \times \tilde{\nu}_{\text{fundamental}} \]

- **Combination bands**: the sum of two interacting vibrational frequencies, but only certain combinations are allowed
  \[ \tilde{\nu}_{\text{combination}} = \tilde{\nu} + \tilde{\nu}_2 \]

- **Difference bands**: similar to combination bands, but the difference of two interacting vibrations
  \[ \tilde{\nu}_{\text{difference}} = \tilde{\nu} - \tilde{\nu}_2 \]

- **Fermi resonance**: when a fundamental absorption couples with an overtone or combination band, most often observed for C=O
**Infrared Spectroscopy**

**Overtones**

1st overtone usually at twice normal $\nu \rightarrow$ typically weak

\[
\text{C}=\text{O} \quad \sim 1720 \text{ cm}^{-1}
\]

1st overtone $\sim 3440 \text{ cm}^{-1}$ → near ROH, R$_2$NH, terminal alkyne

[Diagram showing the 1st overtone in the infrared spectrum]
Infrared Spectroscopy

Fermi Resonance

Overtone falls close to a fundamental band → intensity is greatly enhanced
usually results in doubling of that band
Infrared Spectroscopy

The Infrared Spectrometer

Dispersive Infrared Spectrophotometer

• measures one frequency of light at a time
• scan speed is relatively slow
Infrared Spectroscopy

The Infrared Spectrometer

Fourier Transform Infrared Spectrophotometer (FT-IR)

- measures all frequencies of light at a time
- each scan requires less time; lower resolution than dispersive IR
- collect lots of scans & average → higher resolution overall
- faster acquisition, higher resolution than dispersive instrument overall
Infrared Spectroscopy

Sample Handling

• sample can be gas, liquid or solid
• samples can be taken in solution
  - subtract out solvent by taking background/reference spectrum
• liquids/oils samples often taken neat
• samples typically applied to polished NaCl plate (IR inactive)
• adventitious water can be problematic → lead to false signals
  - false ID of ROH, RCO₂H, R₂NH
• solids more problematic
  - solids can be deposited as thin film on NaCl plate
    • dissolve, drop on plate, then evaporate some solvent
    • solvents: CCl₄, CHCl₃ & CH₂Cl₂
  - sample can be mixed with Nujol (petroleum oil, high boiling)
    • obscures aliphatic region (less useful)
  - sample can pressed into KBr pellet
    • may take some practice
  - ATR: apply solid (or liquid) directly to spectrometer
Infrared Spectroscopy

The IR Spectrum

![IR Spectrum Graph](image)
Infrared Spectroscopy

Troubleshooting

neat: wet sample; sloping to high energy water bands

solid film: film too thick (or solvent evaporated between salt plates)
**Infrared Spectroscopy**

**Troubleshooting**

- **mull:** too much sample applied

- **KBr or solid film:** too little sample applied
Infrared Spectroscopy

General Absorbance Ranges in the IR
### Infrared Spectroscopy

#### Correlation Chart (Adapted from Pavia Table 2.3)

<table>
<thead>
<tr>
<th>Type of Vibration</th>
<th>Frequency (cm(^{-1}))</th>
<th>Int</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-H Alkanes (stretch)</td>
<td>3000-2850</td>
<td>s</td>
</tr>
<tr>
<td>-CH(_3) (bend)</td>
<td>1450 and 1375</td>
<td>m</td>
</tr>
<tr>
<td>-CH(_2) (bend)</td>
<td>1465</td>
<td>m</td>
</tr>
<tr>
<td>Alkenes (stretch)</td>
<td>3100-3000</td>
<td>m</td>
</tr>
<tr>
<td>(out-of-plane bend)</td>
<td>1000-650</td>
<td>s</td>
</tr>
<tr>
<td>Aromatics (stretch)</td>
<td>3150-3050</td>
<td>s</td>
</tr>
<tr>
<td>(out-of-plane bend)</td>
<td>900-690</td>
<td>s</td>
</tr>
<tr>
<td>Alkyne (stretch)</td>
<td>~3300</td>
<td>s</td>
</tr>
<tr>
<td>Aldehyde</td>
<td>2900-2800</td>
<td>w</td>
</tr>
<tr>
<td></td>
<td>2800-2700</td>
<td>w</td>
</tr>
<tr>
<td>C-C Alkane</td>
<td>not interpretatively useful</td>
<td></td>
</tr>
<tr>
<td>C=C Alkene</td>
<td>1680-1600</td>
<td>m-w</td>
</tr>
<tr>
<td>Aromatic</td>
<td>1600 and 1475</td>
<td>m-w</td>
</tr>
<tr>
<td>C≡C Alkyne</td>
<td>2250-2100</td>
<td>m-w</td>
</tr>
<tr>
<td>C=O Aldehyde</td>
<td>1740-1720</td>
<td>s</td>
</tr>
<tr>
<td>Ketone</td>
<td>1725-1705</td>
<td>s</td>
</tr>
<tr>
<td>Carboxylic Acid</td>
<td>1725-1700</td>
<td>s</td>
</tr>
<tr>
<td>Ester</td>
<td>1750-1730</td>
<td>s</td>
</tr>
<tr>
<td>Amide</td>
<td>1670-1640</td>
<td>s</td>
</tr>
<tr>
<td>Anhydride</td>
<td>1810 and 1760</td>
<td>s</td>
</tr>
<tr>
<td>Acid Chloride</td>
<td>1800</td>
<td>s</td>
</tr>
<tr>
<td>C-O Alcohols, Ethers, Esters, Carboxylic Acids, Anhydrides</td>
<td>1300-1000</td>
<td>s</td>
</tr>
</tbody>
</table>

Complete table can be found on class web site...
Infrared Spectroscopy

The IR Spectrum

(s) strong
(m) medium
(w) weak

functional group region

fingerprint region
Infrared Spectroscopy

Alkanes

• Simple spectra with few peaks

• C-H stretch most prominent (around 3000 cm\(^{-1}\))
  - \(\text{sp}^3\) C-H stretch between 3000-2840 cm\(^{-1}\)
    • saturated, unstrained hydrocarbons typically to the right of 3000 cm\(^{-1}\)
    • C-H stretch on vinyl or aromatic carbon to left of 3000 cm\(^{-1}\)

  - CH\(_2\)/CH\(_3\) bending vibrations between 1475-1350 cm\(^{-1}\)
    • CH\(_2\) bend around 1465 cm\(^{-1}\)
    • CH\(_3\) bend around 1375 cm\(^{-1}\)

  - long chain (four or more CH\(_2\) groups in long chain may see a band at 720 cm\(^{-1}\))
    • weak, often obscured in more complex molecules

• C-C stretch – not interpretively useful
Infrared Spectroscopy

Alkanes

decane

cyclohexane
Infrared Spectroscopy

Alkanes

(bromomethyl)cyclopropane

cyclopropane C-H ca. 3100 cm\(^{-1}\)
Infrared Spectroscopy

Alkenes

- Spectra more complex than alkanes

- $=\text{C-H}$ stretch to left of 3000 cm$^{-1}$
  - $sp^2$ C-H stretch between 3095-3010 cm$^{-1}$

- $=\text{C-H}$ out of plane bending vibrations between 1000-650 cm$^{-1}$
  - can sometimes be used to determine degree of alkene substitution
  - may be obscured in complex systems

- $C=C$ stretch occurs between 1660 - 1600 cm$^{-1}$
  - intensity varies with dipole
  - conjugation shifts absorbance to lower frequencies; increases intensity
Infrared Spectroscopy

Alkenes

1-hexene
Infrared Spectroscopy

Alkenes

cis-2-pentene
Infrared Spectroscopy

Alkenes

trans-2-pentene

C=\text{C}  
(very weak)

\text{sp}^2 \text{ C-H}
**Infrared Spectroscopy**

**Alkenes**

**Conjugation Effects**

- Conjugation moves C=C stretch to lower frequencies (~15-20 cm$^{-1}$)

- Conjugation increases amount of s-character; weakens bond, lowers force constant

- May see multiple absorbances if alkene is conjugated to another double bond
Infrared Spectroscopy

Alkenes

trans-1,3-pentadiene

\[
\text{sp}^2 \text{ C-H} \\
\text{C=C}
\]
Infrared Spectroscopy

Alkenes

C=C stretch: effect of ring strain in endocyclic alkenes

\[
\begin{align*}
\text{1650 cm}^{-1} & \quad \text{1646 cm}^{-1} & \quad \text{1611 cm}^{-1} & \quad \text{1566 cm}^{-1} \\
\text{1656 cm}^{-1} &
\end{align*}
\]

decreasing absorption frequency

\[
\begin{align*}
1646 \text{ cm}^{-1} & \quad \sim 1611 \text{ cm}^{-1}
\end{align*}
\]
Infrared Spectroscopy

Alkenes

C=C stretch: substituent effects in endocyclic alkenes

\[
\begin{align*}
\Delta & \quad R \quad R \\
1656 \text{ cm}^{-1} & \quad 1788 \text{ cm}^{-1} & \quad 1883 \text{ cm}^{-1} \\
R & \quad R \\
1566 \text{ cm}^{-1} & \quad 1641 \text{ cm}^{-1} & \quad 1675 \text{ cm}^{-1} \\
R & \quad R \\
1611 \text{ cm}^{-1} & \quad 1650 \text{ cm}^{-1} & \quad 1679 \text{ cm}^{-1} \\
R & \quad R \\
1646 \text{ cm}^{-1} & \quad 1675 \text{ cm}^{-1} & \quad 1681 \text{ cm}^{-1} \\
\end{align*}
\]

increasing absorption frequency
Infrared Spectroscopy

Alkenes

C=C stretch: effect of ring strain in exocyclic alkenes

1940 cm$^{-1}$  1780 cm$^{-1}$  1678 cm$^{-1}$  1657 cm$^{-1}$  1655 cm$^{-1}$  1651 cm$^{-1}$

increasing absorption frequency

more s character

more p character
Infrared Spectroscopy

Alkenes

C=C stretch in acyclic alkenes

* vinyl

\[
\begin{align*}
& \text{cis} \\
& \text{trisubstituted} \\
& \text{vinyl ether}
\end{align*}
\]

~1645 cm\(^{-1}\)

~1660 cm\(^{-1}\)

~1675-1670 cm\(^{-1}\)

~1680-1660 cm\(^{-1}\) (usually strong)

* =C–H bending absorbance may supplement assignment

* vinylidene

\[
\begin{align*}
& \text{trans} \\
& \text{tetrasubstituted}
\end{align*}
\]

~1655 cm\(^{-1}\)

~1675-1670 cm\(^{-1}\)

~1665-1660 cm\(^{-1}\)
Infrared Spectroscopy

Alkenes

Out of Plane Bending and Alkene Substitution

approx frequency
990, 910 cm\(^{-1}\)
700 cm\(^{-1}\)
970 cm\(^{-1}\)
890 cm\(^{-1}\)
815 cm\(^{-1}\)

none

Monosubstituted

\(\text{cis-1,2}\)

\(\text{trans-1,2}\)

1,1-Disubstituted

Trisubstituted

Tetrasubstituted

BEWARE! Fingerprint Region
Infrared Spectroscopy

Alkynes

• ᵃ≡C-H stretch usually near 3300 cm⁻¹
  - sp C-H stretch between 3260-3390 cm⁻¹

• ᵃC≡C stretch vibrations between 2100-2250 cm⁻¹
  - conjugation shifts absorbance to lower frequencies;
  - absorbances for symmetrically substituted alkynes may be weak or absent
Infrared Spectroscopy

Alkynes

1-hexyne
Infrared Spectroscopy

Alkynes

4-octyne

CH₃CHO₂CH₂CH₂-C≡C-CH₂CHO₂CH₃
Infrared Spectroscopy

Alkynes

allyl 2-butyroate

![Infrared Spectrogram of allyl 2-butyroate](image)

- **sp² C-H**
- **C≡C**
- **C=O**
- **C=C**
**Infrared Spectroscopy**

**Aromatic Rings**

- $=\text{C-H}$ stretch to left of 3000 cm$^{-1}$
  - $\text{sp}^2$ C-H stretch between 3050-3010 cm$^{-1}$

- $=\text{C-H}$ out of plane bending vibrations between 900-690 cm$^{-1}$
  - can often be used to determine ring substitution pattern

- C=C stretch between 1500-1600 cm$^{-1}$
  - two to three peaks; often occur in pairs at 1660 and 1475 cm$^{-1}$

- **Overtone/Combination bands** appear between 2000-1667 cm$^{-1}$
  - can sometimes be used to assign ring substitution pattern
Infrared Spectroscopy

Aromatic Rings

toluene
Infrared Spectroscopy

Aromatic Rings

Out of Plane Bending

mono: 690 - 710 cm\(^{-1}\) (strong)
      730 – 770 cm\(^{-1}\) (strong)*

ortho: 735-770 cm\(^{-1}\) (strong)

meta: 690-710 cm\(^{-1}\) (strong)
      780 cm\(^{-1}\) (strong)
      810-880 cm\(^{-1}\) (moderate)*

para 810-850 cm\(^{-1}\) (strong)

* may be absent
Infrared Spectroscopy

Aromatic Rings

overtones
Infrared Spectroscopy

Aromatic Rings

toluene

690 - 710 cm\(^{-1}\) (strong)
730 – 770 cm\(^{-1}\) (strong)*
Infrared Spectroscopy

Aromatic Rings

*o*-diethylbenzene

735-770 cm⁻¹ (strong)
Infrared Spectroscopy

Aromatic Rings

*m*-diethylbenzene

- 690-710 cm\(^{-1}\) (strong)
- 780 cm\(^{-1}\) (strong)
- 810-880 cm\(^{-1}\) (moderate)*
Infrared Spectroscopy

Aromatic Rings

**p-diethylbenzene**

810-850 cm\(^{-1}\) (strong)
Infrared Spectroscopy

Alcohols & Phenols

- **O-H** stretch occurs between 3650-3300 cm\(^{-1}\)
  - position and shape vary depending on amount of hydrogen bonding
    - free O-H: sharp peak between 3650-3600 cm\(^{-1}\)
    - H-bonded O-H: broad peak between 3500-3300 cm\(^{-1}\)

- **C-O-H** bending vibrations between 1440-1220 cm\(^{-1}\)
  - not diagnostic

- **C-O** stretch between 1260-1000 cm\(^{-1}\)
  - can sometimes provide information about alcohol structure
Infrared Spectroscopy

Alcohols & Phenols

2-butanol

<table>
<thead>
<tr>
<th>Wavenumbers (cm⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4000 - 3600</td>
</tr>
<tr>
<td>3200 - 2800</td>
</tr>
<tr>
<td>2400 - 2000</td>
</tr>
<tr>
<td>1800 - 1400</td>
</tr>
<tr>
<td>1400 - 1000</td>
</tr>
<tr>
<td>1000 - 800</td>
</tr>
<tr>
<td>800 - 600</td>
</tr>
<tr>
<td>600 - 400</td>
</tr>
</tbody>
</table>

PMR spectrum of 2-butanol with annotations for different functional groups.

p-cresol

<table>
<thead>
<tr>
<th>Wavenumbers (cm⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4000 - 3600</td>
</tr>
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<tr>
<td>1000 - 800</td>
</tr>
<tr>
<td>800 - 600</td>
</tr>
<tr>
<td>600 - 400</td>
</tr>
</tbody>
</table>

PMR spectrum of p-cresol with annotations for different functional groups.
Infrared Spectroscopy

Alcohols & Phenols

OH Stretch: Hydrogen Bonding vs. Free OH

- Hydrogen bonded OH
- Free and hydrogen bonded OH (dilute solution)
- Free and hydrogen bonded OH (very dilute solution)
**Infrared Spectroscopy**

**Alcohols & Phenols**

**cyclohexanol**

\[\text{OH}\]
neat

\[\text{OH}\]
solution in CCl\(_4\)

3331 cm\(^{-1}\)  C–O–H bend

3623 cm\(^{-1}\)
Infrared Spectroscopy

Alcohols & Phenols

**methyl salicylate**

![Methyl salicylate structure](image)

- Neat: 3190 cm\(^{-1}\)
- Solution in CCl\(_4\): 3199 cm\(^{-1}\)

![Infrared spectrum of methyl salicylate](image)

**Phenol 3322 cm\(^{-1}\)**

![Phenol structure](image)
Infrared Spectroscopy

Alcohols & Phenols

C-O stretch and structure

<table>
<thead>
<tr>
<th></th>
<th>phenol</th>
<th>3° alcohol</th>
<th>2° alcohol</th>
<th>1° alcohol</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-O stretch</td>
<td>1220 cm(^{-1})</td>
<td>1150 cm(^{-1})</td>
<td>1100 cm(^{-1})</td>
<td>1050 cm(^{-1})</td>
</tr>
</tbody>
</table>

decreasing frequency

1237 cm\(^{-1}\)   1159 cm\(^{-1}\)   1113 cm\(^{-1}\)   1069 cm\(^{-1}\)
**Infrared Spectroscopy**

**Alcohols & Phenols**

*effect of unsaturation on C-O stretch*

<table>
<thead>
<tr>
<th></th>
<th>3° alcohol</th>
<th>2° alcohol</th>
<th>1° alcohol</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-O stretch</td>
<td>1150 cm⁻¹</td>
<td>1100 cm⁻¹</td>
<td>1050 cm⁻¹</td>
</tr>
</tbody>
</table>

- **secondary alcohols**
  - ![Cyclohexanol](image)
    - 1070 cm⁻¹
    - ($\Delta$ 70 cm⁻¹)
  - ![Benzyl alcohol](image)
    - 1070 cm⁻¹
    - ($\Delta$ 70 cm⁻¹)
  - ![Vinyl alcohol](image)
    - 1060 cm⁻¹
    - ($\Delta$ 60 cm⁻¹)

- **primary alcohols**
  - ![Phenyl ethyl alcohol](image)
    - 1017 cm⁻¹
    - ($\Delta$ 33 cm⁻¹)
  - ![Acetylene alcohol](image)
    - 1030 cm⁻¹
    - ($\Delta$ 20 cm⁻¹)
Infrared Spectroscopy

Alcohols & Phenols

free OH stretch and structure

<table>
<thead>
<tr>
<th></th>
<th>phenol</th>
<th>3° alcohol</th>
<th>2° alcohol</th>
<th>1° alcohol</th>
</tr>
</thead>
<tbody>
<tr>
<td>free O-H stretch</td>
<td>3610 cm⁻¹</td>
<td>3620 cm⁻¹</td>
<td>3630 cm⁻¹</td>
<td>3640 cm⁻¹</td>
</tr>
</tbody>
</table>

increasing frequency

![Chemical structures and frequencies](image)
Infrared Spectroscopy

Ethers

- Difficult to identify by IR
- C-O stretch most prominent feature (1300-1000 cm\(^{-1}\))
  - aliphatic ethers show one strong band (~1120 cm\(^{-1}\))
  - phenyl/vinyl alkyl ethers show two strong bands (~1250 and 1140 cm\(^{-1}\))
- Many other FG show C-O stretch
  - may distinguish ether from alkane
  - can distinguish from alcohol (no OH stretch)
  - can distinguish from carbonyl derivative (no C=O stretch)
Infrared Spectroscopy

Ethers

dibutyl ether

[Diagram showing infrared spectrum of dibutyl ether with peak at 1023 cm\(^{-1}\)]

decane

[Diagram showing infrared spectrum of decane with various peaks labeled]
**Infrared Spectroscopy**

**Ethers**

ethoxybenzene

\[
\text{O} \begin{array}{c}
\text{C} \\
\text{O} \\
\text{C} \end{array} \\
\text{R}
\]

ethyl vinyl ether

\[
\text{O} \begin{array}{c}
\text{C} \\
\text{O} \\
\text{C} \end{array} \\
\text{R}
\]

- C–O–C: 1250 cm\(^{-1}\) 1040 cm\(^{-1}\)
- C–O–C: 1207 cm\(^{-1}\) 996 cm\(^{-1}\)
Infrared Spectroscopy

Ethers

ethoxybenzene

1,3-dioxolane

dehformation bands
Infrared Spectroscopy

Amines

- N-H stretch occurs between 3500-3300 cm\(^{-1}\)
  - signal varies with amine structure
    - 1° amines show two bands
    - 2° amines have one band
    - 3° amines have no absorbance in this region

- N-H bend vibrations between 1640-1500 cm\(^{-1}\)
  - 1° amines: 1640-1560
  - 2° amines: ~1500 cm\(^{-1}\)
  - not diagnostic

- C-N stretch between 1350-1000 cm\(^{-1}\)
Infrared Spectroscopy

Amines
cyclohexylamine

N-H stretch

N-H bend
Infrared Spectroscopy

Amines

dibutylamine
Infrared Spectroscopy

Amines

N-methylaniline
Infrared Spectroscopy

Amines

tributylamine