Synthesis of Vanillyl Alcohol

Organic Synthesis

How are organic reactions planned and executed?

What characterizes reduction in organic reactions?

What reagents can be used to conduct hydrogenations?

What is the basis for the absorption of IR radiation by molecules?

How is IR spectroscopy used to ascertain the molecular structure of a substance?

Purpose:
To conduct an organic reaction, isolate the product & characterize the product using infrared spectroscopy

Concepts:
Synthesis starting material product theoretical yield percent yield reduction organic functional groups group vibration frequencies characteristic infrared absorptions organic nomenclature melting point as a measure of purity

Techniques:
handling semi-micro-scale quantities of reagents quantitative transfer of liquids and solids crystallization vacuum filtration melting point determination infrared spectroscopy analyzing infrared spectra

Apparatus:
vacuum filtration apparatus (filter flask, Buchner funnel, Aspirator) melting point apparatus

Fourier Transform IR Spectrometer

Organization of this Pre-lab Lecture

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NOMENCLATURE – FUNCTIONAL GROUPS

Vanillin

3-methoxy 4-hydroxy benzaldehyde

N.B. In synthetic exercises, you are expected to know the formulas and structures of the reactants and products! E.g., Vanillyl Alcohol, etc.
SYNTHESIS

Conducting one or more chemical REACTIONS using STARTING MATERIALS to produce a desired PRODUCT.

What makes a synthesis EFFECTIVE?

If it produces the desired product:
- from reasonable STARTING MATERIALS
- under practical CONDITIONS (e.g., accessible temperature & pressure)
- at a reasonable RATE (CATALYSTS may be helpful)
- with relatively high YIELD (Few by-products)

How do you decide what starting materials to use?

OUR OBJECTIVE

To synthesize:

Vanillin $\rightarrow$ Vanillyl Alcohol

What readily available substance has a related structure?

REDUCTION

In organic chemistry, reduction often means addition of a hydrogen molecule to a multiple (e.g., double) bond.

- H - H + $\text{CH}_2=\text{CH}_2$ $\rightarrow$ $\text{H}_2\text{C}_2\text{H}_4$
- H - H + $\text{H}_2\text{CO}$ $\rightarrow$ $\text{H}_3\text{C}_2\text{H}_5$

Hydrogen can be added to organic compounds in many ways.

As hydrogen gas, $\text{H}_2$:

$\text{Ni}$

$\text{H}_2$ will reduce the C=C bonds in the benzene ring in vanillin and the C=O bond all the way to methane.
Different ways of adding hydrogen give different results depending on type of multiple bonds in reactant. We seek a way to add two hydrogen atoms (i.e., reduce) to the \( \text{C} \equiv \text{O} \) bond without reducing \( \text{C} \equiv \text{C} \) bonds in benzene ring. A reagent which accomplishes this is: 

**SODIUM BOROHYDRIDE - NaBH\(_4\)**

\[
\text{H} - \cdot \cdot \cdot \text{Na}^+ \cdot \cdot \cdot \text{BH} \cdot \cdot \cdot \text{H} \cdot \cdot \cdot \text{H}
\]

\( \text{BH}_4^- \) is isoelectronic with \( \text{CH}_4 \) and \( \text{NH}_4^+ \)

**ARE THERE OTHER WAYS TO ADD H\(_2\)?**

Vanillin

**SYNTHETIC PROCEDURE**

You will be handling small quantities of materials. The reagents:

- 400 ± 40 mg of vanillin (\( \text{C}_8\text{H}_8\text{O}_3 \) - [2.6 mmol])
- 2.5 mL of 1.0 M NaOH - [2.5 mmol]
- 80 mg of sodium borohydride (NaBH\(_4\)) - [2.1 mmol]

After reaction is complete,

- Less than 10 mL of 2.5 M HCl - [25 mmol]

Must exercise care in transferring such small amounts between containers.

**STOICHIOMETRY OF THE REACTION**

\[
\text{4 Vanillin } + \text{1 BH}_4^- + 4 \text{H}_2\text{O} \rightarrow 4 \text{Vanillyl Alcohol} + \text{H}_3\text{BO}_3 + \text{OH}^-
\]

Stoichiometry of reaction is 1 borohydride : 4 vanillin

**CALCULATIONS - LIMITING REAGENT**

<table>
<thead>
<tr>
<th>Substance</th>
<th>Initial mmol</th>
<th>Final mmol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vanillin</td>
<td>0.4120 g ( \text{C}_8\text{H}_8\text{O}_3 ) ( (\text{MM} = 152) )</td>
<td>0</td>
</tr>
<tr>
<td>Na(_2)</td>
<td>2.70</td>
<td>2.70</td>
</tr>
<tr>
<td>NaBH(_4)</td>
<td>2.10</td>
<td>2.10</td>
</tr>
<tr>
<td>Na(^+)</td>
<td>2.50</td>
<td>2.50</td>
</tr>
<tr>
<td>OH(^-)</td>
<td>139</td>
<td>139 (- 2.63 = 136)</td>
</tr>
<tr>
<td>Vanillyl Alcohol</td>
<td>0</td>
<td>2.63</td>
</tr>
<tr>
<td>Boric Acid</td>
<td>0</td>
<td>2.63 (\times 0.66)</td>
</tr>
</tbody>
</table>

But, stoichiometry is 1 NaBH\(_4\) ↔ 4 Vanillin so, we only need 2.71 / 4 = 0.68 mmol NaBH\(_4\)

**WHAT IS IN THE REACTION VESSEL**

4 Vanillin + NaBH\(_4\) + 4 H\(_2\)O → 4 Vanillyl Alcohol + H\(_3\)BO\(_3\) + OH\(^-\)
CALCULATIONS – PERCENT YIELD

\[
\text{Pct yield} = \frac{\text{Actual yield}}{\text{Theoretical yield}} \times 100
\]

Theoretical yield = maximum yield that could be produced from actual amount of limiting reagent.

E.g., 0.4120 g vanillin (MM = 152) could make 2.71 mmol vanillyl alcohol.

If you actually recover 349 mg, then:

\[
\text{% Yield} = \frac{349 \times 100}{417} = 83.7\%
\]

The reacted vanillin is the limiting reagent so some NaBH₄ remains unreacted.

WHY WE ADD HCl

What is in the reaction vessel after the reaction? Vanillin is the limiting reagent so some NaBH₄ remains unreacted. In addition,

- we dissolved the vanillin in NaOH and
- OH⁻ was also produced in the reaction

But, H₃BO₃ can react with NaOH to form Na₃BO₃.

Vanillyl alcohol decomposes in either strongly acid or basic solutions.

HCl is added to decompose BH₄⁻ & make solution neutral.

\[
\text{BH}_4^- + 3\text{H}_2\text{O} + \text{H}^+ \rightarrow \text{H}_3\text{BO}_3 + 4\text{H}_2 (g)
\]

PROCEDURE – SOME NOTES

Pay close attention to directions:

- Chill Solution to 0°C
- Add NaBH₄ slowly to cold solution
- Let reaction mixture stand at room temperature for 30 min
- Chill with ice for recommended period for 10 min
- Add HCl, adjusting pH to acid litmus test slowly. Be sure that entire solution is just acidic (pink), but not excessively.

You must dry a small amount (½ spatulaful) of the sample for melting point and IR.

VERIFYING SYNTHETIC SUCCESS – 1

THE MELTING POINT

Melting points are a simple way to obtain evidence in support of the identity and purity of a substance. They are determined using the following apparatus:

The Lecture Notes on IR are in a separate posting.