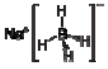
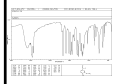


Synthesis of Vanillyl Alcohol

Organic Synthesis



1

? QUESTIONS ?

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?

2

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

3

Organization of this Pre-lab Lecture

Nomenclature – Functional Groups	5	Calculations – Limiting Reagent	17
Vanilla Beans	7	What is in the Reaction Vessel?	18
Synthesis - Principles	8	Calculations – Percent Yield	19
Our Synthetic Objective	10	Product Isolation– Vacuum Filtration	20
Reduction in Organic Reactions	11	Why We Add HCl	21
The Synthetic Procedure	15	Comments on the Procedure	22
The Reaction / Stoichiometry	16	Product Verification – Melting Point	23

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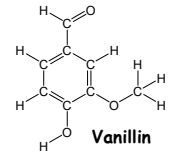
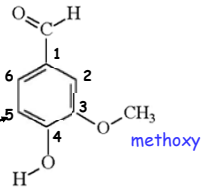
NOMENCLATURE – FUNCTIONAL GROUPS

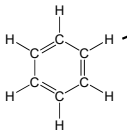


Vanillin

aldehyde



methoxy



benzene

3-methoxy 4-hydroxy benzaldehyde

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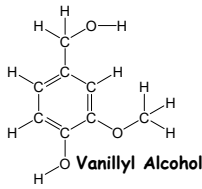
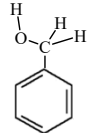
NOMENCLATURE – FUNCTIONAL GROUPS



Vanillyl Alcohol



3-methoxy 4-hydroxy benzyl alcohol

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

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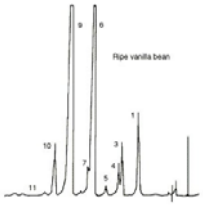
MAJOR CONSTITUENTS OF THE RIPE VANILLA BEAN





vanillin

vanillyl alcohol

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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*)

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- in a chemical environment that permits *practical SEPARATION OF PRODUCT* from excess starting materials and byproducts
- in an *ENVIRONMENTALLY RESPONSIBLE* way *- GREEN CHEMISTRY*
- in a *CO$T-EFFECTIVE* manner

For substances that may be consumed by humans or animals, there is an additional concern:

SYNTHESIS must not involve TOXIC AGENTS – either chemical or biological – that are NOT EASILY REMOVED

How do you decide what starting materials to use?

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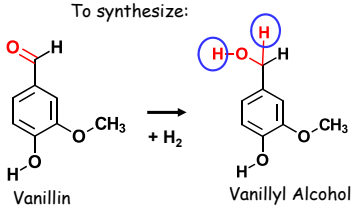
OUR OBJECTIVE

To synthesize:

What *readily available* substance has a *related structure*?



Vanillin + H_2 → Vanillyl Alcohol

What reactions would accomplish the change in structure?

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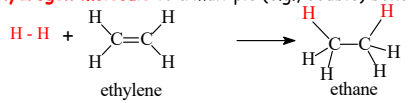
REDUCTION

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



ethylene → ethane

formaldehyde → methyl alcohol

Hydrogen can be added to organic compounds in many ways.

As hydrogen gas, H_2:

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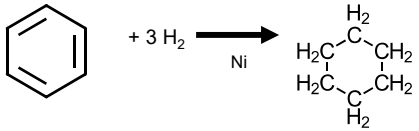
REDUCTION USING H_2



Ni

H_2 will reduce the C≈C bonds in the benzene ring in vanillin andthe C=O bond all the way to methane.

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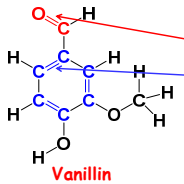
ARE THERE OTHER WAYS TO ADD H_2?

Different ways of adding hydrogen give different results depending on type of multiple bonds in reactant.



Vanillin

We seek a way to add two hydrogen atoms (i.e., reduce) to the C = O bond

without reducing C ≈ C bonds in benzene ring.

A reagent which accomplishes this is:

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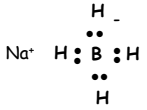
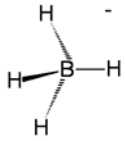
SODIUM BOROHYDRIDE – $NaBH_4$



BH_4^- is isoelectronic with CH_4 and NH_4^+



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SYNTHETIC PROCEDURE

You will be handling ***small*** quantities of materials.

The reagents

400 **mg** of vanillin ($C_8H_8O_3$) - [2.6 mmol] — 400 ± 40 mg but *exactly*

2.5 **mL** of 1.0 M NaOH - [2.5 mmol] — 2.5 ± 0.2 mL

80 **mg** of sodium borohydride ($NaBH_4$)- [2.1 mmol] — 80 ± 8 mg but *exactly*

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.

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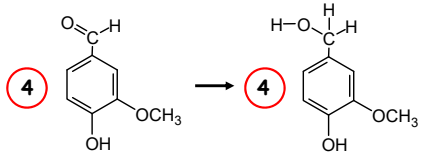
STOICHIOMETRY OF THE REACTION



4 + 1 BH_4^- + 4 H_2O → 4 + H_3BO_3 + OH^-

Stoichiometry of reaction is 1 borohydride : 4 vanillin

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CALCULATIONS – LIMITING REAGENT

$$\textbf{Pct yield} = \frac{100 \times \textit{Actual} \text{ yield}}{\textit{Theoretical} \text{ yield}}$$

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

E.g., 0.4120 g vanillin (MM = 152) — 412 mg / 152 = 2.71 mmol

E.g., 0.0825 g $NaBH_4$ (MM = 38) — 82.5 mg / 38 = 2.2 mmol

But, stoichiometry is 1 $NaBH_4$ ↔ 4 Vanillin

so, we only need 2.71 / 4 = 0.68 mmol $NaBH_4$

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WHAT IS IN THE REACTION VESSEL

SUBSTANCE	Initial mmol	Final mmol
Vanillin – 400 mg	2.63	0
From 80 mg $NaBH_4$	-	-
Na^+	2.10	2.10
BH_4^-	2.10	2.10 – 2.63/4 = 1.44
From 2.50 mL 1.0 M NaOH	-	-
Na^+	2.50	2.50
OH^-	2.50	2.50
H_2O	139	139 – 2.63 = 136
Vanillyl Alcohol	0	2.63
Boric Acid	0	2.63 / 4 = 0.66
Total Na^+	4.60	4.60
Total OH^-	2.50	2.50 + 2.63 / 4 = 3.16
Total BH_4^-		1.44

4 Vanillin + $NaBH_4$ + 4 H_2O → 4 Vanillyl Alchol + H_3BO_3 + OH^-

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CALCULATIONS – PERCENT YIELD

Limiting Reagent

$$\text{Pct yield} = \frac{100 \times \textit{Actual} \text{ yield}}{\textit{Theoretical} \text{ yield}}$$

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

E.g., 0.4120 g vanillin (MM = 152) → 412 mg / 152 = 2.71 mmol

Could make 2.71 mmol vanillyl alcohol → 2.71 X 154 = 417 mg

If you actually recover 349 mg

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

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ISOLATING THE PRODUCT

The vanillyl alcohol product is isolated from the reaction mixture by crystallization from water and **vacuum filtration** (See web supplement.)

We assume the most insoluble component is the product and that its solubility is lowest at low temperatures (ice bath).

http://www.ic.sunysb.edu/Class/che133/techniques/suctfilt/suctfilt.html

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WHY WE ADD HCl

What is in the reaction vessel after the reaction?

Vanillin is the limiting reagent so some $NaBH_4$ remains unreacted.

In addition,
- we dissolved the vanillin in NaOH and
- OH^- was also produced in the reaction

But, H_3BO_3 can react with NaOH to form Na_3BO_3

Vanillyl alcohol decomposes in either strongly acid OR basic solutions.

HCl is added to decompose BH_4^- & make solution neutral.

BH_4^- (and OH^-) react with HCl (aq)

$$BH_4^- + 3H_2O + H^+ \rightarrow H_3BO_3 + 4\,H_2\,(g)$$

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PROCEDURE – SOME NOTES

Pay close attention to directions:

- Chill Solution to 0°C
- Add $NaBH_4$ **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.

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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. (See the web supplement).

They are determined using the following apparatus:

http://www.ic.sunysb.edu/Class/che133/techniques/meltpts/meltpts.html

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The Lecture Notes on IR are in a separate posting

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