Starting off the New Year with AP Chemistry

Paul Price
Trinity Valley School
Fort Worth, Texas
pricep@trinityvalleyschool.org
About Me:

• 17 year AP Chemistry and Physics Teacher
• AP Chemistry Reader, Table Leader, and Question Leader since 2006
• Co-Chair of the AP Test Development Committee

Advanced Placement Chemistry Laboratory Manual

An Inquiry and Forensic Approach Towards Chemical Experimentation
Overview

• What do our students need to do?

• Methods to structure content and skills to meet performance goals

• The role of the laboratory

• Q&A to address your concerns
2. Ethene, C₂H₄(g) (molar mass 28.1 g/mol), may be prepared by the dehydration of ethanol, C₂H₅OH(g) (molar mass 46.1 g/mol), using a solid catalyst. A setup for the lab synthesis is shown in the diagram above. The equation for the dehydration reaction is given below.

\[
\text{C}_2\text{H}_5\text{OH}(g) \rightarrow^{\text{catalyst}} \text{C}_2\text{H}_4(g) + \text{H}_2\text{O}(g) \quad \Delta H^{\circ}_{298} = 45.5 \text{ kJ/mol}_{\text{rxn}}; \quad \Delta S^{\circ}_{298} = 126 \text{ J/(K \cdot mol}_{\text{rxn}})
\]

A student added a 0.200 g sample of C₂H₅OH(l) to a test tube using the setup shown above. The student heated the test tube gently with a Bunsen burner until all of the C₂H₅OH(l) evaporated and gas generation stopped. When the reaction stopped, the volume of collected gas was 0.0854 L at 0.822 atm and 305 K. (The vapor pressure of water at 305 K is 35.7 torr.)

(a) Calculate the number of moles of C₂H₄(g)

(i) that are actually produced in the experiment and measured in the gas collection tube and

(ii) that would be produced if the dehydration reaction went to completion.

(b) Calculate the percent yield of C₂H₄(g) in the experiment.

Because the dehydration reaction is not observed to occur at 298 K, the student claims that the reaction has an equilibrium constant less than 1.00 at 298 K.

(c) Do the thermodynamic data for the reaction support the student’s claim? Justify your answer, including a calculation of \( \Delta G^{\circ}_{298} \) for the reaction.
(d) The Lewis electron-dot diagram for $\text{C}_2\text{H}_4$ is shown below in the box on the left. In the box on the right, complete the Lewis electron-dot diagram for $\text{C}_2\text{H}_5\text{OH}$ by drawing in all of the electron pairs.

(e) What is the approximate value of the C–O–H bond angle in the ethanol molecule?

(f) During the dehydration experiment, $\text{C}_2\text{H}_4(g)$ and unreacted $\text{C}_2\text{H}_5\text{OH}(g)$ passed through the tube into the water. The $\text{C}_2\text{H}_4$ was quantitatively collected as a gas, but the unreacted $\text{C}_2\text{H}_5\text{OH}$ was not. Explain this observation in terms of the intermolecular forces between water and each of the two gases.
Criteria for Free Response Questions

• Does it address a theme?
• Depth vs. breadth?
• Cut across the curriculum?
• Simple?/Straightforward?/Few parts?
• Allow for clear grading rubrics?
• Does it use the full scale of points?
• Is it worth asking?
• Does it discriminate?
• Is it in the curriculum?
  – 6 BI’s, 117 LO’s, 7 SP’s
• Does it probe conceptual understanding?
Chemistry

- Atomic Structure (BI 1)
- Molecular Structure (BI 2)
- Reactions and Stoichiometry (BI 3)
- Kinetics (BI 4)
- Equilibrium (BI 6)
- Thermodynamics (BI 5)
How the Curriculum Framework Is Assessed

The following guidelines are presented to show teachers how the curriculum framework is assessed on the exam:

- All big ideas, **enduring understandings, and essential knowledge** components are required and therefore must be taught in the AP Chemistry course. **Learning objectives** should be used to guide teaching and learning.

- The exam will assess the application of the **science practices**.

- Questions on the AP Chemistry Exam will require a combination of specific knowledge from the concept outline as well as its application through the science practices.

Content + skills!
The “Practical” Science Practices

1. Students can work with representations of chemistry.
2. Students can solve quantitative problems in chemistry.
3. Students can propose and evaluate scientific questions about chemistry.
4. Students can collect data.
5. Students can analyze and evaluate data.
6. Students can predict and explain the chemistry of specific phenomena.
7. Students can connect chemical concepts across various scales and apply those concepts to other disciplines.
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\[ \begin{array}{c}
\text{H} & \text{H} \\
\ddot{\text{C}} & \ddot{\text{C}} \\
\text{H} & \text{H} \\
\end{array} \quad \begin{array}{c}
\text{H} & \text{H} \\
\text{H} & \text{C} & \text{C} & \text{O} & \text{H} \\
\text{H} & \text{H} \\
\end{array} \]

(e) What is the approximate value of the C–O–H bond angle in the ethanol molecule?

(f) During the dehydration experiment, $\text{C}_2\text{H}_4(g)$ and unreacted $\text{C}_2\text{H}_5\text{OH}(g)$ passed through the tube into the water. The $\text{C}_2\text{H}_4$ was quantitatively collected as a gas, but the unreacted $\text{C}_2\text{H}_5\text{OH}$ was not. Explain this observation in terms of the intermolecular forces between water and each of the two gases.
MC Questions have both content and skill

56. Beaker X and beaker Y each contain 1.0 L of solution, as shown above. A student combines the solutions by pouring them into a larger, previously empty beaker Z and observes the formation of a white precipitate. Assuming that volumes are additive, which of the following sets of solutions could be represented by the diagram above?

<table>
<thead>
<tr>
<th>Beaker X</th>
<th>Beaker Y</th>
<th>Beaker Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) 2.0 M AgNO₃</td>
<td>2.0 M MgCl₂</td>
<td>4.0 M Mg(NO₃)₂ and AgCl(s)</td>
</tr>
<tr>
<td>(B) 2.0 M AgNO₃</td>
<td>2.0 M MgCl₂</td>
<td>2.0 M Mg(NO₃)₂ and AgCl(s)</td>
</tr>
<tr>
<td>(C) 2.0 M AgNO₃</td>
<td>1.0 M MgCl₂</td>
<td>1.0 M Mg(NO₃)₂ and AgCl(s)</td>
</tr>
<tr>
<td>(D) 2.0 M AgNO₃</td>
<td>1.0 M MgCl₂</td>
<td>0.50 M Mg(NO₃)₂ and AgCl(s)</td>
</tr>
</tbody>
</table>
The Reality of AP Exam Questions

• Free response questions will always cover multiple topics regardless of the exam design.

• Students are expected to demonstrate both conceptual and quantitative problem solving skills.

• Understanding and application of the big ideas in chemistry will allow for excellent preparation for whatever question the student must tackle.
What you don’t want

Pigeonholing Knowledge

• An inability to determine what is being asked when a question covers several concepts.

• An inability to link concepts.

• The thought that memorization of problem types will lead to success.

• A significant number of critical conceptual misconceptions about chemistry.
Layering the Curriculum

Level I

• The ability to reason conceptually about chemical phenomena.

• The ability to build useful mental models of chemical events.

• The ability to explain, both verbally and in writing, answers to problems.
Building the First Layer

A traditional problem:

Which of the following molecules exhibits hydrogen bonding?

a) HCl
b) HBr
c) PH$_3$
d) HOF
Prompt: Consider the representation of four water molecules and the propanol molecule shown above. Please label a hydrogen bond in the figure. In the space below the picture, justify your reasoning.
Building the First Layer

A Second Example

Consider the acid HA which has a $K_a$ value of $1.0 \times 10^{-2}$. If acid HB is slightly stronger than acid HA, what would be a reasonable $K_a$ value for HB?

a) $2.0 \times 10^{-10}$

b) $1.0 \times 10^{-3}$

c) $1.0 \times 10^{-2}$

d) $1.0 \times 10^{-1}$

e) 10
Building the First Layer

Rewriting the Problem

Shown on the screen is a representation of several molecules of the acid HA that has just been placed in water. Assume at this instant no chemical reaction has occurred. If HA has a $K_a$ less than one, what would contents of the container look like on a molecular level after equilibrium has been reached?

Draw what you would see on a molecular level in the box to the left.
A second acid HB is then placed in the container with the HA sample above. If HB is known to be a strong acid, what would the contents of the container look like on a molecular level after equilibrium has been attained?
Building the First Layer

Classroom Implementation

• Introduction to the material, using relevant definitions and terminology.

• Exploring the applications of the concept using critical thinking questions, demonstrations and molecular visualization in lieu of pure lecture to gauge student understanding and misconceptions.

• Creating informal and formal assessment questions that allow the student to give conceptual answers, using writing skills, to questions.

• Simply adding the words explain to most questions will get level I thinking started.

• Applying mathematics on top of conceptual work.
An Example Level 1 Problem

Many chemistry students would love playing with most nitrogen compounds because many are explosive. Consider the compounds nitrogen gas, hydrazine \((\text{H}_2\text{NNH}_2)\), and diazene \((\text{HNNH})\).

a) Draw Lewis Structures for each of the compounds and rank them on order of increasing bond length.

a) Hydrazine is by far the most dangerous of the three compounds, as it easily decomposes, making nitrogen gas as a byproduct. Based on your knowledge of Lewis Structures and bonding in chemistry, is it surprising to you that hydrazine would be the easiest compound to break apart? Explain.
Molecular Visualization

• Students should be able to “see” what is happening on a molecular level.

• Models must be explorable and customizable.

• Models must utilize realistic algorithms to generate results.
Molecular Visualization

Example Systems

• MOLES: John Gelder and Michael Abraham
• Molecular Workbench: Concord Consortium
• Odyssey: Wavefunction Inc.
• Bitwixt Software: The AtomSmith Classroom

These are excellent resources for:

• States of Matter and IM Forces
• Equilibrium
• Kinetics
• Quantum Mechanics
The Importance of Writing

Students Hate Essays

Explain why the boiling point of water is higher than that of chlorine.

Why does methane not behave as an ideal gas at low temperature and high pressure?
The Importance of Writing

Example: 2008 AP Chemistry Exam — Part B Q6

(b) Structures of the dimethyl ether molecule and the ethanol molecule are shown below. The normal boiling point of dimethyl ether is 250 K, whereas the normal boiling point of ethanol is 351 K. Account for the difference in boiling points. You must discuss both of the substances in your answer.

Dimethyl Ether

Ethanol
The dimethyl ether has a lower boiling point because it is nonpolar, which allows for the compound to be broken down more easily. The ethanol molecule has a higher boiling point because it is polar, which caused it to require more energy to separate.
The Importance of Writing

Write! Write! Write!

You know what I mean!

A writing plan:

• Take a cue from AP English Language.

• Offer directed written questions.

• Let students write and revise in groups.

• Initially, give students unlimited revision and discussion time including both informal and initially formal assessments.

• Wean students from these “cushions” over time.
Building the Second Layer

• The ability to combine quantitative calculations with conceptual reasoning.

• The ability to attack problems involving multiple chemical concepts in the same problem.
Building the Second Layer

An In-Class Example

Consider placing some ethanol in a sealed flask and then observing the pressure in the flask as a function of time:
Building the Second Layer

An In-Class Example

As the data is measured, the following graph is obtained:
Consider the situation shown above in which a small amount of ethanol is placed in a 2.0 L container and the ethanol allowed to come to equilibrium. The temperature of the flask and its contents is 23 degrees C.

1. On the graph below, show how the pressure of ethanol varies with time.

2. Explain why the graph has the shape you have drawn in 1.

3. Explain why the process is considered dynamic.
Building the Second Layer

4. At equilibrium the pressure of the ethanol is found 52 torr.
   (a) Write down a reaction that describes the evaporation process

   (b) How many moles of ethanol evaporated?

   (c) What is the concentration of the evaporated ethanol?

   (d) What are the values of $K_p$ and $K_c$ for the reaction?

   (e) Calculate the $\Delta H^\circ$ for the evaporation reaction and the change in energy when the ethanol evaporated.

5. Valerie adds 3 more ml of ethanol to the two liter container. What happens to the vapor pressure? Explain

6. Ryan increases the temperature of the container to 30 degrees C. What happens to the vapor pressure? Explain
Building the Second Layer

Implementation in the Classroom

• AP Free Response Questions are a good model for “second layer” problems

• Some Caveats:
  
  • Some parts of the question may include content not yet explored in class.
  
  • Too much of a question may not be accessible to students.
  
  • If you use AP FRQs, do not score them on an AP grading scale!
Building the Second Layer

Implementation in the Classroom

• A better way:

  • Begin with an exam question you want to ask students.

  • Incorporate content or topics which have been explored in class.

  • Start small and build to include content from the entire curriculum.
An Example Level 2 Problem

\[ 2\text{SO}_2(g) \rightarrow 2\text{S}(g) + 4\text{O}(g) \quad \Delta H^0 = 7.48 \text{ kJ/mol} \]

• Consider the decomposition shown above.
• What is the Lewis Structure of \( \text{SO}_2 \)?
• Explain why, on a molecular level, this reaction must be endothermic.
• What is the energy change when one mole of \( \text{SO}_2 \) decomposes?
• What is the energy change when 65.8 g of O is made?
• What is the delta H of: \( \text{S}(g) + 2\text{O}(g) \rightarrow \text{SO}_2(g) \)

**BONUS:** Based on your work on this question, estimate the *bond energy* of the SO bond in \( \text{SO}_2 \).
Adding the Final Layer

“Ill Defined” and Chemical Fermi Problems

• Many problems encountered in “real” science require the investigator to pre-define the criterion for answering the question.

• Real-world problems are ill-defined in terms of the steps needed to facilitate the solution(s).

• Fermi Problems
  • For example: “How many piano tuners are there in Chicago?”

  • The problem takes place in the “real world” and requires estimation and use of information from many areas of the curriculum.

• More Information can be found at: http://en.wikipedia.org/wiki/Fermi_problem. This URL can be found on your Resources handout.
I learned in my chemistry class that the combustion of sugar is “spontaneous”.

• Is this true?
• If it is then why does sugar exist?
• Can humans combust spontaneously?
Building the Final Layer

Another “Ill-Defined” Example

• What is a better fuel, ethane or ethanol?
  • Define better.....
  • Heat of combustion values?
    • Ethane = -1561 kJ/mol
    • Ethanol = -1368 kJ/mol
  • How would you get the values?
Building the Final Layer

Another “Ill-Defined” Example

• Why conceptually?
• Bonding
• Storage
• IM Forces?
Building the Final Layer

How do you build problems and implement them in class?

Pick “Real-world” Examples

• From the *Journal of Chemical Education and C&EN*

• From YouTube

• The more-ill-defined the problem is, the better.

• Make sure student has to define the problem.

• Use both conceptual and quantitative problems from multiple parts of curricula.
Building the Final Layer

How do you build problems and implement them in class?

Pick “Real-world’ Examples

- Students have to be able to collaborate in class.
- Let in-class discussion proceed spontaneously.
- The discussion will spontaneously generate homework questions and problems.
- Do not be afraid to not know all the answers!!!
- Perfect review.
Spiraling the Curriculum

Traditional Curriculum Order

• Foundations (Review of First Year)
• Reactions
• Enthalpy and Energy
• Atomic and Molecular Structure
• States of Matter
• Equilibrium
• Kinetics
• Entropy and Free Energy
• Electrochemistry
Spiraling the Curriculum
My Curriculum Order

Semester I

• Foundations (Review of First Year)
• Kinetics I (the mathematics of kinetics + factors that affect rates)
• Atomic and Molecular Structure
• Reactions (redox vs. DR)
• Gases
• Enthalpy and Energy

Semester II

• Equilibrium I ($K_c$, $K_p$, $K_{sp}$, $K_a$, $K_b$)
• Entropy and Free Energy
• Kinetics II (transition state theory + mechanism)
• IM Forces and their consequences
• Electrochemistry
• Equilibrium II (buffers and reactions)

Vertical Alignment is key!
The Role of the Lab

Making Inquiry work for you

• A good chemistry course must have a relevant lab component

  • Different context for displaying and reviewing content
  • Build critical skills for future classes
  • Another opportunity to write and problem solve
  • What to include with inquiry?

• AP Chem: 16 labs  ➔  6 Guided Inquiry
# The Role of the Lab

## Making Inquiry work for you

### Sample learning objectives supported by laboratory work

| LO 1.16 | The student can design and/or interpret the results of an experiment regarding the absorption of light to determine the concentration of an absorbing species in a solution. [See SP 4.2, 5.1] |
| LO 1.19 | The student can design, and/or interpret data from, an experiment that uses gravimetric analysis to determine the concentration of an analyte in a solution. [See SP 4.2, 5.1, 6.4] |
| LO 1.20 | The student can design, and/or interpret data from, an experiment that uses titration to determine the concentration of an analyte in a solution. [See SP 4.2, 5.1, 6.4] |
| LO 2.10 | The student can design and/or interpret the results of a separation experiment (filtration, paper chromatography, column chromatography, or distillation) in terms of the relative strength of interactions among and between the components. [See SP 4.2, 5.1, 6.4] |
| LO 2.22 | The student is able to design or evaluate a plan to collect and/or interpret data needed to deduce the type of bonding in a sample of a solid. [See SP 4.2, 6.4] |
| LO 3.9  | The student is able to design and/or interpret the results of an experiment involving a redox titration. [See SP 4.2, 5.1] |
| LO 4.1  | The student is able to design and/or interpret the results of an experiment regarding the factors (i.e., temperature, concentration, surface area) that may influence the rate of a reaction. [See SP 4.2, 5.1] |
| LO 5.7  | The student is able to design and/or interpret the results of an experiment in which calorimetry is used to determine the change in enthalpy of a chemical process (heating/cooling, phase transition, or chemical reaction) at constant pressure. [See SP 4.2, 5.1, 6.4] |
| LO 6.9  | The student is able to use Le Chatelier’s principle to design a set of conditions that will optimize a desired outcome, such as product yield. [See SP 4.2] |
| LO 6.18 | The student can design a buffer solution with a target pH and buffer capacity by selecting an appropriate conjugate acid-base pair and estimating the concentrations needed to achieve the desired capacity. [See SP 2.3, 4.2, 6.4] |
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The Role of the Lab

Making Inquiry work for you

College Board approach
• Pose Q
• Learn Technique
• Answer Q

How well does this spiral?
The Role of the Lab

Making Inquiry work for you

Alternative Approach

• “Cookbook” to learn technique in interesting context
• Follow-up at later time (pre-AP to AP or twice during year) with inquiry question
• Make inquiry lab “performance based”
The Role of the Lab

Making Inquiry work for you

Names:

Quick Instructions and Data Table for the Determination of the Concentration of Bleach:

1) Out of your drawer you are going to need a clean 125 ml Erlenmeyer flask and a clean 50 ml graduated cylinder. If these are not clean, clean them now. Also, quickly rinse your 100 ml volumetric flask with distilled water (I have cleaned this for you)

2) There are two stations, one per hood, where you can make your bleach solution. You will find in each hood a labeled beaker filled with bleach. Using the 5-ml volumetric pipet in the hood, pipet 5.00 ml of the bleach into your volumetric flask, take the flask back to your station, and dilute to the mark with distilled water. Cover the flask with parafilm and mix well.

3) Pour 30 ml of the diluted bleach solution into your 50 ml graduated cylinder, and using the 25 ml volumetric pipet, pipet 25 ml of the solution into your clean Erlenmeyer flask.

4) Have one member of your lab group weigh out approximately 2.00 g of KI. The exact mass is not important, but near 2.00 g.

5) Go to the hood and add the KI you just measured along with approx. 25 ml of distilled water. Slowly, with stirring, add 2.0 ml of 3M HCl. Record your observations.

Observations:

6) Place your Flask under your buret. Titrate with the 0.10 M thiosulfate solution until the iodine color becomes "morning-urine" yellow. Add 2-3 drops of starch solution, which should cause the solution to become dark blue. Continue the titration until one drop makes the solution clear. Record the final volume of the buret.

7) Repeat the titration until you have two consistent titrations. Note: you only have 4 shots to get this right because you only have 100 ml of solution.

Data Table:

<table>
<thead>
<tr>
<th></th>
<th>Trial I</th>
<th>Trial II</th>
<th>Trial III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume of Diluted Bleach Used:</td>
<td>25.00 ml</td>
<td>25.00 ml</td>
<td></td>
</tr>
<tr>
<td>Mass of KI used:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial Buret Reading (.01 ml)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final Buret Reading (.01 ml)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Lab 11: Peter Piper's Pickles

A.P. Chemistry Class
Name of Your School
Address of Your School
City, State Zip Code

Dear A.P. Chemistry Students,

The process of adding vinegar, salt and spices to pickles to produce a quality of taste and crunch has always been taken for granted. Lately, the pickles being produced have been of a lesser quality. It is important to our industry that the standards that have been set over the many years are continued. Thus, we would ask for your help. Please determine if the amount of vinegar that is present in the brine is within the range set by our industry (0.05 – 0.30 M Acid).

Sincerely,

Dillbert Verjuice
The Role of the Lab

Making Inquiry work for you

Performance Task:
(reversing the cookbook)

I would like a 2.56 g sample of anhydrous magnesium sulfate. You have one hour to produce this sample for me from MgSO$_4 \cdot 7$H$_2$O. Please include relevant data and procedure in addition to the sample.
Final Thoughts

How do you know that:

• Your students are “seeing” the chemistry?
• Your students can express their understanding?
• Your students can examine, analyze, and reduce data, even for experiments not performed?
• Your students can answer questions that “cut across” the curriculum?
Downloads & Feedback

To complete a brief questionnaire about this webinar, and to generate your certificate of attendance, visit:

To Download Resources:
http://bit.ly/1Qmz3zi

Questions?