2005 U.S. NATIONAL CHEMISTRY OLYMPIAD

KEY FOR NATIONAL EXAM – PART III

Lab Problem 1

You have been given three beakers containing $NaHCO_3$ (sodium hydrogen carbonate), $CaCl_2$ (calcium chloride), and tap water. These two compounds react in the presence of water. Propose a balanced chemical equation to account for this reaction, and support your proposal with all possible *qualitative* and *quantitative* observations and measurements.

This problem requires the students to carry out a reaction and make qualitative and quantitative observations.

1. Sample answer:

$$CaCl_2 + 2NaHCO_3 \rightarrow Ca(OH)_2(s) + 2\,CO_2(g) + 2\,Na^+(aq) + 2\,Cl^-(aq)$$

or

$$CaCl_2 + 2NaHCO_3 \rightarrow CaCO_3(s) + CO_2(g) + H_2O + 2\,Na^+(aq) + 2\,Cl^-(aq)$$

Weigh 1 mmol $CaCl_2$ and add to one corner of the plastic bag, then weigh 2 mmol $NaHCO_3$ and add to the other corner of the plastic bag. Add water to the $NaHCO_3$ corner without mixing, seal the bag, and weigh. Allow the reagents to mix, observing for bubbling and inflation of the bag (to verify CO_2 production) and formation of a white insoluble solid (to verify either $Ca(OH)_2$ or $CaCO_3$). Carefully expel the excess gas and reweigh the bag to measure the amount of CO_2 lost, and determine whether that mass corresponds to one or two moles per mole of calcium. The pH of the final mixture will be measured as well; the first reaction should be close to neutral (both a weak base and a weak acid are formed), while the second should be noticeably acidic (from the CO_2).

An *excellent* answer will clearly note both qualitative and quantitative observations that will be made, and will indicate how they will be interpreted to provide evidence of the nature of the reaction.

An *average* answer will note qualitative or quantitative observations that will be made, but will not have clear indications of how those observations will be used.

A *poor answer* will show little awareness of the significance of mixing the reagents, or will not describe observations that will be attempted.

Alternative approaches might include titrating the reagents against each other to determine their mole ratio in the balanced reaction (using cessation of bubbling to mark the endpoint); weight the precipitate formed; measuring the volume of CO_2 produced by inflating the bag and either directly measuring its volume by water displacement or its dimensions, or by measuring the *drop* in weight of the sealed bag after reaction and calculating the volume change from the mass of air displaced; observing the pH of the precipitate after resuspension in pure water ($Ca(OH)_2$) is noticeably basic, $CaCO_3$ is not); observing the exothermicity of the reaction.

2. Data and observations

Weighed 1.15 g $CaCl_2$ into one corner of the bag. Weighed 1.72 g $NaHCO_3$ and carefully added to the other corner of the bag. Added about 15 mL water and carefully added to the $CaCl_2$ side; the compound dissolved and the water got hot. Let the solution cool, then sealed the bag and weighed; total mass – 23.03 g. Allowed the $CaCl_2$ solution to mix with the solid sodium bicarbonate; the solution gets colder and bubbles vigorously, partially inflating the bag. The solution turns milky white. After bubbling stops, open the bag and carefully expel the excess gas; the mass is now 22.51 g. The pH of the suspension is about 6.

3. A balanced chemical equation and evidence of reaction.

$$CaCl_2 \;+\; 2NaHCO_3 \rightarrow CaCO_3(s) + CO_2(g) + H_2O \;+\; 2\,Na^+(aq) \;+\; 2\,Cl^-(aq)$$

An *excellent* equation will be balanced and demonstrate reasonable chemical reactivity; an *average* equation will be chemically reasonable, but may show inappropriate phases (e.g. $NaCl_{(s)}$); a *poor* equation will have chemically unreasonable products (H_2, Cl_2, HOCl; or the production of $Ca(OH)_2$ and H^+ at the same time).

Evidence for reaction:

A colorless gas is evolved, confirming CO_2.
A white precipitate forms, consistent with $CaCO_3$.
The pH of the final solution is weakly acidic, consistent with formation of CO_2 but not with OH^- of H_3O^+.
The solution initially becomes hot, and then cools; $CaCl_2$ dissolves exothermically, but release of CO_2 is endothermic.

An *excellent* answer will clearly relate all observations to the features of the reaction; an *average* answer will relate only some observations to the reaction; a *poor* answer does not relate the observations to the equation.

4. Calculations

1.15 g $CaCl_2$/(110.9 g/mol) = 1.04×10^{-2} mol
1.72 g $NaHCO_3$/(84 g/mol) = 2.05×10^{-2} mol (limiting reagent)

Mass CO_2 released = 23.03 g – 22.51 g = 0.52 g

0.52 g CO_2/(44 g/mol) = 0.012 mol

0.012 mol CO_2/0.0205 mol $NaHCO_3$ = 0.59 mol CO_2 per mol bicarbonate, close to the 0.5 mol expected from the balanced reaction.

An *excellent* answer relates the mass of produced product to the predicted mass of CO_2 based on the balanced equation and the number of moles of the limiting reagent; an *average* answer will note the amount of mass lost but will not relate it to the amounts of reagent; a *poor* answer will note the number of moles of reagent but not of product.

Lab Problem 2

You have been given five vials, labeled #1-5. These vials contain methanol, 2-propanol, acetone, hexane and water (though not necessarily in this order). You have also been given a container of table sugar ($C_{12}H_{22}O_{11}$). Design and carry out an experiment to determine which liquid is in each labeled vial. You have access to a clock or timer.

This problem asks students to distinguish 5 different liquids.

Observations and data can be used to identify each liquid by observing:

1. Relative viscosity
2. Miscibility
3. Evaporation rates
4. Solubility with the provided sucrose sample
5. Rates of solubility with sucrose
6. Odor
7. Densities

Excellent answers for this problem included at least three of these observations in chart or table form as part of their plan. In the data/observations, we looked for quantitative data (time for evaporation, time for completely dissolved sugar samples using set volumes of each liquid and set masses of sugar samples, etc.). Credit was given for multiple trials with quantitative data and for complete observations with all five samples. Conclusions included correct identification of each of the five liquids using more than one observation for each as evidence for student results. The best student answers were organized, provided observations in chart or tabulated form, and had a high degree of specificity with units were included for quantitative data.

Sample data:

A single drop of each liquid was placed on a watch glass and the time was recorded it took for that drop to completely evaporate:

Vial	liquid	evaporation time (one drop) in min. (at room temp.)
#1	2-propanol	2:15
#2	Water	still there
#3	Methanol	1:05
#4	Hexane	0:30
#5	acetone	0:20

These data correspond nicely to predictions based on the degree of hydrogen bonding and relative intermolecular forces of attractions between molecules of each of the samples present.

Solubility with sucrose:
Vial #2 dissolved the sugar easiest and quickest and in the greatest amount, evidence that #2 was water; #1 and #3 slightly; #4 and #5 less so. *Excellent* student answers showed experiments with consistent amounts of sugar and volumes of each vial used with recorded times for completely dissolved sugar observed.

Miscibility:
Vial #4 was immiscible with #2, forming two distinct layers, conclusive evidence that #4 was hexane on the top layer, water on the bottom layer. Vials #1, 2, 3 were miscible with one another; #4 slightly with #5.

Odors:
For *excellent* data, students might have noted that #2 had no apparent odor, #1, 3 had an ‘alcohol-like’ smell, or even ‘smells like rubbing alcohol (#1), that #4 smelled like ‘gasoline’, or that #5 had a ‘nail polish-like’ smell.