> The imagination is the power of the mind over the possibilities of things.--Wallace Stevens

## The Dreaded Nine-bottle Problem

Almost all salts [a salt is an ionic compound] exist in water solutions as separated ions. When solutions of different salts are mixed, the ionic species present may remain in solution as separate entities [i.e., no reaction occurs], may combine to form a precipitate or may react chemically to produce gases or precipitates which slowly change into other compounds upon standing in water.

In this experiment you will be provided with nine different salt solutions, each numbered but otherwise unidentified. All of the solutions are colorless. They are:

| | | |
|---|---|---|
| NaBr | $Na_2SO_4$ | $NH_4Cl$ |
| NaOH | $KClO_3$ | $BaCl_2$ |
| $Na_2S$ | $KIO_3$ | $Pb(NO_3)_2$ |

The object of the experiment is to identify each solution, using either the interactions occurring (if any) when small quantities of the solutions are mixed with one another, or any physical evidence.

To carry out the experiment successfully, you must obviously know what interactions are expected for each mixture. Intelligent preliminary study is therefore essential, and as part of your pre-laboratory preparation you will determine the expected behavior when pairs of solutions are combined.

The information on the following pages is all that is strictly necessary to let you solve the problem, but you may certainly consult your text book or references of any kind.

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*Solubility of salts*

A salt is classified as **soluble** (no precipitate) if more than 1 g will dissolve in 100 mL of water. It is **insoluble** (forms a precipitate) if no more than 0.1 g will dissolve. Between these is the category called "sparingly soluble" which may or may not give a visible precipitate under some conditions. For the problem at hand we note the following:

[this is NOT a complete list; these are only addenda to the rules you have been studying--you will need to use all of this information]

all chlorates are soluble

all iodates are soluble except $Ba(IO_3)_2$ and $Pb(IO_3)_2$

$Ba(OH)_2$ is more or less soluble but it often *appears* to precipitate due to the presence of dissolved $CO_2$ in the hydroxide solution ($BaCO_3$ is very insoluble)

*Other chemical reactions*

1. Two gases, recognizable by their odors, may be produced on mixing some of the solutions:

a. ammonia, $NH_3$, is produced when ammonium salts react with bases:

$$NH_4Cl + NaOH \rightarrow NH_3 + NaCl + H_2O$$

b. hydrogen sulfide, $H_2S$, is generated by reaction of sulfide salts with ammonium salts:

$$2\ NH_4Cl + Na_2S \rightarrow H_2S + 2\ NH_3 + 2\ NaCl$$

[in this case, the odor of $H_2S$ is generally more noticeable than that of $NH_3$]

2. While $Pb(OH)_2$ is insoluble, addition of *excess* hydroxide ions will cause the precipitate to dissolve! This can give some confusing results. *Remember*, precipitation is generally instantaneous while dissolution is much slower.

3. Compounds of the iodate ion may oxidize compounds of the sulfide ion to form elemental sulfur, a fine white precipitate, and iodide ion:

$$IO_3^- + S^{2-} \rightarrow I^- + S \qquad (OH^-)$$

[not balanced]

In terms of what you will be able to see, *there is no difference between elemental sulfur and any other white precipitate.*

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Adapted from: Ionic Interactions and Qualitative Analysis, *Chemical Principles in the Laboratory*, 3rd. ed., Robert F. Bryan and Robert S. Boikess

## Preparing to experiment

**AS PART OF YOUR PRE-LAB**: Prepare a grid such as the example shown in the technique section and fill it in with **P** if the reaction represented by a given box is expected to form a precipitate (including sulfur), **$H_2S$** if the reaction is expected to produce the gas, **$NH_3$** if the reaction is expected to produce ammonia gas, or leave it blank if the mixture is not expected to react. You will have a similar grid to work on in the lab, using a plastic sheet and one drop of each solution.

## Technique

On the shelf above where you work you will find nine bottles. **Write down the SET NUMBER which appears on each bottle.**

**BE SURE TO OBSERVE AN ODOR EACH TIME YOU MIX TWO SOLUTIONS SINCE YOU WILL NOT BE ABLE TO TELL WHERE THE ODOR IS COMING FROM IF YOU HAVE MORE THAN ONE MIXTURE ON THE PLASTIC SHEET!** Once you have identified one odor, it is a good idea to remove the drops so that they will not interfere with later observations. An easy way to do this is to use a small amount of paper towel to blot up the mixture.

The entire plastic sheet should be rinsed thoroughly at the conclusion of the experiment and dried completely.

[the record for this experiment is 24 drops used in a total of 6 minutes with the correct solution given at completion of mixing!]

The grids on the attached page should be used to make your predicitons and record your observations in the lab. They can be part of your pre-lab.

## The chemicals

**Sodium bromide** is a white, crystalline solid, freely soluble in water, with a saline, feebly bitter taste. It is used in photography. It has medical and veterinary applications as a sedative, hypnotic, and anticonvulsant.

**Sodium sulfate** is used for standardizing dyes, in printing textiles, and in the manufacturing of glass and paper pulp. It is used medically as a diuretic.

**Potassium chlorate** is a very reactive oxidizing agent. In solid form it explodes with sulfuric acid and inflames with explosion when exposed to organic materials. It is used in fireworks, matches, dyeing and as a source of oxygen in chemical reactions.

It is irritating to the gastrointestinal tract. A toxic dose is approximately 5 grams.

**Sodium sulfide** is extremely hygroscopic, discoloring on exposure to air. It is unstable and may explode upon percussion or rapid heating. It has the odor of dihydrogen sulfide gas and its solutions are strongly basic.

## Analysis

Your goal is to determine the identity of each solution. Once you have done this, write a balanced *net-ionic* equation for each reaction which you observed in the lab. You should have one equation for each reaction marked on the grid [duplicates, if any, need not be written].

Summarize by giving the identity of each solution by number and formula.

Predicted Results

| | NaOH | $Na_2S$ | $Na_2SO_4$ | $KClO_3$ | $KIO_3$ | $NH_4Cl$ | $BaCl_2$ | $Pb(NO_3)_2$ |
|---|---|---|---|---|---|---|---|---|
| NaBr | | | | | | | | |
| NaOH | | | | | | | | |
| $Na_2S$ | | | | | | | | |
| $Na_2SO_4$ | | | | | | | | |
| $KClO_3$ | | | | | | | | |
| $KIO_3$ | | | | | | | | |
| $NH_4Cl$ | | | | | | | | |
| $BaCl_2$ | | | | | | | | |

Experimental Results

| | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|---|---|---|
| 9 | | | | | | | | |
| 8 | | | | | | | | |
| 7 | | | | | | | | |
| 6 | | | | | | | | |
| 5 | | | | | | | | |
| 4 | | | | | | | | |
| 3 | | | | | | | | |
| 2 | | | | | | | | |