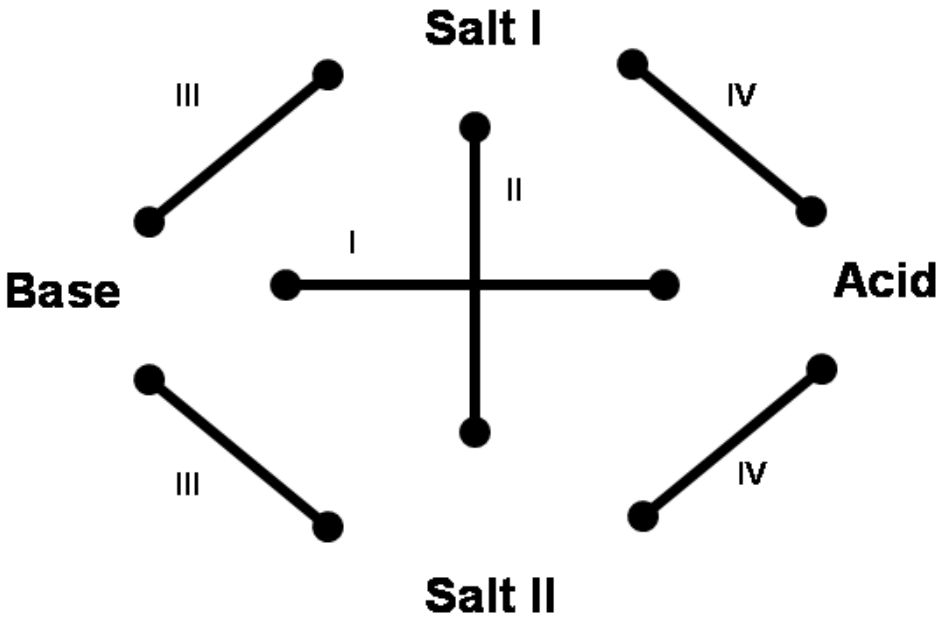
Inorganic Chemistry
Lesson 12
Genetic linkage between major classes of inorganic compounds. Part II.

December 10, 2017

I think it a good time to summarize our current knowledge of inorganic chemistry.

1 Reactions between acids, bases, and salts. A summary.

A whole set of the reaction between acids, bases, and salts can be summarized using the below scheme:



Scheme 1.

In these scheme, solid lines show interactions between two reactants (salt + salt, base + acid, etc). Below are the examples.

1.1 Acid + Base (Type I reaction).

$$H_2SO_4 + 2NaOH \longrightarrow Na_2SO_4 + 2H_2O \tag{1}$$

In this reaction, salt and water are formed.

1.2 Salt I + Salt II (Type II reaction).

$$Na_2SO_4 + Ca(NO_3)_2 \longrightarrow CaSO_{4(s)} + 2\,NaNO_3 \tag{2}$$

Two new salts are formed in this reaction, when at least one of two salts is insoluble.

1.3 Base + Salt (Type III reaction).

$$AlCl_3 + 2NaOH \longrightarrow Al(OH)_{3(s)} + 3\,NaCl \tag{3}$$

A new hydroxide is formed in this reaction if that hydroxide is insoluble. Alternatively, even a soluble hydroxide can be obtained in that reaction, provided that a new salt is not soluble in water. For example, this reaction was used in Antiquity and Middle Ages to produce alkali:[1]

$$Na_2CO_3 + Ca(OH)_2 \longrightarrow 2\,NaOH + CaCO_{3(s)} \tag{4}$$

1.4 Acid + Salt (Type IV reaction).

As in the case of hydroxides, a new acid can be obtained in a reaction of its salt with another acid. For that, a new acid has to be either insoluble (as a silicic acid):

$$Na_2SiO_3 + H_2SO_4 \longrightarrow H_2SiO_{3(s)} + Al(OH)_3 + Na_2SO_4 \tag{5}$$

or volatile (as HCl):

$$2\,NaCl + H_2SO_4 \longrightarrow 2\,HCl_{(g)} + Na_2SO_4 \tag{6}$$

A new acid can also be formed when a salt that forms in the reaction precipitates:

$$Ca(ClO_4)_2 + H_2SO_4 \longrightarrow CaSO_{4(s)} + 2\,HCLO_4 \tag{7}$$

That is a brief summary of the reactions between acids, bases, and salts, which constitute lion's share of inorganic reactions. To make your life easier, below a combined solubility table of acids, bases, and salts is shown. This table will help you to predict the outcome of the type I-IV reactions.

[1] We already know how can calcium hydroxide (a slaked lime) be obtained from limestone.

Solubility chart of acids, bases and salts. Metals are shown in columns, and acidic residues in rows.

	H	Li	Na	K	Ca	Mg	Al	Fe (II)	Fe (III)	Zn	Pb	Cu (II)	Hg (II)	Ag
OH	-	s	s	s	M	I	I	I	I	I	I	I	D	D
Cl	s	s	s	s	s	s	s	s	s	s	M	s	s	I
NO_3	s	s	s	s	s	s	s	s	s	s	s	s	s	s
ClO_4	s	s	s	s	s	s	s	s	s	s	s	s	s	s
S	s	s	s	s	D	D	D	I	D	I	I	I	I	I
SO_3	s	s	s	s	I	M	I	I	D	M	I	D	D	M
SO_4	s	s	s	s	s	s	s	s	s	s	I	s	s	M
PO_4	s	s	s	s	I	I	I	I	I	I	I	I	I	I
SiO_3	I	s	s	s	I	I	I	I	D	I	I	I	D	D
CO_3	D	s	s	s	I	D	I	I	D	I	I	I	I	I

In this table, 's' means the compound is soluble, 'M' means it is marginally soluble, 'I' means it is (virtually) insoluble. 'D' means a compound decomposes in a presence of water, or it doesn't exist. From this table, we see that lead hydroxide, silicic acids and calcium silicate are insoluble, nitric acid, sodium hydroxide and sodium phosphate are soluble, whereas mercury hydroxide, carbonic acid and calcium sulfide decompose in water.

Experiment 21. "Silicate gardens."

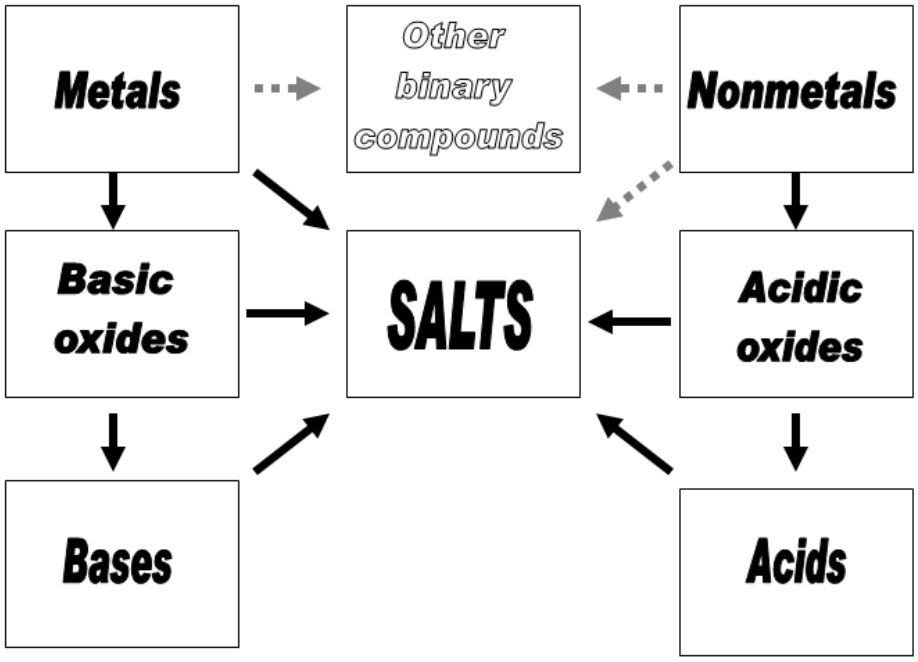
Into a glass beaker, pour a concentrated solution of sodium silicate, dilute it with an equal volume of water, add stir thoroughly. Into this solution, drop few crystals of the following salts: copper (II) nitrate, nickel (II) sulfate, iron (II) sulfate, and chromium (II) chloride. Leave the beaker for half an hour. What do you see?

Figure 1: Silicate gardens.

All salts used for this experiment are soluble in water, however, the corresponding silicates are not. As a result, a thin membrane of insoluble silicate starts to form around the crystals immediately after we dropped them into the Na_2SiO_3 solution. Such a membrane is partially permeable, so an outside water can penetrate into a membrane, and dissolve the salt As a result, the pressure inside the membrane increases, and beautiful colored stalagmites of copper (or nickel, or iron, or chromium) silicates start to grow. *(Please, write the equations of these reaction by yourself.)*

2 Genetic linkage between inorganic compounds.

A diagram of genetic linkages between different types of inorganic compounds is shown below. On this diagram, solid arrows indicate the genetic linkages we already know. Indeed, a metal, for example, magnesium, can produce salt in a reaction with acid, or with another salt, for example, tin sulfate. It also can produce an oxide in a reaction with oxygen. Similarly, a non-metal can produce acidic oxide in a reaction with oxygen; this acidic oxide reacts with water to produce an acid, or with alkali to produce a salt, etc.



Scheme 2.

This is an almost complete set of genetic linkages between major classes of inorganic compounds. In addition, some nometals are capable of reacting with metals to produce salts directly. Thus, sodium metal burns in chlorine to produce a ordinary table salt, NaCl. We haven't studied that type reactions yet, so the corresponding reaction is shown with a gray dashed arrow on the scheme 2. Some binary compounds exists that do not completely meet a definition of a salt. We will devote some time to those compounds in future.

Homework

1. Based on the solubility table, and using the information from the Web, try to predict which other salts can be used for making silicate gardens. If you e-mail this information before Jan 4, we probably can try those salts during the next class. Of course, I expect to get a detailed arguments supporting your choice: just to name a salt is not enough.

2. As a rule, metal ores found in Earth crust are the salts of a metal and some inorganic acid. These salts had been formed in young Earth's crust, when metal rich solutions

were coming into contact with some concentrated salt or acid, so a new salt precipitated. Based on a solubility chart, try to predict which metals were likely to form deposits, and what the composition of their ore is? Which metals are likely to form mixed ores?

3. To 3.8 grams of sodium carbonate, 200 grams of 20% sulfuric acid were added. The gas formed during that reaction was collected and bubbled through a solution of 10 grams of calcium hydroxide in water in such a way that all the gas was absorbed. The solid formed during the bubbling was filtered out, dried and weighed. What was the weight of the solid obtained?

4. How can you perform the following transformations:

$$\mathrm{S} \longrightarrow \mathrm{SO_2} \longrightarrow \mathrm{K_2SO_3} \tag{8}$$

$$\mathrm{NaCl} \longrightarrow \mathrm{HCl} \longrightarrow \mathrm{CaCl_2} \tag{9}$$

$$\mathrm{P} \longrightarrow \mathrm{P_2O_5} \longrightarrow \mathrm{Ca_3(PO_4)_2} \tag{10}$$

Draw separate equations for each step in the above schemes.

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