

Chemical Literacy and Writing Chemical Reactions

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By

Nikolay Gerasimchuk

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To Olga

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PREFACE

Writing chemical reactions in general and inorganic chemistry is not a trivial task. However, writing reactions for chemical processes correctly is a clear indicator of proficiency and competence in a subject. This author's own experience of teaching general, analytical and inorganic chemistry to chemistry majors and non-chemistry majors in two countries for over 27 years has shown that there is a systemic problem for students on this matter. Unfortunately, very few students, grasp the concept of the correct writing of chemical reactions quickly and so are unable to move through topics of general, analytical, and inorganic chemistry freely. Because the ability to write and balance different types of chemical reactions is a fundamental issue, this becomes a key question of **chemical literacy**, like the understanding and use of the *Periodic Table of elements*, or *atomic structure* and *quantum numbers*, or *electronic configurations of atoms and ions*, or *acidity/basicity* of species. These are all very important and necessary topics within chemistry in general.

Students often tend to try and memorize simple reactions, which is impossible given the sheer volume of reactions in these three fields of chemistry. Alternatively, they may simply apply a 'scrambling' tactic when asked to write reactions or perform a chain of transformations between different compounds. Some of the most vivid examples of the erroneous writing of reactions have been taken from original students' tests and problem sets and are presented below. They are accompanied with comments on missing fundamentals for chemical literacy concepts.

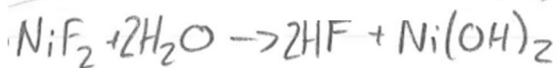




C

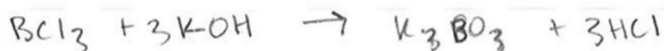


D



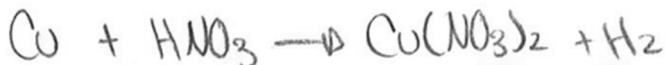
E

The above cases A to E illustrate a lack of understanding of the basic principles of chemical reactivity: *bases and acids are antagonists* and cannot be generated at the same time in the same reaction mixture!



F

Here in case F, acid can't be produced from base, and similarly – base can't be produced from acid! Salts are correct products there.



G



H

Cases G and H: hydrogen gas is never produced from reactions with oxidizing acids such as nitric and concentrated sulfuric! Instead, gaseous products of reduction of nitrogen (NO_2 , NO , N_2) or sulfur (SO_2 , H_2S) will result.



I

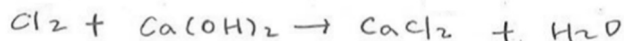


K

L



Cases I, K and L show a 'combinatorial' or 'scrambling' approach, when atoms in different compounds are simply interchanged. This is a total misconception of the chemical properties of individual elements and driving forces in chemical reactivity.



M

Case M shows a lack of understanding of one of the fundamental laws of physics: conservation of charge as the result of chemical reactions. That is, the number of electrons generated (gained) or consumed (lost) as the result of the chemical change must be equal. All the examples shown above evidence a lack of basic chemical literacy. Unless learned, it always will be a problem for those students in any other chemistry courses they take, or in their future professional occupation as chemists.

The successful writing of chemical reactions includes two components: 1) the prediction of products of these reactions and their possible variations, and 2) balancing these reactions providing a material balance between starting compounds and reactions' products; in simple words: placing numerical coefficients in front of reagents and products in such way that the amounts of both will correspond to each other in accordance with the fundamental law of conservation of mass in chemical reactions. The second part of balancing is extremely important in the writing of redox reactions when placing correct coefficients becomes nontrivial.

Unfortunately, to date there is no widely available specialized textbook, brochure, or other source which explains how to write correct chemical equations. The other literature source closest to the content of this book is the 2nd edition of *Descriptive Inorganic Chemistry* by James and Kathleen House, which contains numerous chemical reactions. However, *Descriptive Inorganic Chemistry* does not

rigorously categorize classes of chemical compounds or explain the basic principles of writing chemical reactions including the most difficult ones – redox reactions. This book is aimed precisely at that element of the teaching of the fundamentals of chemical literacy: writing complete equations of chemical reactions and balancing them.

The book contains 49 figures, 22 schemes and 11 tables, 93 problems (with answers) and 10 centerfold pages containing the most interesting and important for the content pictures artworks made in color. All illustrative materials in this book were made or taken by the author during his many years of teaching.

1. THE PERIODIC TABLE AS A BASIS FOR UNDERSTANDING OF CHEMICAL PROPERTIES OF ELEMENTS

The Periodic Table was first presented by Dmitri Mendeleev at the First World exhibition in Karlsruhe, Germany in 1869. According to the author, all the chemical elements known at that time could be arranged in a table format, according to their atomic weights (Figure 1). Being placed in such a way, the elements also formed vertical columns, called groups, in which their chemical properties were similar [1]. These properties were changed periodically, going from the top rows of the table to lower ones. The last provision of chemical similarity was crucial for the whole table, as Mendeleev arranged known elements largely based on their chemistry rather than solely on their atomic weights. So, during his time, I, Te, Co and Ni were known and studied elements, so he placed them into columns (groups) with those which had very similar properties, disregarding the monotonic atomic weight increase sequence. He was criticized by his opponents for that, but he insisted that the order made chemical sense.

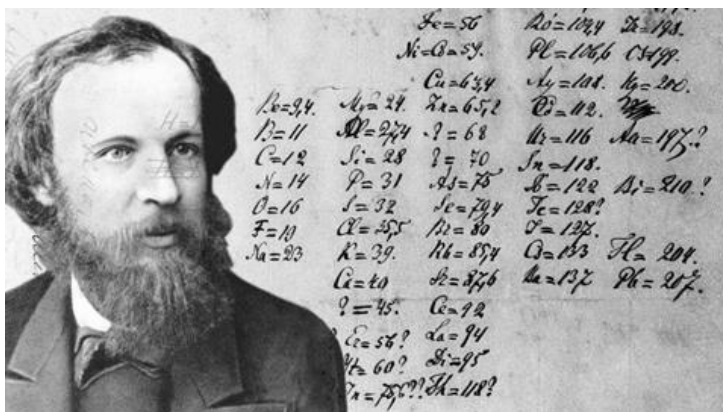


Figure 1. Photograph of D. Mendeleev with the first write-up of his ideas on the organization of elements in an orderly manner.

2 1. Periodic Table as basis for understanding of chemical properties of elements

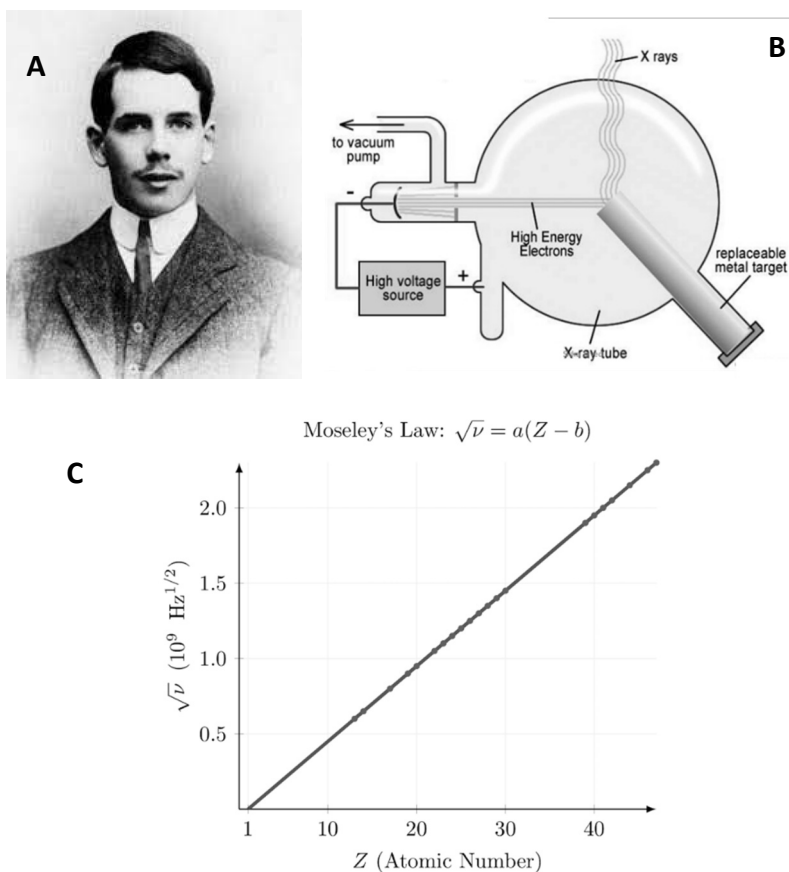


Figure 2. Photograph of H. Moseley (A), schematic representation of the X-ray tube used in his experiments (B) accompanied by the Moseley law plot (C).

His intuition proved to be correct when a brilliant young British physicist, Henry Mosely, (Figure 2) measured the wavelength of X-rays coming out of samples of pure elements, placing the Co/Ni pair in the Periodic Table in the order insisted by Mendeleev [2-4]. He specifically wrote: “After looking at 38 metals I noticed that periodic table works better if you order elements by the protons rather than atomic mass. We should group the atoms by the number of protons instead” [5]. Moreover, the creator of the Table was able to predict

physical and chemical properties of elements that had not yet been discovered. These were Ga (he called *eca*-aluminum), Ge (he called *eca*-silicon), Sc (he named *eca*-boron) as well as element protactinium, Pa. The prefix *eca*- in Latin means 'pseudo' (Table 1).

Table 1. Chemical elements predicted by D. Mendeleev and their chemical/physical properties, in comparison with those reported after discovery.

Predicted elements	Element and year discovered	Properties	Predicted properties	Observed properties
Ekaaluminum	gallium 1875	density of metal	6.0 g/mL	5.96 g/mL
		melting point	low	30°C
		oxide formula	Ea ₂ O ₃	Ga ₂ O ₃
Ekaboron	scandium 1877	density of metal	3.5 g/mL	3.86 g/mL
		oxide formula	Eb ₂ O ₃	Sc ₂ O ₃
		solubility of oxide	dissolves in acid	dissolves in acid
Ekasilicon	germanium 1886	melting point	high	900°C
		density of metal	5.5 g/mL	5.47 g/mL
		color of metal	dark gray	grayish white
		oxide formula	EsO ₂	GeO ₂
		density of oxide	4.7 g/mL	4.70 g/mL
		chloride formula	EsCl ₄	GeCl ₄

It is important to note that during vigorous searches and the discovery of new chemical elements, chemists all over the world were naming elements predominantly using old Latin language, which was a symbol of knowledge at the time. Just recall that the names of species of animals, plants, and later medical remedies and drugs were also Latin. Now, we have a discrepancy in the Periodic Table between the Latin naming scheme and English translation. Thus, Table 2 below makes an adjustment between those two.

Today, there 118 elements, according to the International Union of Pure and Applied Chemistry. Among them there are two elements which are liquid at ambient conditions (T = +25°C and atmospheric pressure of 760 torr): mercury Hg and bromine Br. Also,

4 1. Periodic Table as basis for understanding of chemical properties of elements

there are 11 gaseous elements, with six of them being noble gases positioned at the far-right edge of the table in the column.

Table 2. Latin names of chemical elements vs their English translations.

Chemical symbol in the Table	<i>Latin name</i>	English name
Na	<i>natrium</i>	sodium
K	<i>kalium</i>	potassium
Fe	<i>ferrum</i>	iron
Ag	<i>argentum</i>	silver
Hg	<i>hydrargyrum</i>	mercury
Sn	<i>stannum</i>	tin
Sb	<i>stibium</i>	antimony
W	<i>wolfram</i>	tungsten
Au	<i>aurum</i>	gold
Pb	<i>plumbum</i>	lead

The modern Periodic Table is different from its original format [6]. It contains many more discovered elements, and is presented in Figure 3-A. It also contains periods and groups, but in addition features embedded lines of 10 transition *d*-elements between *s* and *p* elements of main groups (Figure 3-B). The presence of *d*-metals necessitated making their differentiation as subgroups, or B-groups. Thus, gallium (Ga) is an element of IIIA main group, while molybdenum (Mo) is an element of VIB group and represents transition metal. Two more lengthy families of transition elements where the inner *f*-subshell is filling up with electrons were placed below the table in two separate rows, called lanthanides and actinides. A few further comments about the structure and useful properties of the Periodic Table are important here:

a) the common most stable valence of an element corresponds to its group number; this is important information for the prediction of formulas of variety of compounds formed by elements in groups;

b) vertical columns of main groups have received special names: group I is named *alkali metals*, group II is called *alkali-earth metals*, group V is called *pnictogens*, group VI – *chalcogens*, group VII – halogens, and group VIII – noble gases;

Chemical Literacy and Writing Chemical Reactions

A

PERIOD	GROUP	1A	2	13A	14A	15A	16A	17A	18A	
		1	2	13	14	15	16	17	18	
1		1.008	4	9.0122	10.81	12.011	14.007	15.999	18.998	20.180
2		H	He	B	C	N	O	F	Ne	
		HYDROGEN	HELIUM	BORON	CARBON	NITROGEN	OXYGEN	FLUORINE	NEON	
3		6.94	9.0122	10.81	12.011	14.007	15.999	17.003	18.998	
		Li	Be	B	C	N	O	F	Ne	
		LITHIUM	BERYLLIUM	BORON	CARBON	NITROGEN	OXYGEN	FLUORINE	NEON	
4		22.990	24.305	10.81	12.011	14.007	15.999	17.003	18.998	
		Na	Mg	B	C	N	O	F	Ne	
		SODIUM	MAGNESIUM	BORON	CARBON	NITROGEN	OXYGEN	FLUORINE	NEON	
5		39.098	24.305	10.81	12.011	14.007	15.999	17.003	18.998	
		K	Ca	B	C	N	O	F	Ne	
		POTASSIUM	CALCIUM	BORON	CARBON	NITROGEN	OXYGEN	FLUORINE	NEON	
6		85.468	87.62	10.81	12.011	14.007	15.999	17.003	18.998	
		Rb	Sr	B	C	N	O	F	Ne	
		RUBIDIUM	STRONTIUM	BORON	CARBON	NITROGEN	OXYGEN	FLUORINE	NEON	
7		132.91	137.33	10.81	12.011	14.007	15.999	17.003	18.998	
		Cs	Ba	B	C	N	O	F	Ne	
		CAESIUM	BARIUM	BORON	CARBON	NITROGEN	OXYGEN	FLUORINE	NEON	
8		223	226	208	209	209	209	209	209	
		Fr	Ra	B	C	N	O	F	Ne	
		FRANCIUM	RADIUM	BORON	CARBON	NITROGEN	OXYGEN	FLUORINE	NEON	

GROUP NUMBERS IUPAC RECOMMENDATION (1985)	GROUP NUMBERS CHEMICAL ABSTRACT SERVICE (1986)	ATOMIC NUMBER	RELATIVE ATOMIC MASS (1)	SYMBOL	ELEMENT NAME
1	IA	1	1.008	H	HYDROGEN
2	IIA	4	9.0122	Be	BERYLLIUM
13	IIIA	5	10.81	B	BORON
14	IVA	6	12.011	C	CARBON
15	VA	7	14.007	N	NITROGEN
16	VIA	8	15.999	O	OXYGEN
17	VIIA	9	18.998	F	FLUORINE
18	VIIIA	10	20.180	Ne	NEON

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LANTHANIDE

57	138.91	58	140.12	59	140.91	60	144.24	61	(145)	62	150.36	63	151.96	64	157.25	65	158.93	66	162.50	67	164.93	68	167.26	69	168.93	70	173.05	71	174.97
La		Ce		Pr		Nd		Pm		Sm		Eu		Gd		Tb		Dy		Ho		Er		Tm		Yb		Lu	
LANTHANUM		CERUM		PRASEODYMIUM		NEODYMIUM		PROMETHIUM		SAMARIUM		EUROPIUM		GADOLINIUM		TERBIUM		DYSPROSIUM		HOULMIUM		ERBIUM		THULIUM		YTERBIUM		LUTETIUM	



www.periodni.com

89	(227)	90	232.04	91	231.04	92	238.03	93	(237)	94	(244)	95	(243)	96	(247)	97	(247)	98	(251)	99	(252)	100	(257)	101	(259)	102	(259)	103	(262)
Ac		Th		Pa		U		Np		Pu		Am		Cm		Bk		Cf		Es		Fm		Md		No		Lr	
ACTINIUM		THORIUM		PROTACTINIUM		URANIUM		NEPTUNIUM		PLUTONIUM		AMERICIUM		CURCIUM		BERGELIUM		CALIFORNIUM		ENSTENIUM		FERMIUM		MENDELEVIUM		NOBELIUM		LAWRENCIUM	

(1) Atomic weights of the elements 2013, Pure Appl. Chem., 85, 265-291 (2016)

6 1. Periodic Table as basis for understanding of chemical properties of elements

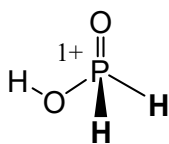
Figure 3 consists of two parts, A and B. Part A shows the modern periodic table with elements color-coded: main group elements (H, Li, Be, Na, Mg, K, Ca, Rb, Sr, Cs, Ba, Fr, Ra, B, C, N, O, F, Ne, Al, Si, P, S, Cl, Ar, Ga, Ge, As, Se, Br, Kr, In, Sn, Sb, Te, I, Xe, Tl, Pb, Bi, Po, At, Rn, Uut, Fl, Uup, Lv, Uus, Uuo) are green, and transition metals (Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Lu, Hf, Ta, W, Re, Os, Ir, Pt, Au, Hg, Lr, Rf, Db, Sg, Bh, Hs, Mt, Ds, Rg, Cn) are blue. Part B shows the same table with blocks labeled: s-Block (H, He), p-Block (B-Ne), d-Block (Sc-Zn), and f-Block (La-Yb, Ac-No).

Figure 3. The modern Periodic Table (A) and its structure based on classification of elements centered on their electronic configuration (B) where the main group elements are green and blue colored.

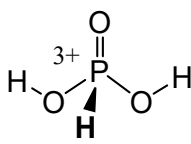
c) in every period there are only eight elements of main groups;

d) among transition metals of *d*-series there are *triades*: Ti-triade, V-, Cr, etc. The triade of copper containing Cu, Ag and Au received the special name of *coinage metals* for the obvious reason that these metal coins are used as money.

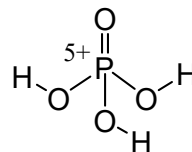
In this part of the book, it is important to make definitions and distinction between terms such as **valence** and **oxidation state**. The first – valence – is the ability of a chemical element to form chemical bonds. Thus, pentavalent phosphorous means that, in a specific chemical compound, P has five chemical bonds, as in PCl_5 or PF_5 . Trivalent antimony means that Sb only forms three chemical bonds, as in the case of SbBr_3 or SbI_3 . Oxidation state is the formal number; a charge assigned to an element in a chemical compound based for convenience on a set of rules. These two terms are not the same, as an element can have the same number of chemical bonds but different oxidation states. For example, in phosphinic H_3PO_2 , phosphonic H_3PO_3 and ortho-phosphoric acid H_3PO_4 phosphorous atom has five bonds with surrounding atoms while its oxidation states are different (Figure 4).



phosphinic



phosphonic



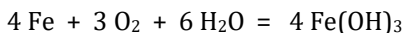
ortho-phosphoric

Figure 4. Example of different oxidation states in acids of pentavalent phosphorous.

2. TYPES OF CHEMICAL REACTIONS

Chemical reactions reflect chemical changes with an element or compound. Chemical reactions always have initial compound(s) and product(s): $A \rightarrow B$, or $A + B \rightarrow C + D$, or even more complex tri-component reactions, such as $A + B + C \rightarrow D + F$, and so on.

That means that the composition of the initial compounds is changing. For example, shiny metal iron pieces rust in moist air to form iron(+3) hydroxide. This entire process of chemical change is described by the chemical reaction:



Before we begin to learn how to write, balance, and predict products of chemical reactions, it is important to provide necessary background information for the reader regarding the main topic – classes of inorganic compounds and their interrelationships. It is vital for developing proficiency in this task to understand and comprehend what these compounds are, how chemical reactivity is manifested in general, and what factors drive chemical reactions to completion.

There are two major categories of chemical reaction commonly used in inorganic and general chemistry:

- 1) reactions in which the *oxidation states* of involved elements *do not change*; and
- 2) reactions in which *there is a change* in the oxidation states (Scheme 1).

Reactions in the first large group are normally called acids-bases reactions, with some of the examples of reactivity displayed below. The second - no less voluminous - group is frequently called redox reactions. Detailed explanation of both categories is in the scope of this book, and we will address them step-by-step in chapters that follow. First, we will describe the classification and reactivity of major classes of inorganic compounds.

The **oxidation state** of an element in a chemical compound is a formal number that is calculated using simple 'rules' and postulates:

1. **Elements** in free state have 0 oxidation state, e.g.: N_2^0 , Na^0 , B^0
2. **Hydrogen** has +1 oxidation state in the vast majority of its compounds. There is a small number of binary compounds [contain two elements!] that are called hydrides, and they have hydrogen in formal oxidation state -1: $\text{NaH}^{(-1)}$, $\text{CaH}_2^{(-1)}$, etc.
3. **Alkali metals** (main group I): Li, Na, K, Rb and Cs always have oxidation state +1.
4. **Alkali-earth metals** (main group II): Be, Mg, Ca, Sr and Ba are always +2 in their chemical compounds.
5. **Main group III elements**: boron B is always +3 in its compounds; Al, Ga, In, Y and La are +3 most of the time in the vast majority of their chemical compounds.
6. **Monoatomic ions** have an oxidation state which is the same as the charge of ion: $\text{N}^{(-3)}$ – nitride, $\text{S}^{(-2)}$ – sulfide, $\text{Ti}^{(+4)}$, $\text{Sr}^{(+2)}$, and so on.
7. **Oxygen** has oxidation state -2 in most of its compounds. Exceptions to this are several other rare binary compounds: superoxides, where O_2 ion has -1 charge (like in KO_2), peroxides, where O_2 ion has -2 charge (like in Na_2O_2 or H_2O_2), ozonides, where O_3 ion has charge -1, and the only known compound with oxygen being +2 is in OF_2 .
8. **Halogens**: *fluorine* always has -1 charge in its compounds; *chlorine*, *bromine* and *iodine* in binary compounds with hydrogen, metals and non-metals have it as -1; the same Cl, Br, I elements in triatomic or more complex compounds containing oxygen (or oxo-ions) may have positive oxidation states such as: +1 (in NaClO), +3 (in HClO_2), +5 (in KClO_3), +7 (in LiClO_4 , or NaBrO_4 and KIO_4).
9. **Compounds and ions**: the sum of the oxidation states of atoms in a compound has to be zero. The sum of oxidation states of atoms in a polyatomic ion equals the charge of the ion. Thus, the total charge of sodium permanganate is 0, and that is: $\text{NaMnO}_4 = \text{Na}^{(+1)} + \text{Mn}^{(+7)} + 4\text{O}^{(-2)} = +8 + (-8) = 0$. Similarly, in arsenate anion AsO_4^{3-} : $\text{As}^{(+5)} + 4\text{O}^{(-2)} = +5 + (-8) = -3$ as stated in the formula of anion.

Using this set of rules allows the student to quickly calculate oxidation states in order to determine whether the reaction is of type 1 –

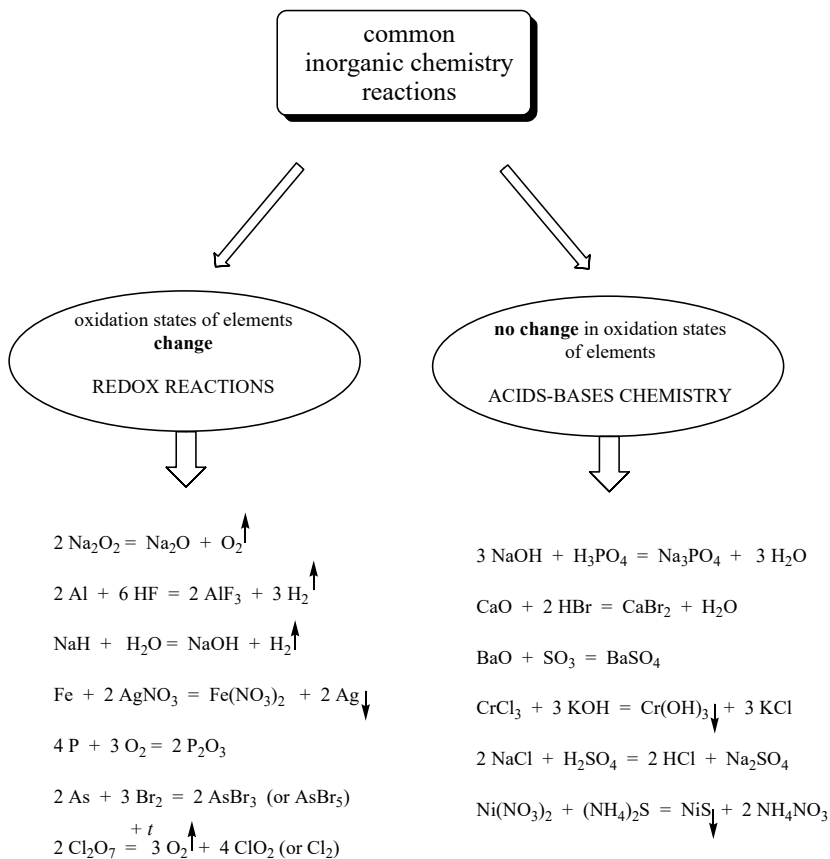
acid/base, or type 2 – redox (Scheme 1). Some practice is necessary to be able to make this process of reactions' classification fast.

Now, moving forward, we need to discuss how we can determine whether chemical change has occurred. There are some empirical (that is, experimental) observations that allow a definite conclusion. The manifestation of the fact that the chemical reaction has indeed occurred is normally visible by:

- a) The reaction mixture's color changes;
- b) Heat is evolved (most commonly, the reaction mixture warms up; exothermic process), or consumed from the environment (fairly rare; endothermic process);
- c) Light is emitted (luminescence);
- d) The precipitate formation is observed;
- e) The precipitate or solid substance is dissolved;
- f) The gas formation is observed.

If there is no obvious or visible change in the system on mixing with the addition - let's say clear and transparent aqueous solutions - some instrumentation should be used to confirm occurrence of the reaction. These instruments could be: I) a calorimeter that registers small heat evolution/consumption to or from the environment, II) a pH meter that measures changes in acid/base media status; III) a potentiometer that registers changes in electric potential between electrodes in solution; IV) an electrical conductivity meter that detects change in a number of ions in a solution due to the formation of a complex particle; or V) a polarimeter that detects changes in the optical rotation of chiral compounds as the result of chemical reaction (for example – racemization; mutarotation of carbohydrates, or complex compounds, etc.).

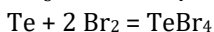
For readers' convenience, small arrows pointing up or down shown in the reactions presented in Scheme 1 and further in the book, indicate the formation of either poorly soluble species or gases.



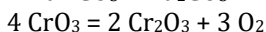
Scheme 1. Types of chemical reactions in inorganic and general chemistry.

By the character of changes that occur during the chemical reaction, these may be further classified as:

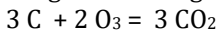
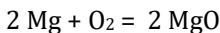
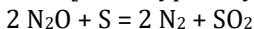
1) Combination (composition) reactions:



2) Decomposition reactions:

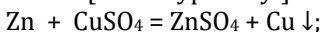


3) Combustion reactions [redox type only!]:



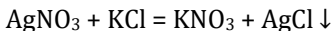
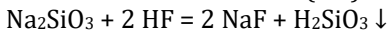
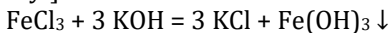
These reactions commonly produce flames.

4) Displacement reactions [redox type only!]:



$2 \text{NaBr} + \text{Cl}_2 = 2 \text{NaCl} + \text{Br}_2 \downarrow$ (as heavy liquid at the bottom of reaction vessel)

5) Double displacement (metathesis, or exchange) reactions [acid-base type only!]



Among the vast number of redox reactions, the *disproportionation* and *comproportionation* take special places because of their unusual characters. Two examples are shown below, but other examples will be fully discussed in detail in Part 2 of this book dedicated to redox reactions.

Consider this reaction:



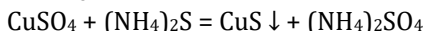
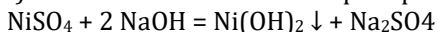
here is the split in oxidation state of chlorine, (0) to -1 in chloride, and +5 in chlorate; it is the *disproportionation* reaction.

In the following reaction between gaseous sulfur compounds dioxide and hydride: $\text{SO}_2 + 2 \text{H}_2\text{S} = 3 \text{S} + 2 \text{H}_2\text{O}$, there is the 'compromise' between the two oxidation states of sulfur; -2 in hydrogen sulfide, and +4 in sulfur dioxide that leads to the formation of elemental sulfur; this is the *comproportionation* reaction.

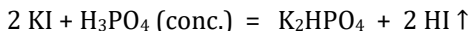
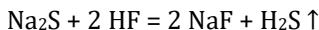
3. DIRECTIONS OF CHEMICAL REACTIONS

A chemical reaction always goes from the reactants to the products, often spontaneously, if there is the possibility of the following:

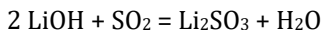
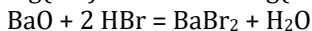
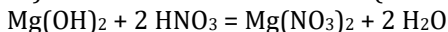
I) The formation of the precipitate:



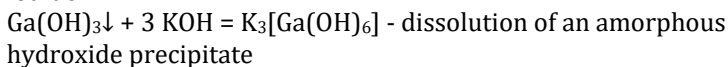
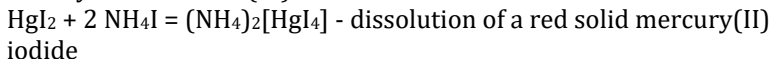
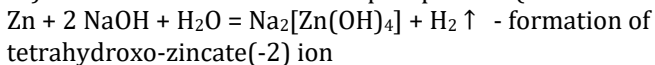
II) The formation of a gaseous product, or more volatile product:



III) The formation of water (neutralization reaction):



IV) The formation of a complex particle (weak electrolyte):



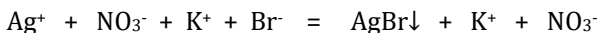
3.1. Reaction in solutions: ionic equations

Most of the chemical reactions described in teaching the general and inorganic chemistry curriculum are carried out in aqueous solutions between dissolved ionic compounds. Dissolution of solid starting compounds leads to electrolytic dissociation and produces hydrated ions (in general: solvated ions if in non-aqueous solutions) that interact and generate products. Now let's discuss this process in detail

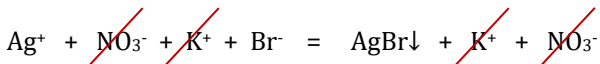
and illustrate it with several reactions between two salts, and between salt and an acid.

- 1) Interaction between silver(I) nitrate, AgNO_3 , and potassium bromide, KBr in water. First of all, dissolution and dissociation of both salts into ions:
 $\text{AgNO}_3 \rightarrow \text{Ag}^+ + \text{NO}_3^-$ and $\text{KBr} \rightarrow \text{K}^+ + \text{Br}^-$

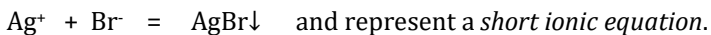
Now, we have all these ions: $\text{Ag}^+ + \text{NO}_3^- + \text{K}^+ + \text{Br}^-$ in solution. The driving force of this reaction is the formation of a precipitate, AgBr , insoluble in water. Therefore, a *complete ionic equation* will look like:



It is easy to see that potassium cations K^+ and nitrate anions NO_3^- are present in both left and right parts of the equation. Therefore, they can be cancelled:

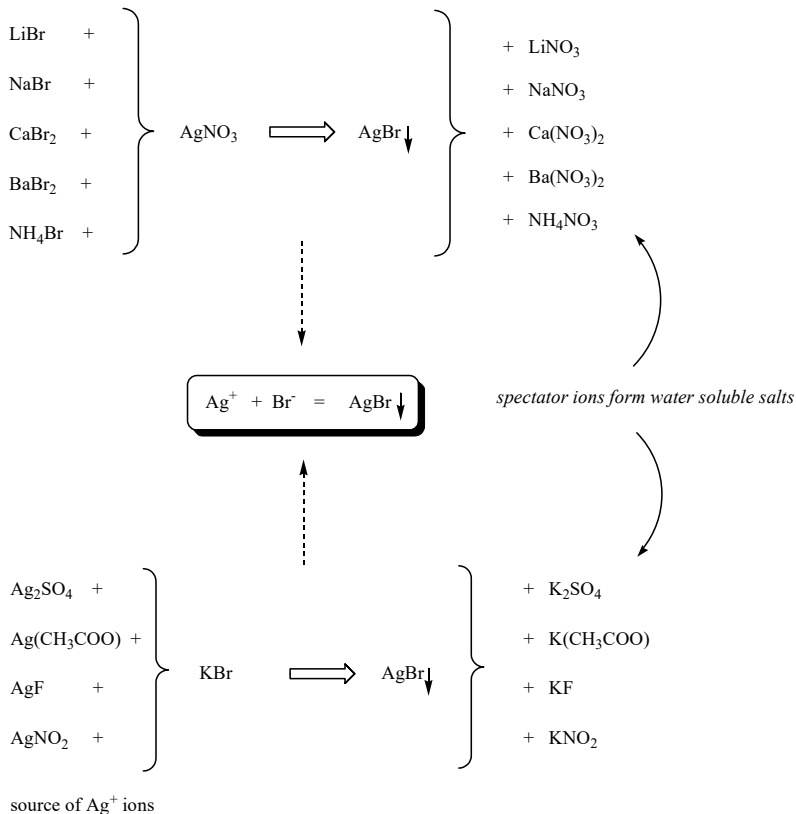


The remaining species can be written as:



Now it is important to note that other soluble silver(I) salts can be used in the formation of AgBr . For example, silver acetate, $\text{Ag}(\text{CH}_3\text{COO})$, sulfate Ag_2SO_4 , silver fluoride AgF , or silver nitrite, AgNO_2 . The same is true for the source of bromide anion! There are plenty of soluble bromides: NaBr , LiBr , NH_4Br , CaBr_2 , BaBr_2 , etc. Hence, cross-interaction between some of these can be presented, as shown below in Scheme 2:

source of Br⁻ ions:



Scheme 2. Variety of reactions of the precipitate formation stemming from one interaction.

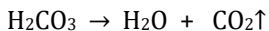
These reactions are often called double-displacement or metathesis reactions as we stated earlier in this chapter. They are very useful in the preparation of numerous inorganic and organometallic compounds and widely used in laboratory practice.

- 2) Interaction between soda ash salt, Na₂CO₃, and hydrochloric acid, HCl, in water.

Again, we should first consider dissolution of both reactants and their dissociation into ions:

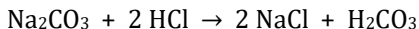
$\text{Na}_2\text{CO}_3 \rightarrow 2 \text{Na}^+ + \text{CO}_3^{2-}$ and $\text{HCl} \rightarrow \text{H}^+ + \text{Cl}^-$ with all ions, of course, being hydrated.

The result of this reaction is the formation of carbonic acid, H_2CO_3 , which is not stable at ambient conditions (room temperature and air pressure) and decomposes very quickly into water and carbon dioxide, CO_2 , which bubbles off the reaction mixture into the atmosphere:

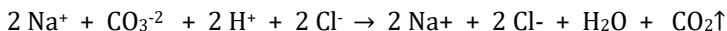


In fact, stronger hydrochloric acid replaces weak carbonic acid, and that is the main principle of this kind of interaction between salts and acids: the resulting acid has to be either weaker or more volatile, and must leave the reaction mixture.

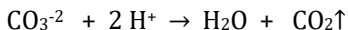
Now we need to balance this equation in order to maintain the same amount of compounds on both sides of the equation. To achieve that we need to have two moles of hydrochloric acid reacting with one mole of soda (sodium carbonate):



This is what is called 'material balance attained'. Numbers in front of molecules of reactants and products are called **coefficients** and reflect the number of moles necessary for the reaction to be carried out to completion. Now, the complete and balanced ionic equation looks like this:



Spectator ions are sodium cations, Na^+ and chloride anions, Cl^- . The short ionic equation after cancelation of spectator ions appears to be:



Similar to the previous case of double-displacement reaction, in this particular example it is also possible to have numerous alternative soluble metal carbonates as well as water soluble acids! Thus, we can use the following salts for the same type of reaction which generates CO_2 : Li_2CO_3 , K_2CO_3 , $(\text{NH}_4)_2\text{CO}_3$. As for the acid we can take hydrobromic acid HBr , sulfuric acid H_2SO_4 , acetic acid CH_3COOH , nitric