

## IONIC COMPOUNDS: REACTIONS AND PRESENTATION

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### ABSTRACT

For clear understanding of substances and chemical reactions especially in low- learning student groups, teachers should consider all three levels of reflection in their instruction: macro-, sub-micro- and symbolic level (see Fig. 1). Many misconceptions have been developed by learners due to wrong models which have been offered during class instruction. For example, many chemistry books do not describe ionic compounds by ions – but by molecules which are not the existing particles. This paper tries to explain how ionic compounds are composed of ions: ionic lattices in solid salt crystals and separated ions in salt solutions. [*African Journal of Chemical Education—AJCE 9(2), July 2019*]

## INTRODUCTION

Ions and ionic symbols are well memorized by chemistry teachers and their students: types of ions, and how ions are formed. But misconceptions arise by the application of such symbols in chemical equations or by presenting ionic compounds either in ionic lattices or in salt solutions. Let us take the simple chemical formula for sodium chloride  $\text{NaCl(s)}$  as an example. Sodium chloride is well known as table salt in the kitchen (macro level), and also the formula is used (representational level). But most chemistry teachers and learners develop wrong mental models by the  $\text{NaCl}$  formula: they regard sodium chloride built up by  $\text{NaCl}$  molecules, they jump from the macro level to the symbolic level without considering the sub-micro level (see Fig. 1). Even chemists who know about the existence of ions in ionic lattices or salt solutions are not writing ionic symbols like  $\text{Na}^+\text{Cl}^-$  – they are still using  $\text{NaCl(s)}$  for salt crystals and  $\text{NaCl(aq)}$  for solutions of sodium chloride. This is may be because of laziness in writing the ions with – and + superscript signs or negligence – but we know that this leads to misconceptions.

To solve this problem chemistry teachers and chemistry book authors should always consider three levels of reflection (see Fig. 1).

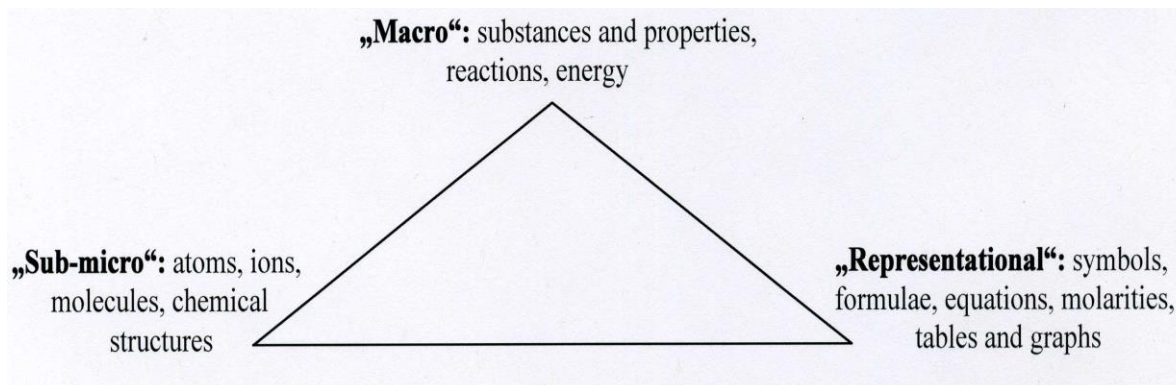


Fig. 1: Chemical Triangle by Johnstone [1]

The sub-micro level of reflection is not much considered in chemistry instruction. So the lack of this knowledge leads to misconceptions when dealing with chemical reactions which involve ionic compounds. From experiences all over the world we know that formulae and chemical equations are memorized very often or are equalized by counting the number of “atoms on the left and right side of the equation” [2]. Looking to our Chemical triangle lecturers and students are jumping from the macro level just to the symbolic level. Effective learning and understanding requires simultaneous use of sub-micro and symbolic representations [3].

Analysis of Tanzanian chemistry syllabus and books of all levels show that there is no critical discussion on relationship between reacting particles and symbolic representation of reacting species. The concept that matter is made of atoms or molecules is well known by any chemistry learner but the problem comes when explaining the composition of salt crystals and salt solutions by the use of chemical symbols. Also acids and bases and their solutions should be described by ions and ionic symbols [4].

The following pages will discuss this problem by salts.

## **PRESENTATION OF IONIC COMPOUNDS**

The misconceptions are transmitted through teaching and learning in schools and colleges due to improper representation of ionic compounds. Most teachers and some books regard ionic compound formulas as molecules, i.e. NaCl. But the molecule is defined as a neutral group of atoms joined together by covalent bond [6] – and NaCl is built up by ions.

*“A chemical formula shows the kind and number of atoms in the smallest representative unit of a substance. NaCl for example is the formula for sodium chloride. Note, the formula NaCl does not represent a single discrete unit because an ionic compound exists as an ionic lattice of negative and positive charged ions arranged in a repeating pattern, its chemical formula refer to a ratio known as a formula unit. A **formula unit***

is lowest whole number ratio of ions in ionic compounds” [6] – so the formula unit of sodium chloride should be  $(\text{Na}^+)_1 (\text{Cl}^-)_1$  or  $\text{Na}^+\text{Cl}^-$ .

Ionic compounds are formed when a metal atom loses electrons to become an ion. One example: if the calcium atom gives two electrons away, it changes to a calcium ion (see Fig. 2). At the same time two electrons lost by the calcium atom are gained by two chlorine atoms to form two chloride ions (see Fig 2):

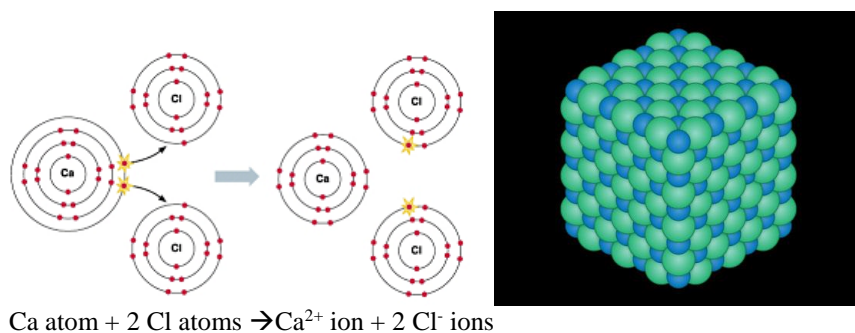
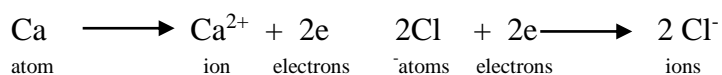
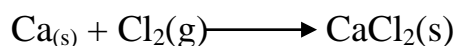


Fig. 2: Formations of ions by electron transfer, ions in an ionic lattice

Then the opposite charged ions generate electrostatic forces and attract each other forming an ionic lattice of  $\text{Ca}^{2+}$  ions and  $\text{Cl}^-$  ions in the ratio of 1 : 2:  $\text{Ca}^{2+}(\text{Cl}^-)_2$  (see Fig. 2). The action of millions and millions of ions leads to the formation of calcium chloride crystals (macro level): 111g of calcium chloride contain  $6.02 \times 10^{23}$  calcium ions and  $12.04 \times 10^{23}$  chloride ions.

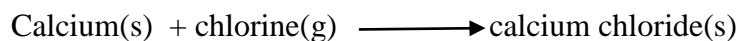
Normally, the calcium-chlorine reaction is described by the following equation:



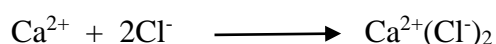
But this presentation leads often to misconceptions of Cl-Ca-Cl molecules in calcium chloride – and not to the mental model of ions in an ionic lattice. To develop a correct mental

model, we have to deal with ionic symbols and to write in the first step  $\text{Ca}^{2+}(\text{Cl}^-)_2$ , additionally we may show models like sphere packing of an ionic lattice (see Fig. 2).

If we consider symbols for physical states (s) for solids and (g) for gases, we should be aware to be on the macro level of our triangle. So it would be better to indicate calcium metal, chlorine gas and solid calcium chloride crystals in an equation by words:



After discussing the electron transfer by calcium and chlorine atoms (see Fig. 2), the proper way to present the formation of calcium chloride by ions and to create the correct mental model for learners is the following equation:



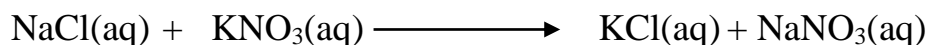
Presenting this chemical equation has the following advantages:

- i. The equation shows actual reacting ions
- ii. It represents the product as an ionic compound and not as a molecule
- iii. It creates a proper mental model to the learner
- iv. It provides for learners the opportunity to trace back to the formation of ions.

But we may consider that the formation of ions by reacting elements is not really necessary: If we take a table salt crystal there are the existing sodium and chloride ions in an ionic lattice – and we have not to think of a chemical reaction of sodium and chlorine. Millions of years ago big layers of salt are formed by ocean water and the evaporation of water by the hot sun. So the ions have been the first existing particles before mankind discovered pure sodium and chlorine and their particles by melt electrolysis in the beginning of the 19<sup>th</sup> century.

### Other examples

We know a lot of reactions of two salt solutions. Let us first consider the equation which show the mixture of sodium chloride and potassium nitrate solutions:



This reaction does not exist because all reactants and products are soluble ionic compounds. Hence all ions are hydrated and surrounded by water molecules – there is no interaction between the ions. All ions and water molecules will act as a mixture because there is no real chemical reaction to stable products – this can occur only if lattice energy of particular ion species is greater than hydration energy. With the above chemical equation, it will be difficult for learners to develop an idea of mixed ions, but if the following equation will be presented and discussed misconceptions can be avoided:

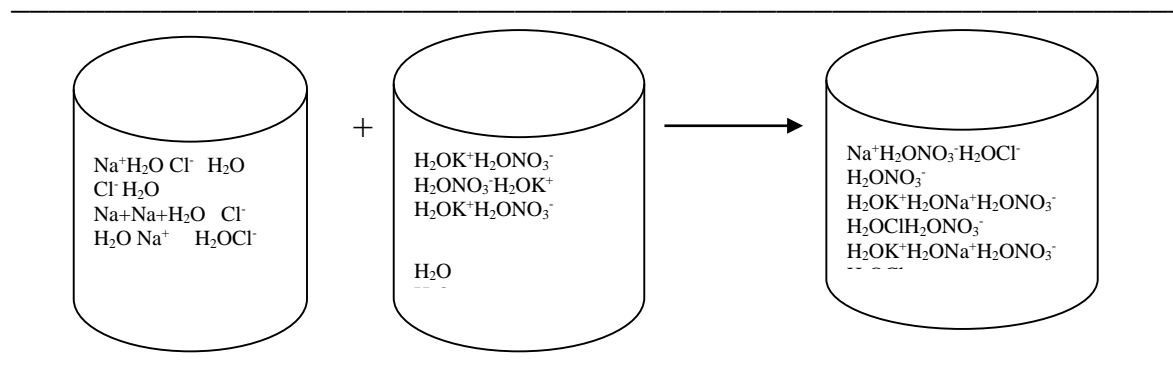
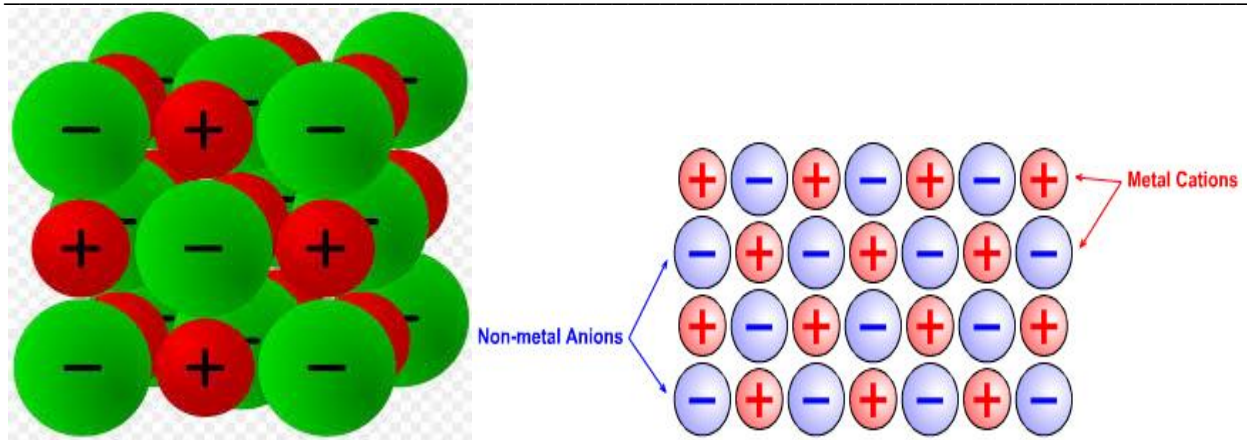


Fig 3: Beaker model of mixing two ionic salt solutions

Many books and teachers held misconceptions of presenting ionic compounds: they introduce them in molecular form and lead learners to misconceptions about ionic compounds. If

they would consider additionally a beaker model those misconceptions can be avoided (see Fig. 3).

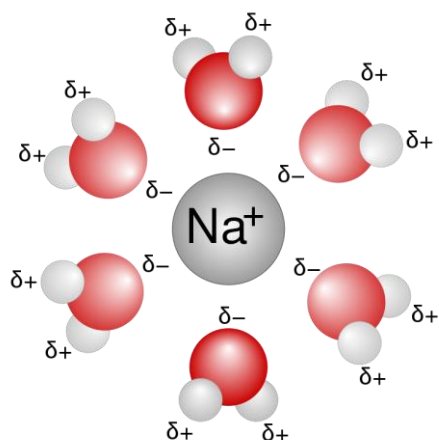
If we trace individual ions in their three dimensional ionic lattice we can find that they are surrounded by identical numbers of their opposite charged ions depending on the size of ions and radius ratio of interacting ions. For sodium chloride the coordination number is 6 (see Fig. 4):



**Fig. 4:** 3D and 2D concrete models of sodium chloride

Every sodium ion is surrounded by 6 chloride ions; every chloride ion is surrounded by 6 sodium ions (see Fig. 4). Those ions are held together by electrostatic forces making crystals with definite shape.

The solubility of such ionic compounds depends on lattice energy. Most of ionic compounds are soluble in water and loose lattice structures when interact with water while some compounds are not soluble and maintain their lattice structure.



Water molecules are polar in nature (they have a positive pole and a negative pole). So the positive charged ion will attract negative poles of water molecules and will be surrounded by water molecules separating the ion completely from negative charged ions of the ionic lattice: the lattice structure will be destroyed.

Ionic solids will be more soluble in water if the force of attraction between ions and water molecules (hydration energy) is greater than the electric force holding ions in the crystal lattice together (lattice energy). Some ionic compounds are not soluble in water because the force of attraction between ions and water molecules (hydration energy) is less than the force of attraction between ions in crystals (lattice energy). One example: Lattice energy of aluminum ions and oxide ions in aluminum oxide is measured with nearly 16.000 kJ/mol(see Table) – so high that this compound is not soluble in water. So insolubility of a certain compound does not mean that there is no ionic lattice of ions. The lattice energy of different compounds is widely variable and lead to wide variability of solubility of those ionic compounds in water (see Table).

**TABLE 6.3** Lattice Energies of Some Ionic Solids (kJ/mol)

Cation	Anion				
	F <sup>-</sup>	Cl <sup>-</sup>	Br <sup>-</sup>	I <sup>-</sup>	O <sup>2-</sup>
Li <sup>+</sup>	1,036	853	807	757	2,925
Na <sup>+</sup>	923	787	747	704	2,695
K <sup>+</sup>	821	715	682	649	2,360
Be <sup>2+</sup>	3,505	3,020	2,914	2,800	4,443
Mg <sup>2+</sup>	2,957	2,524	2,440	2,327	3,791
Ca <sup>2+</sup>	2,630	2,258	2,176	2,074	3,401
Al <sup>3+</sup>	5,215	5,492	5,361	5,218	15,916



The solubility of a certain compound is constant and is calculated by the solubility product. Solubility and precipitation of any compound occurs under LE-CHATelier's PRINCIPLE. If solutions of two ionic compounds are mixed together precipitation reaction can occur only if one pair of ion species concentration exceeds equilibrium constant.

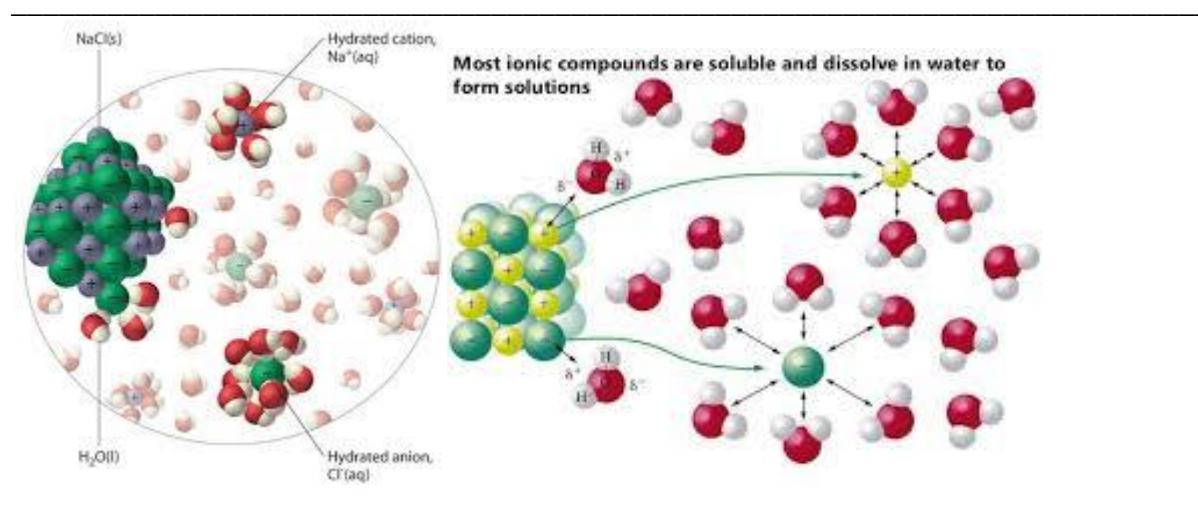


Fig. 5: Concrete model for dissolving sodium chloride crystals in water

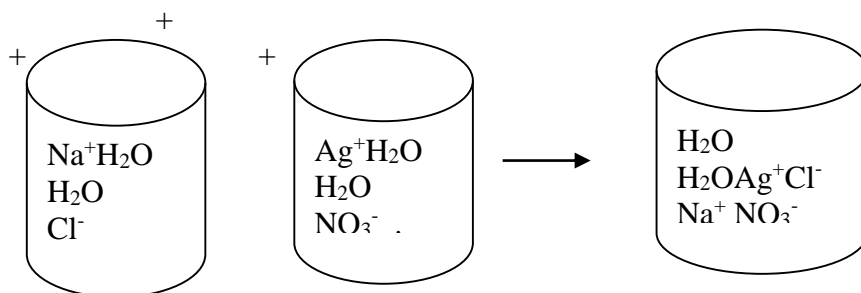
LE-CHATelier's PRINCIPLE states that if the reversible reaction is at equilibrium and one of the factors affecting equilibrium is altered, the equilibrium will shift. Considering this principle, we can also explain why precipitation occurs when saturated solution of a given compound is added with another solution containing same ions. One example: If concentrated hydrochloric acid (high concentration of chloride ions!) is added to saturated solution of sodium chloride the precipitation of white sodium chloride crystals will occur.

Consider the chemical reaction when solutions of sodium chloride (see Fig. 5) and silver nitrate are mixed. These two substances are clear solutions – the learner can observe it (macro level). After mixing both solutions a white solid substance is formed. Most teachers always tell

their students that sodium chloride and silver nitrate solution reacts to show precipitates of silver chloride and a sodium nitrate solution, they show the reaction by this chemical equation:



Above statements support the act of jumping from macro level to representation level – and will not develop actual ideas of reacting ions, the mental model of students will stick on substances. The learners will not get the opportunity to think about the particles involved in this reaction. The ionic equation and the following beaker model can solve to understand the precipitation [5]:



Ionic equations and beaker models are very important to be used by teachers in class to explain the existence of involved particles in crystals and solutions especially to low-level learners. Both models on sub-micro level can bridge the observation of substances (macro level) and chemical formulae and equations (representational level) – learners understand precipitation reactions and have not to memorize formulae and equations!

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