Revista Boliviana de Química, 2026, Vol. 43, N°1, 161-172
Luís C. Resio

Review [1]

Extreme models of substances: a didactic proposal

Luís C. Resio*

High School Number 10 "Juan Bautista Alberdi". O´Higgins 2441, Belgrano, Autonomous City of Buenos Aires, Provincia de Buenos Aires, Argentina; High School Number 8 "Julio A. Roca", Carlos E. Zuberbuhler 1850, C1426, Autonomous City of Buenos Aires, Province of Buenos Aires, Argentina; Juan B. Justo Institute of Higher Education, Lascano 3840, 1417 Villa del Parque, Autonomous City of Buenos Aires, Province of Buenos Aires, Argentina National University of the Litoral, Faculty of Chemical Engineering, Santiago del Estero 2829, S3000AOM, Santa Fe City, Argentina

Keys: *High School, Introductory Chemistry, First-Year Undergraduate, Extreme Models of Substances, Types of Substances, Molecular Substance, Ionic Substance, High School Physical Chemistry;* **Claves:** *Química básica de bachillerato, Química básica de primer año de universidad, Modelos extremos de sustancias, Tipos de sustancias, Sustancia molecular, Sustancia iónica, Química física de bachillerato.*

ABSTRACT

Extreme models of substances: a didactical proposal. It is frequent to encounter concepts designated in an imprecise or misleading manner. A representative case is that of weight and mass, where both expressions are often applied interchangeably in classrooms without recognizing that the former pertains to the domain of vector magnitudes, while the latter belongs to the domain of scalars. A comparable situation arises with the notion of electromotive force, which does not involve any actual force, but instead denotes an electric potential. Taking these examples as reference, this study examines the concept of extreme models of substances. The difficulty identified lies in the insufficient differentiation between molecular substance and ionic substance, both at the strictly conceptual level and in the computational dimension. Such confusion is observed not only in teaching practice but also in textbooks and scientific articles. Ultimately, a methodology is proposed for the instruction of extreme models of substances, aiming to establish a precise conceptual distinction between each category of substance and to perform calculations that properly reflect the extreme models analyzed.

Revista Boliviana de Química, 2026, 43, 161-172
ISSN 0250-5460, Rev. Bol. Quim. ***Paper edition***
ISSN 2078-3949, Rev. boliv. quim. ***e-edition***
***Jan-Jun;* 30 junio 2026**

RESUMEN

Modelos extremos de sustancias: una propuesta didáctica. Es frecuente encontrar conceptos denominados de manera inapropiada o confusa. Un ejemplo ilustrativo es el caso de *peso* y *masa*, términos que suelen emplearse indistintamente en el aula sin considerar que el primero pertenece al ámbito de las magnitudes vectoriales, mientras que el segundo corresponde al de las magnitudes escalares. Algo similar ocurre con la llamada *fuerza electromotriz*, concepto que en realidad no implica ninguna fuerza, sino que se refiere a un potencial eléctrico. A partir de estos ejemplos, en este trabajo se revisa el concepto de modelos extremos de sustancias. El problema identificado radica en la ausencia de una clara distinción entre *sustancia molecular* y *sustancia iónica*, tanto en el plano estrictamente conceptual como en el cálculo. Esta confusión se observa no solo en el aula, sino también en manuales y publicaciones científicas. Finalmente, se propone una metodología para la enseñanza de los modelos extremos de sustancias, con el objetivo de lograr una diferenciación conceptual precisa entre cada tipo de sustancia y de efectuar cálculos que reflejen adecuadamente los modelos estudiados.

https://doi.org/10.53287/pyii9560fa20p
https://bolivianchemistryjournaliiq.umsa.bo

[1]Received May 5, 2026, accepted June 13, 2026, published June 30, 2026. *Mail to: lcresio@chemist.com

INTRODUCTION

Over the years, research in the field of chemical education has focused on how students understand chemistry concepts and reveals that there are several reasons that lead students to consider chemistry as a difficult area to learn, particularly due to the intrinsic complexity of this science and the nature of the construction of its corpus of knowledge, which is carried out by interrelating three distinct conceptual levels: macroscopic, submicroscopic and symbolic[1] (Araújo, 2024). This conceptual framework, known as Johnstone's Triangle, establishes that chemistry education requires the integration of observable phenomena, particle-level explanations, and abstract representations[2] (Johnstone, 1991). The simultaneous processing of these three levels creates substantial cognitive demands on students, particularly at the secondary and introductory undergraduate levels.

The knowledge and interpretation of the atomic scale and the consequent combination of atoms for the consolidation of different types of substances involves a mental process of abstraction. Research on pedagogical content knowledge (PCK) reveals that teachers must deeply understand not only the subject matter but also the most effective ways to represent and teach these concepts to diverse learners[3] (Van Dulmen et al., 2023). This understanding is particularly critical when teaching chemical bonding, as students frequently develop misconceptions that persist throughout their chemistry education[4] (Ünal et al., 2010). The nature and extent of these misconceptions often stem from inadequate conceptual distinctions in how substances are classified and how their properties relate to their bonding characteristics[5] (Stains & Talanquer, 2007).

The atoms that make up a substance are not merely mixed together but are linked together in a specific way. Using scientific terms, these atoms are said to be linked by chemical bonds. While a few substances are made up of individual and uncombined atoms (such as the noble gases), the vast majority of substances are made up of combinations of atoms linked together by chemical bonds. Atoms can be linked together in basically three ways:[6] (Alsina et al., 2015):

• ionic (or electrovalent) bond;

• covalent bond and,

• metallic bond.

From the point of view of the constituent elements of a substance and according to their properties, substances can be classified into four types, classes or models:

• molecular substances;

• ionic substances;

• atomic substances and,

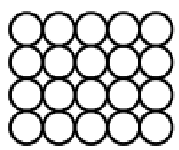
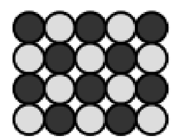
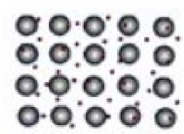
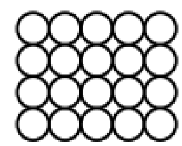
• metallic substances.

Some characteristics of these types of substances are summarized in Table 1. The properties of a substance are directly related to its structural characteristics.

Ionic and covalent bonds represent the two extremes in a continuum and all bonds have some degree of both ionic and covalent character[7] (Chamorro Armas & Barahona Ibarra, 2021). Given this situation, it is possible (although not so frequent) to come across the term "extreme models of substances"[8] (Universidad Nacional del Litoral, 2024) meaning that each "extreme" model represents a substance with a strict and defined chemical bond without presenting any type of intermediate behavior. The pedagogical purpose of this is to allow the student to classify matter in an orderly manner and to be able to easily associate the different physical and chemical properties of the different substances. However, this classification system is not without its challenges. Research indicates that students experience significant difficulties in distinguishing between these models and in understanding why compounds behave as they do based on their bonding characteristics[9] (Enawaty & Sartika, 2015).

Understanding the topics of "chemical bonding" and "extreme models of substances" (or types of substances or models of substances) is fundamental for any university degree in science or engineering. These are the main concepts that allow to arrive at an understanding of how many materials and devices work in the real world, from understanding how an aspirin works to the phenomenon of data transmission over the Internet. But it is common to find concepts named in an inappropriate or confusing way. A typical but recurring example every year that a new group of students enters a high school or university chemistry course are the concepts of mass and weight. Mass and weight are often used interchangeably in everyday conversation. For example, the medical records often show the weight in kilograms but never in the correct units of newtons. In physics, however, there is an important distinction. Weight is the pull of Earth on an object. It depends on the distance from the center of Earth. Unlike weight, mass does not vary with location. The mass of an object is the same on Earth, in orbit, or on the surface of the Moon[10] (Ling et al., 2021). The same applies to concepts such as electromotive force, which does not represent any force per se, but rather a scalar magnitude of electric potential. Another area of nominal debate is the definition of "organic chemistry," on which chemists currently have no consensus[11] (Silverberg, 2021).

Table 1. Extreme models of substances. (Extracted and translated from reference[6] (Alsina et al., 2015)).

	Molecular substances	**Ionic substances**	**Metallic substances**	**Atomic substances**
Constituent chemical elements	Non-metals, at least one with low binding capacity	Metal(s) and non-metal(s) (there are exceptions)	Metals	High bonding capacity non-metals (e.g. C, Si, N, B)
Structural units and microscopic representation in the solid state	○ Molecules 	● Positive ions ◐ Negative ions 	Positive ions (in a "sea of electrons") 	○ Atoms 
Bondings	Covalent (between the atoms that form the molecule)	Ionic (between cations and anions)	Metal	Covalent
State of aggregation at room temperature	gaseous liquid solid	solid	Solid liquid	solid
Examples	Cl_2, CO_2	KF, $CaCl_2$	Na, Mg	SiC, B_4C

This nominal problem also applies to the concepts of substances models. Given this framework, in this work the extreme models of substances and the conceptualization given to the word "molecule" are analyzed. A conceptual distortion is observed between the assignment of the word "molecule" and any type of substance that is not related to the classification of the molecular model. To do this, the study is based on peer-reviewed papers, university-level textbooks and the usual practice of teaching classes in high school and university classrooms where confusion (even indifference) is observed in the definition of some concepts.

RATIONALIZATION AND CONCEPTS TO CONSIDER

Given the structure of this article it is a position paper where the idea is to transmit a methodology for teaching the extreme models of substances topic. To carry out this work, scientific textbooks[12] (Malaver et al., 2004) and peer-reviewed papers were analyzed, and the author drew on his own experience in teaching chemistry.

In a first course of basic chemistry in high school or in general chemistry in college, after classifying extreme models of substances, the concepts of atomic mass, mole, Avogadro number, and other associated concepts are defined. For example, it is common for teachers in class to talk about "atomic weight" which, according to Mortimer[13] (1983) *"is a term that is not literally correct since it refers to masses, not weights, but it has been imposed by its long use."* For their part, Whitten et al.[14] (2015), Chang & Overby[15] (2011) and Silberberg et al.[16] (2006) make a similar observation. This terminological imprecision can lead to conceptual confusion among students and may contribute to persistent misconceptions about the nature of matter and bonding (Rizal et al., 2024)[17].

Given this framework, it became necessary to resume and raise in precise conceptual terms the following concepts (Alsina et al.[6], 2015; Brown, 2003[18]):

- Atomic mass: atoms are particles of matter, therefore they have mass.
- Formula unit: the formula unit of a substance is the fundamental unit of the same expressed by the chemical formula, which indicates the number of atoms of each of the elements that form it.
- Formula mass: the formula mass of a substance is the mass of a formula unit of this substance.
- Mole: the mole is the quantity of matter composed of as many entities as there are atoms in 0.012 kilograms of carbon-12.
- Avogadro's number: establishes that 1 mole of substance is composed of 6.0221415×10^{23} particles (molecules, ions, electrons, atoms, etc.).

In addition to these concepts, it was decided to remember that molecular mass and molar mass seem similar and are related but are not the same (Petrucci et al., 2011)[19]. Molecular mass is the weighted average mass of a molecule expressed in atomic mass units (a.m.u). Molar mass is the mass of one Avogadro number of molecules expressed in grams per mole (g/mol). The two terms have the same numerical value but different units. On the other hand, Dominguez Reboiras (2006)[20] and Masterton et al.[21] (1989) expresses that these concepts are equivalent, but in this work this postulate was rejected because semantically the word "molecular" refers to "molecule" and the word "molar" refers to "mole".

On the other hand, paragraphs were taken from texts and research literature in which inaccuracies in conceptual definitions were detected. These represent systematic patterns of misconception that require careful attention:

- Levine (2009):[22] *"For an ionic compound, the mass of one formula unit replaces the mass of one molecule in the definition of the molecular weight. Thus, we say that the "molecular weight" of NaCl is 58.443 a.m.u, even though there are no individual NaCl molecules in a NaCl crystal".*

Comment: This statement perpetuates the problematic use of "molecular weight" for ionic compounds, which conflates distinct conceptual categories and misleads students about the fundamental nature of these substances.

- Gunasekaran & Anbalagan (2007):[23] *"This behaviour can be attributed to the lower particle size and greater fraction of $CaCO_3$ molecules located on the surface with regard to the bulk".*

Comment: $CaCO_3$ is an ionic compound; referring to it as "molecules" is inappropriate and confusing.

- Yeprem (2007):[24] *"It was suggested that the reason of this is the bond energy of CaO molecules are lower than MgO molecules and they can move in the crystal structure".*

Comment: Both CaO and MgO are ionic compounds with extended lattice structures, not molecular entities with discrete "molecules."

- Thümmel et al. (1989):[25] *"Potential curves for the ground and various excited states of the MgO molecule have been calculated using the multi-reference configuration interaction (MRD CI) method".*

Comment: While theoretical calculations may model MgO as a diatomic species for computational purposes, the fundamental structural reality of solid MgO is an ionic lattice, not a collection of independent molecules.

- Recio et al. (1993):[26] *"The relative stability of neutral and single-ionized clusters has been studied by means of the fragmentation path involving the loss of a neutral MgO molecule".*

Comment: Again, the reference to MgO as a "molecule" in the context of ionic solids requires clarification and reframing.

- Utelbayev (2014):[27] *"The chloride of sodium related to binary chemical compounds and by molecular bond form crystalline lattice structure of substance table salt. That is why chemical compounds and substances of matter have the same composition!"* (The original text has an exclamation mark).

Comment: This statement exemplifies fundamental confusion about bonding types and the distinction between molecular and ionic substances.

- Mahan & Myers (1990):[28] *"There is much evidence that compounds traditionally called salts contain ionic bonds. Compounds such as NaCl, LiBr, K_2SO_4, $Ca(NO_3)_2$, and BaO can be considered to be made up of positive and negative ions, regardless of whether they are solid, liquid, or gaseous molecules"*.

Comment: The phrase "gaseous molecules" is problematic, these compounds in the gas phase may display complex behaviour but should not be uniformly described as molecular.

With all this, on the one hand the terms used were standardized, and on the other hand an orderly calculation scheme was proposed for the molecular or ionic masses as appropriate.

POSITIONING FOR TEACHING

In relation to the concepts

As a starting point, the fundamental concepts that serve as a basis for the development and justification of this work are taken up again.

The formula unit of a molecular substance is the molecule; for example, for the substance sulfur dioxide, with the formula SO_2, the formula unit is an SO_2 molecule, consisting of one sulfur atom and two oxygen atoms, as indicated by its formula. In the case of an ionic substance, for example $CaCl_2$, it cannot say that the formula unit is a molecule but rather it is called an ionic substance unit, and is formed by a Ca^{2+} cation and two Cl^- anions, as indicated by the formula. In atomic substances, the formula unit is not a molecule either, and for example in SiC the formula unit is made up of a carbon atom and a silicon atom. In metallic substances, such as Na, the formula unit is simply an atom of the element indicated by the formula (though electrons are delocalized throughout the structure) (Alsina et al. [6], 2015; Sutton, 2024)[29].

At this point it is necessary to reformulate Levine's statement (2009)[22]. The first step to establish conceptual clarity will be to recommend abandoning the use and custom of confusing language and adopting the terms correctly since, as has been observed, authors of cited books make the clarification. Therefore, classroom teaching should be dictated with instructions of the following form:

- Calculate the molecular mass of one H_2O molecule.
- Calculate the mass of one unit of ionic substance of NaCl.
- Calculate the mass of three H_2O molecules.
- Calculate the mass of three units of ionic substance of NaCl.

To facilitate the matter of nomenclature, the acronyms "MM" for molecular mass, "MUIS" for mass of unit of ionic substance, "MUAS" for mass of unit of atomic substance, and "MUMeS" for mass of unit of metallic substance and "MoM" for molar mass can be used.

In this regard, Petrucci et al.[19] (2011) call molecular compounds "molecule" and ionic compounds "formula unit". For example, they state: "1 mol $MgCl_2$ = 95.211 g $MgCl_2$ = 6.02214×10^{23} $MgCl_2$ formula units". However, this statement is wrong since all compounds, regardless of their nature, constitute a formula unit, according to what was previously expressed.

Regarding the texts of Gunasekaran & Anbalagan[23] (2007), Yeprem[24] (2007), Utelbayev[27] (2014) and Mahan and Myers[28] (1990), there are two things to explain. First, that works like this one are fundamental to standardize and organize nominal type problems. Second, that this type of errors are mitigated with a correct transmission of knowledge in the classrooms and that over the years, just as a certain type of language became used and customary, it is possible, by working permanently, to re-educate in the adequate use of conceptual language in science. An excellent example of this situation is the replacement of the concept of equivalent (for chemical titration) by that of molarity in modern analytical chemistry texts[30] (Skoog et al., 2014). Today it is difficult to find a chemistry student who speaks of normality and equivalent mass. Molarity has been adopted as the universal unit of measurement.

A separate comment is made regarding the texts by Recio et al.[26] (1993) and Thümmel et al. (1989). If the Educaplus online simulator is used, a scientific simulation platform for Spanish speakers at the secondary and university levels (the latter being for first-year subjects such as General Chemistry and Inorganic Chemistry I), the application "Nature of the chemical bond" (Educaplus.org, 2024)[31] allows the ionic character of MgO to be visualized, as shown in Figure 1:

It is understood that the authors are denoting the partial covalent character of MgO, but the nominal reality of the compound is that, if the adequate calculations are carried out based on electronegativity, it is a substance of clearly ionic character (Lima et al., 2021)[32]. Specifically, using Pauling's electronegativity scale, the electronegativity difference between Mg (1.31) and O (3.44) is 2.13, which corresponds to approximately 61% ionic character, placing MgO squarely in the category of ionic compounds («Electronegativity values. In CRC Handbook of Chemistry and Physics», 2023)[33].

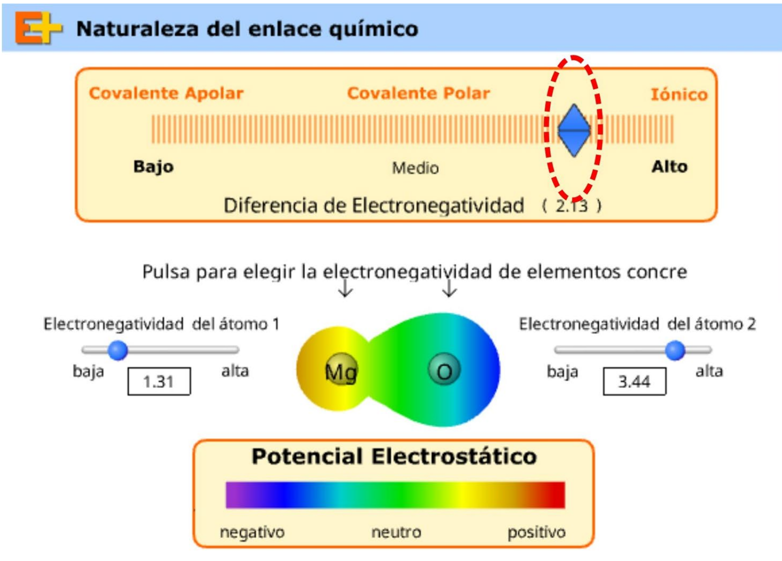


Figure 1. Ionic nature of MgO according to the Educaplus simulator. In the figure is clear the ionic nature of compound, the indicator is displaced to right in the zone of ionic character (red dotted line) showing an electronegativity value of 2.13 according to the Pauling´s scale.

Therefore, it is necessary to clarify that MgO does not belong to the extreme model of molecular substance, but is a unit of ionic substance and that, instead of speaking of molecular orbital (Recio et al., 1993)[26] it is necessary to rethink the text and rewrite it taking into account that MgO belongs to the type of inorganic solids whose bond structure is explained with the band theory and that its lattice energy corresponding to a rock salt structure has been experimentally calculated (West, 2022)[34]. All this phenomenology moves away from molecular orbital theory, which applies to discrete molecular entities in the gas phase or in solution, not to extended ionic lattices.

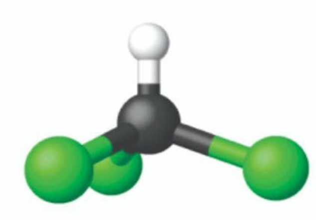
This nominal problem deepens the so-called "model of confusion in chemistry"[35] (Carr, 1984) and contributes to the problems of interpretation typical of students such as heuristics, undifferentiation[5] (Stains & Talanquer, 2007) and the problems of misconception very frequent in the subject of chemical bonding (Rizal et al., 2024)[17]. Recent systematic studies on student understanding reveal that 47% of students experience difficulty in determining bonding types based on electronegativity difference, and 79% have difficulty distinguishing bonding in metallic elements versus non-metallic elements[9] (Enawaty & Sartika, 2015).

In relation to the calculus part

Having observed the conceptual reductionism applied by Levine (2009)[22] and followed by hundreds of thousands of teachers over the years, the scheme for calculating atomic mass and mass of substance used by Flowers et al. (2019)[36], is taken, as shown in Figure 2.

The only change proposed is to replace the concept of “formula mass” with the more precise terminology that distinguishes between different substance types: MUIS for ionic substances, MUAS for atomic substances, and MUMeS for metallic substances, according to the theoretical framework already presented. Therefore, according to a given instruction, the calculation scheme is presented in the following examples (Table 2 a-h):

Element	Quantity		Average atomic mass (amu)		Subtotal (amu)
C	1	×	12.01	=	12.01
H	1	×	1.008	=	1.008
Cl	3	×	35.45	=	106.35
			Molecular mass		119.37



Element	Quantity		Average atomic mass (amu)		Subtotal
Na	1	×	22.99	=	22.99
Cl	1	×	35.45	=	35.45
			Formula mass		58.44

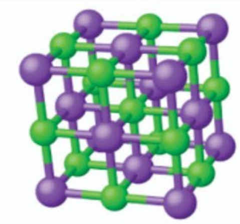


Figure 2. (Top image) The average mass of a chloroform molecule, CHCl3, is 119.37 a.m.u., which is the sum of the average atomic masses of each of its constituent atoms. The model shows the molecular structure of chloroform. (Bottom image) Table salt, NaCl, contains an array of sodium and chloride ions combined in a 1:1 ratio. Its mass of unit of ionic substance is 58.44 a.m.u. (Extracted from reference (Flowers et al., 2019)[36])

Table 2 (a-h). Recommended calculation scheme for use in introductory general chemistry courses at both secondary and university levels.

- Task: calculate the mass of one trichloromethane molecule.

a)

Molecule	$CHCl_3$			
Element	**Quantity**	**Average atomic mass (a.m.u.)**	**Mathematical operation**	**Subtotal**
C	1	12.01	=	12.01
H	1	1.008	=	1.008
Cl	3	35.45	=	106.35
		Molecular mass	MM (a.m.u.)	119.368

- Task: calculate the mass of one unit of ionic substance of NaCl:

b)

Unit of ionic substance	NaCl			
Element	**Quantity**	**Average atomic mass (a.m.u.)**	**Mathematical operation**	**Subtotal**
Na	1	22.99	=	22.99
Cl	1	35.45	=	35.45
		Mass of unit of ionic substance	MUIS (a.m.u.)	58.44

- Task: calculate the mass of one unit of Atomic Substance of C (diamond allotrope):

c)

Unit of Atomic Substance	C (Diamond)			
Element	**Quantity**	**Average atomic mass (a.m.u.)**	**Mathematical operation**	**Subtotal**
C	1	12.01	=	12.01
		Mass of Unit of Atomic Substance	MUAS (a.m.u.)	12.01

- Task: calculate the mass of one unit of metallic substance of Na:

d)

Unit of metallic substance	Na			
Element	**Quantity**	**Average atomic mass (a.m.u.)**	**Mathematical operation**	**Subtotal**
Na	1	22.99	=	22.99
		Mass of Unit of Atomic Substance	MUMeS (a.m.u.)	22.99

- Task: calculate the mass of three H_2O molecules:

In this case, the Flowers table is built to calculate the mass of one molecule (MM):

e)

Unit of Atomic Substance	C (Diamond)			
Element	**Quantity**	**Average atomic mass (a.m.u.)**	**Mathematical operation**	**Subtotal**
H	2	1.008	=	2.016
O	1	15.99	=	15.99
		Molecular mass	MM (a.m.u.)	18.006

Finally, the value obtained is multiplied by the number of molecules requested by the indicated task; in this case the calculation is: 18.006 x 3 = 54.018 a.m.u.

- Task: Calculate the molar mass (MoM) of the molecular compound H_2O:

In this case, as explained in the development of the text, molar mass and molecular mass have the same numerical value but different units. Therefore, the solution to the task is:

MoM of H_2O = 18.006 g/mol

At this point it is necessary to clarify that the molar mass is always the mass of one and only one mole of molecules (or units of ionic substance and so on).

- Task: calculate the mass of 3 moles of H_2O molecules:

In this case, we already have MoM of H_2O, so can be proposed a unitary factor or a simple rule of three. Because it is more intuitive and therefore more didactic, the simple rule of three is proposed:

From the MoM calculation, the following calculation can be made:

1 mole of H_2O molecules → 18.006 g

3 moles of H_2O molecules→ x = 54.018 g

- Task: calculate the mass of 5.5 moles of ionic substance units of KCl.

The first thing to do is to calculate the mass of unit of ionic substance (MUIS) according to the Flowers table:

f)

Unit of Ionic Substance	**KCl**			
Element	**Quantity**	**Average atomic mass (a.m.u.)**	**Mathematical operation**	**Subtotal**
K	1	39.10	=	9.10
Cl	1	35.45	=	35.45
		Mass of ionic unit	MUIS (a.m.u.)	74.55

The next step is to calculate the MoM of KCl, which is:

MoM of KCl = 74.55 g/mol

From the MoM calculation, the following calculation can be made:

1 mole of ionic substance units of KCl → 74.55 g

5.5 moles of ionic substance units of KCl → x = 410.025 g

In the following tasks, the following clarification must be made. Metallic or atomic substances are made up of ions (charged atoms) and neutral atoms respectively. Then it will be said that one mole of metallic substance units or atomic substance units is made up of one Avogadro number of atoms.

- Task: calculate the number of moles equivalent to 122.35 g of units of metallic substance Na.

The atomic mass of a single unit of metallic sodium (Na) is calculated using the Flowers Table:

g)

Unit of metallic substance	**Na**			
Element	**Quantity**	**Average atomic mass (a.m.u.)**	**Mathematical operation**	**Subtotal**
Na	1	22.99	=	22.99
		Mass of Unit of Atomic Substance	MUMeS (a.m.u.)	22.99

The next step is to calculate the MoM of Na, which is:

MoM of Na = 22.99 g/mol

From the MoM calculation, the following calculation can be made:

1 mole of atoms of Na → 22.99 g

5.3218 moles of atoms of Na =x ← 122.35 g

- Task: calculate the number of grams that represent 3.2 moles of atomic substance units of diamond C.

Taking what was previously developed, the calculations are as follows:

h)

Unit of Atomic Substance	C (Diamond)			
Element	**Quantity**	**Average atomic mass (a.m.u.)**	**Mathematical operation**	**Subtotal**
C	1	12.01	=	12.01
		Mass of Unit of Atomic Substance	MUAS (a.m.u.)	12.01

The next step is to calculate the MoM of C, which is:

MoM of C = 12.01 g/mol

From the MoM calculation, the following calculation can be made:

1 mole of atoms of C → 12.01 g

3.2 moles of atoms of C → x=38.432 g

The table designed in this way will be called "Modified Flowers Table" or simply, "Flowers´ Table".

In this way, the extreme models of substances are systematized both in their name and in their calculation scheme. This information is summarized in Table 3.

Table 3. Names, acronyms and calculation instructions for extreme models of substances.

Concept (correct name)	Acronym	Calculation scheme
Atomic mass	AM	Flowers´ Table
Molecular mass	MM	
Molar mass	MoM	
Mass of unit of ionic substance	MUIS	
Mass of Unit of Atomic Substance	MUAS	
Mass of Unit of Metallic Substance	MUMeS	

CONCLUSIONS

The following conclusions can be drawn from this work:

- It is a known fact that in introductory chemistry courses at both secondary and university levels, concepts are conveyed in an imprecise or confusing manner. The most illustrative example is the concept of "weight" exchanged for that of "mass". In this paper, a conceptual imprecision has been observed in the teaching of extreme models of substances. This imprecision has systematic origins and contributes to persistent student misconceptions.
- Textbooks (even the oldest ones) clarify this problem of conceptual definition although some authors accept the (incorrect) linguistic use adopted over time. This creates a mixed message for students and practitioners.
- Inappropriate terminological use can be observed even in research articles published in peer-reviewed journals. This suggests that the issue has not received sufficient attention in the scientific community.
- With works such as this one, a process of re-education and necessary diffusion of a clear and correct language that does not give rise to confusion is proposed. The process of language standardization in science is slow but necessary.

- When calculating the atomic masses of atoms or the masses of substances, the pedagogical design of a table like the one shown in this work is proposed, which will help students, over the years, to affirm the correct use of technical language without giving rise to the ambiguities observed in textbooks, papers and in the explanatory language of teachers.
- This work aims to ensure that students learn the extreme models of substances accurately from the beginning of their training in a clear and orderly manner. It is known at the pedagogical level that in order for students to understand the intermediate behavior of substances (partial covalent or ionic bonds) in the advancement of their learning in the field of chemical sciences, it is necessary that they first conceptualize the "extreme" models of substances. This principle of order was established by Comenius himself in The Great Didactic of 1657[37] (Gadotti, 1998) in order to avoid disorder in the mind of the student.
- Since the topic "Extreme Models of Substances" involves a high degree of abstraction and therefore complexity for its understanding, the use of the so-called Extended Laboratory (EL) can be used as a teaching tool. The EL includes the use of Experimental Activities (EA) or homemade developments, simulators, Mobile Laboratories (ML), Virtual Laboratories (VL), Remote Laboratories (RM) and other technologies[38] (Salazar et al., 2024). The Educaplus simulator for determining chemical bond nature represents one such tool that can enhance student understanding of the continuum between extreme models.

Future research should investigate the effectiveness of explicit instruction using the Modified Flowers Table approach in reducing student misconceptions about chemical bonding and the classification of substances. Longitudinal studies tracking students' conceptual understanding over multiple levels of chemistry courses would provide valuable evidence for the pedagogical value of this systematized approach.

REFERENCES

[1] Araújo, J. L., Desenvolvimento da literacia química de alunos do ensino básico: Contributos de um projeto educacional de ciência cidadã., *Educación Química*, 2024 **35**, 6. https://doi.org/10.22201/fq.18708404e.2024.4.87280.

[2] Johnstone, A. H., Why is science difficult to learn? Things are seldom what they seem, *Journal of Computer Assisted Learning*, 1991, **7**, 75. https://doi.org/10.1111/j.1365-2729.1991.tb00230.x.

[3] Van Dulmen, T. H. H., Visser, T. C., Coenders, F. G. M., Pepin, B., and McKenney, S., Learning to teach chemical bonding: A framework for preservice teacher educators, *Chemistry Education Research and Practice*, 2023, **24**, 96. https://doi.org/10.1039/D2RP00049K.

[4] Ünal, S., Coştu, B., Ayas, A., *Secondary School Students' Misconceptions of Covalent Bonding*, 2010

[5] Stains, M. and Talanquer, V., Classification of Chemical Substances using Particulate Representations of Matter: An analysis of student thinking, *International Journal of Science Education*, 2007, **29**, 643. https://doi.org/10.1080/09500690600931129.

[6] Alsina, D., Cagnola, E., Güemes, R., Noseda, J. C., Odetti, H., Pacífico, A., Zimmermann, L., and Cano de Candioti, E., 'Química Conceptos fundamentales: Capítulo 5 Sustancias', Universidad Nacional del Litoral, Santa Fe, 2015.

[7] Chamorro Armas, S. and Barahona Ibarra, A. 'Fundamentos de Química General con enfoque universitario'. Ediciones Ecuafuturo, 2021.

[8] Universidad Nacional del Litoral, 'Sustancias Extremas', 2024. https://www.unl.edu.ar/comunicaciondelaciencia/sustancias-extremas/.

[9] Enawaty, E., and Sartika, R. P., 'Description of students' misconception in chemical bonding', 2015

[10] Ling, S., Sanny, J., Moebs, W., 'University physics, Volume 1'. OpenStax, 2021.

[11] Silverberg, L. J., What is an organic substance?, *Foundations of Chemistry*, 2021, **23**, 329. https://doi.org/10.1007/s10698-021-09400-z.

[12] Malaver, M., Pujol, R., and D'Alessandro Martínez, A., Los estilos de prosa y el enfoque ciencia-tecnología-sociedad en textos universitarios de química general, *Enseñanza de las Ciencias. Revista de investigación y experiencias didácticas*, 2004, **22**, https://doi.org/10.5565/rev/ensciencias.3875.

[13] Mortimer, C. E., 'Química', Editorial Iberoamericana, 1983.

[14] Whitten, K. W., Gailey, K. D., Davis, R. E., de Sandoval, M. T. A. O., and Muradás, R. M. G., 'Química general'. Cengage Learning, 2015.

[15] Chang, R., and Overby, J. S., 'General chemistry: The essential concepts', 6th edition, McGraw-Hill, 2011.

[16] Silberberg, M. S., Amateis, P., Venkateswaran, R., and Chen, L., 'Chemistry: The molecular nature of matter and change', Vol. 4, McGraw-Hill, New York, 2006.
[17] Rizal, Wiji, Tuszie Widhiyanti, and Novianti Islahiah, Multi-representation Analysis of General Chemistry Books on Chemical Bonding Subject, *Orbital: Jurnal Pendidikan Kimia*, **2024** *8*, 61. https://doi.org/10.19109/ojpk.v8i1.21609.
[18] Brown, T. L. 'Chemistry: The central science', 9th edition, student edition, Prentice Hall, Pearson Education, 2003
[19] Petrucci, R. H., Harwood, W. S., Herring, F. G., Perry, S. S., García-Pumarino, C. P., Cabo, N. I., and Renuncio, J. A. R., 'Química general', Pearson Educación, S. A., 2011.
[20] Domínguez Reboiras, M. A., 'Química la ciencia básica', 2006.
[21] Masterton, W. L., Emil J, S., and Stanitski, C. L. 'Química General Superior', 6ª edición, McGraw-Hill, 1989.
[22] Levine, I. N., 'Physical chemistry', 6th edition, McGraw-Hill, 2009.
[23] Gunasekaran, S. and Anbalagan, G., Thermal decomposition of natural dolomite, *Bull. Mater. Sci.*, 2007, **30**, 339.
[24] Yeprem, H. A., Effect of iron oxide addition on the hydration resistance and bulk density of doloma, *Journal of the European Ceramic Society*, 2007, **27**, 1651. https://doi.org/10.1016/j.jeurceramsoc.2006.05.010.
[25] Thümmel, H., Klotz, R., and Peyerimhoff, S. D., The electronic structure of the MgO molecule in ground and excited states, *Chemical Physics*, 1989, **129**, 417. https://doi.org/10.1016/0301-0104(89)85011-6.
[26] Recio, J. M., Pandey, R., Ayuela, A., and Kunz, A. B., Molecular orbital calculations on (MgO) *n* and (MgO) *n* + clusters (*n* =1–13), *The Journal of Chemical Physics*, 1993, **98**, 4783. https://doi.org/10.1063/1.464982.
[27] Utelbayev, B., Some Concepts about Substance, Chemical Compound and an Element, *American Chemical Science Journal*, 2014, **4**, 166. https://doi.org/10.9734/ACSJ/2014/6732.
[28] Mahan, B. M., and Myers, R. J., 'Química: Un curso universitario', 4ª edición, Addison-Wesley Iberoamericana, 1990.
[29] Sutton, A. P., Misconceptions about Metals, *Journal of Chemical Education*, 2024, **101**, 2710. https://doi.org/10.1021/acs.jchemed.4c00010.
[30] Skoog, D. A., West, D. M., Holler, F. J., Crouch, S. R., and others, 'Fundamentals of analytical chemistry, Vol. 33', Cengage Learning, 2014.
[31] Peñas, J., 'Naturaleza del Enlace Químico', Universidad de Sevilla, 2024, https://www.educaplus.org/game/naturaleza-del-enlace-quimico.
[32] Lima, H., Ferreira, D., Souza, A., and Dos Santos, M., An Alternative Description for the Electronegativity Difference in Binary Ionic Solids, *Journal of the Brazilian Chemical Society*. 2021. https://doi.org/10.21577/0103-5053.20200193.
[33] 'CRC Handbook of Chemistry and Physics: Electronegativity values'. 104th edition, CRC Press, 2023.
[34] West, A. R., 'Solid state chemistry and its applications', John Wiley and Sons, 2022.
[35] Carr, M., Model confusion in chemistry, *Research in Science Education*, 1984.
[36] Flowers, P., Theopold, K., Langley, R., Neth, E. J., and Robinson, W. R., 'Chemistry: Atoms First', 2nd edition, 2019.
[37] Gadotti, M., 'Historia de las ideas pedagógicas', Siglo XXI, 1998.
[38] Salazar, M., Arias-Navarro, E., Arguedas-Matarrita, C., and Montero-Miranda, E., Diseño de una secuencia didáctica para el abordaje del tema Valoración Ácido Base bajo el modelo del Laboratorio Extendido con estudiantes de undécimo año del Colegio Científico Costarricense de Alajuela, *Educación Química*, **35**, 75. https://doi.org/10.22201/fq.18708404e.2024.4.88177.