

An Innovative Way of Balancing Chemical Equations

Ravijot Sandhu

Abstract

Chemical equations are balanced in order to satisfy the Law of Conservation of Mass and to establish the mole relationship needed for stoichiometric calculations. It has been observed that students find balancing of chemical equations difficult. Review of the related literature also shows that balancing of chemical equations is difficult for students across the globe. In this paper an attempt has been made to show an innovative way of balancing chemical equations during teaching-learning process. The innovative way also enhances the learning curve and interest quotient amongst students.

Key Words: Innovative ways, Balancing of equations, Children with visual impairment, Coefficients. Subscripts.

Introduction and Review of Literature

A chemical reaction can be represented by a chemical equation. This means whenever a chemical change occurs, we can say a chemical reaction has taken place. The chemical reaction needs to be balanced as it is only rearrangement of atoms. Atoms are neither created nor destroyed during a chemical reaction. Therefore, the chemical reaction needs to be balanced to follow the law of conservation of mass. In chemistry, the Balancing of Equations has been introduced at the secondary level of school education.

Researchers and science educators found that varied factors contributed to students' difficulties about balancing chemical equations.

Researches have shown that the understanding, balancing, and interpreting chemical equations depend on understanding the structure and physical state of the reactants and products, the dynamic nature of particular interaction, the qualitative relationships among the particles, and the large number of particles involved (Ben-Zui et al., 1987; Ross 1989).

Nakhleh 1992, attributed students' prescientific conceptions of chemical equilibrium to the lack of chemical knowledge concerning how to regard and apply symbolism of a chemical equation.

It has been pointed out that the lack of mastering conceptual ecology of chemistry contributed to students' difficulties (Hesse & Andersson 1992). It has also been found that students' understanding of chemical formulas significantly influences overall equation balancing performance (Staver & Jacks 1988).

Researches have also concluded that many students do not differentiate between subscripts of chemical formulas and coefficients in chemical equations. Also, they possess a poor understanding of those two concepts and are willing to violate the chemical equation balancing rules (Savoy 1988; Schmidt 1984, 1986, 1989; Yaroch 1985).

Dr. Ravijot Sandhu, PGT-Chemistry, Navyug School, Laxmi Bai Nagar, New Delhi, India.

Savoy, 1988 believes that the lack of knowledge of valency numbers and a failure to understand concepts, such as atomicity, use of brackets, and the significance of subscripts and coefficients, contribute to students' difficulties.

Gabel et al., 1987 and Yaroch 1984, 1985 concluded that the lack of performing simple arithmetic operations involved the lack of understanding of the chemical concepts and their significance as well as students' inability to read and interpret scientific language—all contributed to students' difficulties in chemistry. It has also been found that the beginners equate chemical equations with actual reactions (Filgueiras, 1992).

As a teacher-researcher, while teaching students of Grade X from last 27 years, it has been observed that **students face difficulty in learning balancing of equations**. Review of the related literature strengthened the belief of the researcher to create innovative way for teaching-learning of balancing of chemical equations. In the beginning of researcher's career, she used to transact the topic of **Balancing of Chemical Equations** by using 'chalk and talk' method; by writing unbalanced equations on the black board and involving students to balance these equations by inviting them one by one to the blackboard. This was probably because she was trained in her pre-service professional training to teach this topic in this manner only. Over the years, teacher-researcher realised that students find this topic as a burden and stressful. This she realized by taking feedback from her students and following were students' responses:

Students: *We find the balancing of equations difficult and the reactions along with the coefficients. Some students said they don't understand why they can't change the subscript instead of coefficient!*

The researcher also enquired about the experiences of her fellow colleagues about this topic.

Following were the responses-

Teacher 1: *It's difficult for students even to remember the correct symbols, formulae and valencies, as a result they would make mistakes while balancing the equations.*

Teacher 2: *I have to struggle to make students visualise the abstract concept about how to represent the actual reaction happening in their test tubes or beakers in chemical equations format....They often ask questions like why we take two Mg atoms and not four to represent 'Burning of Magnesium ribbon in air?' As shown in equation $2 \text{Mg} + \text{O}_2 \rightarrow 2 \text{MgO}$*

Teacher 3: *Some students consider arrow ($\rightarrow$) in the reaction as 'equal to' ($=$) as how it is in the quadratic equations and some students, instead of placing coefficients in front of atom or molecule, simply add extra element!*

Teacher 4: *Some students master the technique of balancing a chemical equation by picturing a chemical equation as a mathematical puzzle in which the number of atoms on each side of the equation has to be equal to each other.*

Similarly, many more teachers showed equal discomfort in teaching this topic.

Researcher also tried to make this topic interesting using ICT, showing students online lessons and videos to strengthen this topic.

Literature shows that very limited research studies have been done on teaching-learning strategies of Balancing of Equations. Considering this a universal problem, researcher developed an innovative teaching-learning strategy to make this topic interesting.

And the Journey Began

A holistic lesson developed by a teacher requires the inclusion of all three domains in constructing learning tasks for students, which include cognitive (thinking), affective (emotions or feeling) and Psychomotor (Physical or kinesthetics) to be achieved.

During teaching-learning of balancing chemical equations, researcher improvised 'Hit and Trial' method, and invented most suitable strategy to make students visualize about the balancing of atoms on both the reactants and products side.

Students were asked to bring colourful chart papers or any available colourful sheets, clay/ locally available mud to make dough balls etc. Researcher also provided materials such as, chart paper strips, colourful sketch pens, coloured clay etc., to students. Students were also encouraged to share their materials.

Science through Games

First challenge was to find an easy way to recapitulate formulae writing. Grade X class of 42 students was divided into 7 groups and students were made to do an ice breaker to recall the symbols and valencies of elements. For those who had difficulty recalling correct symbols, formulae and valencies, they were made to play '**Elementola' Science Game**, in which teacher with the help of students prepare slips/ tickets having a box with nine squares with symbols of any 5 of the first twenty elements in the periodic table written in random squares. It was ensured that all the tickets did not have 5 symbols of same elements. To start the game the facilitator picked up a coin with symbols and atomic numbers written on it from the bowl and spoke aloud either the name or atomic number of the element.

(Coins were made from locally available materials or used bottle caps).

Players/students strike out symbol of that element if it is there on their ticket. The student who is first to strike out all the elements in the given ticket was declared the winner!

For Children with Visual Impairment (CWVI), tickets were made in Braille and tactile (NCERT 2020).

Staver & Jacks 1988 found that students' understanding of chemical formulas significantly influences overall chemical equation balancing performance. Another **Science Game 'Ion Combos'** was played in the classroom to practice making chemical formulae from the given set of cards having cations and anions written on them. *The objective was to explore students' conceptions of a chemical formula's significance, recognition, manipulation, and writing.* (Al-kunified, Ali Abdallah, 1993)

After intervention, an assessment sheet was given to ascertain whether there was any improvement in their understanding and competency of writing chemical formulae.

Science through Activity

Researcher first demonstrated an activity of '**Burning of Magnesium Ribbon**'. After observing the burning of Magnesium ribbon, students were asked to write the chemical reaction in a sentence form. Different responses were-

- i. 5 students said -Magnesium ribbon burnt with white smoke
- ii. 8 students said -Sparkling white light is seen and ash is formed
- iii. 3 students said -The magnesium burned easily.
- iv. 6 students said -We got ashes.
- v. 8 students said -We got white substance.
- vi. 7 students said -The magnesium is flammable so it caught fire
- vii. 5 students said -The magnesium reacted with the fire.

Teacher noticed that students have described the product (magnesium oxide) as ash. She explained that the magnesium strip on burning in air turned into white ash ie magnesium oxide.

She helped students to arrive at the chemical reaction in a sentence form.

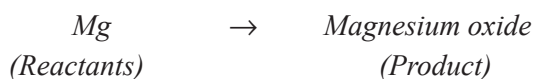
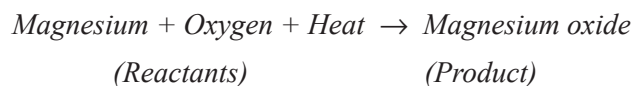
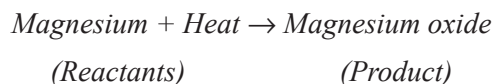
STEP 1: Writing the chemical reaction in a sentence form-

"When a magnesium ribbon is burnt in oxygen, it gets converted to magnesium oxide".

STEP 2: Writing the chemical reaction in the form of a word-equation.

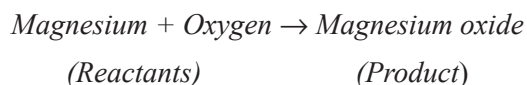
Since the description in a sentence form is quite long, the simplest way to write it in the short form is by writing a word-equation.

Students exhibited variety of responses -



It was interesting to note that twelve students indicated in their responses that the heat was one of the reactants. 14 students ignored the presence of the oxygen as one of the reactants but considered it in the product. After having discussion with students and explaining them by giving more examples such as burning

of coal etc., students realized that burning of magnesium ribbon is possible only in the presence of oxygen. The researcher helped students to arrive at the word-equation for the above reaction –



The students were told to identify reactants and products from the above reaction. 85 % of the students gave correct answers which were shared in the classroom: **the substances that undergo chemical change in the reaction i.e magnesium and oxygen, were the reactants and the new substance i.e magnesium oxide, formed during the reaction, was the product.**

Then was the time to emphasise on the importance of placing arrow and plus sign (+). A word-equation shows change of reactants to products through an arrow placed between them. The reactants are written on the left-hand side (LHS) with a plus sign (+) between them. Similarly, products are written on the right-hand side (RHS) with a plus sign (+) between them. Always remember that **the arrowhead points towards the products, and shows the direction of the reaction.**

STEP 3: Writing of Chemical equations:

Chemical reactions can be made more concise and useful if we use the language of chemistry i.e .chemical formulae instead of words.

By using the formulae of magnesium, oxygen and magnesium oxide, the above word-equation was written as shown in Figure 1:

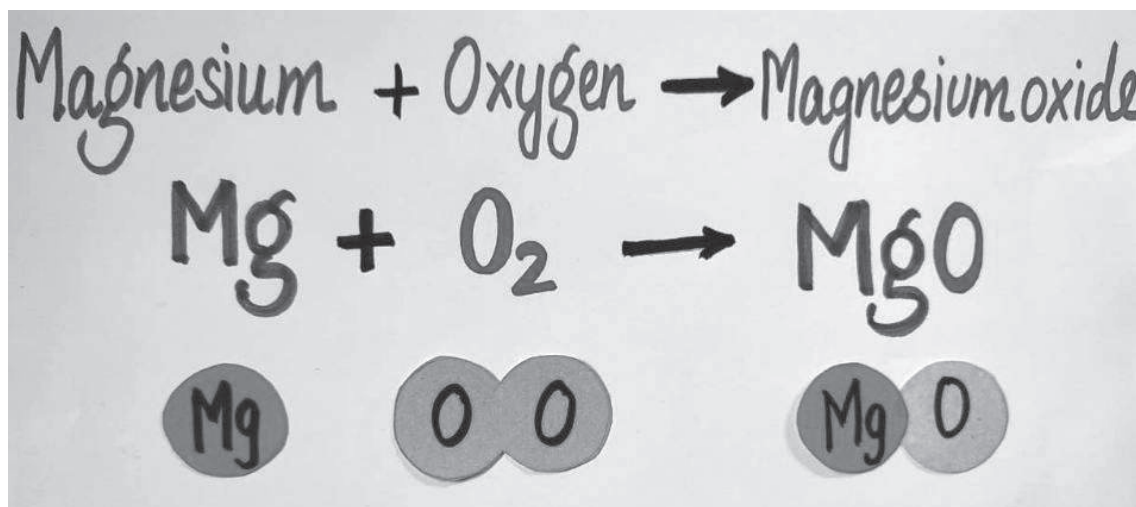


Figure 1

STEP 4: Now students were motivated to Count and Compare the Number of Atoms of Each Element on the LHS and RHS of the Arrow by probing questions such as-

Is the number of atoms of each element the same on both the sides?

If not, then the equation is unbalanced because the mass is not the same on both sides of the equation.

Such a chemical equation is a **skeletal chemical equation for a reaction** (Figure 2).

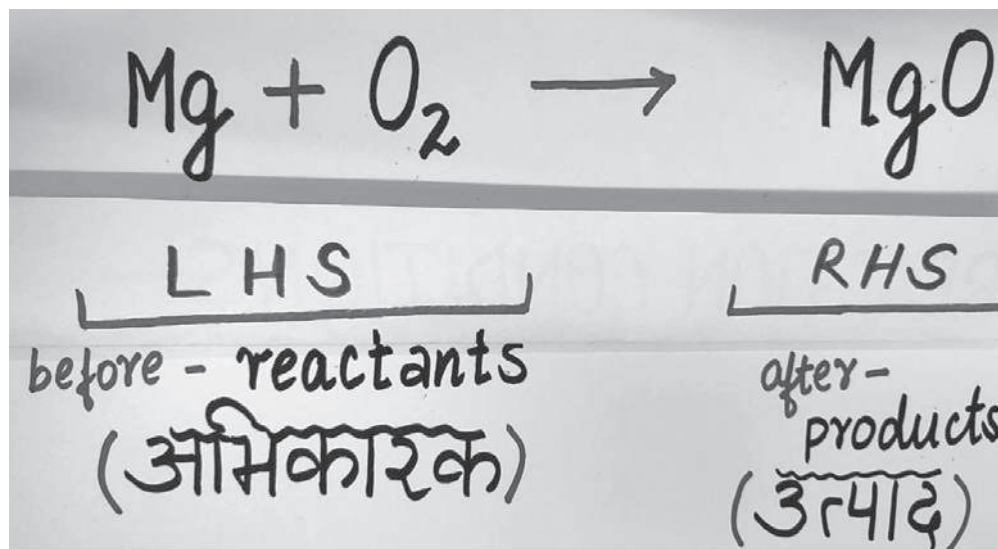
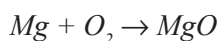


Figure 2

This equation is a skeletal chemical equation for the burning of magnesium in air because it is unbalanced.

Students were made to recall about the **law of conservation of mass**, which they have learnt in their previous classes; mass can neither be created nor destroyed in a chemical reaction. That is, the **total mass of the elements present in the products of a chemical reaction has to be equal to the total mass of the elements present in the reactants** (Figure 3). In other words, the number of atoms of each element remains the same, before and after a chemical reaction.

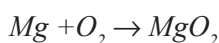
Hence, we need to balance a skeletal chemical equation.



Students were quick to observe that on LHS there is one atom of magnesium, two atoms of oxygen and on the RHS there is one atom each of magnesium and oxygen.

*Some students wondered- why do we need to balance equations? Some even asked questions such as: will our marks get deducted in exam/test if we do not balance the chemical equations? **Unbalanced equations in science aren't particularly useful to us and we have to make them balanced before we can use them for problem solving or doing calculations.***

12 students assumed that to balance a chemical equation you make the left side equal to the right side.... same elements on both the sides... Few students indicated in their answers that the product was MgO_2 . They combined the reactants (Mg and O_2) and completed the formula equation. For example, one student wrote the following equation:



Let's Clear Our Concepts: Science Through Concept Clarification

Next step was to make them differentiate between - Coefficients and Subscripts. Many students struggle because they are not sure which number they have to change in order to balance an equation. Ben-Zui, Eylon, and Silberstein 1987; Hackling and Garnett 1985; Savoy 1988; and Yarroch 1989 found in their studies that students lacked understanding of the significance and function of coefficients and subscripts in formulas and equations. Besides, Lazonby, Morris, and Waddington 1982; Savoy 1988; Schmidt 1984; and Yarroch 1985 concluded from their studies that students confused stoichiometric coefficients in equations with subscripts in formulas.

Students were told that when they balance an equation they can change only coefficients as shown in Figure 3. (*Coefficients are the numbers in front of the molecules or atoms*).

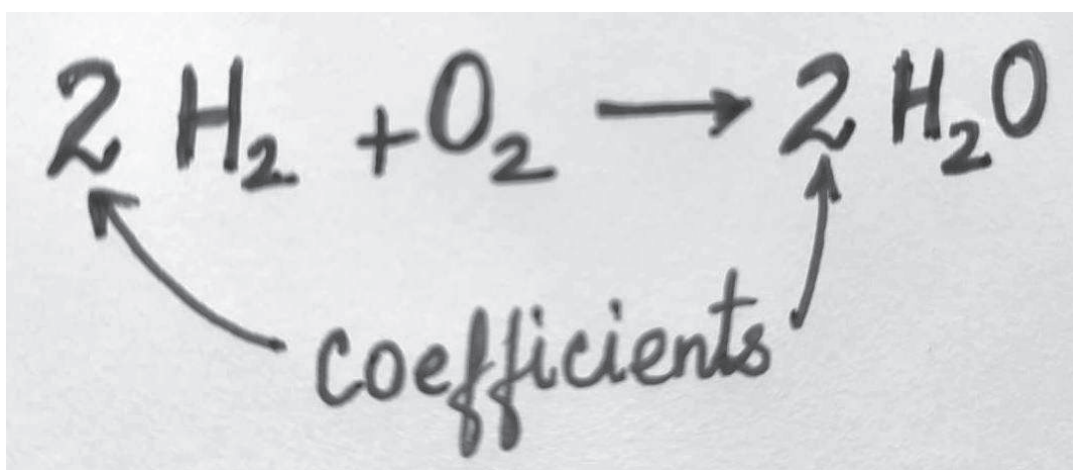


Figure 3

Subscript are the smaller numbers found after atoms as shown in Figure 4. These cannot be changed when balancing chemical equations.

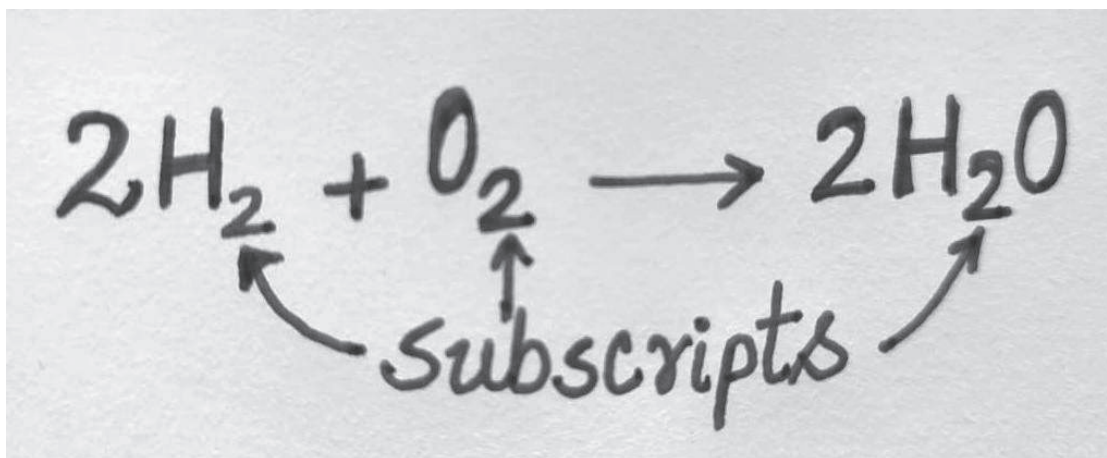


Figure 4

Subscripts tell us how many atoms of a given element are in one molecule whereas, coefficients tell us how many of that molecule or atoms are present in the reaction.

After the students were convinced and satisfied that why one cannot change the subscript only then we moved on.....

Science through Art form:

Visualization of number of atoms or molecules taking part in a chemical reaction:

After interaction with the students over the years during teaching-learning, it was clear to the researcher that the students used their everyday language to understand the chemical reactions. To **understand the concepts behind the balancing a chemical equation, the researcher made an attempt to utilize an innovative way of teaching-learning of balancing of a chemical equation to help the students to visualise number of atoms and molecules taking part in the chemical reaction** by placing paper cutouts in circular shape or clay balls or colourful buttons or sticker bindis etc., under the written skeletal chemical equations. The class was full of fun and laughter as students helped each other in preparing various cut outs as shown in Figure 5.

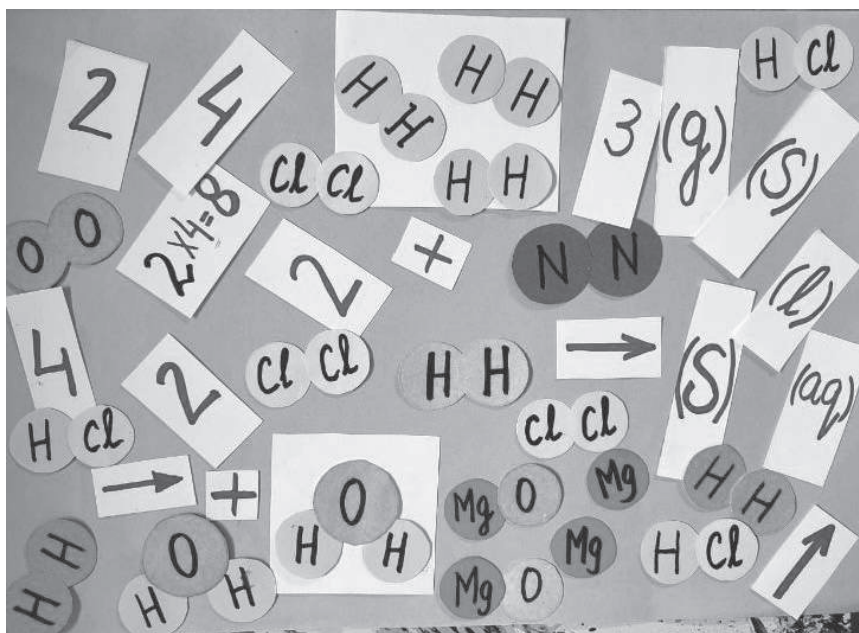


Figure 5

The students' demonstrated Magnesium atom with one circle of orange colour cut out and Oxygen molecule with two circles attached with each other of different colour say green as shown in Figure 6. The product Magnesium oxide was represented with one circle cut out of orange attached to green circle. Such coloured cut outs were easy for students to see that both the colour cutouts were not equal in number on LHS and RHS. **The researcher represented the same chemical equation using different coloured buttons for Children with Visual Impairment (CWVI) to touch and feel the number of atoms/ molecules** as shown in Figure 7

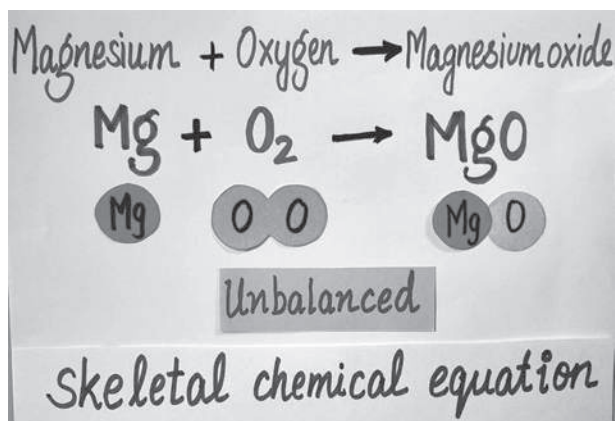


Figure 6

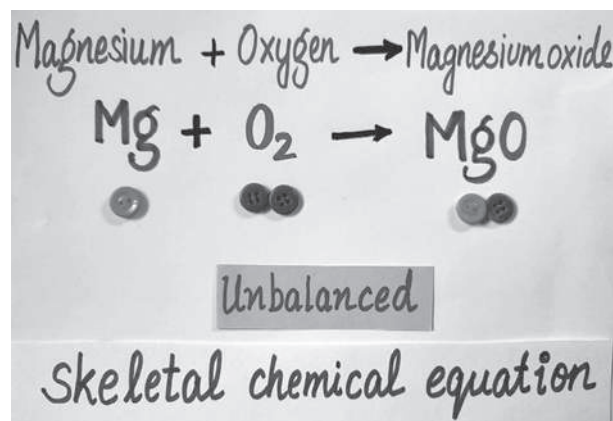


Figure 7

For CWVI were also were excited like sighted students to tell that how many atoms need to be adjusted to balance the chemical equation.

This becomes interesting for students as it is like solving a bit of a puzzle by making few adjustments.

Figure 8 and Figure 9 show balanced chemical equation with same number of buttons or paper cutouts on LHS and RHS.

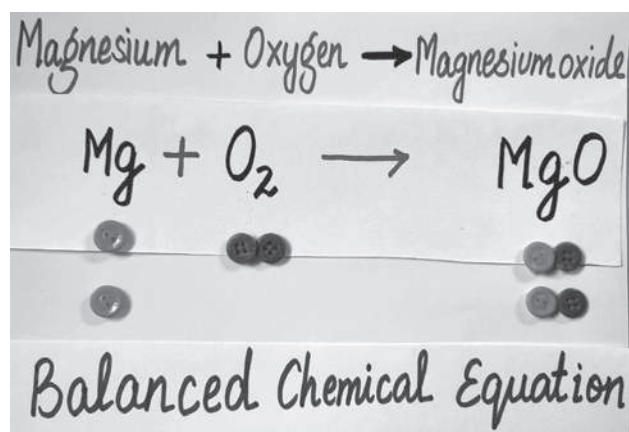


Figure 8

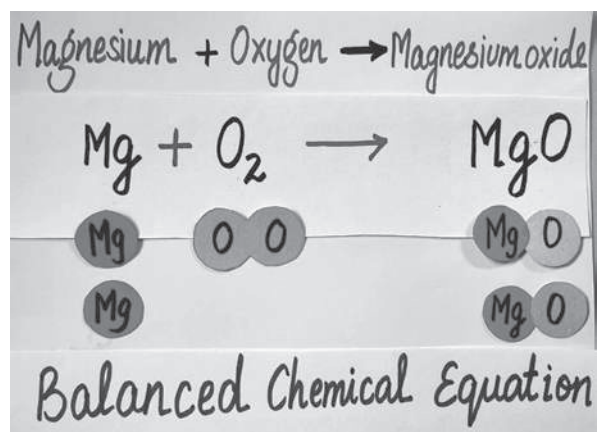


Figure 9

Students were motivated to play till they get same number of atoms on each side. Students had fun in doing this activity.

After the coloured paper cutouts or clay balls or buttons (representation of atoms) were equal on LHS and RHS then cut outs of coefficients (2) were kept accordingly in front of the Magnesium atom on LHS and Magnesium oxide on RHS as shown in Figures 10 and 11.

By now students were excited and it was clear to them that number of magnesium and oxygen atoms on both the sides of the arrow was two each, though on LHS two Magnesium atoms were present and on RHS Magnesium was a part of the molecule. Visually impaired students were also happy as they were made to feel the number of atoms represented by colourful buttons or clay dough or soil or crumpled paper balls of different shapes.

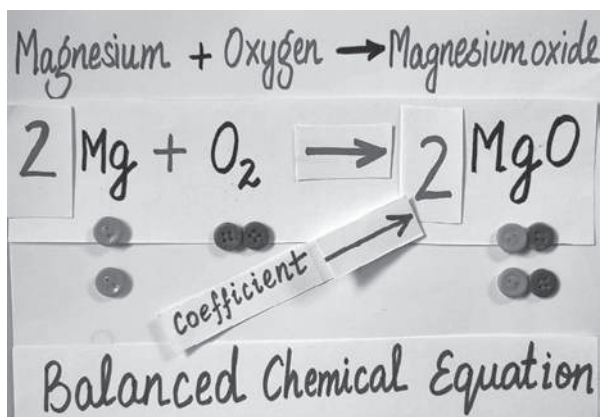


Figure 10

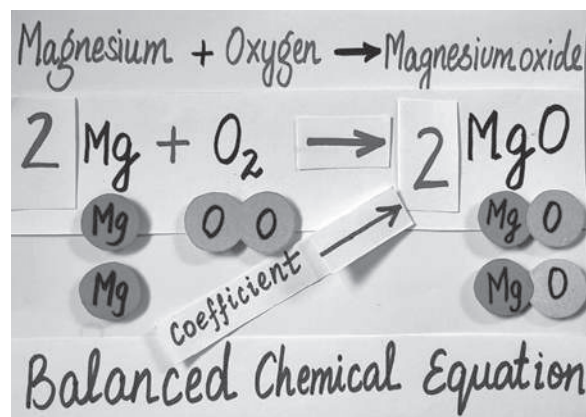


Figure 11

Science through Task

To further strengthen the concept and assess the students understanding, the class was once again divided into 4 groups and each group was assigned a chemical equation to balance. This was as innovative and engaging assignment. These kinds of peer and self-assessment can foster a number of skills, such as reflection, critical thinking and self-awareness among students.

Group 1: Hydrogen gas and Chlorine gas combine to make Hydrochloric acid.

This group was told to make clay ball visuals to show the atoms and molecules participating in the reaction. Their presentation is shown in Figure 12 and Figure 13.

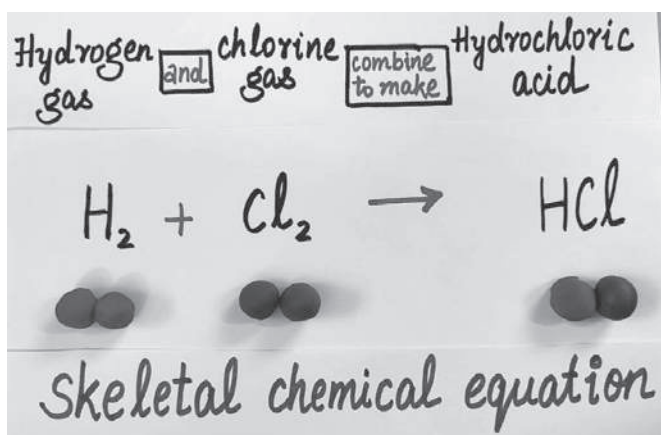


Figure 12

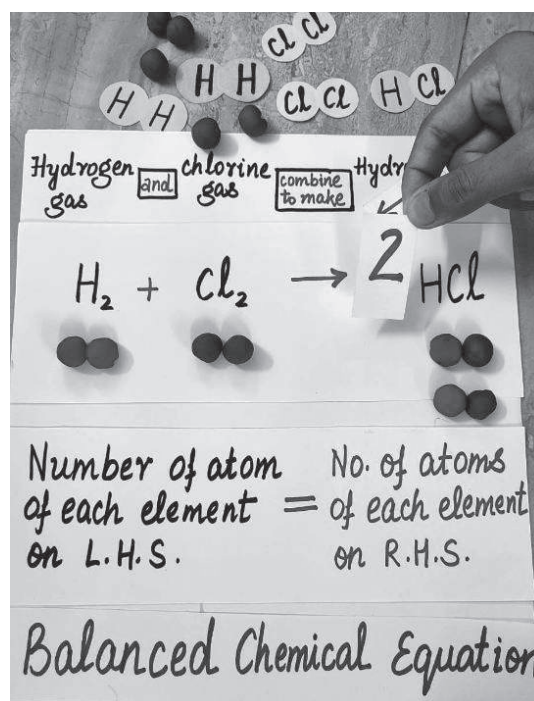


Figure 13

Group 2: Hydrogen gas and Oxygen gas combine to form Water. Group 2 was told to make round/ circle paper structures to show the atoms and molecules participating in the reaction as shown in Figure 14 and Figure 15.

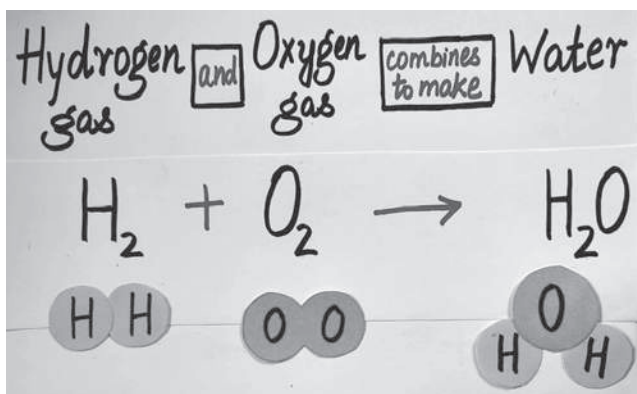


Figure 14

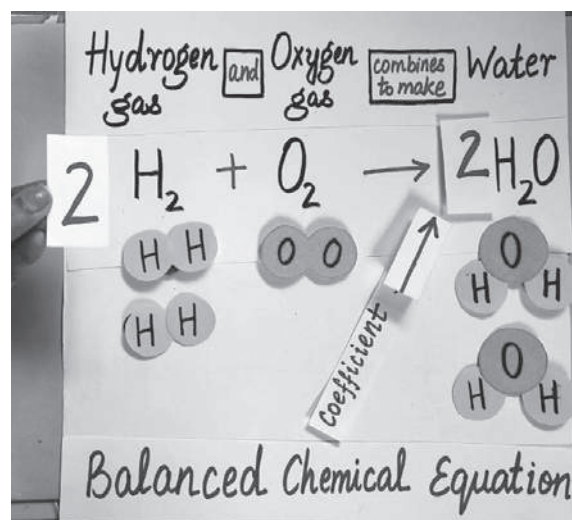
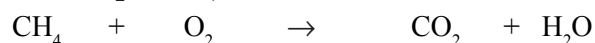


Figure 15

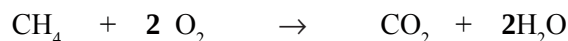
Group 3: Methane gas on reaction with Oxygen form Carbon dioxide gas and Water.

Group 3 was told to make paper structures of different shapes to show the atoms and molecules participating in the reaction.

Unbalanced (skeletal chemical equation)



Balanced Chemical Equation-



Group 3 students reported that it was much easier to make the number of molecules on reactants and products sides equal as they simply made sure that there were equal numbers of shapes on both the sides.

Group 4: Iron reacts with moisture (water) to form rust (ferric oxide) and hydrogen gas

The students were told that to balance chemical equations they cannot always be using visuals or drawings. The visuals were used to help to understand the concept better. Actually to balance equations they have to use charts or tables and basic mathematics.

Group 4 were told to make tables/ charts to show the atoms and molecules participating in the reaction. These charts or tables help to keep track of atoms on both sides.

Once again students were taken through journey of Balancing of Equations and made to hop on imaginary bus which will halt at various stops-

STOP 1: Write the skeletal chemical equation as shown in Figure 16.

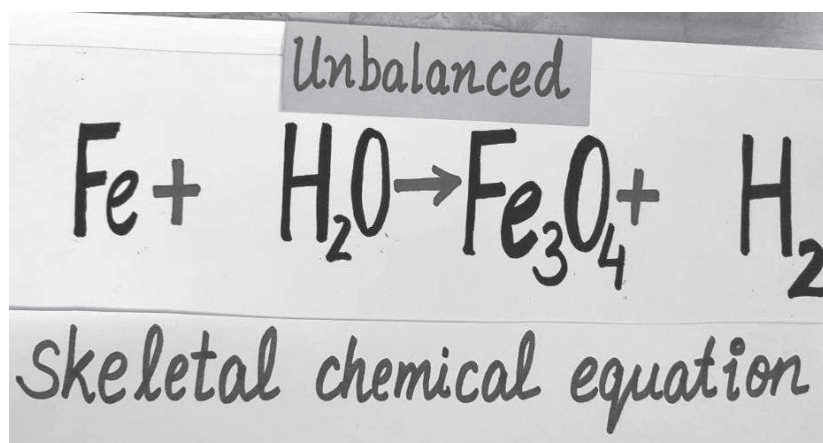


Figure 16

STOP 2: List the number of atoms of different elements present in the unbalanced equation (Figure 17)

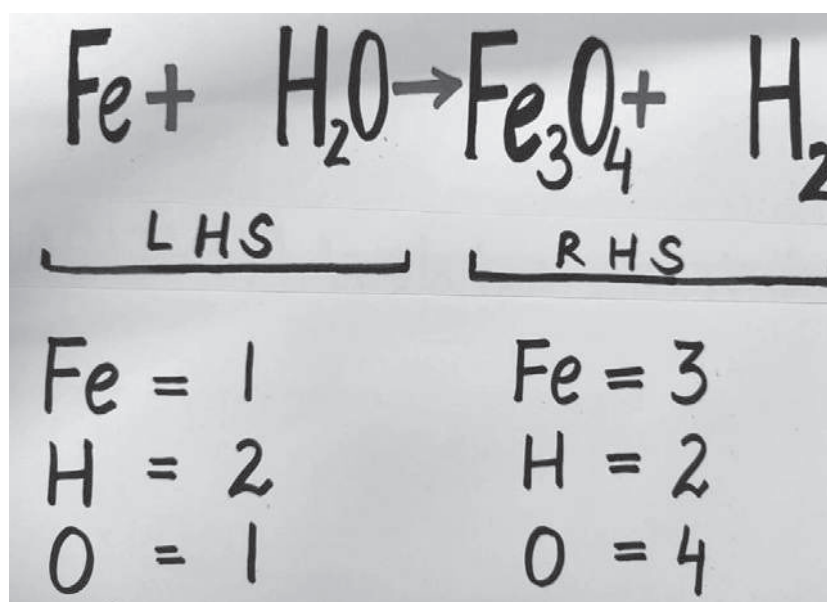


Figure 17

STOP 3: It is often convenient to start balancing with the compound that contains the maximum number of atoms. It may be a reactant or a product. In that compound, select the element which has the maximum number of atoms. Using these criteria, we select Fe_3O_4 and the element oxygen in it. There are four oxygen atoms on the RHS and only one on the LHS.

To balance the oxygen atoms –

Students here were reminded that to equalise the number of atoms, we cannot alter the formulae of the compounds or elements involved in the reactions, they were quick to answer that to balance oxygen atoms we can put coefficient '4' as $4 \text{H}_2\text{O}$ (Figure 18) and not H_2O_4 .

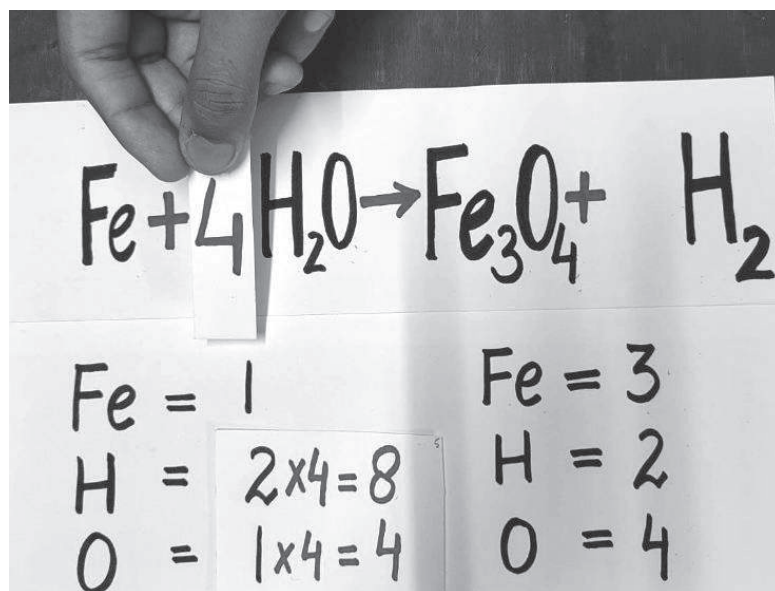
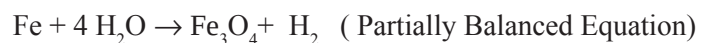


Figure 18

Now the partly balanced equation becomes –



STOP 4: Fe and H were still not balanced. Students were encouraged to pick any of these elements to proceed further. So first they balanced hydrogen. To equalize the number of H atoms, they made the number of molecules of hydrogen as four on RHS. (Figure 19)

The equation became-

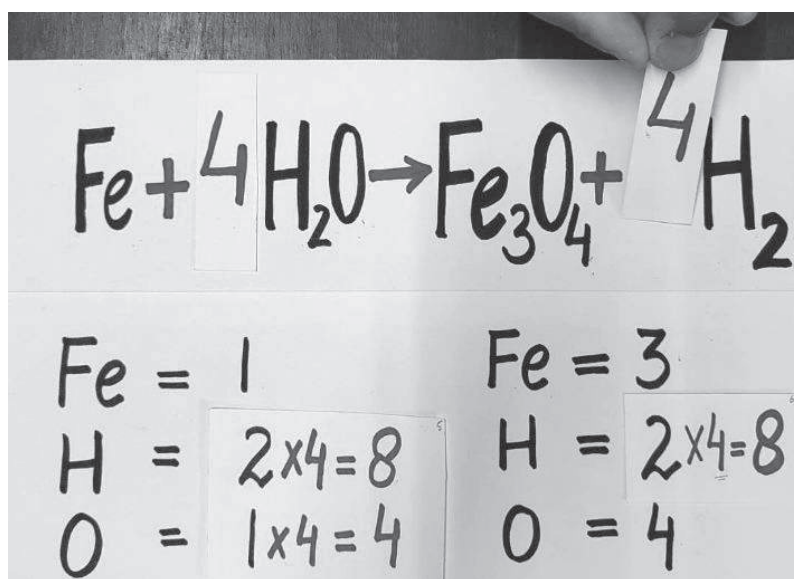
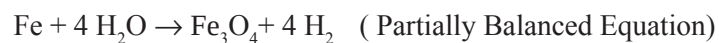


Figure 19

STOP 5: Then they picked up the third element Fe and balanced it by adding coefficient 3 to make 3 atoms of Fe on LHS. (Figure20)

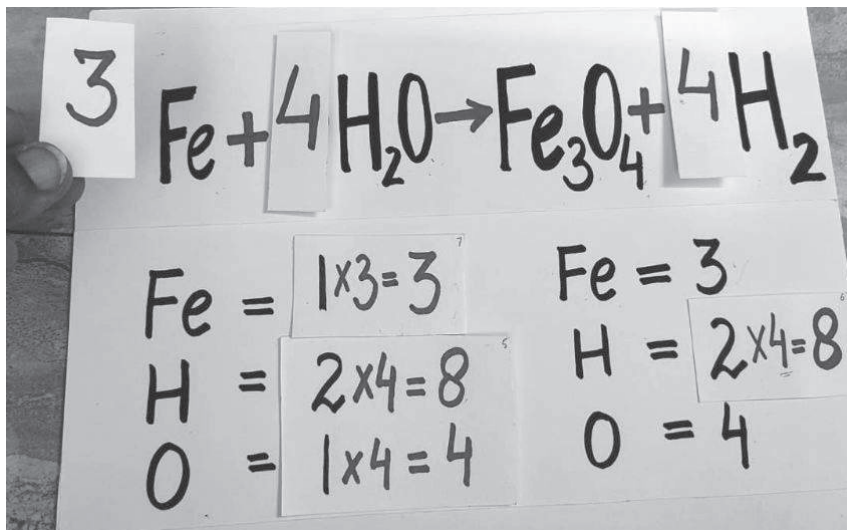


Figure 20



STOP 6: Students here were told that to make a chemical equation more informative, the physical states of the reactants and products are mentioned along with their chemical formulae.

The balanced equation thus became- (Figure 21)

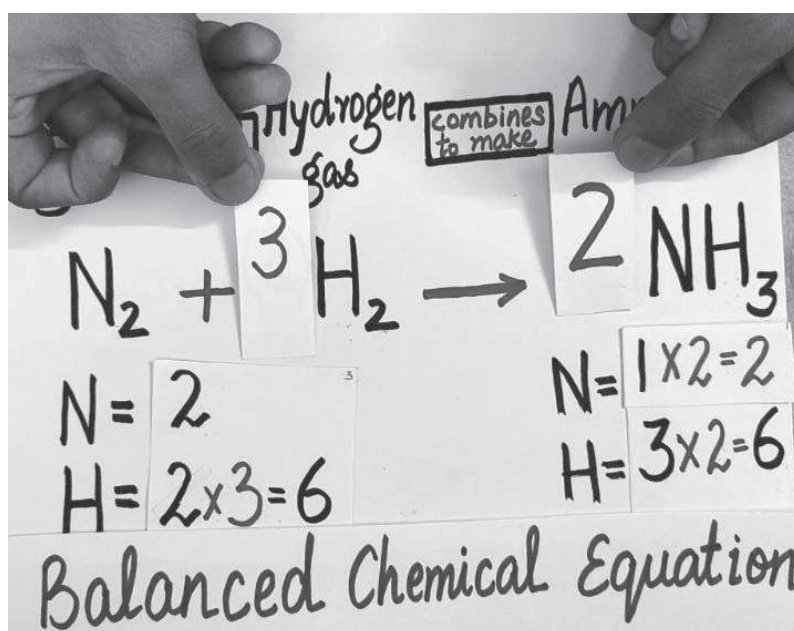


Figure 21

Assessment Task:

Towards the end of the session all the students were given the reaction -

“Nitrogen gas and Hydrogen gas combine to form Ammonia” to balance. Almost all the students balanced it correctly, some used the cut out method and others used the tabular form. (Figures 22 and 23) Students’ excitement new no bound when they placed the correct coefficient in front of the molecules.

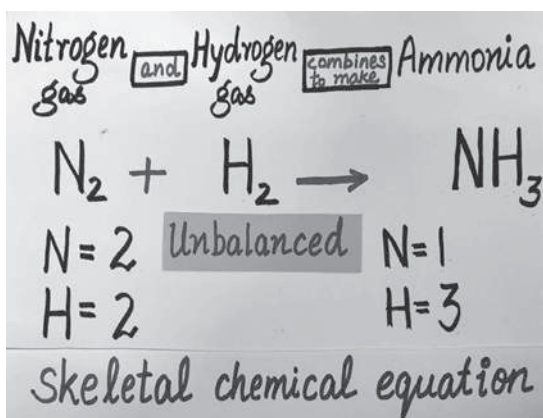


Figure 22

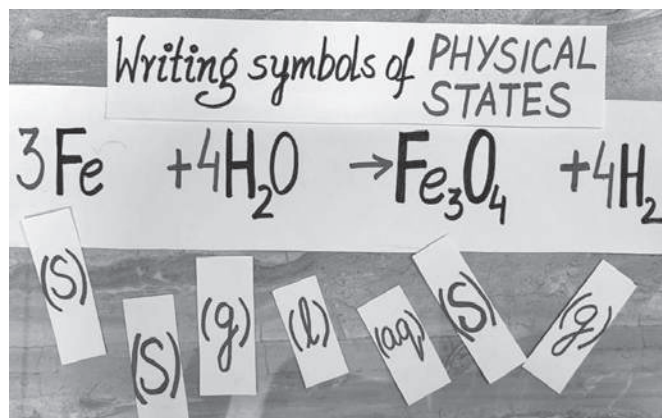


Figure 23

Conclusion

Students were interviewed when the session was over (Annexure 1) and to assess students’ understanding of the basic chemical concepts involved in writing of Chemical equation: recognition, manipulation, writing, balancing, the meaning of plus sign (+) in each side, the meaning of arrow sign ($\rightarrow$), role of coefficient, the relation between subscript and coefficient.

The interview session allowed students to ask questions, to clarify actual ambiguities before answering and also giving flexibility in discussing reasons for particular answers (Gilbert, Osborne, & Fensham 1982). It was clear from their answers that now students were able to visualize the microscopic level of chemical reactions while balancing Chemical Equations. This became possible only when a culture of excitement, curiosity, open thinking and exploration was created. It was observed that the students who participated in this study attempted all the questions related to the Balancing of Chemical Equations and gave correct responses in the term end exam as well, which established that there was retention of the concepts taught through innovative ways. An important implication of the study is that teaching-learning of Balancing of Chemical Equations by Innovative methods resulted in high level of achievement in terms of scores and deep understanding of concepts. In classrooms, there are different categories of learners who have varying needs. Therefore, different methods must be adopted in the planning and delivery of lessons to ensure that such needs are addressed.

An important implication of the study is that curriculum planners can take a hint from the curious questions/ responses of the learners and design innovative models/games on the science topics. In an increasingly complex and changing pedagogical context, it is vital for teachers to move away from traditional way of teaching and embrace pedagogical shift in science education by providing more opportunities to students for scientific exploration and making it inclusive and meaningful.

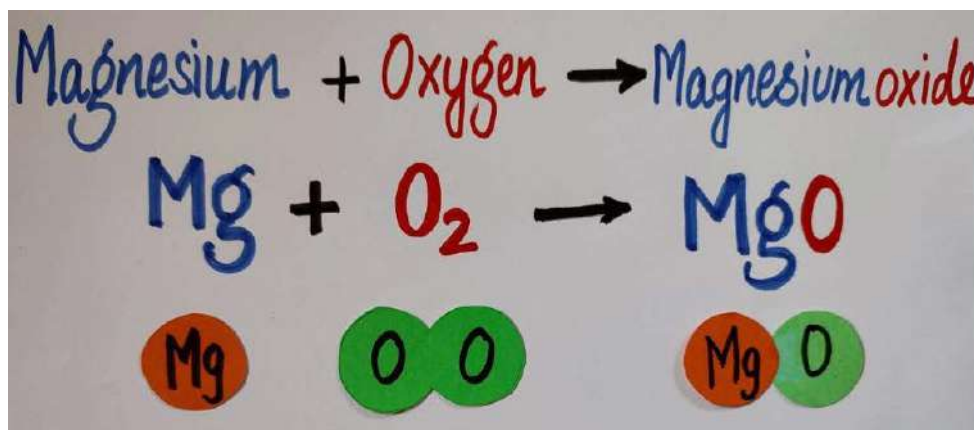


Figure 1

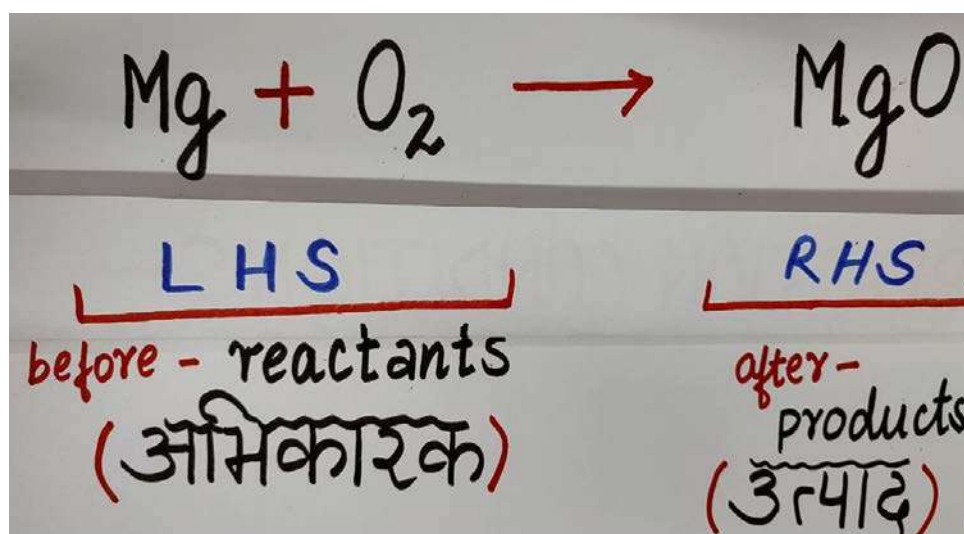


Figure 2

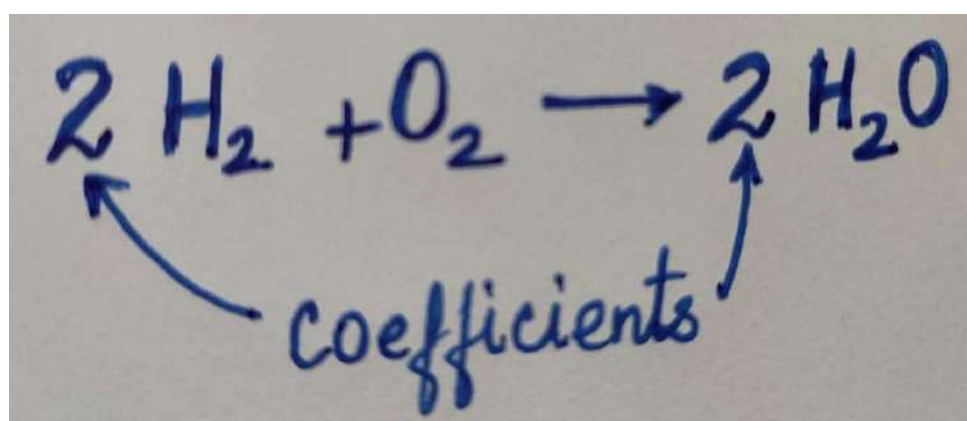


Figure 3

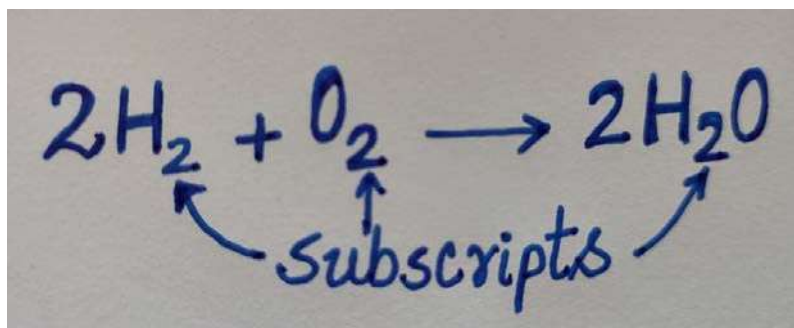


Figure 4



Figure 5

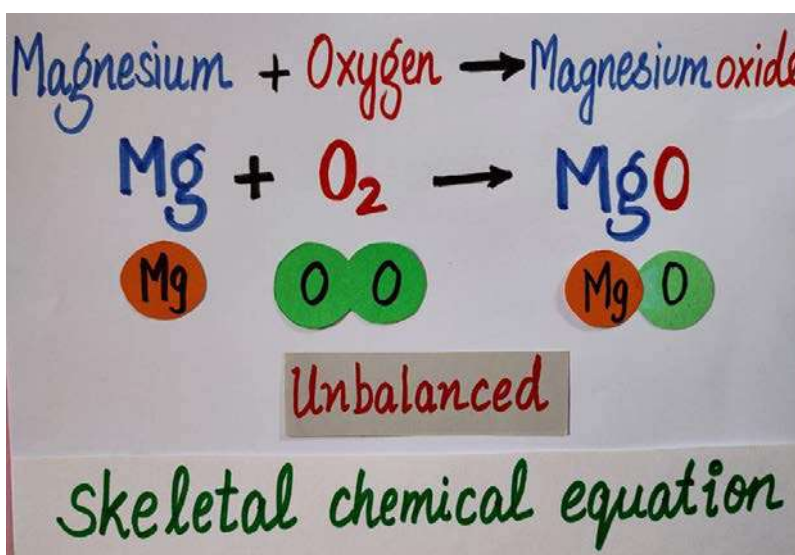


Figure 6

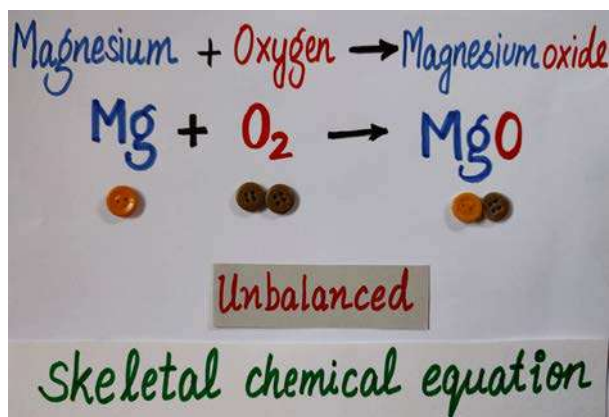


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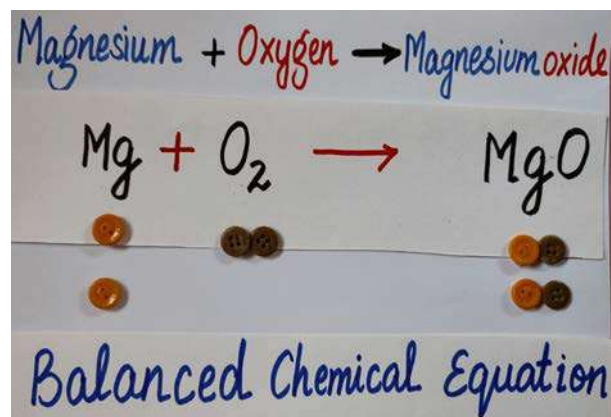


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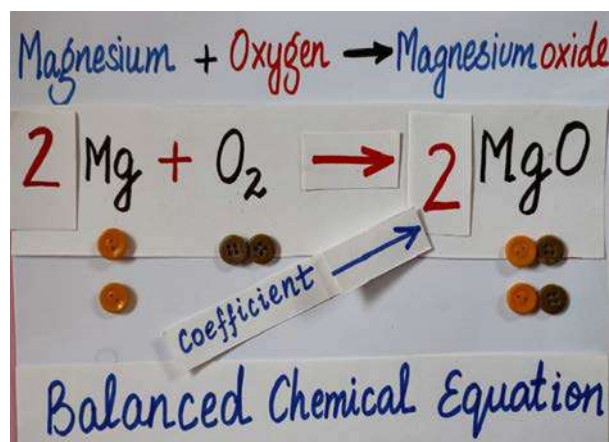


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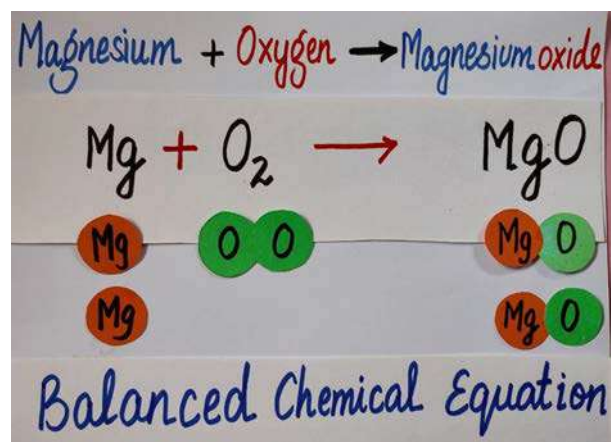


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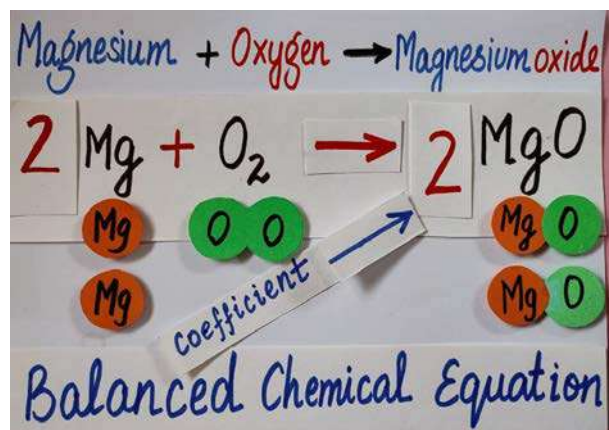


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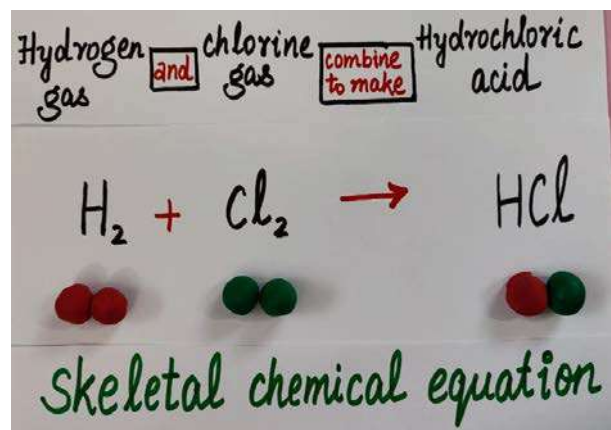


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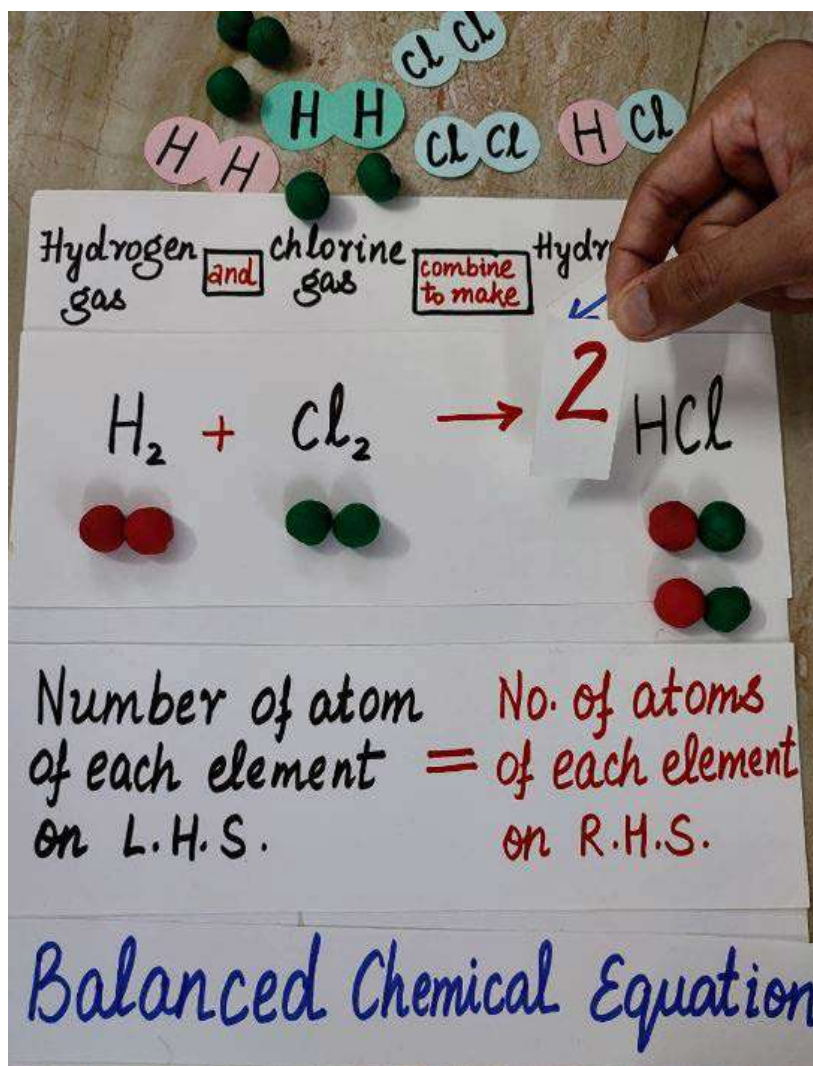


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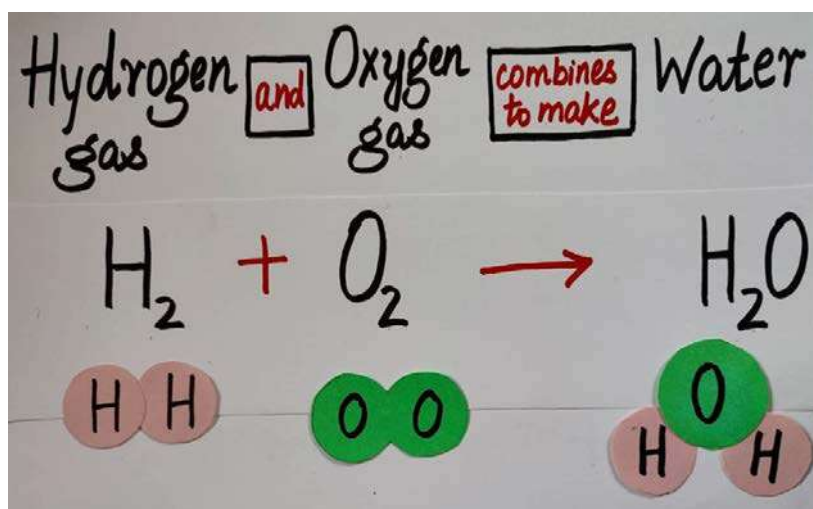


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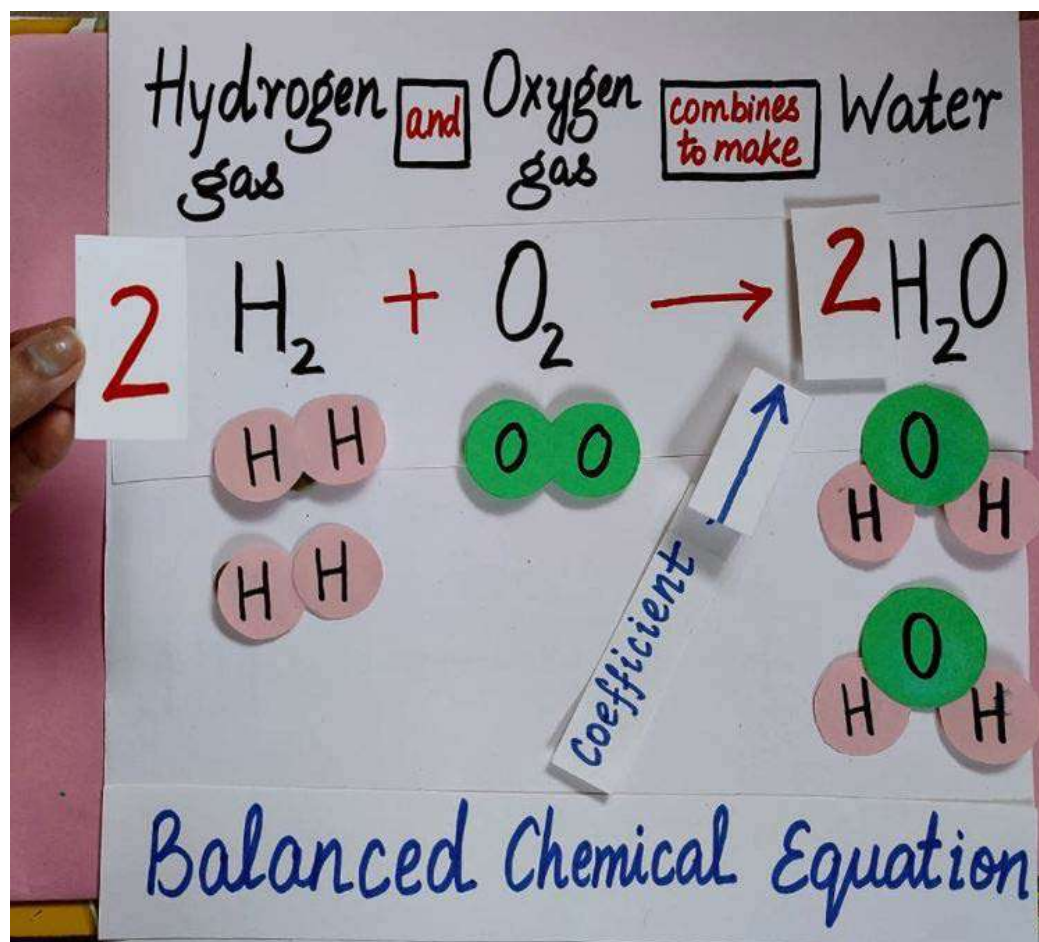


Figure 15

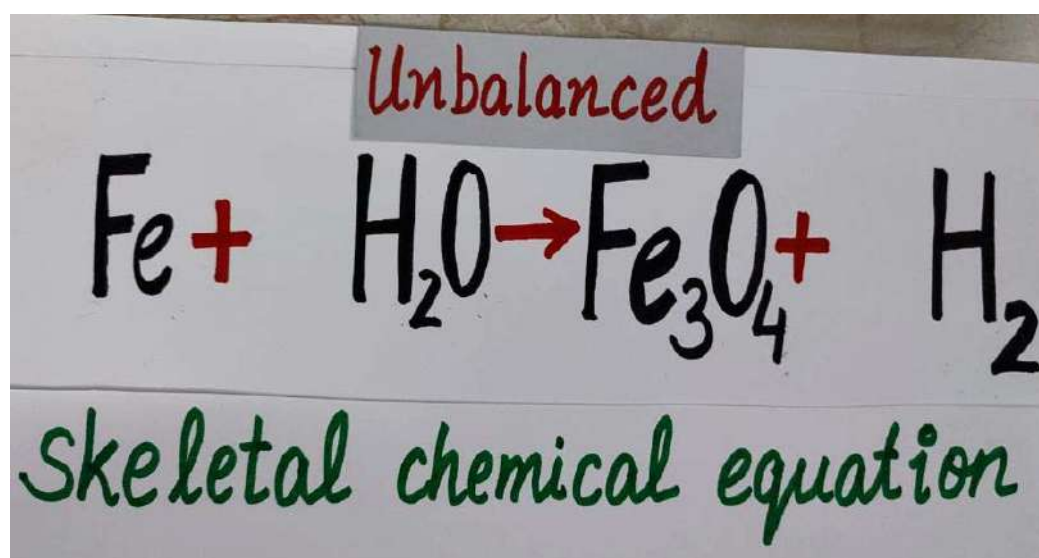


Figure 16

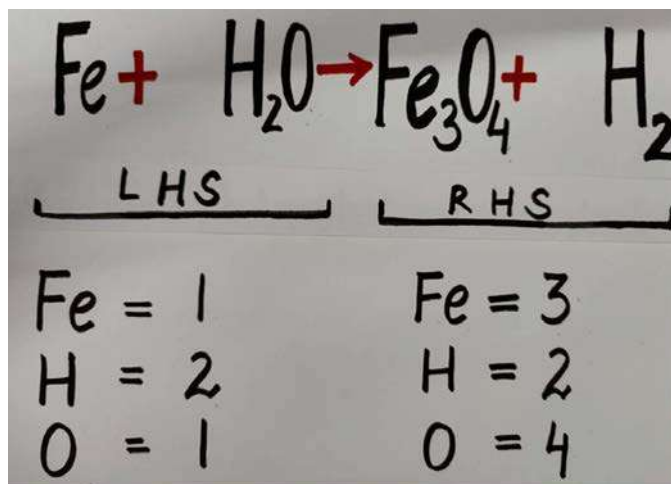


Figure 17

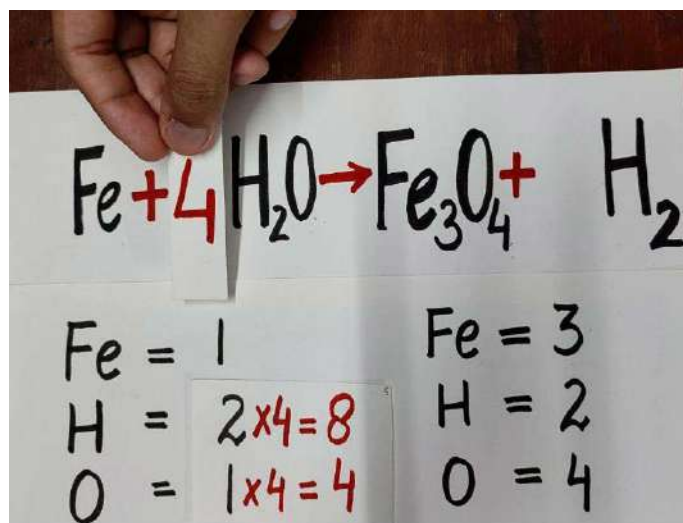


Figure 18

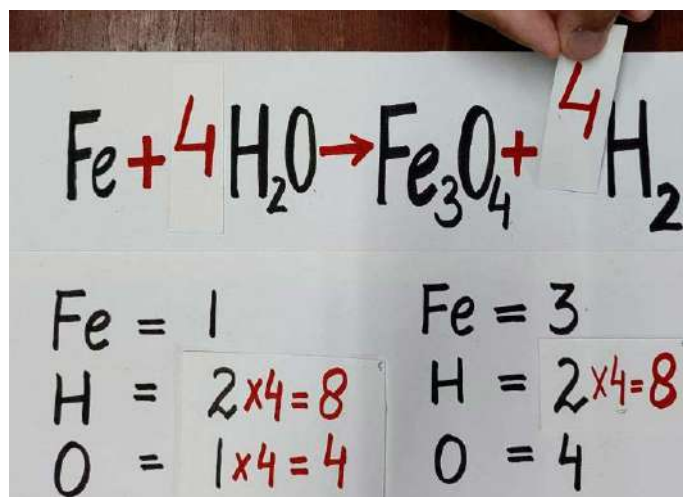


Figure 19

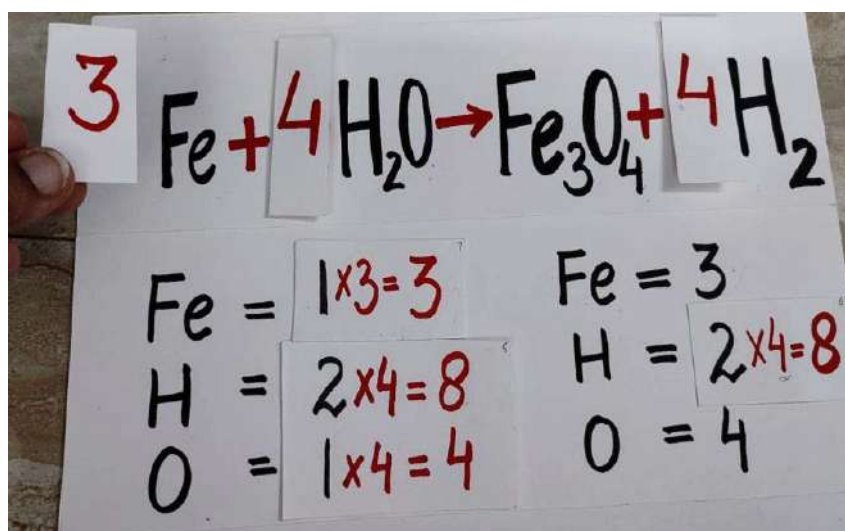


Figure 20

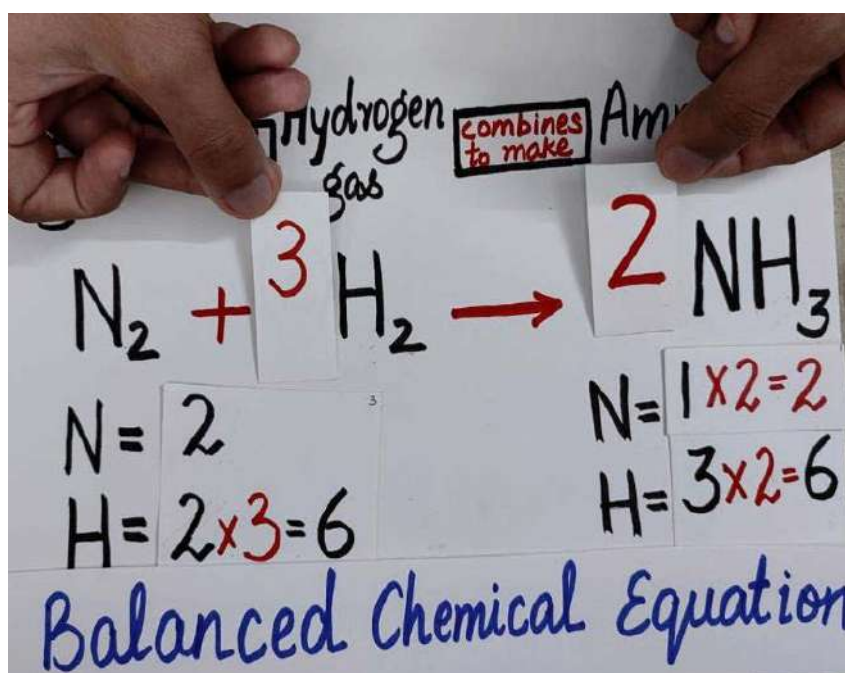


Figure 21

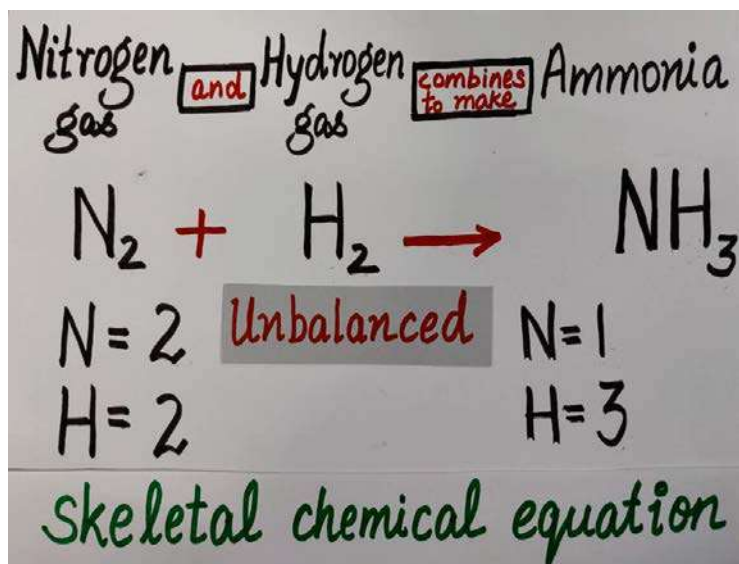


Figure 22

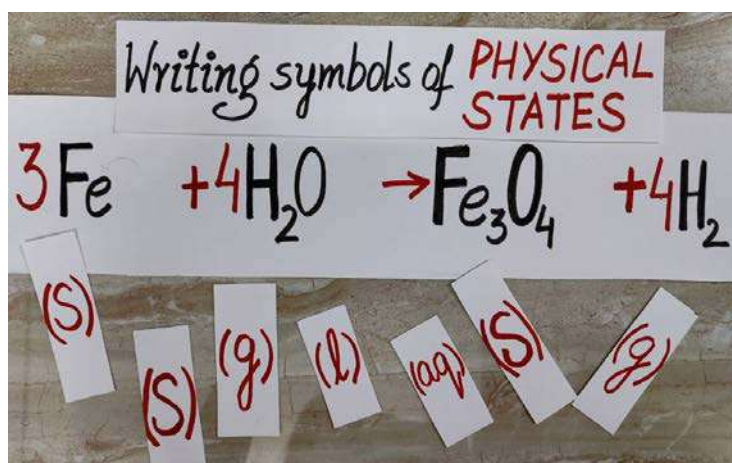


Figure 23

Annexure 1

Interview Questions (Al-kunifed, Ali Abdallah, 1993)

What is the significance of a chemical equation?

What is the role of arrow ($\rightarrow$) in a chemical equation?

How do you read the plus (+) signs on the left and on the right side of the chemical equation?

What is the difference between Coefficient and Sub-script ?

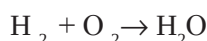
What is the need to balance a chemical equation?

Do you use chemical symbols or chemical formulas while writing a chemical equation?

What does a chemical symbol represent?

What does a chemical formula represent?

While balancing the following equation-



One student balanced it as $\text{H}_2 + \text{O}_2 \rightarrow \text{H}_2\text{O}_2$.

What is this correct way of Balancing a Chemical Equation.

What is the difference between the left and right sides of the chemical equation?

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