Scope, Sequence & Coordination

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Student Materials

Learning Sequence Item:

963

Chemical Formulas for Molecules

March 1996
**Adapted by: Jesse Jones and Dorothy Gabel*

Contents

This micro-unit was adapted by **Jesse Jones** (Rocky Mount, N.C.) and **Dorothy Gabel** (Indiana Univ., Bloomington, Ind.)

Science as Inquiry

Water + O

How do the properties of water and hydrogen peroxide differ?

Overview:

The formula for water contains one less oxygen than that of hydrogen peroxide. What differences does this make in its properties?

Procedure:

Compare the chemical activity of water and hydrogen peroxide with potatoes, with manganese dioxide, and on colored cloth. Place 20 mL of water and hydrogen peroxide in two separate test tubes and add a small cube of potato to each. Observe what happens. Test any gas that evolves. To test for hydrogen gas place a burning splint near the mouth of the test tube. If hydrogen is present, it will burn with a pop. To test for oxygen gas, hold a glowing splint (one that was flaming, but now blown out) in the test tube. If oxygen is present, it will burst into flame. Once the gas bubbles have diminished, then add the same piece of potato to a new sample of hydrogen peroxide and note that the potato what happens. Repeat this activity substituting a pinch of manganese dioxide for the potato.

Obtain some strips of colored cloth. Add some stains to the cloth. Place these in test tubes containing water and hydrogen peroxide. Note the results.

Write the formulas for water and hydrogen peroxide. Construct models of each using balls and sticks.

Questions:

1. Describe the differences in the reactivity of water and hydrogen peroxide.

2. A catalyst is a substance that speeds up a chemical reaction yet does not undergo any permanent change itself. Were any catalysts used in this activity?

3. How much hydrogen peroxide do you think a piece of potato that is 1 cm on a side could decompose?

4. Is hydrogen peroxide a good bleach? Give arguments for your decision.

5. Indicate the number of each kind of atom in the following formulas: H_2SO_4, $Ca_3(PO_4)_2$, $Pb(NO_3)_2$, 5NaCl, $6H_2O$.

6. What is the difference between $2H_2$ and 4H? Draw circles representing atoms to illustrate the difference.

Science as Inquiry

Formulas and Molecules

How do the properties of substances with closely related formulas differ from one another?

Overview:

Examine the differences in the properties of pairs of compounds each having similar formulas.

Procedure:

Copper reacts with chloride to form CuCl (copper (I) chloride) and $CuCl_2$ (copper (II) chloride). Compare the physical appearance of copper (I) chloride and copper (II) chloride.

Cobalt chloride exists in both the anhydrous (without water) and hydrated forms (with water). Dissolve one teaspoon of $CoCl_2 \cdot 6H_2O$ in about 20 mL of water. Place in an evaporating dish. Take a piece of filter paper and cut it into a coil or make it into a flower. Dip this in the cobalt chloride solution being careful not to touch the solution. Use tongs. Hold the filter paper in the stream of hot air produced by a hair dryer. Note the difference in color of the hydrate and the anhydrous forms of cobalt chloride. You may wish to attach the flower to a pipe cleaner "stem!"

Copper sulfate can exist in the hydrated form as $CuSO_4 \cdot 5H_2O$, or as anhydrous $CuSO_4$. Note the appearance of the hydrated copper sulfate. Then place a few crystals of hydrated copper sulfate in a test tube. Light a Bunsen burner. Using a test tube holder, hold the test tube containing the crystals almost horizontally—slant it slightly downward. Heat the crystals, and note what happens. Test the liquid to determine whether it is water.

Questions:

1. What conclusion can you reach about the relationship of the chemical formula of a compound to its physical appearance?

2. What is the test for water?

3. Suppose you added a few drops of rubbing alcohol to a piece of blue cobalt chloride paper. Predict what you think would happen? Explain.

4. Tell how many atoms of each element are present in the following :

   $CoCl_2 \cdot 2H_2O$
   $4CuSO_4 \cdot 5H_2O$
   $3Al_2(SO_4)_3 \cdot 9H_2O$

Science as Inquiry

Accounting for Atoms

What happens to atoms in chemical reactions?

Overview:

Chemical reactions occur all around you. Chemists represent chemical reactions using equations. Before they can do this, they must first identify the reactants and products of the reaction. They then represent the reaction with a chemical equation. After observing some chemical reactions, you will write some chemical equations.

Procedure:

You will first observe a series of chemical reactions. Before making any observations, prepare a data table to record the appearance of each reactant and each product for the six reactions that you will observe.

A. You have probably observed charcoal burning in a barbecue grill. Charcoal is made by heating wood in the absence of air. It consists primarily of carbon, but contains some mineral deposits. Hold a piece of charcoal with a pair of tongs and place it in the Bunsen burner flame.

B. Methane gas is a natural gas found in deposits in the earth. Light your Bunsen burner and observe methane gas burning.

C. Butane gas is another natural gas and is commonly found in cigarette lighters. Light a butane lighter and observe butane burning.

D. Carbonated beverages contain carbonic acid, which gives the soft drink a slightly sour taste. When you open the bottle or can, the drink goes "flat." This happens when the carbonic acid decomposes.

E. Silverware tarnishes when it comes in contact with certain foods. Eggs cause this to happen. Pour some egg yolk on a silver utensil, and note what happens.

F. Iron nails in a moist environment rust. Examine a new iron nail and one that has rusted. You may wish to moisten the new one and look at it the following week.

Questions:

1. Listed below are the chemical formulas for the reactants and products of all substances involved in the reactions of A through F. The formulas are scrambled. Using balls and sticks (or as directed by your teacher), make a model of each of the substances.

water	H_2O	**carbon dioxide**	CO_2	**iron oxide**	Fe_3O_4
carbonic acid	H_2CO_3	**silver sulfide**	Ag_2S	**carbon**	**C**
methane	CH_4	**butane**	C_4H_{10}	**sulfur**	**S**
silver	**Ag**	**oxygen**	O_2	**iron**	**Fe**

2. Use the data table of your observations to write a word equation for each of the reactions that occurred in A.

3. For the reaction in A, match each substance in the word equation with the model you have made.

4. Now count the number of each kind of atoms in each reactant and in each product. Record beneath the reactants and products in the word equation.

5. How does the number of atoms of each element in the reactants compare to the number in the products? If they are equal write a chemical equation under your word equation using coefficients of “1” before each substance. The equation is said to be “balanced” because the numbers of atoms of each element on the reactants is equal to the number of atoms of each element in the products.

If they are not equal, create models of more molecules of reactants or products so that the number of atoms of each element in the reactants are equal to the number of atoms of each element in the products. Then write a formula equation using the number of models of each substance that you created as the coefficient in front of the formula for that substance (model).

6. Repeat steps 2 through 5, for B through F.

7. Explain how the conservation of atoms is related to the conservation of mass.

8. Is each of the following equations are atoms conserved? Describe how you made your decision.
   a. $H_2O = H_2 + O_2$
   b. $NaHCO_3 + HCl = NaCl + H_2O + CO_2$
   c. $C_3H_8 + 3O_2 = 3CO_2 + 4H_2O$

History and Nature of Science

Galileo's Atomism

Now this which has been said concerning simple lines must be understood to hold also in the case of surfaces and solid bodies, it being assumed that they are made up of an infinite, not a finite number of atoms. Such a body once divided into a finite number of parts it is impossible to reassemble them so as to occupy more space than before unless we interpose a finite number of empty spaces, that is to say, spaces free from the substance of which the solid is made. But if we imagine the body, by some extreme and final analysis, resolved into its primary elements, infinite in number, then we shall be able to think of them as indefinitely extended in space, not by the interposition of a finite, but of an infinite number of empty spaces. Then one can easily imagine a small ball of gold expanded into a very large space without the introduction of a finite number of empty spaces, always provided the gold is made up of an infinite number of indivisible parts.

SIMP. It seems to me that you are traveling along toward those vacua advocated by a certain ancient philosopher, b.

SALV. But you have failed to add, "who denied Divine Providence," an inapt remark made on a similar occasion by a certain antagonist of our Academician.

SIMP. I noticed, and not without indignation, the rancor of this ill-natured opponent; further references to these affairs I omit, not only as a matter of good form, but also because I know how unpleasant they are to the good tempered and well ordered mind of one so religious and pious, so orthodox and God-fearing as you.

But to return to our subject, you previous discourse leaves me with so many difficulties which I am unable to solve. First among these is that, if the circumference of the two circles are equal to the straight lines, CE and BF, the latter considered as a continuum, the former as interrupted with an infinity of empty point, I do not see how it is possible to say that the line AD described by the center, and made up of an infinity of points, is equal to this center which is a single point. Besides, this building up of lines out of points, divisibles out of indivisibles, and finites out of infinities, offers me an obstacle difficult to avoid; and the necessity of introducing a vacuum, so conclusively refuted by Aristotle, presents the same difficulty.

SALV. These difficulties are real; and they are not the only ones. But let us remember that we are dealing with infinities and indivisibles, both of which transcend our finite understanding, the former on account of their magnitude, the latter because of their smallness. In spite of this, men cannot refrain from discussing them, even though it must be done in a round-about way . . . . I am willing, Simplicio at the outset, to grant the Peripatetics the truth of their opinion that a continuous quantity is divisible only into parts which are still further divisible so that however far the division and subdivision be continued no end will be researched; but I am not so certain that they will concede to me that none of these divisions of

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Reprinted from Galileo, *Two New Sciences*, Translated by Crew and de Salvio, pp. 25–26, 48–49, 52–53, 55. Permission pending.

theirs can be final one, as is surely the fact, because there always remains “another;” the final and ultimate division is rather one which resolves a continuous quantity into an infinite number of indivisible quantities, a result which I grant can never be researched by successive division into an ever- increasing number of parts. But if they employ the method which I propose for separating and resolving the whole of infinity at a single stroke (an artifice which surely ought not be denied me), I think that they would be contented to admit that a continuous quantity is built up out of absolutely indivisible atoms, especially since this method, perhaps better than any other, enables us to avoid many intricate labyrinths, such as cohesion in solids, already mentioned, and the question of expansion and contraction, without forcing upon us the objectionable admission of empty spaces in solids which carries with it the penetrability of bodies. Both of these objections it appears to me, are avoided if we accept the above mentioned view of indivisible constituents.

SIMP. I hardly know what the Peripatetics would say since the views advanced by you would strike them mostly new, and as such we must consider them. It is however not unlikely that they would find answers and solutions for these problems which I, for want of time and critical ability, am at present unable to solve. Leaving this to one side for the moment, I should like to hear how the introduction of these indivisible quantities helps us to understand contraction and expansion avoiding at the same time the vacuum and the penetrability of bodies . . . .

SALV. I do not know whether you have observed the method employed by those who are skilled in drawing gold wire, of which really only the surface is gold, the inside material being silver. The way they draw it is as follows: they take a cylinder or, if you please, a rod of silver, about half a cubit long and three or four times as wide as one’s thumb; this rod they cover with gold-leaf which is so thin that it almost floats in air, putting on not more than eight or ten thicknesses, Once gilded they begin to pull it, with great force, through the holes of a draw-plate; again and again it is made to pass through smaller and smaller holes, until, after very many passages, it is reduced to the fineness of a lady’s hair, or perhaps even finer; yet the surface remains gilded. Imagine now how the substance of this gold has been expanded and to what fineness it has be reduced . . . . Consider now what degree of fineness it must have and whether one could conceive it to happen in any other way than by enormous expansion of parts; consider also whether this experiment does not suggest that physical bodies are composed of infinitely small indivisible particles, a view which is supported by other more striking and conclusive examples. ❖

History and Nature of Science

Descartes on the Nature of Bodies

IV. That the nature of body consists not in weight, hardness, colour, and the like, but in extension alone.

In this way we will discern that the nature of matter or body, consider in general, does not consist in its being hard, or ponderous, or coloured, or that which affects our senses in any other way, but simply in its being a substance extended in length, breadth, and depth. For, with respect to hardness, we know nothing of it by sense farther than that the parts of hard bodies resist the motion of our hands on coming into contact with them; but if every time our hands moved towards any part, all the bodies in that place receded as quickly as our hands approached, we should never feel hardness; and yet we have no reason to believe that bodies which might thus recede would on this account lose that which makes them bodies. The nature of body does not, therefore, consist in hardness. In the same way, it may be shown that weight, colour, and all the other qualities of this sort, which are perceived in corporeal matter, may be taken from it, itself mean while remaining entire: it thus follows that the nature of body depends on none of these . . . .

XI. How space is not in reality different from corporeal substance.

And indeed it will be easy to discern that it is the same extension which constitutes the nature of body as of space, and that these two things are mutually diverse only as the nature of genus and species differs from that of the individual, provided we reflect on the idea we have of anybody, taking a stone for example, and reject all that is not essential to the nature of body. In the first place, then, hardness may be rejected, because if the stone were liquefied or reduced to powder, it would no longer possess hardness, and yet would not cease to be a body; colour also may be thrown out of account, because we have frequently seen stones so transparent as to have no colour; again, we may reject weight, because we have the case of fire, which, though very light, is still a body; and, finally, we may reject cold, heat, and all the other qualities of this sort, either because the are not considered as in the stone, or because, with the change of these qualities, the stone is not supposed to have lost the nature of body. After this examination we will find that nothing remains in the idea of body, except that it is something extended in length, breadth, and depth; and this something is comprised in our idea of space, not only of that which is full of body, but even of what is called void space.

XVI. That a vacuum or space in which there is absolutely no body is repugnant to reason.

With regard to a vacuum, in the philosophical sense of the term, that is, a space in which there is no substance, it is evident that such does not exist, seeing the extension of space or internal place is not different from that of body. For since from this alone, that a body has extension in length, breath,

Reprinted from Descartes, R., *A Discourse on Method*, London, 1949, pp. 200–201, 204, 207, 209–210, 222–226. Permission pending.

and depth, we have reason to conclude that it is a substance, it being absolutely contradictory that nothing should possess extension, we ought to form a similar inference regarding the space which is supposed void, viz., that since there is extension in it there is necessarily also substance.

XVII. That a vacuum in the ordinary use of the term does not exclude all body.

And, in truth, by the term vacuum in its common use, we do not mean a place or space in which there is absolutely nothing, but only a place in which there is none of those things we presume ought to be there. Thus, because a pitcher is made to hold water, it is said to be empty when it is merely filled with air; or if there are no fish in a fish-pond, we say there is nothing in it, although it be full of water; thus a vessel is said to be empty, when, in place of the merchandise which it was designed to carry, it is loaded with sand only, to enable it to resist the violence of the wind; and, finally, it is in the same sense that we say space is void when it contains nothing sensible, although it contain created and self-subsisting matter; for we are not in the habit of considering the bodies near us, unless in so far as they cause in our organs of sense impressions strong enough to enable us to perceive them. And if, in place of keeping in mind what ought to be understood by these terms a vacuum and nothing, we afterwards suppose that in the space we b called a vacuum, there is not only no sensible object, but no object at all, we will fall into the same error as if, because a pitcher in which there is nothing but air, is, in common speech, said to be empty, we were therefore to judge that the air contained in it is not a substance (*res subsistens*).

XX. That from this the non-existence of atoms may likewise be demonstrated.

We likewise discover that there cannot exist any atoms or parts of matter that are of their own nature indivisible. For however small we suppose these parts to be yet because they are necessarily extended, we are always able in thought to divide any one of them into two or more smaller parts, and may accordingly admit their divisibility. For there is nothing we can divide in thought which we do not thereby recognize to be divisible; and, therefore, were we to judge it indivisible our judgment would not be in harmony with the knowledge we have of the thing; and although we should even suppose that God had reduced any particle of matter to a smallness so extreme that it did not admit of begin further divided, it would nevertheless be improperly styled indivisible, for though God had rendered the particle so small that it was not in the power of any creature to divide it, he could not however deprive himself of the ability to do so, since it is absolutely impossible for him to lessen his own omnipotence, as was before observed.

Wherefore, absolutely speaking, the smallest extended particle is always divisible, since it is such of its very nature.

XXIII. That all the variety of matter, or the diversity of its form, depends on motion.

There is therefore but one kind of matter in the whole universe, and this we know only by its being extended. All the properties we distinctly perceive to belong to it are reducible to its capacity of being divided and moved according to its parts; and accordingly it is capable of all those affections which we perceive can arise from the motion of its parts. For the partition of mater in thought makes no change in it; but all variation of it, or diversity of form, depends on motion. The philosophers even seem universally to have observed this, for they said that nature was the principle of motion and rest, and by nature they understood that by which all corporeal things become such as they are found in experience.

XIV. That sensible bodies are composed of insensible particles.

But I allow many particles in each body that are perceived by none of our senses, and this will not perhaps be approved of by those who take the senses for the measure of the knowable.

We greatly wrong human reason, however, as appears to me, if we suppose that it does not go beyond the eyesight; for no one can doubt that there are bodies so small as not to be perceptible by any of our senses, provided he only consider what is each moment added to those bodies that are being increased little by little, and what is taken from those that are diminished in the same way. A tree increases daily and it is impossible to conceive how it becomes greater than it was before, unless we at the same time conceive that some body is added to it. But who ever observed by the senses those small bodies that are in one day added to a tree while growing?

Among the philosophers at least, those who hold that quantity is indefinitely divisible, ought to admit that in the division the parts may become so small as to be wholly imperceptible. And indeed it ought not to be a matter of surprise that we are unable to perceive very minute bodies; for the nerves that must be moved by objects to cause perception are not themselves very minute, but are like small cords, being composed of a quantity of smaller fibres, and thus the most minute bodies are not capable of moving them. Nor do I think that anyone who makes use of his reason will deny that we philosophise with much greater truth when we judge of what takes place in those small bodies which are imperceptible from their minuteness only, after the analogy of what we see occurring in those we do perceive (and in this way explain all that is in nature, as I have essayed to do in this treatise), than when we give an explanation of the same things by inventing I know not what novelties, that have no relation to the things we actually perceive (as first matter, substantial forms, and all that grand array of qualities which many are in the habit of supposing, each of which it is more difficult to comprehend than all that is professed to be explained by means of them).

XV. That the philosophy of Democritus is not less different from ours than from the common.

But it may be said that Democritus also supposed certain corpuscles that were of various figures, sizes, and motion, from the heaping together and mutual concourse of which all sensible bodies arose; and, nevertheless, his mode of philosophizing is commonly rejected by all. To this I reply that the philosophy of Democritus was never rejected by anyone, because he allowed the existence of bodies smaller than those we perceive, and attributed to them diverse sizes, figures, and motions, for no one can doubt that there are in reality such, as we have already shown; but it was rejected, in the first place, because he supposed that these corpuscles were indivisible, on which ground I also reject it; in the second place, because he imagined there was a vacuum about them, which I show to be impossible; thirdly, because he attributed gravity to these bodies, of which I deny existence in any body, in so far as a body is considered by itself, because it is a quality that depends on the relations of situation and motion which several bodies bear to each other; and, finally, because he has not explained in particular how all things arose from the concourse of corpuscles alone, or, if he gave this explanation with regard to a few of the, his whole reasoning was far from being coherent (or such as would warrant us in extending the same explanation to the whole of nature). This, at least, is the verdict we must give regarding his philosophy, if we may judge of his opinions from what has been handed down to us in writing. I leave it to others to determine whether the philosophy I profess possesses a valid coherency (and whether on its principles we can make the requisite number of deductions; and, in as much as the consideration of figure, magnitude, and motion has been admitted by Aristotle and by all the other, as well as by Democritus, and since I reject all that the latter has supposed, with this single exception, while I reject generally all that has been supposed by the others, it is plain that this modes of philosophizing has no more affinity with that of Democritus than of any other particular sect).

XVI. How may we arrive at the knowledge of the figures (magnitudes), and motions of the insensible particles of bodies.

But, since I assign determinate figures, magnitudes, and motions to the insensible particles of bodies, as if I had seen them, whereas I admit that they do not fall under the senses, some one will perhaps demand how I have come by my knowledge of them, (to this I reply, that I first considered in general all the clear and distinct notions of material things that are to be found in our understanding, and that, finding no others except those of figures, magnitudes, and motions, and of the rules according to which these three things can be diversified by each other, which rules are the principles of geometry and mechanics, I judged that all the knowledge man can have of nature. must of necessity be drawn from this source; because all the other notions we have of sensible things, as confused and obscure, can be of no avail in affording us the knowledge of anything out of ourselves, but must serve rather to impede it). Thereupon, taking as my ground of inference the simplest and best known of the principles that have been implanted in our minds by nature, I considered the chief differences that could possibly subsist between the magnitudes, and figures, and situations of bodies insensible on account of their smallness alone, and what sensible effects could be produced by their various modes of coming into contact; and afterwards, when I found like effects in the bodies that we perceive by our senses, I judged that they could have been thus produced,, especially since no other mode of explaining them could be devised. And in this matter the example of several bodies made by art was of great service to me; for I recognize no difference between these and natural bodies beyond this, that the effects of machines depend for the most part on the agency of certain instruments, which, as they must bear some proportion to the hands of those who make them, are always so large that their figures and motions can be seen: in place of which, the effects of natural bodies almost always depend upon certain organs so minute as to escape our senses. And it is certain that all the rules of mechanics belong also to physics, of which it is a part or species (so that all that is artificial is withal natural): For it is not less natural for a clock, made of the requisite number of wheels, to mark the hours, than for a tree, which has sprung from this or that seed, to produce the fruit peculiar to it. Accordingly, just as those who are familiar with automata, when they are informed of the use of a machine, and see some of its parts, easily infer from these the way in which the others, that are not seen by them, are made; so from considering the sensible effects and parts of natural bodies, I have essayed to determine the character of their causes and insensible parts. ◆