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III

Salts, Acids and Bases: Chemistry in Grade 10

Crystallization of Salts

In this class, we start with salts—that is with substances which being crystalline are totally earthy, but earth that is strongly, regularly-formed and transparent.

With that we have also exactly struck a theme which is so important for students of this age. They have gone through puberty, and the subtle connections they still had with the cosmos have been severed now, for the most part. They have now become earth-dwellers and must learn to orient themselves with clear thoughts in this realm, which is for them as yet, unknown. Their life, which for their consciousness takes place in first instance on earth, must be given structure through the power of thinking. Their thinking must be so strengthened that it can order the multitude of individual phenomena, but it should also remain so sensitive, so subtle, that it can really grasp the noble organization of the universe.

The whole main lesson block should have the following style: a pronounced clear conceptual structure, that orders the wealth of phenomena, through which it becomes possible to understand and even to use this structure. A nobly shaped, beautifully colored salt crystal can actually become an ideal for us, when thinking about this main lesson.

We start by showing a number of crystals. From the beginning, it is a good habit to use certain devices, so that the impressions become as expressive and characteristic as possible. Such a transparent substance with its shining surfaces doesn't show up very well on white paper. On black paper and with illumination from the side it shows an exiting beauty.

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We could perhaps let some salts crystallize beforehand: table salt, copper sulfate, potassium nitrate and others. A wonderful fresh brilliance and beauty meets the eye, if we choose the proper lighting.

If now we reflect on the essence of salts, then we should stress their marvelous precise shape, their transparency and clarity. The real wonder of salts only becomes evident when we consider them in relation to the whole of nature. The salt is earthy, dense, rigid matter, and yet it opens itself to a large extent to the play of light. Actually, the earthy region beneath us is dark, dull, silent and pressing, while in the region above the earth light weaves in a very rarefied, clear world. The greatest contrast exists between the realm of light above and the realm of matter below us. The salt crystal, which actually belongs to the realm of heaviness, is nevertheless largely open to raying-in from the realm of light.

We may take the following thought for our own consideration: In primeval times, matter was separated from the realm of light and condensed. Light has become rarefied; matter has lost its ability to shine on its own and is subject to gravity. Such a crystal shows its isolation from light to a high degree. In its essence it exhibits the *memory* of light, but just because of that it can make such a dull, empty impression on us. If we illuminate it in such a way that it seems as if it is shining of its own accord (backlit or from beneath), then we can achieve a splendid effect. In a sense, we raise it up from its fall and bring it back to its origin. That can be done in various ways. For example, cut small holes in a piece of black paper; in front of every opening place a well-formed salt crystal. Then, darken the room and illuminate the holes one after the other. Then the crystals will radiate beautifully. We can also show crystallization in front of a dark screen strongly illuminated from the side. For example, take a saturated solution of table salt and add some concentrated hydrochloric acid. That gives rise to a magnificent brilliance of crystals, which very often may be so small that individual ones cannot clearly be distinguished. When the crystals are somewhat larger, they are seen forming themselves like delicate clouds, slowly sinking to the bottom, white and pure as freshly-fallen snow.

To experiment on a large scale, use a 3-litre conical flask filled with a hot, nearly saturated solution of potassium nitrate. When the carefully wrapped up flask is allowed to cool slowly, the crystals build enchanting forms—impressive highly transparent shapes with a subtle play of color (the slower, the better the crystals—editor's note).

Crystallization in general, but especially with table salt, evokes the image of the primordial coming-into-being of matter, the original densification of spirit to matter. A sort of "fall" takes place, an expulsion from a surrounding world, but in the magical purity of the forms, a memory of its origin remains.

It's a good thing to let the students totally experience how, in the liquid state everything is in flowing, swirling motion, and how crystallization is something like a protest against fluidity repeated again. Time and again some salt will shoot out of the liquid and becoming rigid and sharply formed, enclosed by planes; repeatedly the fluid movement is thwarted. This is especially apparent with cubic crystals such as table salt. Such a crystallization consists of many jumps from one stage to another that are specially dramatic. Every time, there is a transition that seems impossible but nevertheless happens.

Now is the time to investigate the salts in our body. We find them above all in the skeleton. Here this also happens through a continuous deposition and fixation of salty substance from the flowing blood. However, it is remarkable that here the salts don't take on their own form, but totally adapt to the necessities of the human body.

If the teacher feels justified in mentioning it, then they can draw attention to the fact that especially in relation to the crystallization of table salt, we have here something of a process that also occurs very subtly in our whole organism when we form a thought. Just as in a crystal the earth opens itself to the light, so in ourselves matter must, so to speak, take on crystalline form, if our bodily organs are to become transparent for a spiritual reality, to which our thoughts give expression.

Phenomena Occurring when Salts Dissolve

Once we have occupied ourselves with these considerations for a few days, we can move on to the process of dissolving of salts. We place an ~~orange-colored potassium dichromate~~ crystal, for example, in a beaker glass with water, and let the students observe what happens. The crystal slowly gets smaller and takes on a rounded form, while all around the crystal the water begins to share its color. ~~If someone has enough courage to taste the water, one can taste its saltiness (HAZARD with potassium dichromate—try it with dissolving spears of saltpeter).~~ The crystalline salt, first enclosed within its walls, lets go of itself and loses itself into the surroundings. This process is like a longing for infinity, for perpetual expansion and rarefaction.

Crystallization is a continuous falling-out of unity into multiplicity, a sort of splitting-up, but at the same time a drawing into specific, individualized forms. From solutions of various salts we see each salt taking on its own shape. During dissolving the opposite takes place—the multitude of salt crystals become one with the water. Many salts even dissolve without interfering with each other.

If we suspend potassium permanganate crystals just under the surface in a large glass cylinder filled with water, a particularly lovely process of dissolving can be observed. For example, we can attach the

crystals with Vaseline to the underside of a floating cork or to a loop of copper wire. The strongly-colored violet solution sinks, and thereby creates a number of elegant streamers with eddies and vortices. The best results are achieved against a white background, which is strongly side-lit. Then it is possible to observe it all even from a distance.

To be able to do calculations later on, it is now time for a preliminary discussion of various concepts, which will be developed more precisely later on: solubility, concentration, saturated, unsaturated, supersaturated solution, water of crystallization, osmosis, diffusion, heat of solution and of crystallization, elevation of the boiling point, depression of the freezing point. We will treat these in another chapter.¹ Here it is necessary only to point to the fact, that all these concepts can be related to an inner experience of the specific dynamics of the phenomena, and only later be developed into mathematical relationships. If we don't proceed very carefully here, we only add to an aspect that is already being cultivated to a high degree: forming concepts which are very precise and make it possible to manipulate natural phenomena, but are not very helpful in creating a living picture of reality. During the last centuries man has ever more moved away from nature by using such concepts, and has become more and more a prisoner of his own thoughts. We are concerned, therefore, with preserving just that quality that is specific to children, namely their unity with the surrounding world. We must teach the students to develop thoughts which do not break their connection with the world, but elevate them out of the sphere of mere instinctive feeling, to a sphere where conscious precision rules.

It is, of course, good and necessary to bear in mind all the phenomena that occur in life, specially those that occur in human beings. A few indications may point the direction in which they may be found.

We have already discussed the relation between crystallization with thinking, and with the formation of the skeleton. We can also show how aging is accompanied by a continuous deposition of salt in the skeleton, and finally also in the walls of the arteries.

During sleep a large amount dissolves which had been deposited during waking. During the growth of the skeleton a continuous dissolving of certain parts takes place, while at other places new substance is precipitated.

We can speak about the blood as a salt solution, and about the kidneys as strict regulators of the salt levels. This constant salt level is most closely connected to the fact that the tissues, and in particular the red blood cells, depend on a specific osmotic pressure. That must be taken into consideration when giving a blood transfusion after a heavy loss of blood. We can discuss the problems of osmosis that a young salmon encounters when going from fresh to salt water, and vice versa for the adult going to spawn. We can describe how a frog doesn't drink, but a

nearly dehydrated frog only needs to place its finger in water to fully recover.

So, there are many topics, some of which are important or must be dealt with at any rate, while others may be included as desired.

Splitting of Salt by Fire: Acid and Alkali

When we have dealt extensively in this manner with these phenomena relating to salts, especially those that occur in interaction with water, we can examine how fire acts on salts. For example, a piece of blue copper sulfate is held in a flame. We see that it gradually loses its transparency, and it becomes opaque white, then brown, and even black. It becomes an inert, earthly, insoluble mass. If we heat the crystal in a heat resistant test tube, then we notice how water of crystallization initially appears as vapor. That is the reason for the cloudy white substance. Subsequently, an acidic pungent gas evolves. This gas colors blue litmus paper red.

If we heat a salt like calcium nitrate, then brown, acidic fumes are generated, and we are left with a moderately soluble milky white substance, which is chemically reactive. This substance colors red litmus paper blue. So we have before us the process of splitting salt. Out of a single substance, which for our perception formed a complete unity, entirely different substances have come about. The original substance has disappeared to the same extent as new substance is formed. These are typical examples for the decomposition of salts. Now we must direct our attention to the transition, to the "interval" between the first state of the substance and the next, as we already did with crystallization. However, we will confine ourselves to the essentials, in that we will not focus on the water of crystallization. We observe, therefore, a well formed, transparent substance changed to a shapeless mass. The "memory of light" spoken of earlier, disappears, and in its place something arises that makes an earthly impression on us.

If we turn our attention specifically to the "phase" of vapor production, then we observe how a gaseous, fine dispersing substance is freed from a clearly defined, rigid, heavy substance. The immobile salt changes into a mobile, active, here even aggressive, gas.

First, there was a piece of earth that was transparent (open to light); now, on the one hand, we have a piece of earth that shuts itself off from light (is opaque), and on the other hand, a substance that seeks out the light filled space and identifies itself with it. The substance that remains behind has retained the solidity of the original salt. Therefore, it is called "the basis" or "base" of the salt. The substance which escaped has taken with it the transparency.

We already mentioned previously, that it can be economical to make a distinction between topics which are dealt with in more detail, and

others where we don't do more than give a list of facts. We can use this principle now.

After discussing the creation of acidic and alkaline substances, due to the decomposition of salts, with great care we can list the names of the most important acids and bases:

<i>Some important bases</i>	<i>Some important acids</i>
sodium hydroxide ("caustic soda")	sulfuric acid
potassium hydroxide ("caustic potash")	sulphurous acids
calcium hydroxide ("slaked lime")	nitric acid
magnesium oxide ("magnesia")	nitrous acid
ammonium hydroxide ("ammonia")	hydrochloric acid
iron oxide ("iron rust")	silicic acid
copper oxide ("copper rust" ²)	phosphoric acid
	phosphorus acid
	carbonic acid

These substances can also be exhibited, at the same time and, if one has sufficient time, also be characterized with the aid of typical phenomena.

Now we consider the acidic and the alkaline state in greater detail. For example, place three beaker glasses filled with water colored with litmus solution. In the left beaker we pour some sodium hydroxide solution, so that the liquid colors blue; in the right beaker glass we pour hydrochloric acid, so that the liquid turns red. Then we add to the left beaker glass some hydrochloric acid, to the right one some sodium hydroxide solution, whereby the colors change.

It can be made clear to the students that red is a typical expression of the active, aggressive acid, blue that of the more passive base. Although there are other indicator substances that reveal the acidity by a color, and that these colors can be quite different, is not so important here; most are synthetic products which have very little relation with life in nature. Instead, litmus shows us the original and typical phenomena, which we have isolated from nature and are demonstrating on the laboratory bench.

Although litmus is obtained from lichens, it does have the character of a flower pigment. Now, draw attention to the variety of color

changes in flowers, for example in forget-me-nots when they change from red to blue. Also, the extract of red cabbage could also be shown as a substitute for litmus.

We arrange three beakers: one with dilute sodium hydroxide, one with dilute hydrochloric acid, and one with tap water; some litmus solution can be added to all three beakers if desired. Then, we have the whole class come up and let them feel how the first solution makes the finger slippery, the second counteracts that, making them "squeaky" or "rough." The third glass is used to rinse the fingers. Remind the students of the similar slippery feeling they had when dipping their fingers into a solution of soap or washing-soda (sodium sulfate).

We now try to discover where we can find acid and base in our bodies. Our whole skin is slightly acidic because of perspiring. Our blood in contrast has to be slightly alkaline. Our saliva is somewhat alkaline, our stomach quite acidic, the intestines again alkaline. In general we can say, everything that is directed outwards (open to the outside world) is acidic, and everything that is directed inwardly is alkaline. The function of the stomach, besides being a storage place, is in the first place to defend against harmful influences that arise from assimilating food. Hardly any nutrients pass through the stomach wall into the blood. A muscle that contracts tends towards the acidic; on relaxation the alkaline comes to the fore.

In 1929 a little book *Ten Years of the Free Waldorf School* was published.³ It contains a very inspiring article by Eugen Kolisko (1893 - 1939) entitled "On the development and forming of science curriculum in the Waldorf schools."^{3a} He quotes therein a remark of Rudolf Steiner made in a class where they were just discussing the making of acids and bases: "All right, now you have seen all this demonstrated. Now also think, does any of that take place in my body? When you move your limbs, some acid is always formed; but when you are really quiet and are only active in your head, then something alkaline-like forms in your brain." Such a remark is at least as important for the teacher as for the students. From it we can gather in which direction to look.

In the *Curriculum Indications*,⁴ Rudolf Steiner particularly emphasizes the circumstances in the bees, the polarity between the acidic nectar and the alkaline bee blood.

In this context, the contrast between acidic and alkaline types of soil is also very interesting.

Salt Formation by Adding an Acid and a Base

Now we will turn to the action of acids and bases on each other. We take, for example, a beaker glass full with water and add copper oxide, whereby the clear water becomes dark and cloudy. (The copper

oxide can be prepared beforehand from a hot solution of copper sulfate and a hot solution of sodium hydroxide. The freshly prepared copper oxide reacts more quickly). Now add a dilute solution of sulfuric acid. We can notice that the dark mass clears and changes into a crystal-clear blue liquid. Also, if water is heated beforehand, everything then proceeds much more quickly. Illuminating the moderately large beaker glass from underneath makes the process visible from a large distance, and many exciting details become observable.

This experiment shows us again a certain peculiarity of acids. They have the ability to consume excessive earthiness and to open the way for light. Precisely because of the illumination, this effect of the acid comes so clearly to the fore. If the blue solution were then evaporated, the well formed, deep blue, transparent copper sulfate crystals would be obtained. A process just as dramatic as the decomposition of a salt has taken place. Here, a shapeless and lusterless mass changes into clear crystals. Also, an active, mobile acid changes into an inactive, motionless salt.

We can now pour some concentrated hydrochloric acid into a test tube and bring a piece of sodium hydroxide in contact with the surface. A sharp sizzling can be heard, while a number of clear salt crystals fly away like dust and sink like snow to the bottom. The experiment can also be arranged in such a way that it takes on a slight sensational touch. Place the test tube with hydrochloric acid in a test tube stand, and drop a pellet of sodium hydroxide in the tube. The liquid begins to boil violently, and the tube begins to dance up and down.

When different ways of salt formation have been dealt with extensively in this way, then a lot of scientific knowledge can be introduced in a concise way.

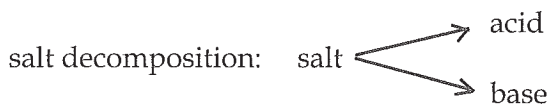
We discuss the rule according to which we can, in principle, combine every acid with every base and always arrive at a salt. This can be done diagrammatically as follows:



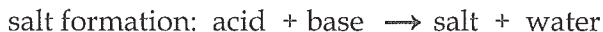
Then we discuss how we find the names of the salts and make a list of the acids and their related salts. Then we make a list with their common everyday names and also their scientific names.

Transition to Chemical Equations

Now show how the general rules for the formation and decomposition of salts can be put into simple schema:



or, even more abstractly:



With the help of these general schemes, specific reactions can be inferred by inserting the names as required. So for example:



Or a salt decomposition:



In such a way the foundation is laid step by step for the subsequent use of reaction equations and formulas.

It isn't really possible to introduce formulas on the basis of the curriculum of grade 10. If the path going from the whole to the parts is consequently followed, if the whole is taken as the origin, and the parts that come from that as secondary, we just don't get that far. Besides, it isn't yet possible to treat the chemical elements so extensively and in such a lively way that could counterbalance such a far reaching abstraction. If we do it anyhow, a distinction is very easily created between the students. The more intellectually inclined will fall into the illusion that they now really have understood it, while in reality they have lost the connection with existence, and besides they don't grasp the difficulty of the formulas (they are abstractions). The formulas become an intellectual game. For the intellectually less-inclined, the formulas become a more or less unfathomable and unconquerable wall that discourages them from taking a real interest in the world of matter.

Yet, something important must be added. We have mentioned at the beginning of the discussion of grade 10 that we must be careful that the conceptual development is clear and lucid. The general reaction equations as mentioned for the salt formation and salt decomposition are in agreement with this; the area of the formulas, however, contains so many facts that the clarity quickly diminishes.

We will see that the full treatment of formulas, if postponed until grade 11, are better discussed from a different angle and then present an unexpected possibility for schooling.⁵

Besides, formulas have the disadvantage of unintentionally diverting our attention from the fact that every substance, be it an element or a compound, presents itself as a wholeness. Talking about sulfuric acid is in harmony with this fact. Writing down the formula H_2SO_4 however, specifically draws attention to the fact that this substance can be produced in a reaction from other substances.

However, it is possible to abbreviate our "general" equations somewhat and make them more lucid. We can do that in the following way:



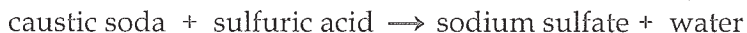
Strictly speaking, the formula BA for a salt is already too analytical; in the end every abstraction, even the most circumspect, removes us from reality. But doubtless we have to put up with this.

On getting this far in the treatment of the curriculum, we have reached an important point. The students now possess the concepts not only to be able to gain insight into the processes to a certain extent, but also to know beforehand how a chemical process will proceed. They can even put reactions together for a specific purpose. For example, if we want to make copper nitrate, then we have to react copper hydroxide (copper base) with nitric acid. In this domain, students can predict and then check through experimentation if their thinking was correct.

Weight Relationships

If you wish to introduce the concepts of atomic and molecular weight later on, then I think it is appropriate to point out here that all these reactions proceed according to definite weight proportions. It is easier to treat this fact now as an expression of a strict harmony in nature than it is later on, as long as you don't yet have to do quick calculations. It is quite possible to proceed from the equivalent (combining) weights, e.g.:

caustic soda	40
sulfuric acid	49
sodium sulfate	71
water	9



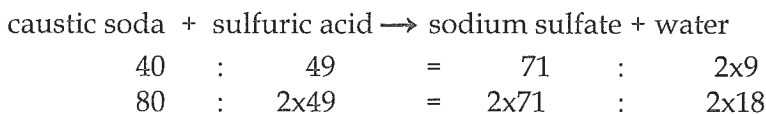
40

49

71

2 x 9

It seems to me absolutely necessary to remain in the realm of abstract numbers, because only then will it be clear that we are dealing with ratios (of weights) and not with absolute weights. Nevertheless, it is possible to make simple calculations with these simple numbers. For example, we can find how many grams of sodium sulfate we get, when using 80 grams, or else using 2 grams of caustic soda (sodium hydroxide).



or (dividing all weights by 40):

$$2 : 49/20 = 71/20 : 18/20$$

If we give the students a list of the equivalent weights, then any number of calculations can be done.

Oxygen, Oxidation, Burning, and Rusting

We now demonstrate that acids come about when we burn certain non-metallic substances, and bases when we let metals rust. So, we must investigate in more detail the role oxygen plays when an acid or a base is formed.

It is quite possible to start historically and discuss how oxygen was discovered by Priestly. This presents us with the great advantage of being able to follow the historical development, which is mostly accompanied by an instructive struggle for the clarification of concepts. Moreover, this gives the opportunity to include biographies. This is particularly important for the girls, who more than the boys are inclined to assimilate everything with the soul and relate to people.

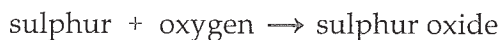
Priestley produced an unknown gas by heating mercury "rust" (oxide) and established that this gas stimulates the breathing process and also keeps the burning process going. It was, therefore, a gas with "enhanced air qualities."

Now, for example, burn some sulphur or phosphorus and demonstrate how the rising vapor and smoke will color a piece of moist blue litmus paper red. For completeness sake we can demonstrate that these substances will only burn if there is sufficient oxygen in the surroundings. If necessary, we can enhance the burning process by supplying pure oxygen (although this is not usually necessary, except with charcoal).

We then place a piece of iron in humid surroundings and let it rust. The tough, shiny metal slowly tarnishes, becoming rough and finally becoming a brittle, reddish-brown, crusty mass. The most interesting thing about this process is its slowness and lethargy—but this will not usually mean much to the students. Best of all, also, is to show the students a piece of severely rusted iron.

Going further, a bright piece of iron can be heated, and then copper. You can observe then how quickly the shiny surfaces tarnish. You can then discuss, and perhaps demonstrate, that the resulting copper oxide is the same substance as the base which we got from the decomposition (heating) of copper sulfate salt.

We now compare these processes of burning and rusting. In principle, both are caused by the action of oxygen. If both are expressed in chemical equations, then they both look quite similar.



However, looking at the dynamics of the process and the qualitative image they give us, each processes shows a totally opposite character.

Burning proceeds quickly. It is a particularly striking and radiant process, because of the production of light and heat, and through the pungent smells that normally occur also. The substance that was before us initially as a solid object becomes totally consumed and changed into a mobile, space-filling gas. The whole process is primarily directed upwards.

Rusting is a slow process. The smooth, bright surface of the metal turns itself, as it were, away from the light to become tarnished and earth-like. Very little heat production can be noticed. While the burning substance goes with the oxygen into its sphere of gases, the rusting substance draws the oxygen down into the earthy realm.

Here is something mysterious, in that combustion only occurs when a certain (kindling) temperature is reached, while rusting also takes place even at low temperatures. However, this riddle can form the key to understanding the pattern that underlies all this. Combustion occurs through heat, rusting through moisture. During combustion mostly gasses and other volatile substances are formed. During rusting earthy substances are formed.

Combustion:	caused by heat	Firey
	result: gas/vapor	Airy
Rusting:	caused by moisture	Watery
	result: earthy substance	Earthy

We observe that the relatedness of both processes becomes clear, as soon as the four elemental qualities are taken into consideration. From that viewpoint it is particularly interesting to note that metals can be protected from rusting (watery) using an oily coating—stopped by combustible, “Firey” substances, while we fight fire with water.

Now we demonstrate how the products of combustion of substances like carbon, sulphur and phosphorus become acids in water, while metal oxides appear as bases. All this contributes to clarifying the typical properties of acids and bases. The acid, as it were, is the chemical herald of the two higher elements (Firey and Airy). This explains a lot of their aggressive mobility and their ability to open up the way for light. The alkaline is the chemical herald of both lower elements (Watery and Earthy). That explains their property of avidly absorbing acid vapors and binding them. Strong bases like caustic soda have more affinity to the Watery element; the insoluble bases, like the rusts of the heavy metals, have more affinity to the element of Earth.

Later on we will see how the properties of silicic acid are generally opposite to those mentioned, for silicic acid contributes a lot to the solidity of the earth, and it also has a special relationship with the cosmic aspect of nature. With bases, ammonia forms the exception; it is a volatile gas instead of a solid.

The Importance of the Approach Chosen

We could ask again, why does all this have to be treated in such a complicated way? Why don't we just start the block deriving acids from combustion and bases from rusting, and then the salts from reacting the acids and bases? From our description built up so far, we can make various answers. If we had started with burning and rusting, this would have followed an analytical method (emphasizing weights as Lavoisier did), even though we are seemingly proceeding on a synthetic path. But, this way gets into treating the substances that constitute a higher unity (such as acids, bases, and salts) as if they were made up out of these parts. Unconsciously, we lose sight of the wholeness. Taking the opposite approach, as we did, then we keep the wholeness in sight, even when going into the greatest detail.

From this it follows that this method is in harmony with the laws of evolution of a living being. This always begins as a unity with slight variations and goes on into ever finer differentiated detail. Using our

method means we are working in accordance with the development of the child, which of course also follows the general laws of life.

Through the analytical methods widely used in science, there is always a danger of destroying the image of nature, resulting in unintelligible parts. Of course, this forms very well-defined concepts in relation to the phenomena, but then we wouldn't be very concerned whether they were an expression of the *context of reality*, within which the phenomena are embedded.⁶

Indeed, with our exact concepts, and infallible definitions we are continuously cutting parts out of the whole of nature. We are often so impressed by the clarity of the concepts, that we start to view the details as independent entities. The creators of mechanical theories, for example, suffer from this malady. They want to explain reality by using such parts from which they can develop the most lucid thoughts. If, however, you start from the whole, as we have been trying to do, then the concepts of the details developed will always remain in a harmonious relation with one another and with the wholeness of nature. They then acquire an aspect which reminds us of the organs of a living being. In this way, we create in the students quite a different orientation towards life. They develop the habit of keeping sight of the whole of nature and come to their own judgement and point of view from that whole.

In connection with the formation of acids and bases, it can be very fruitful to discuss the great French scientist Lavoisier. He is indeed the actual discover of the role of oxygen in this process. But to clarify the direction of his work, it is really necessary to talk about the alchemists. We can explain how the serious alchemists weren't after riches, but rather their striving was directed towards inner development with the help of chemical experiments. Related to that is also the strange names they gave, which is a way of expressing processes in imagistic form. Here we are dealing, on the one hand, with suggestions and hints about substances and their states, but also, on the other hand, with descriptions of inner changes occurring in human observers. During experiments they concentrated specially on the image-like aspects of the processes, on which we also have focused. They perceived the divine in nature in these images and the changes in themselves.

In Lavoisier's time the alchemical movement was long past its prime; it had become confused and decadent. Indeed, he has contributed a lot to the thorough extinction of the residue of alchemical views.

For him, the balance was the most important instrument, and this means that he tried to approach all phenomena from the aspect of weight. By that approach, the pictorial was totally eliminated. It is very remarkable that he was able to weigh oxygen before he even knew that it existed. In a closed vessel he let zinc oxidize and was able to show that

something went from the air into the rusting metal. The total weight of the vessel and contents remained the same; however, the metal increased in weight. When he heard from Priestley about his studies of combustion in an oxygen atmosphere, he quickly developed his theory of combustion.

He also contributed a lot to the modern non-pictorial nomenclature. He proposed the name "oxygen" (from Greek, oxoos-gen = acid producer), and also the name "oxide" for an oxygen compound. He is also associated with the Law of Conservation of Matter. As a practical person he was primarily interested in an experimental method. He based his experiments on the conviction that the total weight of the substances taking part in a reaction remained unchanged. That really is only a working hypothesis. He most probably never would have drawn the conclusion, as materialists later did, that everlasting existence, and not even the human soul, had no divine being as its essence, but only matter. If matter can't be created or destroyed, then Creation isn't possible. Because of such considerations, in a sense God was robbed of his power, and matter was set upon God's throne.

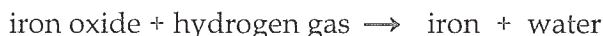
Lavoisier is seen as the founder of modern chemistry, and in practice, chemistry views the material world primarily from the viewpoint of matter and energy. Maybe it is right to discuss such things with the students, mostly because we've learned since then that matter can actually be destroyed and created. Materialism, on this level, has been disproven. Besides, we can show the one-sidedness of such considerations precisely by studying rusting and combustion. If only the weight is considered, then the qualitative differences between these processes disappear. If, however, we pay attention to the image and the process, then the greatest differences can be discovered. Up to a certain extent it makes sense to consider rusting only from the aspect of weight. However, fire is in constant contradiction with gravity, and in the same manner, it is in harmony with the radiant light side of nature, just as rusting is related to gravity. With such thoughts the students are not only given a harmonious world view, but it should even be possible to help them find their own relation to nature. The young students have just recently deeply experienced in puberty the falling apart of human beings into male and female. At the same time, they became caught up in an interplay of soul forces that, although they may elate or fill them with idealism, can also pull them down. They feel fractured.

An image of this drama stands objectively before them in the decomposition of salt into acid and base, in the process of combustion and rusting, and what may be followed up from there. While they feel themselves more or less ejected from the care of a divine world-unity, this image may also contribute to the feeling that what they are going through now is also founded on profound laws of the universe. This drama

becomes part of the world-drama. Their task is to acquire a new dignified bearing in the interplay of forces in which they find themselves. Once, they had to achieve an upright stance, between the world of light above and the world of gravity below them. At this age, they become mentally aware that there is something which wants to pull them into illusory worlds and also something that wants to pull them down and bind them to unconscious forces. They must learn to stand spiritually upright in this mental field, as previously they had to do this with their body. They must consciously find a new spiritual equilibrium. The curriculum, as reviewed above, may be a support for this.

Reduction

We have now reached a point where we can discuss the phenomena of reduction more closely. We place some brown, powdery iron oxide in a heat resistant glass tube. We then conduct natural gas (methane) or hydrogen gas through the reaction tube, and heat it where the iron oxide is. We observe the powder becoming gray-black, while a precipitate of water becomes visible on the walls. We can put this directly into a reaction equation. First we had iron oxide and hydrogen gas, now iron and water.



This can also be expressed as follows:



After it has cooled down, the powder can be attracted by a magnet, a clear proof that metallic iron has been formed. It is also possible, while the tube is still hot, to pass air through. We see then that the powder immediately changes color back into reddish iron oxide.

A very impressive way of showing the alteration between oxidation and reduction is by quietly and strongly heating a piece of copper and letting the flame play over the surface. Inside the sphere of the flame, the metal becomes shiny; where the flame is removed, a rapid oxidation starts, that initially displays itself in a beautiful play of colours but ends in a gray-black zone. The longer the flame is moved about, the more splendid the colours shine out.

The students already have an idea of what occurs during a reduction, because photosynthesis has been discussed extensively in grade 9. We should recognize in it the archetypal phenomenon of a reduction process.

During the discussion of the discovery of oxygen, we also mentioned the decomposition of mercury oxide by heat.

Often, reduction is brought about by really combustible substances, like hydrogen gas, carbon, or carbon monoxide. From this, we may realize why all this occurs. The combustible substances are in a state of tension with regards to their surroundings. They are laden with energy, so to speak, which they radiate primarily as light and heat. In contrast, the oxides have reached a totally relaxed state. If we want to conjure up the initial substances from a combustion product (oxide or metal ore), we achieve this tension again by applying light and heat.

During photosynthesis carbon dioxide is changed to carbon by sunlight.* When decomposing mercuric oxide, the heat of the gas flame, or, in the case of Priestley, the warmth of sunlight, was used. During the reduction of iron oxide, hydrogen gas "snatches up" the oxygen, and gives some of its energy to the iron.

It's a good thing to draw attention to the fact that not only combustion, but also oxidation of metals, is accompanied by heat radiation. Mostly we don't notice this, because it goes so slowly. But, for example, if the process is accelerated by scattering iron into a flame as powder, the metal is seen forming glowing sparks—a kind of "meteoric burning."

In this way, we can discuss that with every chemical process an interchange takes between the ponderable and the imponderable. And each time, light or heat is either absorbed or emitted.

This point in the review of reduction can be discussed in such a way that we still keep completely within the sphere of the qualitative, connect up with life processes, and put things into thoughts that remain in the realm of images.

Solution of Metals in Strong Acids

Besides the normal way of salt formation by reacting acid with base, there is also the possibility of producing a salt by dissolving a metal in a strong acid. Many significant changes take place during this process.

For example, pour some dilute sulfuric acid in a test tube and add a small piece of zinc. The zinc is immediately consumed, accompanied by loud sizzling, a very combustible gas evolves, and finally, a clear mass of crystals accumulates at the bottom of the tube.

Once again, the qualitative reaction equation for the process taking place can easily be written out:



The metal is changed into salt crystals by the acid.

* (Not directly; the process is much more complicated.) (D. Rohde)

We are here faced with one of the strangest, most remarkable transformations. We have already previously characterized matter as that part of the universe which has been abandoned by light.⁷ With the metals there has arisen a sort of contrast to light. If a piece of metal is held against the light, it appears as a dark opaque mass—indeed, it is completely opaque. Metals are the most reflective materials; they send the light back to the highest degree. However, at the same time this reflective ability points to the fact that they are also attuned to light. That becomes more pronounced the stronger they reflect, silver being most pronounced.

If a metal is dissolved in an acid, then the light repulsive properties are totally conquered. Again, acid opens the way for light.

If salt crystals are allowed to form immediately, as in the experiment described above, then the elasticity of the metal, its malleability, changes into the brittle, hardness of crystal structure.

In this context it is specially interesting that transparent solids are never good conductors for electricity, while the best conductors, the metals, reflect light the strongest. Here the polarity between electricity and light becomes very evident. Where one has access, the other is excluded.⁸

From all these phenomena we may conclude that there are polar states of matter; the metal state and the transparent crystal state form such a contrast.⁹

Electrolysis

Having come so far, it is quite possible to incorporate the first phenomena of electrolysis. Again, this will have to be done in a particular "Grade 10-way" and not anticipate the electricity curriculum of grade 11.

Start with a diluted salt solution (not table salt or other halogen salts) colored by litmus. For electrodes one can initially use carbon rods, and later on certain other metals. The results are as follows:

CATHODE (-) tendency towards	ANODE (+) tendency towards
base formation separation of hydrogen gas phenomena of reduction precipitation of metals	acid formation separation of oxygen gas phenomena of oxidation dissolving of metals

In this way we achieve a "phenomenology of the electrode." We can see how electricity, in its polarity, is related to the contrasts we have already discussed.

We should set aside all theory. In the light of practice and application, it is much more important at this point to give a characterization of the phenomena, rather than abstract explanations.

In this way we even are already laying a certain kind of foundation for the physics block (Electricity) in grade 11.

Finishing the Main Lesson Block

Acid or Base Substitutions—Double Substitutions (Displacements)

We now come to a part of the main lesson block wherein many new phenomena occur, which often include the most impressive ones we can observe. Generally, we will be able to use the concepts we have learned up to now. That makes possible constant repetition and practice. The students learn to play, as it were, with the concepts. They must be made to find explanations for many cases and to devise examples which can then be experimentally verified.

Furthermore, it is a question of finding all the possibilities that can occur when combining salts with acids and bases. Chiefly, there are three such combinations: base and acid, acid and salt, salt and base. We bring them together and observe the results.

For example, we begin by adding a base to a salt solution. If we take table salt and copper oxide, nothing will happen, just as with sodium hydroxide (a stronger base) and table salt. But, an impressive phenomena occurs if sodium hydroxide is gently poured into a bright blue solution of copper sulfate that is not too dilute. This results in a magnificent, veil-like translucent blue precipitate. If we follow the process carefully, small globules are observed. Within these globules there is sodium hydroxide; the walls consist of a delicate jelly-like substance, surrounded by copper sulfate solution. These globules, which also can occur with other salts, often look like protozoa. If one of them is destroyed, the contents will indeed flow out. However, a new skin is immediately formed; something like the of healing of a wound comes about. These bubbles are, therefore, rather stable, notwithstanding their delicacy.

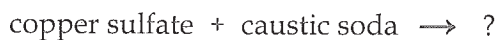
Of course, the teacher should try the experiment in all possible variations, to ensure that they can demonstrate the phenomena in the most impressive way possible. Several glass vessels containing different concentrations can be used. If large glass containers and bottom illumination are used, the most enchanting phenomena can be achieved.

In a certain sense, the image becomes more clear if the copper sulfate solution is instead poured into a sodium hydroxide solution. The

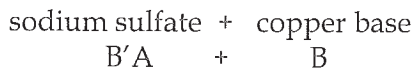
blue flakes then are quite visible in a colorless solution. Also, something very surprising happens when we hang a copper sulfate crystal in a sodium hydroxide solution—it is possible for pillars of precipitate to form.

Similar experiments can be done, if salts of other heavy metals are used with strong alkaline solutions.

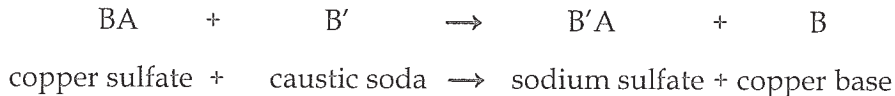
We pose the question to the students: what may have occurred? We can write:



There certainly will be some who will be able to discover the answer. Hardly any other reaction is possible than that a new combination has come about, and in fact this is what has resulted:



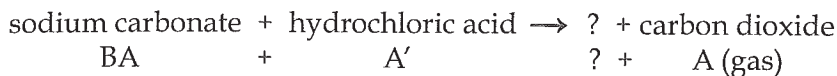
The whole process looks like this:



The strong, readily-soluble base has displaced the weak, slightly soluble one. If that is right, then we must be able to dissolve the blue precipitate with a strong acid. Indeed that can be done. Of course, we shouldn't forget to show such an image of dissolving to its best advantage.

If our chain of reasoning was accurate, then the solution must contain sodium sulfate, and the blue precipitate must be some sort of copper base. To prove the first is difficult. However, the students will accept our statement that sodium sulfate really was formed. The second can easily be proven by heating the blue, jelly-like precipitate. Then a brown, black mass of copper oxide is produced. It then isn't very difficult to understand that the blue precipitate is copper hydroxide, a "watery" (hydrated) copper oxide. Such a hydroxide can be viewed as a base that has become stuck halfway to becoming a solid. If we add an acid to a salt, the phenomena can again be quite varied.

On addition of hydrochloric acid to a solution of sodium sulfate, no changes are seen. However, if hydrochloric acid is poured over soda (sodium carbonate), then it starts to sizzle and effervesce, volatile carbon dioxide escapes. Again, it isn't very difficult to understand what has happened here:



From the equation it becomes clear that BA', sodium chloride, must be produced.



Again, a general rule is achieved here: if we add a strong acid (HCl) to the salt of a weak acid (carbonate), the weak acid will be displaced and a salt of the strong acid will be formed. If necessary, we can draw attention to the fact that the volatility of the acid plays a role.

For practical purposes, acid displacement is of great importance. It could perhaps make sense to discuss the production of nitric acid, hydrochloric acid, carbon dioxide, and other acids from their salts.

It is important to show with such experiments how during a typical base displacement reaction, a substance falls prey to gravity, and how during an acid displacement reaction, a substance is taken up by levity.

As a last possibility of the interaction between acids, bases and salts we still have that of two salts. If we add a table salt solution to a potassium sulfate solution, no visible reaction occurs. However, using calcium chloride and sodium carbonate produces a white precipitate. It is strange to observe how two, clear fluids, on mixing, produce an opaque, solid mass as if by magic. This precipitate is not jelly-like, but is more likely to be powder-like. What has happened?



The precipitate could be either calcium carbonate or sodium chloride. Since sodium chloride is soluble, it has to be calcium carbonate. Because of the different combination of acids and bases, two new salts have been produced. The following rule can be deduced: If solutions of two salts are poured together, then a double displacement reaction will occur with the formation of a precipitate, if one of the possible products is an insoluble salt.

Now, which salts are soluble and which are not should be overviewed. In case the students haven't already got such an overview, a list of the most important insoluble salts can be handed out, and also for those acids and bases whose salts are always soluble. The students can then explain and even predict the phenomena.

How double displacement reactions are used as a method of identification of certain salts in solution can be pointed out. With sea water very nice experiments can be done.

The problem of hard water can also be discussed—why soap becomes flaky and why soda softens water.

Lastly, different salts can also be produced via the double displacement reaction, e.g. lead chromate (chrome-yellow), lead carbonate, mercuric chloride or potassium nitrate (as always, CAUTION with toxicity hazards).

Endnotes

- ¹ See Chapter 6 of this book: "Process of Solution - Phenomena, Concepts, Laws."
- ² In Dutch, "roest" and "roesten" (to rust) are used quite generally for corrosion changes in other metals, similar to when iron rusts.
- ³ Special volume of *Zur Paedagogik Rudolf Steiners*, 1929, III, vol. 3/4.
- ⁴ Steiner, R. *Discussions with Teachers* 1919 - 1924, Jan./Nov 1921, 17/6, p41; GA 295, Chapter 3.
- ⁵ See "Formula," Chapter IV.
- ⁶ See Chap. VI, the "Concept of Concentration."
- ⁷ See Chapter III, "Crystallization of salts."
- ⁸ Steiner, R, *First Scientific Lecture-course* (Light-course); GA 320.
- ⁹ See Chapter X.
- ¹⁰ *This article is included in this Chemistry reader. (D. Rohde)*