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The Chemical Effects of Electricity

1. Preliminary notes on the subject and its instruction

We have already put electrical energy to use at two points in our chemical experiments, namely, in the oxidation of nitrogen and the reduction of phosphorus. In both of these instances, however, this energy did not work *directly*, in accordance with its essential nature, but only *indirectly*, through the production of extremely high heat in the form of an electric arc. It is certainly very interesting to note how simple it is, with electricity's help, to produce extreme temperatures that allow substances to combine or separate in ways that are simply not possible at ordinary temperatures. In most cases, electrically induced combination or separation works contrary to the natural processes of the substances in question. For example, when nitrogen is oxidized, its extreme resistance to combining with oxygen is overcome and the combination is forced upon it, so to speak. Similarly, reduction of phosphorus wrests it out of its natural combination with calcium to expose it in its pure, elemental form.

We must also expect to see surprising transformations of substances (which would be very difficult or impossible to accomplish without electricity's help) when electricity is actually applied to chemical processes in accordance with its true nature. In fact, the very first manifestations of electrical energy, discovered by Galvani and Volta, were intimately related to chemistry. The very fact that electrical energy was discovered in the context of chemical reactions spoke in favor of applying it to chemical substances. Moreover, the newly discovered force of electricity appeared as chemistry's best possible helper just at the time when that field was reinventing itself, which seemed like a grand synergy in the realm of global discoveries and ideas. Galvani made his first discovery (the famous frog-legs experiment) in 1789. On the basis of this discovery by the physician from Bologna, Volta then constructed his first battery cell (1790) out of copper, zinc, and sulfuric acid. Shortly thereafter, from 1807 to 1820, the brilliant English chemist Davy used a strong battery of Volta's cells when he made his significant discoveries of new chemical elements among the alkalis and alkaline earth metals, thus shedding light on a whole series of previously unexplained issues in chemistry. Davy's work was facilitated by the French chemist *Proust's* formulation of *the law of definite proportions* in chemical compounds (1799), which was soon followed (in 1802) by the discovery of the *law of multiple proportions* by the Englishman *Dalton*.

Thus when we consider the chemical phenomena related to these discoveries in greater detail in subsequent chapters, we will be retracing the

development of chemistry itself. Completely new relationships will emerge, but we will also encounter familiar chemical changes that are now taking place under completely new and different circumstances.

In this chapter, however, our efforts must focus specifically on articulating the laws that emerge, fully honoring their purely phenomenological premises and refraining from imposing any preconceived notions on them. This is done here deliberately and in full knowledge of the usual conceptions such as ion theory and the like. My intent is to demonstrate the extent to which the phenomena themselves can be the teaching if it is simply presented in *a form of nature's own choosing*, so to speak. The task of self-cognizant thinking is not to come up with theories to explain phenomena but rather to *arrange phenomena in a way that allows the natural world to reveal its own laws clearly*. It is in this sense that we will proceed here.

As to the pedagogical aspect of this chapter, suffice it to say that we are dealing with subject matter appropriate to grade 10 [and 11: D. Rohde]. This material offers excellent opportunities for new and interesting observations that will deepen and refine the students' understanding of fundamental concepts in chemistry: acids, bases, salts; sulfur and other chemical elements; oxidation and reduction. Upon completion of grade 10 [or 11: D. Rohde], the young people will have had experiences with chemical activity that can – and should! – serve them for the rest of their lives. They will also have learned about the history of the field of chemistry itself, which will help them to understand the purpose and significance of the time in which they live and to find their way in it – which is the basic purpose of any subject taught in school, of course. In particular, these “proposals for a living view of chemistry” are meant to serve this purpose.

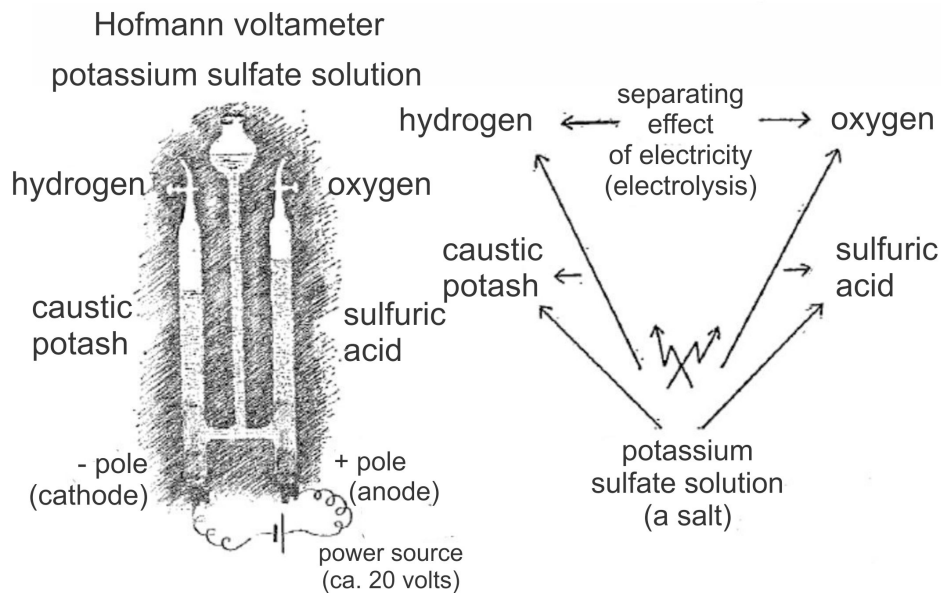
Of course the suggestions presented in this chapter are merely suggestions, and it is not only absolutely possible but also desirable to add other phenomena. You may notice, however, that the basic laws have been articulated in ways that allow such additions from any direction.

2. Electrolysis of potassium sulfate: the basic processes in the electrolysis of a typical salt formed from a base (alkali) and an acid

Let us begin right away with an experiment that sets us down in the thick of the phenomena. Its sequence of events is so interesting that it will promptly catch the attention of this age group.

The apparatus, the so-called *Hofmann voltameter* (see illustration) consists of three joined glass tubes. The two side tubes are equipped with valves at the top and platinum electrodes at the bottom, while the open central tube is used for filling. We fill the tubes completely with a solution of potassium sulfate tinted with neutral litmus solution. Then we connect the electrodes to an ordinary 20-volt DC power source to create an electrical circuit in which the salt solution functions as a conductor.

chemical decomposition of potassium sulfate solution



We soon notice bubbles ascending from each electrode as gases develop. The bubbles developing at the positive electrode (anode) are significantly larger than those forming at the negative electrode (cathode). We can collect larger volumes of the ascending gases by closing the valves at the tops of the tubes. We soon also notice that the volume of gas that collects above the + pole (anode) is only half as great as the amount that collects above the - pole (cathode). Assuming that the valves close tightly, the ratio of volumes at the anode and cathode is always exactly 1:2.¹ We can confirm this at any time by checking the markings on the calibrated tubes. If we allow the process to continue for a longer period of time, the volume of gas in both tubes will increase steadily but always in the same 1:2 ratio. This experiment demonstrates how *nature itself* shows us that its processes are governed by strict numerical laws that we must then learn to understand.

It is of great educational importance to link discussions of numerical laws in the material world to sensory perceptions that elicit astonishment, as in this experiment. Only then will the students experience an *active desire* to learn to comprehend these laws. Teachers know that this active interest is an important prerequisite to learning about subjects that may otherwise seem dull.

At this point, however, there may be only enough time to notice and articulate this sense-perceptible fact, because this experiment will soon catch the students' attention with an even more striking

¹ If the water is saturated with O₂, which can be accomplished by running the experiment with the valves open for a short time, if needed. (note by D. Rohde)

phenomenon: The uniform color of neutral litmus solution soon disappears from the two tubes.² Distinctly different tints gradually emerge: red in the liquid above the anode, blue above the cathode, while the salt solution in the central tube retains the original purple color of neutral litmus and can therefore serve as a comparison throughout the experiment.

If we repeat the experiment using fresh-pressed red cabbage juice to color the potassium sulfate solution, the color difference is even more striking: One tube turns a wonderful shade of *carmine red*, the other a brilliant *emerald green*, while the central tube retains the normal purplish color of fresh-pressed red cabbage juice. Because of the immediate impression of complementary colors, this experiment is especially visually striking for the students.

Both litmus and red cabbage juice, as we will demonstrate again later, always change color when combined with acids or bases of any kind. The pronounced reddening of the cabbage juice under the influence of acid is as informative with regard to the inherent laws of this organic material as is its shift to green (or, ultimately, yellowish).

This change in color, therefore, is an incontrovertible confirmation that the effect of electricity on the initially neutral salt solution is to “split” it or “break it down” into the polar opposites of an acid and a base, specifically, sulfuric acid and caustic potash.³ That the entire process proceeds from the poles can be made even more obvious by inducing electrolysis in a U-shaped glass tube with electrodes inserted into the potassium sulfate solution *from above*, using the same potassium sulfate solution tinted with red cabbage juice. The changes in color (to red and green) then begin at the poles and work their way downward, while the original color is retained in the middle and lower portions of the U-shaped tube. This variation on the previous experiment is especially informative because the fact that the color change begins at the poles is a clear indication that the conversion to acid and base also proceeds from those locations. Of course the gases also develop in this version, and lateral glass tubes installed above the two electrodes allow them to escape.

So, what is happening here? Electrical energy is a natural force that is already inherently polar in its manifestation. When it works through the + and - poles, its effect is to reveal the *natural polarity inherent in any salt*. Through the action of electricity, the salt separates into actual acid and alkaline substances, which were already present as potentials. At the same time, the electricity undertakes a ‘state of being’ switch by working in a fluid medium to transform the salt from the “sal”

² This works better with litmus solution than with universal indicator, which can alter the 1:2 ratio. (note by D. Rohde)

³ Only in concept; acid/base development is due entirely to the decomposition of *water*. Under these conditions, K^+ and SO_4^{2-} are not discharged (note by D. Rohde).

state into acid and alkaline substances, which we recognize as belonging to the middle, “mercurial” state.⁴

Formulated in this way, what we have accomplished here is nothing more than identifying the obvious facts of the case. These facts, however, prove to be of far-reaching significance. It is also not too soon to state this presumption: Whenever a natural force is capable of producing such strong chemical contrasts, it must also – as much as it originates in chemical processes – take chemical opposites as its starting point.

Our observation of the experiment would not be complete, however, if we neglected to confirm the nature of the two gases produced in the course of this same electrolytic process. When we open the valve located above the anode of the *Hofmann voltameter* and hold a glowing ember in the gas that escapes, the wood immediately begins to burn with a bright flame. This gas can only be oxygen. In contrast, if we open the valve located above the cathode and hold a burning match in the escaping gas, the gas ignites and burns off quietly. Here, the gas we are dealing with is hydrogen. (The flame gradually turns yellow, but that is due to the sodium content of the glass.) The development of hydrogen and oxygen – which are also polar substances – takes place at the same time as the separation into acid and base.

Now, however, the question arises, why do oxygen and hydrogen develop? Has the water in which the potassium salt was dissolved been “split” by the electric current?

⁴ Ott is assuming that the reader is familiar with the *Tria Principia of Alchemy* (note by P. Glasby).