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Toward a Rational Chemistry

“The man of intellect finds almost everything laughable,
The man of reason, practically nothing.”
Goethe, Maxims and Reflections

All too many of our contemporaries have come to view chemistry as the specter of crass materialism, environmental pollution, and a detached and antipathetic response to nature. Anyone buying a beverage in the supermarket wonders how many “chemicals” it contains: ascorbic acid, artificial colors, emulsifiers, “natural” flavors.... Not everyone is so skeptical, however. Youngsters in Waldorf middle school chemistry blocks taught by the class teacher are still enthusiastic about chemistry, but by the time they reach the upper school, where they encounter science and society in contemporary terms, chemistry usually becomes a curiosity at best. How many Waldorf graduates who absolutely loved their school years go on to study chemistry and become career chemists or enthusiastic chemistry teachers? Where are these people? Isn't their nonexistence actually a *positive* reflection on Waldorf culture? The unspoken sentiment today is that chemistry, rather than being a life-enhancing profession, is downright ahrimanic! Or so we often think.

From the historical perspective, neither the extreme materialism of the natural sciences (including chemistry) nor their claim to the exclusive right to explain natural phenomena is inherent in the fields themselves. According to Rudolf Steiner's analysis, this state of affairs dates back to 869 A.D., the year of the Council of Constantinople, which downplayed the human being's spirit aspect and had consequences for all further cultural development in Europe. Ever since the sixteenth century, the representatives of “spirit” – namely, religious leaders – have turned their backs on all the grand and tempestuous discoveries of the emerging natural sciences. Both churches, stuck in the rigid vocabulary of their creeds, were unable to cope either with the increasingly explainable natural world or with the realization that the world is capable of transformation – and especially with the idea of evolution. Because God is omnipotent and good, he must have created a perfect world, so why should it have evolved from a state of presumed imperfection? That idea was simply unacceptable and could not be permitted to persist. Religious circles had no inkling of the living, active spirit that indwells all change and development. In today's world, refusing to think in terms of metamorphosis and insisting on formally deriving evolution from either confessional or philosophical eternal types (God and the completed world of ideas, respectively) is an indication of distancing oneself from spirit. In 1870, the Vatican rescued itself by resorting to the dogma of papal infallibility – a tactic later reinforced by the beatification of the pope in question, Pius

IX, on September 3, 2000. In any case, the sciences were abandoned spiritually, and the effect, which rigid representatives failed to notice within their self-defined limitations, was to reinforce materialism. (*Steiner*, GA 93a:72; GA 293:150) As a result, scientists themselves often became inflexible and could more easily take the opposing position of denying spirit altogether. (*Steiner* 1917:217) The problem does not lie in the sciences themselves: "Science is full of benevolent spirit, although scientists are not always." (*Steiner*). We, however, should attempt to avoid falling into either of the camps with their reciprocally entrenched positions. On closer acquaintance, the know-it-all antagonists on both sides prove to share the same incapacity. All this in preface to our topic, the effort to bring *reason* into chemistry in addition to the intellectual understanding (or lack of understanding) with which we usually confront it.

All of the natural sciences share three basic perspectives. The *observational* approach fully embraces everything that can be discovered at present. In addition to identifying things as they are, however, we would all like to understand how they came to be, so we also take the *retrospective* approach, looking to the past for the original causes. Not content with that, either, we also want to be able to preemptively trace world trends into the future, so we take the *prospective* approach, asking how our discoveries might be applied in future. We demand predictability and replicability, although in doing so we run the risk of viewing the future only as an extension of the past. A case in point is our technological civilization, which applies the laws of causation as if they were finalities and then concludes that there is nothing more that can be done. All this makes it obvious that scientific understanding in this form has at least one advantage, namely, extending our temporal relationship to the world beyond preoccupation with the present moment, even if our view of time remains linear (that is, spatially conceived).

A fourth perspective, however, is a transcendent temporalization that takes a full view of the present and includes its antecedents and subsequent development in a comprehensive field of vision. This perspective achieves long-term sustainability, since there is nothing more practical than overcoming our temporal worm's eye view and replacing it with a temporally integrated bird's eye view, which will serve as a second starting point for the topic that we will now tackle in the narrower sense.

On the existential level, chemistry is deeply ingrained in our human existence. Its greatest accomplishments occur in the organ systems most removed from our consciousness: in protein synthesis, hormone synthesis and secretion, immunochemistry, muscle metabolism – and also in the highest form of bodily chemistry, the actual development of the embryonic body. Who among us knows anything about this chemistry of life as it unfolds, except from books?

Our experience of anything unconscious is holistic. In order to experience it consciously, we must extract it from the context of the whole and subject it to analysis. That is why the second approach to chemistry as a science has always focused on the "art of separation." Elemental analysis identified the chemical elements in both qualitative and quantitative terms. Soon the question became, what still remains to be done once enough separation has been accomplished? Once we confronted such an abundance of elements that we lost the overview, a counter-movement began. Which elements belonged together according to their chemical properties? Were they metals or non-metals, base-formers or acid-formers? Goethe was extremely interested in this question. In his color theory, he assigned the red and blue color poles to acids and bases, respectively. He also wrote to W. F. Wackenroder (1798-1854), hoping to elicit important information on the physiological

chemistry of plant fluids in the sequence of leaf modifications in individual flowering plants (letter to Wackenroder, January 21, 1832).

In 1810, Goethe recruited Johann Wolfgang Döbereiner to the University of Jena where, at Goethe's request, he soon demonstrated the conversion of starch into sugar and the catalytic effect of platinum and explained the laws of stoichiometry. Goethe supported Döbereiner in whatever ways he could. "In years past I have met many an excellent young man in this way, but none who gave me more pleasure or, in my inmost conviction, offered me more hope" (letter to F. A. G. von Ende, April 28, 1812). When Goethe discovered celestine in Dornburg in 1817, he asked Döbereiner to analyze it. Döbereiner then proceeded to discover the first elemental triad (calcium, strontium, and barium), and his Law of Triads laid the foundation for the incremental development of the periodic table (*van Spronsen* 1969:1; *Krätz* 1992:207). Goethe would have been overjoyed if he had lived to experience the discovery of the *law of octaves* by J. A. R. Newland (1838 – 1889): in every eighth element the same chemical tonic note is repeated.

Both of Döbereiner's discoveries, the use of platinum as a catalyst and the elemental triads, would have unexpected consequences. The entire field of biochemistry is inconceivable without catalysts – substances that can cause chemical reactions without being affected themselves. The Law of Triads later culminated in the discovery of the periodic table of the elements: Order is indeed inherent in matter. According to Plato and Aristotle, philosophy begins with wonder, but Steiner recommends the reverse: "We must stimulate wonder whenever we get to the end of a lesson. We must make the students understand that even a Novalis would get down on bended knee in the face of such grandeur." (*Steiner*, GA 300/11: 42/43)

There are two sides to materialism. Its justified aspect draws our attention to the material world and researches it with all the means available to the sense-bound natural sciences. But with regard to its other aspect, its claim to universality (i.e., the claim that only matter exists), materialism is an ideology like any other that claims ownership of the absolute truth. Every anthroposophist is always ready – and justifiably so – to refute this second aspect, but we must always quote Rudolf Steiner himself on the first: "Can we say that the claims of the materialists are correct? Well, with regard to matter and its laws, they may be able to bring to light much that is extremely useful and valuable." (*Steiner*, GA 151, lecture of January 1, 1914; GA 237, lecture of August 4, 1924) For Steiner, materialism was one of *twelve* justified ways of viewing the world. It is always important to make a clear distinction between the ideological and methodological aspects of materialism. (*Schad* 2004)

The Main Groups of the Periodic Table

That last Steiner quote certainly applies to the periodic table, which is one of the most important and fruitful discoveries in the history of chemistry. Since the discovery of this organized arrangement, the field of chemistry would no longer be either meaningful or viable without it. Wherever predictability of the basic properties of elements is required, insight into the laws of the periodic table provides chemists with an abundance of initial answers. Which valences and transitions among the three main types of compounds are possible? Where does each element fall on the scale of alkalinity and acidity? What can we expect it to look like? Having achieved

the first major view of periodicity in 1869, Mendeleev was soon able to predict many such properties. In many cases, the periodic table also allows us to estimate the time required for chemical reactions to take place. We are interested not only in acquiring knowledge for the sake of control, however, but also in a Goethean view of the qualitative aspects of this lawful arrangement.

For example, it is worthwhile to explore the periodic table with an eye to discovering which periods and groups include the elements most supportive of life. To the extent that life can be observed, it always consists in temporally active tensions between antagonists of different energy levels. Equilibrium is never finally achieved because it would result in death. The most obvious polarity or tension in chemistry is between alkalis and halogens, groups one and seven. Alkalis form strong bases, halogens highly reactive acids. Both are hostile to life at even moderate concentrations. Life requires moderate but never balanced conditions; strong bases and acids destroy it. Furthermore, the low molecular weight elements in the first few periods are quantitatively dominant in the chemistry of life. Life prefers lightweight elements over heavy ones. Beyond zinc (atomic number 30), very few elements are essential to life (see Zeeck 1997:16ff). In photosynthesis, life's central biochemical process, the preference for lighter elements goes so far that lighter $^{12}\text{CO}_2$ is selected over heavier $^{13}\text{CO}_2$ out of the natural mixture.

The fundamental characteristics of life processes explain make two phenomena: one, that the basic biochemical material of organic chemistry is supplied by *carbon*, the lightest representative of the middle (fourth) group, rather than by any element in the outer groups. Thus organic chemistry has been described as the chemistry of carbon compounds, even though water makes up a much higher proportion of every living cell, at least if the water in the hydration shells of hydrophilic carbon compounds is not counted as part of these organic compounds. Eugen Kolisko was the first to recognize carbon's position in the second period as an instance of the Goethean law of enhancement [“*Steigerung*”] between polarities, the two “drive wheels of nature.”(Goethe, CW, Hamburg edition 13:48)

The next heavier element in the same group as carbon is silicon, an element often involved in physiological processes. It converts readily from soluble H_2SiO_3 to silica (opal, amorphous SiO_2) and thus easily moves from the soluble state in cell plasma to the solid state in silica structures. Just think of the silica “skeletons” of siliceous sponges, radiolaria, silicoflagellates, and (most especially) diatoms, or of the role silica plays in the support structures of all *Equisetum* species, the vascular bundles of bracken, the leaf edges and awns of grasses, the stinging hairs of nettles, etc.

Even more obvious is the scope of silicon's occurrence in the material processes of the Earth's crust, which consists largely of silicates, including all the intrusive igneous rocks (granite, gneiss, gabbro) and most extrusive igneous rocks, especially the products of subduction volcanism. (Schmutz 1986:12ff). In the Earth's crust (that is, to a depth of 16 km), silicon and oxygen, at 25.75 percent and 49.52 percent, respectively, are by far the most abundant elements, together comprising 75.27 percent. Comparatively speaking, silicon (always in oxidized form) is the “carbon” in the structure and metabolism of the accessible portion of our planet. Even ancient intrusive igneous rocks contain an average of three percent carbon in the form of graphite. (Pflug 1984:127) This means that there is more carbon in the Earth's crust than in the entire biosphere with all its organisms. In contrast, biogenic silicon dioxide is present in all organisms but in smaller quantities than carbon. As

closely related as these two elements are, they are represented in inverse proportions in individual organisms and the body of the Earth itself.

With increasing atomic weight, alkalinity increases in group 1 elements while acidity decreases in group 7. As a result, the greatest contrast in this respect is between francium and chlorine (hydrofluoric acid remains too associated). All of the other main group elements form a cascade of transitional forms. The resulting arrangement makes it clear that shared similarities exist not only among elements of the same group or period but also among those located on diagonals running from upper left to lower right. Since these diagonal connections make a Goethean “archetypal phenomenon” visible, it is time to do away with any remaining barriers to understanding them.

One of the main criticisms of a Goethean approach to the chemical elements is that in most instances we are dealing with elements in their humanly or technologically altered states, not with given facts of nature. Under natural conditions, only a few elements occur in elemental form – carbon, nitrogen, oxygen, sulfur, copper, and mercury; all of the precious metals such as gold, platinum, silver, etc.; and the inert gases. This list is very short indeed in comparison to the majority of the 92 natural elements! At this point we will not consider how seriously Rudolf Steiner took the concept of individual elements in agriculture and medicine, in issues of fertility and medication, but will refer only to Goethean methodology:

“Let each of us take this opportunity to say that separating and combining are two inseparable acts of life, [...] and the more actively these functions of spirit (such as inhaling and exhaling) interact, the better it is for the sciences and the friends of science.” (Goethe, CW, Hamburg Edition 13:233)

Goethe, the greatest biophilic synthesizer, has frequently but quite unjustifiably been seen as opposing the analytical approach. In practice and as a matter of conviction, however, Goethe never pitted synthesis against analysis but made use of both in alternation. In fact, most of his zoological studies were based on osteology, not on observing living animals. The skeleton, however, is a secondary or reductionist phenomenon and is often available only as a consequence of human intervention; it must first be extracted from the larger context before it can be reinstated. For Goethe, synthesis and analysis belonged together like inhaling and exhaling, “because throughout my life, whether in writing or in observation, I had engaged in synthesis and then in analysis. For me, this systole and diastole of the human spirit were like a second form of respiration, never separated and always pulsing.” (CW, Hamburg Edition, 13: 27) We should therefore refrain from further fruitless polarization and instead ensure that both synthesis and analysis always occur. Coming to agreement on this point should not be difficult; the fruitlessness of one-sided approaches should be sufficient warning. On its own, analysis leads only to data graveyards and synthesis to overviews with no sense of the facts. Our upper school students are vehemently allergic to both of these approaches and often offer the best possible reality check for teachers who apply Goethean methodology.

Now let’s look at the elements as they manifest under normal circumstances, first concentrating on group 1 and paying attention only to their relationship to light. A large number of metals are concentrated in the lower left of the periodic table. They appear in the form of free elements and are reflective and shiny, which means that most of the light falling on them is bounced back largely unchanged while they themselves remain dark within. Non-metals dominate the opposite pole at the upper right. Primarily gases, they are often transparent and colorless; light passes through them almost without resistance. If we look at the second period (lithium to fluoride),

we note a progressive decrease in the elements' metallic sheen, beginning with beryllium and continuing through boron to the totally dull black of carbon. Carbon, however, is subject to modifications that reveal visible differences: it is blackest as amorphous soot, while the more mineralized graphite is blackish gray or even shiny. The recently discovered C₆₀ fullerene appears reddish violet when dissolved in toluene, and pure diamonds are completely colorless and transparent. Carbon's neighbors nitrogen and oxygen are colorless gases, as are all of the inert gases. At room temperature, fluorine is an almost colorless, pale yellow-green gas.

In the second period, the metallic sheen persists from sodium through magnesium and aluminum to silicon, although the latter's chemical properties are largely non-metallic. Phosphorus (diagonally related to carbon) can be as black as carbon, but in its red and white forms it also establishes the transition to colorful elements such as yellow sulfur and chlorine.

In periods 3 through 7, the elements that are dull black in color are increasingly located farther to the right: Arsenic appears in red and yellow modifications, selenium in black, dark red, and red. In particular, the elements in the halogen series achieve increasing depth of color, until iodine ("violet" as a gas) becomes black and shining. Astatine is a radioactive element with such a short half-life that its color remains unknown, but it is expected to be dark and metallic. Between the solid metals and the lightest gaseous non-metals of the main groups – that is, between complete opacity and complete transparency – lies a shimmering "seam" of color. These transition elements absorb light superficially and disperse it transformed. In other words, their relationship to light is characterized by enhanced activity. As we have already seen, pure carbon can assume all three color attributes – black, colorful, and colorless/transparent – and in this context, too, it also represents the integrating middle. In the table below, the colorful elements of the main-group periods appear in ***bold italics*** for emphasis:

H	-	-	-	-	-	-	He
Li	Be	B	<i>C</i>	N	O	F	Ne
Na	Mg	Al	Si	<i>P</i>	<i>S</i>	<i>Cl</i>	Ar
K	Ca	Ga	Ge	<i>As</i>	<i>Se</i>	<i>Br</i>	Kr
Rb	Sr	In	Sn	Sb	Te	<i>I</i>	Xe
Cs	Ba	Tl	Pb	Bi	Po	At	Rn
Fr	Ra						

Light and darkness interact not only in shades of gray but also in colors that break out between them. The colorful seam in the periodic table, like countless natural phenomena, reveals this fact to a Goethean view.

Fluorescent Substances

The Spanish physician Niccolo Monardes was probably the first (in 1570) to describe a fluorescent fluid, presumably an organic solution. In 1602, Vincenzo Casciarolo, a cobbler from Bologna with an interested in alchemy, discovered that heavy spar (BaSO₄), after being heated with flour (a carbon source!) and exposed to light, continues to shine in the dark. (*Schulz 1975*) Since then, we have learned to

distinguish between luminescence due to various energy inputs – such as photoluminescence, thermoluminescence, electroluminescence, crystalloluminescence (e.g., during crystallization of AsCl_3), and triboluminescence (generation of light through mechanical rubbing) – and the *bioluminescence* of lightning bugs, the mycelium of *Armillaria* fungi, luminescent bacteria, etc. (Cf. *Gehlig* 1995) Luminescence following exposure to light is traditionally called “phosphorescence.” However, white phosphorus (discovered by Henning Brand in 1669) glows in the dark as a result of oxidation upon exposure to air and is therefore actually “chemoluminescent,” not “phosphorescent,” in spite of its name (phosphorus = “light-bearer”).

The aurora borealis (luminescence of upper atmospheric layers) is one example of natural luminescence. Luminescence, therefore, can occur in gases, liquids, or solids. For example, green chlorophyll glows red when backlit, even in normal dispersed light. Ever since Stokes described the phenomenon in 1852, all such examples of photoluminescence have also been called “fluorescence.” (The name comes from fluorite, CaF_2 .) Many fluorites that appear violet when light falls on them shine greenish when backlit, and fluorites exposed to “black” (UV) light are even more impressive, often fluorescing in intense blue. (Very inexpensive little UV bulbs are readily available online.)

We will limit ourselves here to mineral fluorescence, which is extremely interesting in relationship to our topic. *Gleason* (1960) listed over 210 fluorescent minerals, 31 of which are also phosphorescent. The most important ones are fluorite, calcite, apatite, rock salt, sphalerite, willemite, scheelite, wollastonite, zircon, ruby, diamond, and autunite.

In most cases, the colors of mineral fluorescence are not at all characteristic of the primary mineral but only of finely dispersed mixtures. Zinc sulfide heated with trace amounts of copper fluoresces yellow-green, with the optimum ratio of Cu to ZnS being 1:10,000. (*Winkler* 1955) The color is entirely due to gaps in the crystalline structure and the addition of metal ions. An important difference emerges here between the elements of the main and sub-groups of the periodic table, which is why we are including this whole topic.

Most of the crystal-forming compounds of main group elements are colorless/transparent. Think of rock salt (NaCl), fluorite (CaF_2), calcite (CaCO_3), gypsum (CaSO_4), apatite ($\text{Ca}_3(\text{PO}_4)_2$), barite (BaSO_4), potash alum ($\text{KAl}(\text{SO}_4)_2$), quartz (SiO_2), corundum (Al_2O_3), or even pure diamond (C). Even cerussite (PbCO_3) can form clear, colorless crystals. These are consistently compounds of elements from the metal side of the periodic table with main-group non-metals. None of them are fluorescent in their purest forms, which allow light to pass through unhindered. Conversely, most sub-group compounds have strong colors of their own; the more idiochromatic they are, the less likely they are to fluoresce. Exceptions are the colorless compounds of zinc, cadmium, mercury, and zircon. Iron oxide and manganese oxides, even in trace amounts, extinguish fluorescence; iron is the most “earthy” of solid elements, and manganese is its closest relative in the periodic system. But when the other colorless main-group crystals are interspersed with homeopathic traces of sub-group metal ions, fluorescence generally appears under UV light in all colors of the rainbow, depending on the element and its valence. (*Lieber* 1957)

This is why ruby (corundum tinted red with traces of chromium) fluoresces even in visible light and the red color intensifies under UV light. In contrast, sapphire (corundum tinted blue with traces of iron) does not fluoresce at all due to the

fluorescence-suppressing effects of iron. In fluorites, deep blue fluorescence under UV light is often due to trace amounts of rare earth elements, and in calcite, divalent manganese is often the “activator” of red fluorescence while europium – presumably along with other rare earth elements – is again responsible for blue fluorescence. (Robbins 1983) The most important activators are chromium, manganese, copper, silver, yttrium, many of the rare earth elements, and uranium. Uranium fluoresces under UV light even in the moderate concentrations found in ores, but only in the form of the 6-valent uranyl ion $(\text{UO}_2)^{2+}$. Calcium tungstate (scheelite, CaWO_4) and calcium molybdate (powellite, CaMoO_4) fluoresce even in their purest, uncontaminated forms. Here, main and sub-group elements come together in what appear to be especially quantitatively suitable combinations in which the sub-group elements tungsten and molybdenum, unlike typical metals, function not as cations but as quasi non-metals, forming acid radicals in combination with large amounts of oxygen.

Although there are exceptions, the general rule with regard to fluorescent minerals is that the basic mineral consists of main group elements while the trace amounts of activators are metals from the sub-groups of the periodic table, especially from the sub-groups within the sub-groups (rare earth elements). Here we encounter a concrete expression of an archetypal phenomenon: It is well-known that many sub-group compounds are highly colorful under normal light and fluoresce under UV light. This enhanced middle section of the periodic table is not merely a “colored seam,” as Goethe put it, but a wide colored band inserted between the contrasting poles of the metals and non-metals of the main-group periods, although it leans more toward the metal side, since all of these elements are metals. The following arrangement of the periodic table (from *Lexicon der Chemie*) makes it easy to visualize the situation:

Within the entire cosmos of elements, the polarity in the main groups is richly enhanced in the subgroups, where most of the fluorescent minerals are found and provide the most esthetically beautiful impression.

The Iron Group

The subgroups deviate substantially from the general rule that applies to the main groups (see above). They are inserted between the second and third main groups and only from the fourth period on down, so without exception they are all metals. Because the chemical similarities among the sub-group elements in each period are greater than those among main group elements, the “horizontal relationship” plays a greater role here than either vertical or diagonal connections. For all of their similarities, however, the subtle differences among these elements are impressive. The first subgroup merits special emphasis because it consists primarily

of trace elements essential to life. We will disregard the first two (Sc, Ti) and the last (Zn) and look at the elements of the central group (vanadium, chromium, manganese, iron, cobalt, nickel, and copper) from the perspective of comparative morphology. In this context, it makes sense to consider not only these elements' metallic properties but also the colors they impart to their water-soluble salt compounds. Divalent iron, for example, yields a delicate, restrained green, whereas trivalent iron appears in shades of yellow, orange, red, and brown. Lower valency (ferrous) iron therefore tends toward passive colors, higher valency (ferric) iron toward the active colors of the spectrum. The former trait is intensified in the deep blue color that predominates in compounds of divalent cobalt, which turn a delicate pink only when chemically combined with water. The salt of divalent nickel is grass-green in combination with water but blue in combination with ammonia. Its neighbor, copper, is deep blue in many such complexes (such as azurite, its carbonate mineral) but depending on the water content, it may also be a saturated dark green (malachite). Its ammonia complex is a deep, dark blue. In addition to its common Fe (II) and Fe (III) compounds, iron can be chemically "forced" into a 6-valent oxidation state, yielding the red-violet ferrates. Such high valences are much more the natural, normal state of affairs in iron's lighter sisters. Manganese can easily be made to run the gamut of valences two through seven, manifesting in almost all the colors of the spectrum depending on the valences, complexes, and particle size (*Mohr 1954: 202f.*) Its most stable compounds tend toward the red end of the spectrum and include the naturally occurring manganese minerals rhodochrosite (manganese carbonate) and thulite (a manganese-bearing ziosite) and the well-known potassium permanganate, which is a deep red-violet. Although the colors of manganese compounds are very varied, they are all subdued, as is also the case with iron.

In contrast, chromium salts are strikingly colored, as the name of the element (from the Greek *chroma* = color) suggests. Again, this is especially true of higher-valency compounds, i.e., the 6-valent chromates and dichromates. Even trivalent chromium gives a violet color to chrome alum. When shaken in ether, trivalent chromium peroxide turns a brilliant blue. Most of the rainbow beauty of tourmaline is due to a range of chromium valences. Chromium is close to vanadium, which also tends to form higher-valence vanadates and is especially stable in the form of vanadium pentoxide, V_2O_5 . The predominate colors of vanadium ores are yellows through reds, but salts created in the laboratory range through all the other colors as well. (*Mohr 1954:193f.*)

When all of its ions and complexes are spread out in front of an eleventh grade class, the color wheel of iron's seven relatives is an esthetic prize. It reveals the great wealth of nuanced color inherent in these otherwise completely colorless-looking pure metals (copper and gold are exceptions). In addition, in spite of the great diversity of color, each of the seven strikes an individual note of color saturation that is very characteristic yet difficult to describe in qualitative terms. How subdued the colors of most iron compounds are, and how gaudy most chromium compounds! Here the individualities of the metals are revealed.

We must not neglect the metallic properties of these elements. In appearance, they range from the dull steel-gray of pure vanadium to the warm, dark red of copper. The characteristic polarity in this sequence is evident in their alloys with iron. Steel that contains vanadium, chromium, or manganese is especially hard but tends to be brittle; it is good for making chisels and drill bits. In contrast, cobalt, nickel, and copper alloys of iron are distinctly elastic and make good ball bearings. At this point,

it becomes possible to adequately incorporate the chemical properties of these metals into our summary of their sense-perceptible characteristics:

	V	Cr	Mn	Fe	Co	Ni	Cu	
gray	←			bright and shiny			→	reddish
hard	←			iron alloys			→	elastic
reds, yellows	←			colors of compounds: salts and complexes			→	greens, blues
high	←			valence			→	low
brittle	←			iron alloys			→	elastic

The role these metals play in biochemistry are also very informative. All of them function as biocatalysts. The essential vitamin B₁₂ contains cobalt. Vanadium, iron, and copper play especially important roles in respiratory complex pigments. Iron (only divalent, in this case!) is of central importance in the heme of hemoglobin, the red pigment in blood, and even heme's precursor, iron-free protoporphyrin, is already red. Copper is the corresponding respiratory metal in hemocyanin, which carries oxygen in the blood of most mollusks (snails, mussels, squids). Copper (II) ions tint this blood blue when it is oxidized; it is colorless when reduced. Vanadium is concentrated in the blood of sea cucumbers, which are holothurian species related to sea urchins and starfish; like them (and also the tunicates), holothurians have parts arranged around a central axis in five equal sectors. At this point in the discussion, it is instructive to compare a holothurian, a vertebrate, and a snail.

As we have just seen, iron's central position is fully expressed only in comparison to its sister elements. Iron occupies the middle between extremes and occurs almost everywhere. This central position is reinforced when we look at the entire periodic table in terms of the invariability of the elements. In modern times, all the paradigms of invariability that have come down to us from antiquity are becoming dynamic: As early as 1440, Nicholas of Cusa realized that the Earth does not stand still but rotates and revolves around the Sun. Based on measurements made by Tycho de Brahe, Johannes Kepler concluded that planets, instead of moving at fixed speeds along circular orbits, revolve on ellipses and at variable speeds. As early as 1698, Leibnitz postulated the variability of species. The astronomers Edmond Halley (1718) and Johann Tobias Mayer (1760) then discovered even fixed stars can move and their relationships to each other are not fixed. Similarly, the discovery of radioactivity by Henri Bequerel in 1896 soon put an end to the notion of invariable elements. And as early as 1912, Alfred Wegener was talking about continental drift.

The heaviest elements (with molecular weights greater than that of lead) do not have fully stable isotopes.¹ Through nuclear disintegration, they are transformed either slowly or rapidly into lighter elements, one of which is often an inert gas. This

¹ For many years, bismuth was considered the heaviest stable element, but according to the most recent investigations, it is metastable, with a half-life of 2×10^{19} years (Nature 422: 876-878, April 24, 2003).

is also true even of the lighter radioactive elements technetium and promethium. In contrast, the lightest elements can be transformed into more stable elements through nuclear fusion. Whether through fission or fusion, nuclear energy is released at both ends of the periodic table and the resulting persistent elements are more stable than their source elements. The energy potentials of elements decrease toward the center of the periodic table. In this sense, iron has proven to be the most stable element and is therefore the central element of the entire periodic table in terms of nuclear energy.

The Arrangement of the Periodic Table

It was once hoped that chemistry, as the “art of separation,” would be able to gain a better overview off the immeasurable abundance of substances by tracing all of them back to only a few chemical elements. To date, however, an unexpected wealth of elements (currently 109) have been identified, and the next step – describing them as comprised of three basic types of subatomic particles (protons, neutrons, and electrons) – has also been unable to avoid a plethora of new discoveries. For this reason, our students experience the inherent mathematical order of the periodic table as a major triumph of knowledge. We count the number of elements in each of the seven periods:

I	2
II	8
III	8
IV	18
V	18
VI	32
VII	19 + x

The second and third periods turn out to be the same size, as do the fourth and fifth. We can imagine the seventh period being completed, making another pair of equals together with the sixth. The resulting number sequence would then be 2/8/8/18/18/32/32. Even by itself, this sequence satisfies our need for order, symmetry, and periodicity, and the satisfaction is enhanced when we demonstrate the common formula shared by these numbers, namely, $2 \times n^2$ where $n = 1, 2, 3, 4$:

$$\left. \begin{array}{l} 2 = 2 \times 1^2 \\ 8 = 2 \times 2^2 \\ 18 = 2 \times 3^2 \\ 32 = 2 \times 4^2 \end{array} \right\} 2 \times n^2 \quad (n = 1, 2, 3, 4)$$

Matter, therefore, is not mere chaos. It possesses an inherent structure that can be formulated in mathematical terms – a fact that leaves students astonished and impressed with the esthetics of the idea.

It is worthwhile to allow this discovery to go through the night and then to approach it from a different perspective the next morning. Although the structure of

the number series $2 \times n^2$ is unambiguous, the reality does not quite live up to it: The last period breaks off naturally at element 92 (uranium) and artificially (at least as of this writing) at 109 (meitnerium). Nine elements are missing, and the period would need to end with an inert gas (atomic number 118). These elements, however, remain unknown because all elements heavier than lead are radioactive and therefore constantly disintegrating into lighter elements

Moreover, the periodic table is also incomplete at the beginning, not just at the end. Just as there are two periods each for $n = 2, 3,$ and $4,$ symmetry would actually require two periods for $n = 1.$ In spite of its pervasive regularity, therefore, the periodic table is not complete. The material world simply is not complete, perfect, and self-contained. Whenever I have presented this problem to a grade 10 or 11 class, the students have always arrived spontaneously at a significant conclusion: Since the world of matter is not complete, it must be still evolving. A developing plant discards its cotyledons before its last shoots emerge, and something similar is true of the material universe. Realizing that even matter is not “finished” gives seventeen-year-olds verifiable knowledge that they can then use to free themselves from the dogma of material determinism.

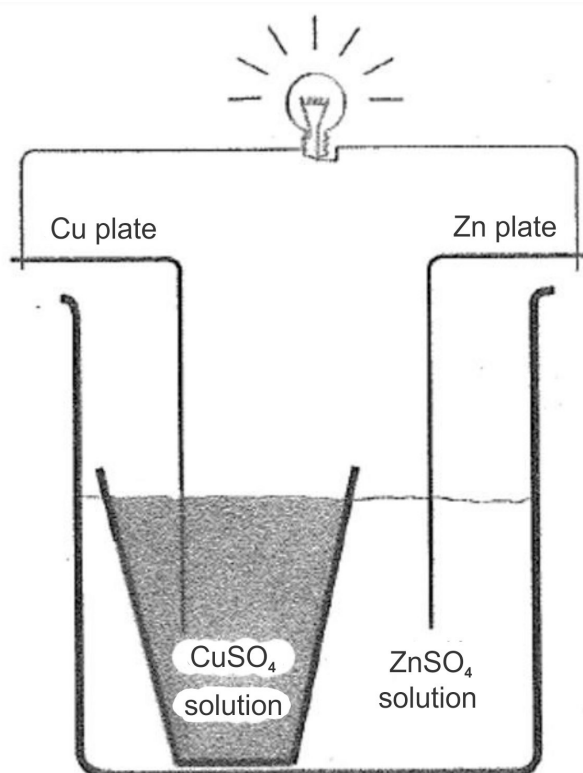
The mere conceivability of a *dynamic* physical and chemical image of the world is valuable in itself. At the end of the block, when I ask the class what meant the most to them, they often respond – irrespective of their scientific talents as individuals – that the most important activity for them was the discussion of the open-endedness of the periodic table. It resonates with them because they are at the age when adolescent consciousness begins to experiment with developing a personal world-view.

As early as the 1950s, the anthroposophical physicist-mathematicians Arnold Blickle and Ernst Bindel (*Bindel & Blickle* 1952) tackled the truncated evolution of the periodic system. In their article, still eminently worth reading for its expertise, they relate the four stages in the numbers of elements per period (2/8/18/32) to the four elapsed stages of the Earth’s evolution (out of a total of seven). In 1913, Rudolf Steiner described these four stages as four embodiments of the planetary cosmos. Consequently, there are also four kingdoms of nature, four Greek elements, and four members of the human constitution. Blickle and Bindel, however, interpreted the temporal context of the periodic table in terms of Proust’s theory – in other words, they viewed hydrogen as the oldest element and thus as the basis of all others. This view is similar to that of modern cosmogony, which calculates that 99 percent of all matter in the universe exists in the form of hydrogen. However, if we view the modern astrophysical cosmos as the latest in a series of four embodiments, our interpretation becomes much more dynamic: For example, periods 7 and 8 are then the last disintegrating remnants of the earliest, most ancient epoch (“Old Saturn”), when these elements were still in a nascent state and therefore very light. Correspondingly, in our own epoch of Earth’s evolution, hydrogen and helium are the nascent Sun elements that provide the planetary cosmos with energy for life. In between these extremes lie substances at various stages of evolution that represent the intervening epochal stages. This view is a meaningful starting point for deepening the study of chemistry.

Electrochemistry and the Theory of Chemical Bonding

Apart from discussing its technological applications (electric batteries, electrolysis, galvanization), electrochemistry is important for the empirical

development of the theory of chemical bonding. At this point, it is best to avoid a formal theoretical introduction, beginning instead by presenting experiments that demonstrate the archetypal phenomena. Here are two such experiments:

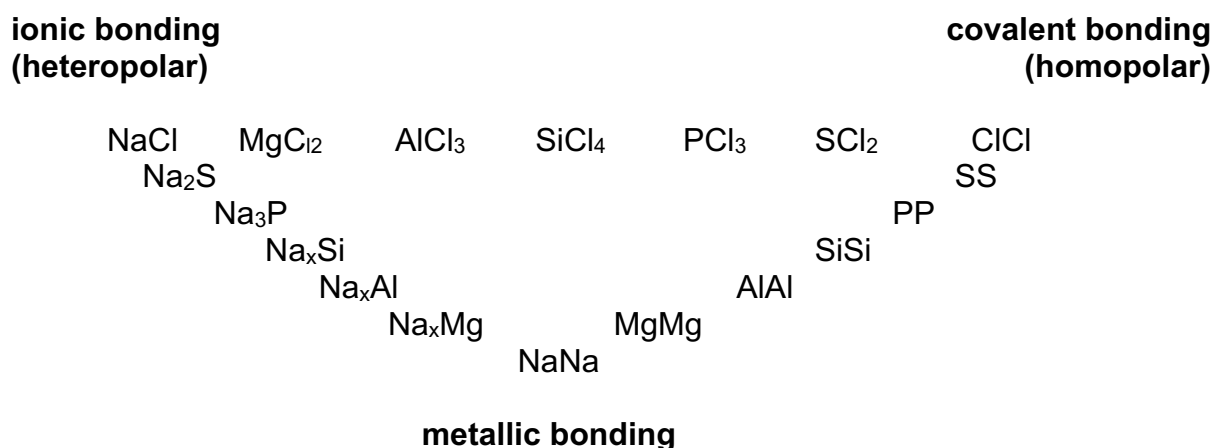


In the first experiment, we illustrate the possibility of deriving electricity directly from certain substances by constructing a *Daniell cell*. The light bulb lights up when an unglazed earthenware flower pot with a closed bottom is used as the inner container. We fill that container with a copper sulfate solution and the larger beaker with zinc sulfate solution and then insert a thin plate of the corresponding metal into each solution. With time, the copper plate becomes heavier and the zinc plate lighter, as we can confirm by weighing them. This means that zinc goes into solution as electricity is given off while metallic copper precipitates as electricity is taken up. The wandering charge carriers (dissolved zinc, copper, and sulfate) travel through the solutions in the form of *ions* (from the Greek *ión*, “going”). Sulfate ions must be passing through the semi-permeable membrane of the earthenware pot, since otherwise a surplus of sulfate would develop inside the pot and a shortage outside. We can see that this movement completes the circuit. As we view and think about this experiment, the basic concepts of ionic chemistry develop seamlessly.

The second, more phenomenologically comprehensive experiment is the inverse of the first: This time, electricity is actively added from outside. A solution of sodium sulfate plus a universal indicator is electrolyzed in a U-shaped tube with platinum electrodes (iron florist wire also works for a short time).

on December 26, 1812: “As long as we never abandon the magnificent conceptual guidelines of electrochemistry, the rest will also not elude us.”

Analytical chemistry has always been concerned with the nature of the chemical forces that unite elements into compounds. The clearest approach is derived from the periodic table, as in the example below, which shows the series of compounds formed from the elements in period 3 (from *Holleman & Wiberg 1955*).



This chart reveals the three main types of bonds and makes us aware of all the transitional types. Clearly, pure heteropolar, pure homopolar, and pure metallic bonding occur only in the extreme cases. Intermediate states are the norm. The following sequence of compounds also illustrates the transition from ionic to covalent bonding:



If we look at the chemical properties and activity of lithium fluoride, beryllium oxide, boron nitride, and carbon, we see a progressive decrease in the compounds' salt-like character and an increase in polymeric capacity. At one pole, *dissociation* processes occur readily in water, generating electrical activity; at the other, *association* tends to occur, resulting in electrically neutral substances.

When we look at the theoretical model of bonding types, we are struck by the fact that very characteristic inorganic compounds such as salts, acids, and bases – in other words, all electrolytes – are easiest to explain in terms of the classical electrophysical attraction of oppositely charged ions, which can be interpreted as the donation and acceptance of particulate, separated electrons to complete the electron octet for each of the combining elements, held together by simple electrostatic attraction of the resulting ions. But as the bonding approaches covalency, which is responsible for the polymers that support life, the point-wise distribution of electrons imagined as particles no longer applies. How can a covalent bond possibly hold together when both electrons have the same charge? This phenomenon can be interpreted only in terms of quantum theory – that is, by “relaxing” the laws of classical physics so that the space vector and impulse (or temporal axis and energy) become undefined. Location and time can no longer be pinpointed, becoming nothing more than probabilities or potentials that cannot be conceived precisely. It is

very interesting to note that such limit-experiences inevitably appear when dynamized forms of thinking approach organic substances and thus the biochemistry of living matter.

This is all the more true of the *mesomerism* that almost all organic compounds exhibit: the type of bonding falls somewhere between two structural formulas with covalent bonds. Even in any carboxyl group, the hydrogen belongs to both of its oxygen partners. The single hydrogen bond is generally broken down into two half-bonds, and where is the covalent bonding in that arrangement? In either covalent bonding or mesomerism, quantum relationships apply that do not describe any identifiable state of affairs but only probabilities or potentials. The wave theory of electrons that is applied here also deals only with probable waves rather than factual ones.

Inorganic matter with its characteristic electrolytes can be explained in terms of sums of particulate entities, whereas the world of living matter, like life itself, cannot. Of course highly polymeric minerals also exist, especially among the silicates, but this is no contradiction if they are understood as the Earth's "biochemistry" or the geochemistry of the Earth's life.

In his own way, Rudolf Steiner had the "relaxation" of rigid conceptions of molecules in mind when he spoke in 1921 about the step from inorganic crystalline structures to the inherent configurations of living matter:

"Here, however, substances are constantly forming for chemists to investigate, substances that do not always exhibit outer crystallization. Instead, their configuration is internal. Even the recent trend toward structural formulas in chemistry hints at this internal configuration. [...] But here is the mystery: The more organic the connection between substances, the less they bond chemically and the more chaotic the intermixture of substances becomes." (*Steiner*, GA 205: 88/89, June 1, 1921)

In life, formerly inorganic substances relinquish their forces of crystallization. This speaks qualitatively to the transition from ionogenic to merely covalent bonding, which can be described only in terms of chaos or quantum theory. Acceptance of the theory of covalent bonding was the subject of dramatic discussion among leading experts as late as the 1930s. At issue were Einstein's objectivistic determinism versus Bohr's probabilistic indeterminism. The latter was victorious, and Einstein at least conceded, as William Bragg is purported to have said, that everything that has already happened is particulate, and everything in the future is waves. In 1970, Bragg's son Lawrence formulated it like this: "The advancing sieve of time coagulates waves into particles at the moment 'Now.'" (*Clark* 1973) Clearly, the physical reality of substances is incomprehensible if time is excluded, since substances are also constantly coagulating out of the nascent state into reality.

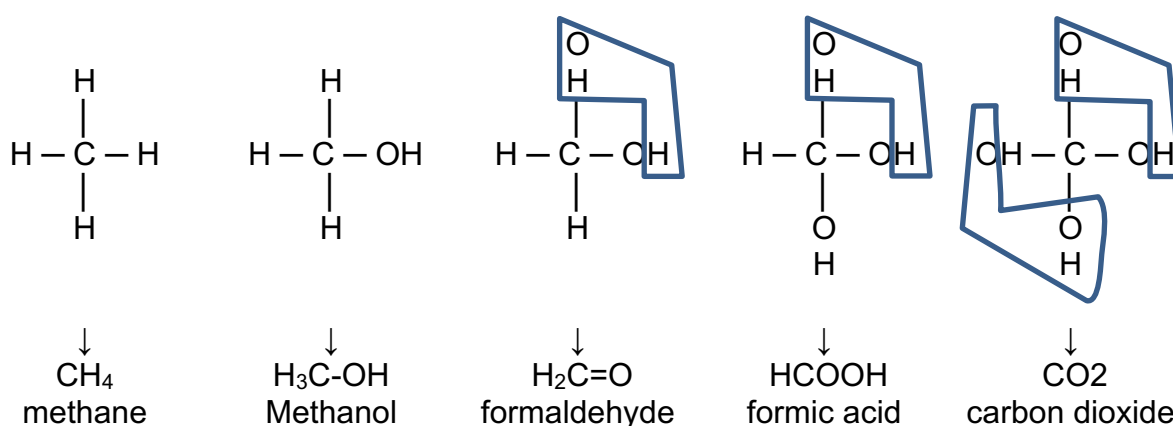
At this point, the problem with chemistry as taught in our schools is that chemistry teachers themselves generally have not had the opportunity to delve into the fundamental contents of quantum theory with any degree of understanding. Ideally, however, what fundamental principles of quantum theory should a Waldorf upper school teachers have grasped? There is an urgent need here. In the long run, it makes no sense for teachers to respond to the probing questions of twelfth and thirteenth graders if all they can say is that they themselves also do not fully understand the quantum theory behind the octet rule, covalent bonding, mesomerism, and the benzene ring but that the students must be able to replicate the customary wording on exams. Unfortunately, the same situation applies in public schools. We must make the effort to acquire at least a beginner's understanding of

the principles, as Steiner intended. We would find it well worth our while to take this step toward achieving the working goal of the chemistry of the future, a goal that Goethe himself already foresaw in his later years:

“In this field (i.e., teaching about organic nature), we owe a great deal to chemists, who bypass the content and structure (of an organism) and devote their attention entirely to the properties of substances and the ratios of their mixtures. We will become even more indebted to them because recent discoveries permit very subtle analyses and syntheses, giving us hope that we may approach the infinitely delicate workings of a living organic body. Just as we have been able to achieve an anatomical physiology through precise observation of structures, we aspire in time to develop a physical/chemical physiology, and it is to be hoped that both sciences will continue to advance as if each one alone were to bring the entire matter to its conclusion.” (*Walden* 1943: 81/82)

Here we are interested primarily in the *process* character of bonding types, i.e., with their temporal configurations. In this respect, heteropolar and homopolar bonding are true polarities. Ions bond with incalculable rapidity. When we mix caustic soda and hydrochloric acid, most of the hydrogen and hydroxyl ions form water instantly. The opposite is true of bonds between electrically uncharged partners (i.e., atoms or molecules rather than ions): In classic instances, this type of bonding occurs very slowly. Charcoal from the first fires used by prehistoric humans (> 1 million years) is still being found embedded in sediments, and petroleum, for example, has remained practically unchanged from the Paleozoic Era until today. Graphite, which surely passed through the photosynthetic process at one time, is found even in the oldest rocks on Earth (3.8 billion years). (*Pflug* 1984) Carbon compounds move into the world of living processes only by passing through heteropolarizing stages.

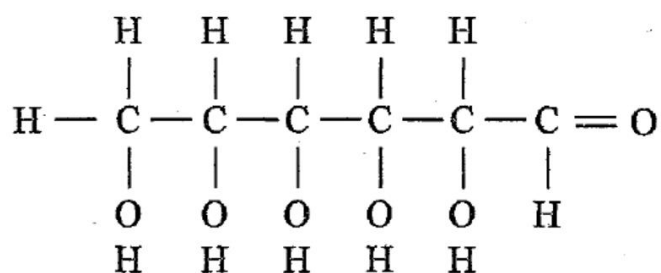
It is the temporal aspect that makes the oxidation series of aliphatic hydrocarbons (commonly used as an introduction to organic chemistry) so instructive on an ongoing basis. We begin with the four stages in the oxidation of methane, the simplest of these compounds; the end product, carbon dioxide, is the lowest in energy of the compounds in the sequence.



Because methane's bonds are all covalent; it is relatively inert unless activated by the addition of energy. Methanol is more chemically active and formaldehyde even more so. Formic or methanoic acid, however, dissociates into ions and is therefore highly reactive, readily entering into ionic reactions. The same is true of the carbonic acid ions that develop out of carbon dioxide. If we consider the

alkane, alkanol, alkanal, and carboxylic acid series in a very general way, simply with regard to their suitability for life, it soon becomes clear that an organism composed entirely of compounds with ionic bonds would rapidly reach the end of its life due to the speed of the reactions that would take place within it. Conversely, if it consisted entirely of covalently bonded substances, necessary reactions would never even begin and the organism and it would remain metastable, at its initial high energy potential, with no means of changing. Obviously, therefore, real life often makes use of intermediate-stage compounds. If we take a not overly long carbon chain with a few oxygen bonds as an energy source, several alcohol groups as weakly reactive potentials, and at least one aldehyde group as a more reactive component (but less reactive than an ionogenic alkanic acid), the natural outcome is a compound well suited to supporting life – a simple sugar such as glucose, which is the product of photosynthesis. Only now does it begin to make sense why such an important metabolite consists of a multivalent alcohol and a monovalent aldehyde (e.g., a ketone): It needs to occupy the moderate middle ground between extreme temporal patterns.

Thus we can (and should) read not only the compound's spatial structure but also its temporal gesture. By doing so, we move from the chemistry of individual substances to the chemistry of processes, which makes chemical reaction kinetics one of the most interesting aspects of modern chemistry.



Amino acids, the building blocks of proteins, also incorporate both alkalinity and acidity into their molecular structures. Amino acids are *zwitterions*, molecules with both positive and negative centers. They are designed for rapid reactivity, since both their amino groups and their carboxyl groups are ionogenic, the former through proton acceptance, yielding R-NH_3^+ , the latter through proton release, yielding R-COO^- . In qualitative terms, it is not surprising that the plant kingdom consists predominantly of carbohydrates and mobile animals primarily of proteins. It is equally interesting to note that in water, which is so essential to life, the elements hydrogen and oxygen are held together primarily but not exclusively by covalent bonds. Water is weakly capable of dissociation; the ionized product $[\text{H}^+] \times [\text{OH}^-] = 10^{-14}$ accounts for its reactivity – in hydration, for example – and thus as a solvent of all water soluble ions. On the other hand, the predominance of covalent bonds means dilution retards many reactions that would otherwise occur too quickly in water. Even simply in terms of the gradient between homopolar and heteropolar bonding qualities, however, the chemistry of water has certainly not been exhaustively explored, because additional, weaker types of bonding also come into play – the hydrogen bridge bonding that results from the dipolar effect of water's imbalanced (angled) structure, or van der Waals forces that can be explained only in terms of quantum theory, to give just a few examples. Because water has access to a rich spectrum of graduated bonding types, it is capable of many subtly structured combining forms

and reaction speeds, much to the benefit of life. Every good chemist knows that water is more than just (H₂O)_x.

Most physiologically active organic compounds slowly lose reactivity, either by condensing into long-chain macromolecules (i.e., by releasing water) or through polymerization (without releasing water). For example, glucose can transform into cellulose, n-acetylglucosamine into chitin, the phenylpropanols into lignins, acetic acid into fatty acids or isoprenoids such as caoutchouc, simple alkanes into waxes, amino acids into scleroproteins (horn). Structural compounds are not the only products of this phenomenon, however. Even energy sources such as starches, hemilcelluloses, long-chain fats, etc. can develop in the same way. All of these condensates or polymers are primarily covalently bonded, energy-rich, and contribute structure and bulk to the organism. In contrast, fully ionizable substances present the opposite picture: These compounds become physiologically active through dissociation rather than association and are characterized by electrical polarization, not electrical neutrality as in the polymers. Where fully ionizable compounds play a role in the organism, lower energy levels are achieved through rapid ionic reactions. All neurological rhythms are based on rapid ion migration.

The protein fraction of a living cell receives its internal structure from the cytoskeleton (with predominantly covalent bonds) and its reactivity from the supply of ions in the cytosol. In living proteins – whether gels or colloids – these two features always collaborate closely: Long chains contain the potential energy developed through anabolism, while weakly ionogenic amino and carboxyl groups initiate catabolic reaction cascades and alter electrical potentials by releasing energy. In most amino acids, the α-position of the amino group in relation to the carboxyl group prevents the possibility of mere salinization of the cell content. Any other position would rapidly lead to “intrinsic salinization” even within the molecule. *Life, even when described in chemical terms, consists not in eliminating tension but in preserving it in moderated form by partially (!) balancing out differences in potentials.* We arrive, therefore, at the following comparison of the basic polar bonding types:

homopolar = covalent = atomic bonding	Bonding	heteropolar = ionogenic = ionic bonding
polymerization condensation association	molecular structure	electrolytic dissociation
energy-rich	Energy	energy-poor
build-up of organic substance including structural matter	Metabolism	breakdown into lower molecular or Inorganic compounds
development of the body, biography, incarnation	Configuration	dissolution of life processes; excarnation

To those who understand nature in anthroposophical terms, it soon becomes evident that this contrast involves the vehicles of the two polar activities of the etheric. On the one hand, the etheric body of every living entity is devoted to building up its physical body. This is the domain of the plant kingdom. Ever since plants first dominated the landscape in the Devonian period, increasingly dramatic tree forms have developed. Today, giant redwoods and eucalyptus trees are the tallest living things on earth. The development of bodily mass, therefore, is also the “plant” aspect in animals and humans. Conversely, breakdown processes move from substances of high molecular weight to those of lower molecular weight, accompanied by the release of energy. This physiological breakdown makes perception possible on the soul level in animal and human bodies (*Fortlage* 1869). (With regard to breakdown processes in the plant kingdom, Rudolf Steiner pointed out that in that kingdom, sensory activity belongs to the entire landscape – the “earth soul” – rather than to individual plants. See GA 60, lecture of December 8, 1910.) Rapid ion reactions are necessary if the astral element is to take hold. In the spectrum of human rhythms, the most rapid physiological alternation is the neurological rhythm of polarization and depolarization via the migration of Na^+/K^+ ions within the cell membranes. The etheric approaches the physical and astral members of the constitution by utilizing covalent and ionogenic bonding, respectively. On the chemical level, this dual aspect of the etheric is graphically expressed in the antagonism between homopolar and heteropolar bonds.

It is also worth taking a look at metallic bonding and actual metal compounds (alloys, coordination complexes, and metallic salts). We are initially struck by the fact that the majority of chemical elements are metals. The flowing transition from heteropolar to metallic bonds takes place from the light metals to the precious metals, based on the broad spectrum of their redox performance, which forms the basis of electrochemistry, for example. *Between* the light and precious metals, the middle ground is occupied by most of the heavy metals, whose compounds display a superabundance of colors, hence the beauty of many ores. These metals are the most stable in terms of their nuclear chemistry and are physiologically active in a great variety of ways. Their coordination complexes in particular illustrate the transition to homopolar bonding in organic chemistry.

Life’s circumstances never consist only in opposites but rather in the enhanced dynamic between opposites. On the soul level, our most direct connection to our body chemistry is through eating for the sake of nourishment. Which substances do we especially enjoy tasting? Sugar is an intermediary between starch on the one hand and carbon dioxide and water on the other. Both of these poles are relatively tasteless; only the mono- and disaccharides in the transitional range taste sweet! Something similar is true of proteins. Their parent materials – carbon, hydrogen, oxygen, nitrogen, and water – have neither flavor nor odor, and the same is true of high-value proteins such as egg white or pure, untreated meat. They taste good to us only in the intermediate stages, on the boundary between buildup and breakdown. The tasteless plant proteins used in making soy sauce, for example, develop their savory flavor only through partial fermentation that breaks them down into amino acids. Pure fats and oils taste like nothing, so we spice them up with ions, adding table salt to solid fats and vinegar to salad oils. Relatively short-chain fatty acids esterified with short-chain alcohols, however, yield the wonderful fruity aromas of strawberries, raspberries, peaches, pears, and bananas. Here again we see an enhanced chemical middle ground between substances of high and low molecular weight, neither of which is especially appealing to us. Goethe’s “colored seam,”

presented in his theory of colors as the archetype of dynamic enhancement between darkness and light, has its counterpart in the world of chemicals as a “seam” of flavors and odors centered between opposite poles.

Chemistry as a Reaction to Formative Forces?

What has become of chemical reactions and tests for formative forces – for example, the “sensitive flame” test, copper chloride crystallization, the *Steigbild* technique, or the drop picture method – that initially claimed to be able to distinguish among and record supersensible influences in the lab? None of these imaging techniques has stood up to even well-meaning critiques. Copper chloride crystallization imaging has the best record with regard to replicability, achieved through standardization of all parameters. Characteristically structured images have even been produced using purely synthetic polymers. (*Hummel 1992*) In the *Steigbild* technique, standardization is limited by the type of paper, because cellulose fibers are always a mixture of different lengths and each batch of paper – even of the same type and brand – is always slightly different. For this reason, modern thin-layer chromatography on silica gel offers greater replicability

For many years, scientific exchange among experimenters using the *Steigbild* technique – or rather the notable lack of exchange – was an overt problem. It took this author ten years to bring about unrestricted sharing in a meeting held in the Scientific Section of the Goetheanum in Dornach. Results of that meeting were published in issue 46 of “Elemente der Naturwissenschaft” [Elements of Natural Science] in 1987. The unanimous conclusion was that anthroposophical imaging methods do not reflect the direct effects of etheric formative forces but rather the characteristic features of groups of substances previously arranged by formative forces within the living body. In each case, the end result is a reductionist phenomenon because the plant in question is killed, chopped, and pressed to extract its juice, which then undergoes preliminary refining before testing. In other words, the test substance is extracted from the holistic context of life. Even identifying the connection between the crystallization image and the plant in question – its organs, its harvest date, etc. – takes considerable effort. Jochen Bockemühl is right in saying that much more is visible in the morphology of an intact, living plant and its dynamic transformations than in any laboratory treatment.

And yet laboratory imaging techniques do have a certain relevance, especially if we consider multiple methods. The working group of Ruth Mander and Hans-Joachim Strüh of the Wala research lab (*Mander 1987, Strüh 1987*) took a fresh approach to working with the *Steigbild* and identified three conspicuous types, which they named the “loose” type, the “sugar” type, and the “colloid” type.

These three types relate to the observed rate of speed at which the juice rises in the absorbent paper: slowly, remaining in the lower portion of the paper; at a moderate rate; or distinctly fast and high-rising. From the Goethean view of bonding theory described above, it soon becomes obvious that the colloid type encompasses all organic mucilaginous substances that are highly condensed or polymerized yet still marginally water-soluble. Conversely, ionogenic substances – for example, the anthocyanins that color cherry juice – rise easily and quickly to form the upper colored bands of the “loose” type. Between these extremes are the more balanced, substances that have access to both poles and whose action is harmonizing, mediating, and balancing – sugars, for example! If the organic fractions themselves

are not colored, they can be made visible or “developed” after the fact with metal complex salts, as Friedrich Ferdinand Runge (1795-1867) had already discovered during Goethe’s time (*Harsch/Bussema* 1985).

This interpretation of *Steigbild* testing of organic juices in connection with the spectrum of bonds from homopolar to heteropolar can elicit two diametrically opposed reactions. The first is disappointment: We see something explained that we would rather not see explained, and so we evoke the bogeymen of materialism and rationalism in an attempt to discredit it. The other possible response is that if we hope to achieve qualitative augmentation of explicability, we must accept it rather than reject it. The spiritual aspect should never be a gap-filler for what remains unexplained. Quite the contrary: It leaves its most telling expressions in the world of effects and needs to be celebrated there. How did Rudolf Steiner put it to the first Waldorf teachers?

“Similarly, we must not encourage the much-loved notion that the unknown is proof of presence of spirit. After all, don’t people say, ‘Oh, that’s impossible to know, so spirit must be revealing itself there!’? Instead of sensing that spirit is knowable and reveals itself in matter, people are distracted into thinking that any unexplainable event is evidence of the divine.” (*Steiner*, GA 300/I: 100, lecture of September 26, 1919)

Thomas Aquinas was one of the first to speak out against the misuse of the spiritual world as a “refuge of ignorance,” a mere *asylum ignorantiae*, in our thought practices.

Dynamic Equilibriums

Transformation always takes place in the intervening field between opposites. As we have already seen, ideal covalent bonds are just as uncommon as pure ionogenic bonds, and intermediate stages account for the plethora of remaining compounds. Although these transformed substances may appear outwardly stable, they are not; rather, they are in states of *dynamic equilibrium*. For example, think of all the buffer systems in intracellular and extracellular biochemistry, or even simply the blood’s pH buffer. These systems are always based on *intermediate-stage bonding* of the substances involved, especially weak acids and weak bases. Thus all carboxyl acids and amino compounds are capable of buffering activity, modulating excessive acidity or alkalinity whenever it occurs. The “law of mass action,” discovered in 1867 by two Norwegians – the chemist Peter Waage (1833-1900) and the mathematician Cato Maximilian Guldberg (1836-1900) – describes this phenomenon exactly. The name is worse than unfortunate, however, because what is involved here is not the effect of *mass* but the effect of *concentration*, as we realize as soon as we understood that the size of the dose determines its effect.

The law of mass action itself, however, is just a special instance of *Le Chatelier’s principle*, a much more comprehensive principle that encompasses such adjustments in dynamic equilibrium while also including energetic processes. As the energy supply increases, endothermic combinations occur, reducing the amount of energy. Conversely, when the supply of energy is low, exothermic reactions are more likely to occur, releasing energy. This applies not only to chemical changes but

also to physical changes, if we do not count transitions to different states of matter as chemical changes (which they actually are, since bonding forces and gradations of heat are just as involved in the reorganization of molecular structures during changes of state as they are in most “chemical” reactions).

This principle governs all of the weather patterns that make up climate. As heat is added, energy-binding processes such as melting and evaporation occur. As available heat decreases, it redevelops through condensation and crystallization. Water, therefore, is capable of any type of adjustment, which is what makes the Earth’s biosphere possible. Thus Le Chatelier’s principle is at work in all compensatory processes, and life can be achieved only by balancing opposites without ever coming to complete equilibrium. The latter is possible only after death and in the inorganic realm, and to this extent the principle of “minimized external forcing” in its mathematical form applies to the chemistry and physics of dead matter. For our purposes, however, it also reflects something characteristic of life, because it forms an enhanced middle ground – in this case, between polar bonding types, for example – in order to develop fully. Buffer solutions can be produced only with weak acids, not with strong ones. We might even say that Le Chatelier’s principle is a fundamental biological law that has found its way into the world of physics and chemistry. Does inorganic matter, including its laws, originate in organic matter? The anthroposophical understanding of evolution answers this question in the affirmative.

The capacity for constant compensatory adjustment resides in the etheric. Goethe himself discovered the compensation principle in living bodies, which governs the organization of our senses, for example. After looking at intense light, the eyes become less sensitive and see only relative darkness, but when we walk outside at night, we see the faintest traces of light. Our eyes are sensitized to red when we see green and to yellow when we see purple. When we extend our limbs, the flexor muscles prepare for action, and so on. Colored shadows are neither objective nor subjective but a consequence of our sensory physiology, which – like all etheric life – transcends objectivity and subjectivity and takes up residence where the dualistic gap between body and soul is bridged, namely, in life, the link that connects them. The existential legality of Le Chatelier’s principle emerges when projected from life into the inorganic realm, which is why that principle is indispensable to the physical existence of life.

Stereoisomerism

Stereoisomerism was discovered by Louis Pasteur (1822-1895), Jacobus Henricus van’t Hoff (1852-1911), and Joseph Achille Le Bel ((1847-1930), among others, and has proved to be one of the most significant discoveries in all of biochemistry: *How* a substance is constituted is as noteworthy as *what* it consists of. In addition to the actual elements involved, their spatial configuration also determines the properties of their compounds. Configuration, not mass, is the primary determining factor. This discovery transformed chemistry, formerly the mere study of matter, into molecular morphology. We should not say that structural chemistry is simply a “theoretical construct.” Until satellite photos became available, the same was true of maps, which did not make them any less reliable for planning trips. Meanwhile, good comparable photos of molecular morphology are also available to make the theoretical discovery perceptible. Steiner advised the first Waldorf teachers that if formulas had to be used in chemistry, it was preferable to

introduce spatial formulas from the beginning. (*Steiner* GA 300/111:32). C₂H₆O can be either ethanol or dimethyl ether – two vastly different substances with the same components. Matter alone is not the essential factor; *how* it is put together is more important. This is the essence of any understanding of structure.

The most impressive stereochemical phenomenon in biochemistry is *chirality*. There are almost no organic compounds that are not chiral, and in fact their physiological effects essentially depend on their clearly asymmetrical directions of rotation. Pasteur discovered this phenomenon in dextrorotatory and levorotatory lactic acid. Le Bel and van't Hoff, working independent of each other, discovered that in most cases the asymmetry of the four carbon ligands is the deciding factor. In many cases, the human nose can smell the difference: One of the two enantiomers (mirror image forms) of *carvone* smells like caraway, the other like spearmint; they are structurally identical but mirror-image reversed. By using two polarizing films, it is easy to make the difference in the spiral structures of dextrorotatory (e.g. glucose, saccharose) and levorotatory sugars (e.g. fructose) visible. (*Wenger* instructional materials) All chemical microstructures important to life are clearly asymmetrical. It is all the more astonishing that macroscopic symmetries are possible in the bodily structures of living things. Regardless of the organism's radial or bilateral symmetry (e.g. sea urchin versus fish), the centrally located vital organs of metabolism tend to be asymmetrical. The midgut glands that regulate digestion are located in the center of every spiral snail shell, and the majority of snail shells (helixid species) are dextral-coiling, although sinistral coiling is obligate in clausiliid species.

Chirality is almost unknown in inorganic chemistry (*Schad* 2000: 107), which makes the exception all the more surprising: Rock crystal and related silicates, which make up the greater part of the earth's crust (the part of the Earth closest to the biosphere) and are familiar to us as *plutonites* or intrusive igneous rocks, are chiral. There are dextral and sinistral quartzes (see *Schad* 1981a). Might they also be physiologically active, and in different ways?

This idea suggests itself readily to anthroposophical thinking, which understands every living organism as an entity unto itself, albeit an open one. As early as 1886, in his "Fundamentals of the Goethean World View with Special Reference to Schiller," Rudolf Steiner, then still a student, looked for the comparable whole in the inorganic realm and found it, not in any detail, but in the "totality of inorganic matter as a system," which is the entire cosmos. (*Steiner*, GA 2, 1886) To a certain extent, therefore, each individual living thing, as an entirety, is a reproduction in miniature of the entire cosmos. To our geometrical everyday consciousness, the external cosmos appears to be homogeneous and equivalent in all directions. Steiner took a stand against this view, stating that the cosmos has non-equivalent directions: If we insist on visualizing it in geometrical terms, we should imagine it as egg-shaped, not spherical. (*Steiner*, GA 136, lecture of April 11, 1912; GA 205: 90-91, lecture of July 1, 1921) Embryologists know that in the earliest stages of a chick's development, the body axis is perpendicular to axis of the egg. In 70 percent of cases, the head pole points away from and the head pole toward an observer looking at the egg with the blunt end on the left and the pointed end on the right. The chick's original position in the egg, therefore, is always asymmetrical and its orientation also varies unequally. Seen from this perspective, the fact that all complex organic products of metabolism are asymmetrical even in the details of their structure is an expression of the holistic, cosmic nature of life processes.

In physics, the first inherent dissymmetry (in beta decay) in the physical world was discovered in 1956. (*Lee and Yang* 1956) In 1997, the American astronomers

Nodland and Ralston discovered the asymmetrical spiral structure of the physical universe experimentally, based on radio signals from 160 distant galaxies displaying asymmetrical changes in their diameters. All previous work in this field had been based upon the strict assumption of isotropy in all directions of space.

An obvious idea, first suggested years ago by the anthroposophical physician Otto Wolff (1921-2003) is that the chirality of quartz is responsible for the efficacy of the biodynamic horn-silica preparation (produced in a cow horn that is an asymmetrical spiral, by the way). In 1982, together with Rainer Dietrich, I conducted the first experiments using separate sprayings of dextrorotatory and levorotatory quartzes in the experimental garden at the Institute for Waldorf Education in Witten-Annen. In most instances, pole beans responded better in terms of size and depth of leaf color to d-rotatory rather than l-rotatory quartz. Ms. Christina Senger, under the aegis of Professor Wolfram Achtnich, confirmed these findings in a dissertation based on field crop experiments in Göttingen. In spite of multiple attempts, however, the biodynamic research circle has not achieved conclusive results. We can only admire Rudolf Steiner's masterful grasp of the subject in choosing quartz, a mineral so closely associated with the physiology of life, for the horn-silica preparation. As Goethe said in his *Maxims and Reflections* (no. 839):

If Nature in her lifeless beginnings had not been so fundamentally stereometric, how is she ultimately supposed to have achieved incalculable and immeasurable life?

And how did the wise man of Weimar already know about this?

The Image of the Divine in Matter

Rudolf Steiner once predicted that people of the future would learn to identify the working of Christ even in the laws of chemistry. (*Steiner*, GA 15: 66) When that happens, spiritualism and materialism will no longer be irreconcilable opposites. The future always has seeds in the present – such as this statement by Steiner, for example. Are such seeds also already present in the content of the inorganic sciences? Probably only as the first inconspicuous approximations. How do nuclear physics and nuclear chemistry describe of the submicroscopic structure of matter? The over one hundred elements are explained in terms of significantly fewer elementary particles. At least three characteristic properties are attributed to each elementary particle. One is *mass*: The particles is concentrated and centered in a very small space and is therefore also surrounded by a minimal gravitational field. In addition, most elementary particles carry specific *electrical charges*, and the electrical field that surrounds each one is much stronger than its gravitational field. In principle, these electrical fields extend out into space indefinitely, although their strength decreases rapidly, with the square of the distance. These are the principle opposing gestures in the structure of matter.

Mass number and charge by themselves, however, are not enough to completely characterize an elementary particle. That requires a third quantifiable factor, its *spin*. Spin is an asymmetrical torque that incorporates the direction of rotation of both the mass and the charge. Here we encounter a unifying, rhythmically oscillating characteristic that is just as fundamental and essential as mass and charge. Only all three quantities taken together describe an individual elementary particle.

Similar dynamics are inherent in the configuration of every atom. The nucleons that contribute to the atom's mass are clustered together in the nucleus. The neutrons among them contribute only to the atom's mass while not affecting its charge. Neutrons are often needed to prevent the protons, all positively charged, from repelling each other. In other words, the neutrons counteract the effects of the protons' charges. In contrast, the atomic shell consists of low mass, highly negatively charged electrons that determine the strength of the surrounding electrical field. The electron "shell" (an overly mechanical and therefore poor choice of words) that lies between the nucleus and the outer shell are characterized by rhythmical activity, full of "quantum leaps," that can be interpreted only in terms of wave theory. In 1895, Johann Jakob Balmer (1825-1898) was the first to discover the mathematical formula for computing this rhythmical sequence, the wavelengths of the visible hydrogen emission spectrum (the Balmer series). Balmer saw a pronounced Pythagorean character in the relationship he discovered. (Cf. *Hagenbach* 1941, *Hartmann* 1949)

Any further interpretation of this description seems unnecessary at this point. Clearly, however, the structure of all matter is ultimately threefold in the sense of polarity and dynamic enhancement. As revealed by anthroposophically illuminated Goetheanism, this trinitarian aspect gives meaning to data that are otherwise only technologically interesting, allowing them to serve as an aid to our human self-conception as it orients itself in the natural order that surrounds us.

Herder poked fun at Goethe for subscribing to this approach: "One of the most ridiculous periods in the history of genius was the period in Weimar when the mines in Ilmenau were to be put back into operation. Human beings were nothing; rock was everything. In the structure of granite, Goethe discovered the divine trinity, which only a mystery could explain." (Herder, conversation with Falk) Herder is referring here to the essay "On Granite," which emerged from Goethe's geological observations on a walking tour of the Harz Mountains. Rudolf Steiner, however, spoke of this essay with great admiration and recommended it in the Supplementary Course for teachers (GA 302: 36):

Above all, we must always present history, geography, geology, and so on with true feeling. Geology is especially interesting if we present it with deep feeling for the rock formations under the earth. In this connection, a sympathetic read-through of Goethe's treatise on granite should be recommended to all educators. It illustrates how immersing ourselves in nature with our whole being rather than merely through conceptual activity allows us to develop a human relationship to the archetypal father that is ancient, holy granite. And of course this process must be extended to other features of nature as well. (*Steiner*, lecture of June 13, 1921)

In Rudolf Steiner's work, the threefold aspect of granite even finds therapeutic applications in the threefold human body. (*Steiner*, GA 349:19; lecture of February 17, 1923)

Goethe had access to all the geological expertise of his time, having been introduced to it by his personal friend Heinrich von Treba, assistant director of the Clausthal-Zellerfeld mining authority. In their relationship to light, quartz and mica illustrate the polarity of transparency and reflectivity, feldspar the dynamic enhancement to color. Goethe's entire theory of color, therefore, is also an attempt to grasp this branch of physics in terms of trinitarian qualities.

Today our knowledge of almost all natural phenomena is incomparably greater, more precise, more multifaceted, and more differentiated. In terms of both its educational value and our understanding and appreciation of nature, however, it is sadly lacking. Natural science remains unintegrated into spiritual culture because our educated, spiritually inclined contemporaries turn up their noses and purse their lips at science, distaining it as mere reductionism and materialism. And yet the natural sciences, far from being the work of the devil, are full of good spirit that we should continue to discover. The methodology has been available for a long time, but the discovery must be actively desired and pursued. The alternative is that a detached, ivory-tower form of spiritualism will misconstrue its task and give rise to an increasingly degenerate and negative materialism. (*Steiner, GA 295:167*) Now, however, we finally have the opportunity to free ourselves from the tragic centuries-old tradition described at the beginning of this article.

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