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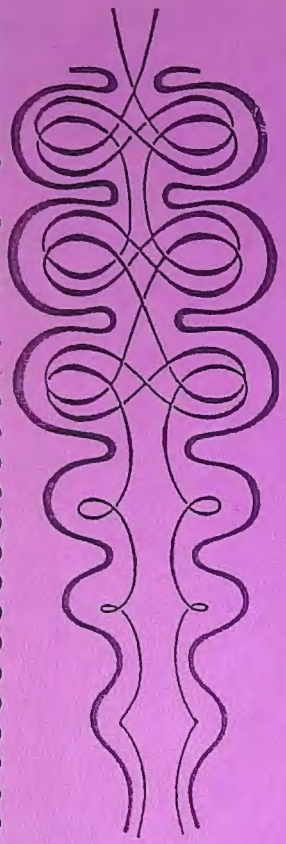

WALDORF SCIENCE NEWSLETTER

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Waldorf Science

Explorations in Phenomenology as Practiced in Waldorf Schools

A Science News Roundletter

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NOTE FROM THE EDITORS

This edition takes a look at the Arabic contribution to science and mathematics, research into the Waldorf 12th grade Chemistry curriculum, and a teachers observations of a water spider in nature and its relation to optics and physics.

The editors continue to ask for contributions on science from Waldorf teachers from all grade levels. Please send any material to the address on the masthead.

In June 2001, a small group of Waldorf chemistry and science teachers met in Saratoga Springs, NY to continue the research into a deepened phenomenology of chemistry. They spent nine full days observing and discussing experiments with Dr. Manfred von Mackensen. It is hoped that further individual research can be published in future newsletters.

The AWSNA Waldorf High School Research Group had a significant and exciting conference October 2001. Present were Waldorf high school teachers, medical doctors, therapists, counselors, and a Christian Community priest. The assembled group examined the changes (physiological, soul, and spiritual) which have taken place in the last decade or so with adolescents. Look for the forthcoming *Proceedings*, research papers, and videos that will soon be available from AWSNA Publications.

The WHSRP will have three colloquia this winter/spring. The first will be on American literature and history, the next will be on the Computer and Communication, and the last will be on the Environment and Life Science, specifically focussing on metamorphosis. Again, the *Proceedings* from each colloquium will be available from AWSNA Publications when completed.

SPECIAL NOTICE

This June's annual AWSNA Conference to be held at the Kimberton Waldorf School from June 22-26. 2002 will be unique. The title of the conference is "Ascending the Developmental Staircase" and is inclusive for all teachers from preschool/Kindergarten and elementary grades, through high school. Your school AWSNA Delegate will be returning from the Delegates' Meeting in Pasadena with brochures and a poster in January. Look for it, and plan on attending!

Book Reviews

THE WONDERS OF WALDORF CHEMISTRY
From a teacher's notebook grades 7-9
by Davis S. Mitchell

AWSNA Publications
Fair Oaks, Calif. 2001
271 pages, $20.00

Reviewed by Arthur Auer, M.ED.
Professor, Antioch Graduate School

As a seventh and eighth grade class teacher "two times around," I struggled to interpret and digest the numerous suggestions from the "Waldorf "chemistry books available at the time. Being untrained in the sciences, I found it a challenge to translate the often theoretical descriptions I found into practical lessons with the limited equipment I had. My efforts were successful, but what a monumental effort it was to sort out all the materials and possibilities before even artistically starting to implement them!

Here, at last, is a book that cuts to the quick. This essential and profound and is readily applicable. David Mitchell's *The Wonders of Waldorf Chemistry* is a clearly written description of how to go about inspiring students to become absorbed in the marvels of chemistry. (Two of its chapters, in fact, are devoted to "Creating Wonder" and "Enthusiasm"). In the preface, John Petering, a science teacher in Sacramento, who has closely collaborated with the David Mitchell over the years, points to why this particular book is so immediately understandable and accessible to teachers at the "ground level" of classroom science. He characterizes the work aptly as a " harvest from the notebooks of a teacher with a breadth of experience" [who] has taught chemistry in these three classes over a dozen times at the request of class teachers."

The book offers a rich but manageable array of the essential topics and experiments for teachers to choose and freely adapt at the seventh, eight, and ninth grade levels. It begins with valuable perspectives on how children develop scientific thinking, stage by stage, the process of learning and classroom pedagogy. The book provides critical guidelines for teachers preparing themselves for a real phenomenon-based science in the service of the healthy mental and spiritual growth of their students. For example, the author gives valuable reminders: Put questions—then pause, at least 5 whole seconds before expecting an answer—Don't answer your own question, draw it out of your students— Use activities to allow students to discover the concept.

The book is, above all, a "hands-on" manual containing a wealth of practical insights and tips on chemistry (equipment, supplies, safety, disposal of chemicals, etc.), numerous experiments for each grade, and even text material readily adaptable for main lesson books. The seventh grade section on "Combustion," for example vividly describes and explains 28 demontrations on the subject. Demonstration #17 starts with the words: The students are amazed to see a fire start with no match but just powder and liquid.

The Wonders of Waldorf Chemistry proves not only to be a substantial and valuable science book, but ultimately actualizes what I would call "hard science with a human touch." Besides the insights into child development that permeates it throughout, the book also includes biographies of great chemists, a history of chemistry, a delightful selection of poems, aphorisms, literary excerpts, and even humor to help teachers cope with adolescents. An artistic element pervades the book and demonstrates how the arts can enhance the sciences and help to make them human and even humorous at times.

. . . Beware the Carbon atom, my class,
The molecules that form, the vapors that come to pass.
Beware the mixtures which rumble and grow.
Observe them in detail and note where they go. . . .
(From a skit written by seventh graders and
David Mitchell for an all school assembly)

ARTHUR AUER is the Coordinator of the Year Round Program and Internships of the Waldorf Teacher Training Program at Antioch New England Graduate School in New Hampshire. He was a class teacher at Pine Hill Waldorf School for twenty years.

♦

The Riddle of America
John Wulsin, Jr., editor

AWSNA Publications
Fair Oaks, CA
371 pages, $30.00

Perhaps one of the most relevant books to recently become available, this collection of essays explores the question of Americas "native expression." What is the spiritual task of North America? Every teacher should become familiar with its contents. Essays deal with American mythology, the etheric geography of North America, American art, American loneliness, American literature and more. Contributors include: Thornton Wilder, Henry & Christy Barnes, David Adams, John Wulsin, Virginia Sease, Ted Warren, Gertude Reif Hughes and others.

♦

Rudolf Steiner's Observations on Adolescence
David Mitchell & Christopher Clouder, editors

AWSNA Publications
Fair Oaks, CA
175 pages, $16.00

The editors have collected, and made available through first-time translation, many of Rudolf Steiner's observations on the third stage of human development. Included are Steiner's advice to teachers on how to prepare the children for adolescence and how to inspire in teenagers a desire for the noble.

Arabic Science

by
Dennis Overbye
The New York Times

Nasir al-Din at-Tusi was still a young man when the Assassins made him an offer he couldn't refuse.

His hometown had been devastated by Mongol armies, and so, early in the 13th century, al-Tusi, a promising astronomer and philosopher, came to dwell in the legendary fortress city of Alamut in the mountains of northern Persia.

He lived among a heretical and secretive sect of Shiite Muslims, whose members practiced political murder as a tactic and were dubbed hashishinn, legend has it, because of their use of hashish.

Although al-Tusi later said he had been held in Alamut against his will, the library there was renowned for its excellence, and al-Tusi thrived there, publishing works on astronomy, ethics, mathematics, and philosophy that marked him as one of the great intellectuals of his age.

But when the armies of Halagu, the grandson of Genghis Khan, massed outside the city in 1256, al-Tusi had little trouble deciding where his loyalties lay. He joined Halagu and accompanied him to Baghdad, which fell in 1258. The grateful Halagu built him an observatory at Maragha, in what is now northwestern Iran.

Al-Tusi's deftness and ideological flexibility in pursuit of the resources to do science paid off. The road to modern astronomy, scholars say, leads through the work that he and his followers performed at Maragha and Alamut in the 13th and 14th centuries. It is a road that winds from Athens to Alexandria, Baghdad, Damascus, and Cordoba, through the palaces of caliphs and the basement laboratories of alchemists, and it was traveled not just by astronomy but by all science.

Commanded by the Koran to seek knowledge and read nature for signs of the Creator, and inspired by a treasure trove of ancient Greek learning, Muslims created a society that in the Middle Ages was the scientific center of the world. The Arabic language was synonymous with learning and science for 500 years, a golden age that can count among its credits the precursors to modern universities, algebra, the names of the stars, and even the notion of science as an empirical inquiry.

"Nothing in Europe could hold a candle to what was going on in the Islamic world until about 1600," said Dr. Jamil Ragep, a professor of the history of science at the University of Oklahoma.

It was the infusion of this knowledge into Western Europe, historians say, that fueled the Renaissance and the scientific revolution.

"Civilizations don't just clash," said Dr. Abdelhamid Sabra, a retired professor of the history of Arabic science who taught at Harvard. "They can learn from each other. Islam is a good example of that." The intellectual meeting of Arabia and Greece was one of the greatest events in history, he said "Its scale and consequences are enormous, not just for Islam but for Europe and the world."

But historians say they still know very little about this golden age. Few of the major scientific works from that era have been translated from Arabic, and thousands of manuscripts have never even been read by modern scholars. Sabra characterizes the history of Islamic science as a field that "hasn't even begun yet."

Islam's rich intellectual history, scholars are at pains and seem saddened and embarrassed to point out, belies the image cast by recent world events. Traditionally, Islam has encouraged science and learning. "There is no conflict between Islam and science," said Dr. Osman Bakar of the Center for Mustim-Christian Understanding at Georgetown.

"Knowledge is part of the creed," added Dr. Farouk El-Baz, a geologist at Boston University, who was science adviser to President Anwar Sadat of Egypt. "When you know more, you see more evidence of God."

So the notion that modern Islamic science is now considered "abysmal," as Abdus Salam, the first Muslim to win a Nobel Prize in physics, once put it, haunts Eastern scholars.

"Muslims have a kind of nostalgia for the past, when they could contend that they were the dominant cultivators of science," Bakar said. The relation between science and religion has generated much debate in the Islamic world, he and other scholars said. Some scientists and historians call for an "Islamic science" informed by spiritual values that they say Western science ignores, but others argue that a religious conservatism in the East has dampened the skeptical spirit necessary for good science.

When Muhammad's armies swept out from the Arabian peninsula in the seventh and eighth centuries, annexing territory from Spain to Persia, they also annexed the works of Plato, Aristotle, Democritus, Pythagoras, Archimedes, Hippocrates, and other Greek thinkers.

Hellenistic culture was spread eastward by the armies of Alexander the Great and by religious minorities, including various Christian sects, according to Dr. David Lindberg, a medieval science historian at the University of Wisconsin.

The largely illiterate Muslim conquerors turned to the local intelligentsia to help them govern, Lindberg said. In the process, he said, they absorbed Greek learning that had yet to be transmitted to the West in a serious way, or even translated into Latin.

In ninth-century Baghdad, the Caliph Abu al-Abbas al-Mamun set up an institute, the House of Wisdom, to translate manuscripts. Among the first works rendered into Arabic was the Alexandrian astronomer Ptolemy's "Great Work."

which described a universe in which the sun, moon, planets and stars revolved around Earth; Al-Magest, as the work was known to Arabic scholars, became the basis for cosmology for the next 500 years.

Jews, Christians, and Muslims all participated in this flowering of science, art, medicine and philosophy, which endured for at least 500 years and spread from Spain to Persia. Its height, historians say, was in the 10th and 11th centuries, when three great thinkers strode the East: Abu Ali at-Hasan ibn al-Haytham, also known as Alhazen; Abu Rayham Muhammad al-Biruni, and Abu Ali al-Hussein Ibn Sina, also known as Avicenna.

Al-Haytham, born in Iraq in 965, experimented with light and vision, laying the foundation for modern optics and for the notion that science should be based on experiment as well as on philosophical arguments. "He ranks with Archimedes, Kepler, and Newton as a great mathematical scientist," Lindberg said.

The mathematician, astronomer and geographer at-Biruni, born in what is now part of Uzbekistan in 973, wrote some 146 works totaling 13,000 pages, including a vast sociological and geographical study of India.

Ibn Sina was a physician and philosopher born near Bukhara (now in Uzbekistan) in 981. He compiled a million-word medical encyclopedia, the *Canons of Medicine*, that was used as a textbook in parts of the West until the 17th century.

Scholars say science found such favor in medieval Islam for several reasons. Part of the allure was mystical; it was another way to experience the unity of creation that was the central message of Islam.

"Anyone who studies anatomy will increase his faith in the omnipotence and oneness of God the almighty," goes a saying often attributed to Abut-Walid Muhammad Ibn Rushd, also known as Averroes, a 13th-century anatomist and philosopher.

Another reason is that Islam is one of the few religions in human history in which scientific procedures are necessary for religious ritual, Dr. David King, a historian of science at Johann Wolfgang Goethe University in Frankfurt, Germany, pointed out in his book *Astronomy in the Service of Islam,* published in 1993.

The requirement that Muslims face in the direction of Mecca when they pray. for example, required knowledge of the size and shape of the earth. The best astronomical minds of the Muslim world tackled the job of producing tables or diagrams by which the qibla, or sacred directions, could be found from any point in the Islamic world. Their efforts rose to a precision far beyond the needs of the peasants who would use them, King noted.

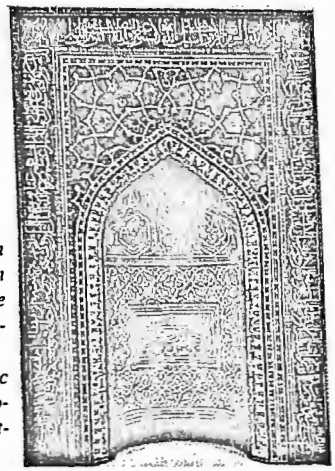
From the 10th to the 13th century Europeans, especially in Spain, were translating Arabic works into Hebrew and Latin "as fast as they could," King said. The result was a rebirth of learning that ultimately transformed Western civilization.

Why didn't Eastern science go forward as well? "Nobody has answered that question satisfactorily," said Sabra of Harvard. Among other things, the Islamic empire began to be whittled away in the 13th century by Crusaders from the West and Mongols from the East.

As a result, Islamic centers of learning began to lose touch with one another, leading to a gradual erosion in two of the main pillars of science—communication and financial support.

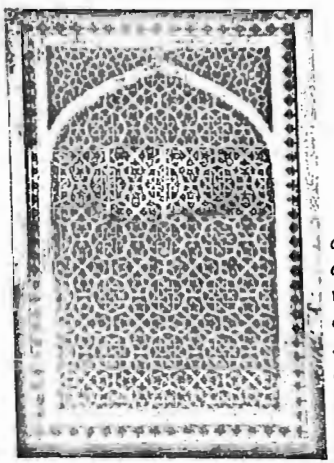
In the West, science was able to pay for itself in new technology, such as the steam engine, and to attract financing from industry, but in the East it remained dependent on the patronage and curiosity of sultans and caliphs.

Further, the Ottomans, who took over the Arabic lands in the 16th century, were builders and conquerors, not thinkers, said El-Baz of Boston University, and support waned. "You cannot expect the science to be excellent while the society is not," he said.



A Mirhab, circa 1354. The Mirhab is an element in a mosque. The niche indicates the direction of Mecca.

The mosaic glazed tiles are set in geometric and floral patterns.



***A Jali Screen** carved in red sandstone, circa 1500. This screen was probably set in an outside window providing security, light, and air circulation. The shadow patterns danced across the inside floor as the sun moved during the day.*

A Golden Age of Research and Discovery

An eastern astrolabe from Baghdad, dated A.D. 1136

Muhammad's trek from Mecca to Medina in 622 marked the start of the Islamic calendar, and the official version of the Koran appeared in 650. Soon after, a thriving era of scientific discovery began in the Islamic world.

Arabic Mathematics: Forgotten Brilliance?

taken from

http://www-history.mcs.st-andrews.ac.uk/history/

There is a widely held view that, after a brilliant period for mathematics when the Greeks laid the foundations for modern mathematics, there was a period of stagnation before the Europeans took over where the Greeks left off at the beginning of the sixteenth century. The common perception of the period of 1000 years or so between the ancient Greeks and the European Renaissance is that little happened in the world of mathematics except that some Arabic translations of Greek texts were made which preserved the Greek learning so that it was available to the Europeans at the beginning of the sixteenth century.

That such views should be generally held is of no surprise. Many leading historians of mathematics have contributed to the perception by either omitting any mention of Arabic/Islamic mathematics in the historical development of the subject or with statements such as that made by Duhem in [Endnote #3]: . . . Arabic science only reproduced the teachings received from Greek science.

Recent research, however, is painting a very different picture of the debt that we owe to Arabic/Islamic mathematics. In many respects the mathematics studied today is far closer in style to that of the Arabic/Islamic contribution than to that of the Greeks. Certainly many of the ideas which were previously thought to have been brilliant new conceptions due to European mathematicians of the sixteenth, seventeenth, and eighteenth centuries are now known to have been developed by Arabic/Islamic mathematicians around four centuries earlier.

Before we proceed it is worth trying to define the period that this article covers and give an overall description to cover the mathematicians who contributed. The period we cover is easy to describe: it stretches from the end of the eighth century to about the middle of the fifteenth century. Giving a description to cover the mathematicians who contributed, however, is much harder. The works [6] and [17] are on "Islamic mathematics," similar to [1] which uses the title the "Muslim contribution to mathematics". Other authors try the description "Arabic mathematics," see for example [10] and [11]. However, certainly not all the mathematicians we wish to include were Muslims; some were Jews, some Christians, some of other faiths. Nor were all these mathematicians Arabs, but for convenience we will call our topic "Arab mathematics."

The regions from which the "Arab mathematicians" came was centred on Iran/Iraq but varied with military conquest during the period. At its greatest extent it stretched to the west through Turkey and North Africa to include most of Spain, and to the east as far as the borders of China.

The background to the mathematical developments which began in Baghdad around 800 is not well understood. Certainly there was an important influence which came from the Hindu mathematicians whose earlier development of the decimal system and numerals was important. There began a remarkable period of mathematical progress with al-Khwarizmi's work and the translations of Greek texts.

This period begins under the Caliph Harun al-Rashid, the fifth Caliph of the Abbasid dynasty, whose reign began in 786. He encouraged scholarship and the first translations of Greek texts into Arabic, such as Euclid's Elements by al-Hajjaj, were made during al-Rashid's reign. The next Caliph, al-Ma'mun, encouraged learning even more strongly than his father al-Rashid, and he set up the House of Wisdom in Baghdad which became the centre for both the work of translating and of of research. Al-Kindi (born 801) and the three Banu Musa brothers worked there, as did the famous translator Hunayn ibn Ishaq.

We should emphasise that the translations into Arabic at this time were made by scientists and mathematicians such as those named above, not by language experts ignorant of mathematics, and the need for the translations was stimulated by the most advanced research of the time. It is important to realise that the translating was not done for its own sake, but was done as part of the current research effort. The most important Greek mathematical texts which were translated are listed in [17].

Of Euclid's works, the Elements, the Data, the Optics, the Phaenomena, and On Divisions were translated. Of Archimedes' works only two—*Sphere and Cylinder and Measurement of the Circle*—are known to have been translated, but these were sufficient to stimulate independent researches from the 9th to the 15th century. On the other hand, virtually all of Apollonius's works were translated, and of Diophantus and Menelaus one book each, the *Arithmetica* and the *Sphaerica*, respectively, were translated into Arabic. Finally, the translation of Ptolemy's *Almagest* furnished important astronomical material. The more minor Greek mathematical texts which were translated are also given in [17]: . . . Diocles' treatise on mirrors, Theodosius's *Spherics*, Pappus's work on mechanics, Ptolemy's *Planisphaerium*, and Hypsicles' treatises on regular polyhedra (the so-called Books XIV and XV of Euclid's *Elements*). . . .

Perhaps one of the most significant advances made by Arabic mathematics began at this time with the work of al-Khwarizmi, namely the beginnings of algebra. It is important to understand just how significant this new idea was. It was a revolutionary move away from the Greek concept of mathematics which was essentially geometry.

Algebra was a unifying theory which allowed rational numbers, irrational numbers, geometrical magnitudes, etc., to all be treated as "algebraic objects." It gave mathematics a whole new development path so much broader in concept to that which had existed before, and provided a vehicle for future development of the subject. Another important aspect of the introduction of algebraic ideas was that it allowed mathematics to be applied to itself in a way which had not happened before. As Rashed writes in [11] (see also [10]):

> Al-Khwarizmi's successors undertook a systematic application of arithmetic to algebra, algebra to arithmetic, both to trigonometry, algebra to the Euclidean theory of numbers, algebra to geometry, and geometry to algebra. This was how the creation of polynomial algebra, combinatorial analysis, numerical analysis, the numerical solution of equations, the new elementary theory of numbers, and the geometric construction of equations arose.

Let us follow the development of algebra for a moment and look at al-Khwarizmi's successors. About forty years after al-Khwarizmi is the work of al-Mahani (born 820), who conceived the idea of reducing geometrical problems such as duplicating the cube to problems in algebra. Abu Kamil (born 850) forms an important link in the development of algebra between al-Khwarizmi and al-Karaji. Despite not using symbols, but writing powers of x in words, he had begun to understand what we would write in symbols as $xn \cdot xm = xm + n$. Let us remark that symbols did not appear in Arabic mathematics until much later. Ibn al-Banna and al-Qalasadi used symbols in the 15th century and, although we do not know exactly when their use began, we know that symbols were used at least a century before this.

Al-Karaji (born 953) is seen by many as the first person to completely free algebra from geometrical operations and to replace them with the arithmetical type of operations which are at the core of algebra today. He was first to define the monomials x, x2, x3 . . . and 1/x, 1/x2, 1/x3 . . . and to give rules for products of any two of these. He started a school of algebra which flourished for several hundreds of years. Al-Samawal, nearly 200 years later, was an important member of al-Karaji's school. Al-Samawal (born 1130) was the first to give the new topic of algebra a precise description when he wrote that it was concerned: . . . with operating on unknowns using all the arithmetical tools, in the same way as the arithmetician operates on the known.

Omar Khayyam (born 1048) gave a complete classification of cubic equations with geometric solutions found by means of intersecting conic sections. Khayyam also wrote that he hoped to give a full description of the algebraic solution of cubic equations in a later work [18]:

> If the opportunity arises and I can succeed, I shall give all these fourteen forms with all their branches and cases, and how to distinguish whatever is possible or impossible so that a paper, containing elements which are greatly useful in this art will be prepared.

Sharaf al-Din al-Tusi (born 1135), although almost exactly the same age as al-Samawal, does not follow the general development that came through al-Karaji's school of algebra but rather follows Khayyam's application of algebra to geometry. He wrote a treatise on cubic equations, which [11]: . . . represents an essential contribution to another algebra which aimed to study curves by means of equations, thus inaugurating the beginning of algebraic geometry.

Let us give other examples of the development of Arabic mathematics. Returning to the House of Wisdom in Baghdad in the 9th century, one mathematician who was educated there by the Banu Musa brothers was Thabit ibn Qurra (born 836). He made many contributions to mathematics, but let us consider for the moment consider his contributions to number theory. He discovered a beautiful theorem which allowed pairs of amicable numbers to be found, that is two numbers such that each is the sum of the proper divisors of the other. Al-Baghdadi (born 980) looked at a slight variant of Thabit ibn Qurra's theorem, while al-Haytham (born 965) seems to have been the first to attempt to classify all even perfect numbers (numbers equal to the sum of their proper divisors) as those of the form $2k - 1(2k - 1)$ where $2k - 1$ is prime.

Al-Haytham, is also the first person that we know to state Wilson's theorem, namely that if p is prime then $1 + (p - 1)!$ is divisible by p. It is unclear whether he knew how to prove this result. It is called Wilson's theorem because of a comment made by Waring in 1770 that John Wilson had noticed the result. There is no evidence that John Wilson knew how to prove it and most certainly Waring did not. Lagrange gave the first proof in 1771 and it should be noticed that it is more than 750 years after al-Haytham before number theory surpasses this achievement of Arabic mathematics.

Continuing the story of amicable numbers, from which we have taken a diversion, it is worth noting that they play a large role in Arabic mathematics. Al-Farisi (born 1260) gave a new proof of Thabit ibn Qurra's theorem, introducing important new ideas concerning factorisation and combinatorial methods. He also gave the pair of amicable numbers 17296, 18416 which have been attributed to Euler, but we know that these were known earlier than al-Farisi, perhaps even by Thabit ibn Qurra himself. Although outside our time range for Arabic mathematics in this article, it is worth noting that in the 17th century the Arabic mathematician Mohammed Baqir Yazdi gave the pair of amicable numbers 9,363,584 and 9,437,056 still many years before Euler's contribution.

Let us turn to the different systems of counting which were is use around the 10th century in Arabic countries. There were three different types of arithmetic used around this period and, by the end of the 10th century, authors such as al-Baghdadi were writing texts comparing the three systems.

1. Finger-reckoning arithmetic. This system derived from counting on the fingers with the numerals written entirely in words; this finger-reckoning arithmetic was the system used by the business community. Mathematicians such as Abu'l-Wafa (born 940) wrote several treatises using this system. Abu'l-Wafa himself was an expert in the use of Indian numerals but these: . . . did not find application in business circles and among the population of the Eastern Caliphate for a long time.

Hence he wrote his text using finger-reckoning arithmetic since this was the system used by the business community.

2. Sexagesimal system. The second of the three systems was the sexagesimal system, with numerals denoted by letters of the Arabic alphabet. It came originally from the Babylonians and was most frequently used by the Arabic mathematicians in astronomical work

3. Indian numeral system. The third system was the arithmetic of the Indian numerals and fractions with the decimal place-value system. The numerals used were taken over from India, but there was not a standard set of symbols. Different parts of the Arabic world used slightly different forms of the numerals. At first the Indian methods were used by the Arabs with a dust board. A dust board was needed because the methods required the moving of numbers around in the calculation and rubbing some out as the calculation proceeded. The dust board allowed this to be done in the same sort of way that one can use a blackboard, chalk and a blackboard eraser. However, al-Uqlidisi (born 920) showed how to modify the methods for pen and paper use. Al-Baghdadi also contributed to improvements in the decimal system.

It was this third system of calculating which allowed most of the advances in numerical methods by the Arabs. It allowed the extraction of roots by mathematicians such as Abu'l-Wafa and Omar Khayyam (born 1048). The discovery of the binomial theorem for integer exponents by al-Karaji (born 953) was a major factor in the development of numerical analysis based on the decimal system. Al-Kashi (born 1380) contributed to the development of decimal fractions not only for approximating algebraic numbers, but also for real numbers such as 1. His contribution to decimal fractions is so major that for many years he was considered as their inventor. Although not the first to do so, al-Kashi gave an algorithm for calculating nth roots which is a special case of the methods given many centuries later by Ruffini and Horner.

Although the Arabic mathematicians are most famed for their work on algebra, number theory, and number systems, they also made considerable contributions to geometry, trigonometry, and mathematical astronomy. Ibrahim ibn Sinan (born 908), who introduced a method of integration more general than that of Archimedes, and al-Quhi (born 940) were leading figures in a revival and continuation of Greek higher geometry in the Islamic world. These mathematicians, and in particular al-Haytham, studied optics and investigated the optical properties of mirrors made from conic sections. Omar Khayyam combined the use of trigonometry and approximation theory to provide methods of solving algebraic equations by geometrical means.

Astronomy, time-keeping, and geography provided other motivations for geometrical and trigonometrical research. For example, Ibrahim ibn Sinan and his grandfather Thabit ibn Qurra both studied curves required in the construction of sundials. Abu'l-Wafa and Abu Nasr Mansur both applied spherical geometry to astronomy and also used formulas involving sin and tan. Al-Biruni (born 973) used the sine formula in both astronomy and in the calculation of longitudes and latitudes of many cities. Again both astronomy and geography motivated al-Biruni's extensive studies of projecting a hemisphere onto the plane.

Thabit ibn Qurra undertook both theoretical and observational work in astronomy. Al-Battani (born 850) made accurate observations which allowed him to improve on Ptolemy's data for the sun and the moon. Nasir al-Din al-Tusi (born 1201), like many other Arabic mathematicians, based his theoretical astronomy on Ptolemy's work but al-Tusi made the most significant development of Ptolemy's model of the planetary system up to the development of the heliocentric model in the time of Copernicus.

Many of the Arabic mathematicians produced tables of trigonometric functions as part of their studies of astronomy. These include Ulugh Beg (born 1393) and al-Kashi. The construction of astronomical instruments such as the astrolabe was also a speciality of the Arabs. Al-Mahani used an astrolabe while Ahmed (born 835), al-Khazin (born 900), Ibrahim ibn Sinan, al-Quhi, Abu Nasr Mansur (born 965), al-Biruni, and others, all wrote important treatises on the astrolabe. Sharaf al-Din al-Tusi (born 1201) invented the linear astrolabe. The importance of the Arabic mathematicians in the development of the astrolabe is described in [17]:

> The astrolabe, whose mathematical theory is based on the stereographic projection of the sphere, was invented in late antiquity, but its extensive development in Islam made it the pocket watch of the medievals. In its original form, it required a different plate of horizon coordinates for each latitude, but in the 11th century the Spanish Muslim astronomer az-Zarqallu invented a single plate that worked for all latitudes. Slightly earlier, astronomers in the East had experimented with plane projections of the sphere, and al-Biruni invented such a projection that could be used to produce a map of a hemisphere. The culminating

masterpiece was the astrolabe of the Syrian Ibn ash-Shatir (1305-75), a mathematical tool that could be used to solve all the standard problems of spherical astronomy in five different ways.

Nur al-Din Room, an upper-class Syrian home of the Ottoman Period, circa 1707.

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Making Natural Dyes

Many natural materials for making dyes can be easily collected. There are two methods you can use to create the color: boiling and soaking in closed bottles placed in the refrigerator. The following colors can be made:

Red
- fresh beets
- cherries (fresh or frozen)
- strawberries (fresh or frozen)
- cranberries
- honeysuckle berries
- boysenberries

Yellow
- yellow onion skins
- turmeric
- goldenrod petals
- marigold petals

Blue
- red cabbage leaves
- concord grapes

Green
- fresh spinach
- green tops of carrots
- moss
- lily-of-the valley stalk and leaves
- morning glory

Orange
- red onion skins
- cosmos diablo petals
- coreopsis petals

Brown
- Oregon grape skins
- Concord grape skins
- purple mulberries
- red geranium leaves

Black
- charcoal from burned wood

The charcoal can be made into paint by mixing the liquid with egg yolk. The other dyes can be heated in a cast iron pot with a teaspoon of cornstarch in order to make paint.

The liquid mixtures can become rancid over time. If the mixture starts to emit foul odors, throw it away and start again. Refrigeration and freezing will keep it from going bad.

General cooking preparations: cut, chop, peel or shred and add to 2/3 cups of water in a cast iron pot. Simmer but do not boil for 30 minutes. Remove from heat and let stand overnight. Strain and use, or freeze for later use.

General soaking preparations: cut, chop, peel or shred and add to a covered jar. Cover ingredients with water, screw the cap on the jar and place in the refrigerator for a week or so. Remove, strain liquid and use, or freeze for later use.

- If the dyes will be used on cloth you can add 2 tablespoons of vinegar per pint of dye to help retard fading. Heat the mixture to the simmering point.
- Ironing the cloth will help to set the dye.
- If you wish the color to be permanent you will have to add a mordant such as alum.

— DSM

Exploring the Qualities of Iron

Report on 12th Grade Chemistry Conference
With Dr. Manfred von Mackensen
Saratoga Springs, NY, June 16-26, 2001

by

Gary Banks and Cedar Oliver
High Mowing School

The June conference at Sarasota Springs, NY with Dr. von Mackensen was enlivening and inspiring in the breadth and depth of its content. Dr. von Mackensen outlined three topics indicated by Rudolf Steiner for the twelfth-grade chemistry curriculum, topics which have proven very perplexing to Waldorf science teachers over the decades:

1. The role of metals in living system, such as lead
2. Uric acid, oxalic acid, and formic acid
3. The digestion of proteins and the difference between proteins in plants, animals, and human beings.

During the intensive ten days of our meetings, we began covering the first topic, working intensively with iron, gold, and lead, trying to develop a living, imaginative picture of these processes within the human being. In this article, we will make an effort to summarize our experiences with iron and give indications for the active demonstrations given by Dr. von Mackensen.

In developing a phenomenological approach to the teaching of metals, Dr. von Mackensen reminds us, "Concepts given before experiences are dry, but concepts that arise out of experiences are light-filled. You can develop living concepts by bringing the will into thinking." He asserted that we must have an experience of the metals before we can understand them. "To make an experiment with something, you must have an experience, an idea, of its totality. You can only approach the thing if you have a feeling for it."

Investigating Iron

With iron, we begin developing the imagination of a substance tending toward both fine distribution over the face of the earth and intense concentration. Iron, being the second most abundant metal (after aluminum), pervades the very dust under our feet, the deadest substance on earth. Chief Seattle, as quoted more accurately in an original newspaper article, said in his famous speech, "We will honor our ancestors *in the dust that is under our feet*." Perhaps we can begin to re-enliven the dust itself by picturing it containing the iron that flowed in the veins of our ancestors, in Chief Seattle himself, or in a Julius Caesar, a Joan of Arc, or in a Galileo.

While iron disperses finely, it also bears the gesture of intense concentration. The oldest pieces of iron are from meteors, found around 6000-5000 BC. Human beings have been making iron since 3000 BC. The original use of iron, first made in copper furnaces, was for first for ritual, then jewelry, decoration, and finally tools. The concentration of iron can be vividly pictured in the Roman Legions. It took 30 tons of iron to outfit the armor and weapons for one Legion.

Prosenna, the King of the Etruscans who conquered Rome, wisely comprehended the Roman need for iron. He forbade the Romans from producing too much iron. The Romans had possessed an intensive capacity for generating iron. Over 200,000 iron-smelting furnaces were found in the Roman Europe. These were built so skillfully to capture the prevailing winds on hilltops that no bellows were needed.

Porsenna was not only concerned with the physical use of iron, but also the effect on man's spiritual being. Iron allows the lower ego to experience itself. It allows one to concentrate from the world what one would have for one's own existence. Consider the steamships of the early 20th century. As iron allowed the development of machines and travel speeds increased, the understanding of distance went from an external to an internal experience. The steamship was built not only as a means of travel, but as a luxurious means by which the traveler could bring the familiar with him—the opulent palm gardens, decorative fireplaces, and

freshwater swimming pools are examples of the ability of iron to gather from the world what one desires for one's own comfortable existence.

This contrast of the fine distribution and its forces of intense concentration reminds us of expansion and contraction, the gesture of human breathing. Breathing in, or contracting, helps one prepare, for instance, before asking a question. Breathing out, or expanding, is a release, a way of leaving the past behind. All activities of the ego are living in the activity of breathing in and out. Some beings can breathe in all the time, but they do not develop consciousness. The activity of rhythmical breathing is essential for the development of consciousness.

Dr. von Mackensen said that, "Iron by itself is nothing. Only your thinking can bring out its concept. Think away the physical substance of iron until you come to an impulse world, a world of intentions." On reading (and/or carrying out) the following experiments the observer is challenged to perceive through the physical substance of iron to the intentions and gestures behind the substance itself.

It should be noted that Dr. von Mackensen clearly indicated that the following experiments were chosen by him to create an experience appropriate for adult science teachers, and that he would not necessarily choose the same experiments or mode of presentation for adolescent students. Certainly this should not be considered an authoritative statement of what should "be done," but rather one possible path to help our exploration.

EXPERIMENT #1: "LIFE" PROPERTIES OF IRON

Procedure and Observations: We observed a sample of "silver steel," containing only 1% carbon. This was in the form of approximately 10-gauge wire. The wire was soft and malleable. We then heated the steel red hot in a Bunsen burner and quenched it in cold water. We tested the wire for malleability and found it to be very brittle but much stronger. Before heating, the wire could not scratch glass, whereas afterwards, it could.

Discussion (done the following morning for every experiment): After the steel was heated to glowing, it had to return to room temperature. The quenching we did in water can also be done in oil, fat, mud, and so forth. "Secret recipes" affect what the product is like. The time sequence also influences the properties obtained through quenching.

Annealing leads to a spring being formed. A spring has a living quality. Flexibility and elasticity—the ability for a material to "remember" a past shape and return to it—are properties of life. The manufacture of springs was not possible with the bronze of ancient times. Only carbon steel shows these intimations of life when subjected to the right composition and the right process. We conclude that iron is more pronounced in its "life qualities" than any other metal, though copper shows certain intimations as well.

EXPERIMENT #2: BURNING STEEL WOOL

Procedure and Observations: A sample of steel wool was examined and found to have a gray, metallic sheen and some tensile strength. The steel wool was burned in a Bunsen burner. The greenish/blue ash was collected. We noted that the sulfurous smell was due to impurities in the metal and not an essential part of the experiment. We could see "melting pearls" of iron, which were rubbed off and fell on the paper placed below. The remains did not have the fibrous quality of the steel wool, but were blue and brittle.

Discussion: The remains of the burnt steel wool had a different quality. They were blue, brittle, and had more weight. These "melted pearls" were less dense. This could be confirmed through a specific gravity test. Through burning, the iron lost its cohesiveness. It is not the nature of iron to make wool-like fibers, but rather to make clumps or drops.

Oxygen brings its own properties to the iron. Consider the process of rusting, in which layer after layer of rust falls away. The formula for rust is not defined. It depends on the environmental conditions. It is not fixed, though it can appear fixed when we write a chemical formula on paper.

$$2\,Fe + {}^{3}/_{2}\,O_2 + H_2O \rightarrow 2\,FeOOH \rightarrow Fe_2O_3 + H_2O$$

We must also keep in mind that a small amount of carbon dioxide is needed to give a slightly acidic milieu.

EXPERIMENT #3: NAILS IN "ACID SAUCE"

Procedure and Observations: For this experiment, we used un-galvanized nails composed of nearly pure iron. **Warning: although the cyanate compounds in this experiment are not highly toxic, it is possible to produce deadly cyanide compounds from them. Do not attempt to create your own variations on this experiment unless you are very certain of the chemistry of each reaction you carry out.**

A. Some nails were placed in a test tube and covered with concentrated sulfuric acid. There appeared a "slow cooking," and it appeared that the acid was boiling by itself as the hydrogen gas bubbles escaped. The next day we observed a green color in the liquid.
B. This time, some nails were covered in concentrated hydrochloric acid and heated gently over a Bunsen burner flame. A yellowish green color emerged. The liquid was filtered through filter paper. We then tasted this "nail sauce" in minute quantities. The strongly acid filtrate had a penetrating contracting, sour taste with an astringent quality. Surprisingly, none of us suffered any acid burns.
C. The filtrate from part B was added to a new test tube. An approximately equal amount of concentrated nitric acid was added. The color changed to gold-orange. The solution was heated to a strong boil to complete the reaction.
D. In a new test tube, we placed potassium thiocyanate (KSCN) and water. We then added the solution from part C. A dark orange-red color appeared. The solution was diluted some with water until it became a light caramel color.
E. A new test tube was filled part way with potassium ferrocyanate, $K_4Fe(CN)_6$. The filtrate from part C was added to this test tube. A blue color developed.
F. Copper sulfate crystals were added to distilled water and dissolved by gentle heating. The color developed was almost the same as in part E. To this blue solution we added concentrated ammonia. A dark blue color developed which fully dissolved the light blue color.
G. Potassium dichromate was placed in a test tube with water and heated. A vivid, tangerine color developed.

Discussion: Returning to the imaginative picture of metals we are attempting to develop, we are asked to picture the start of time in which the metals came as colored clouds. The precious gems are the remnants of these colors. We can re-create them in the metal salts, as this experiment shows.

We considered the earthly sources of iron ores. Olivine, or "earth iron," tends to come from the depths of dark earth. Olivine (Fe_2SiO_4) and other ores with darker colors, including pyrite (FeS_2) and magnetite (Fe_3O_4) tend to come from deep underground whereas the more "rarefied" forms of iron, hematite, $FeIII_2O_3$, and limonite, $FeIIOOH \cdot nH_2O$ tend to contain more silica and are found nearer to the earth's surface. In general, FeII minerals tend towards green while FeIII minerals tend toward brown and yellow.

Dr. von Mackensen gave some general indications for making an iron-smelting furnace. For this, the teacher will need 100 kg charcoal, some sand, and 50 kg hematite or limonite in order to yield a small amount of metallic iron. A shallow pit can serve as the foundation for a kiln built up with firebricks. An air source must be provided on both sides of the kiln. Perhaps this could be a student manufactured bellows or even something as simple as a hair dryer (no heat) or reversed vacuum.

On the bottom of the kiln is placed a layer of charcoal, then a layer of ore followed by a thin layer of sand. These layers are to be continued up the kiln. A 12-hour burn is needed, so a means of continuing to feed charcoal is needed throughout the burn.

The reaction for this would be:

$$Fe_2O_3 + 3CO \rightarrow 2\,Fe + 3\,CO_2$$

Carbon plays an essential role in reducing metals. The carbon of the charcoal combines with oxygen to form carbon monoxide. The carbon monoxide gas forms a layer around the iron, spreading the forces of carbon through the whole furnace. At the end, a small amount of iron will have collected. Three-fourths of the ore goes into the slag.

Here lies an opportunity for the students to have a very practical experience with chemistry, involving mining, smelting, and later forging of the iron collected. Helpful to our experience at the conference was a field trip to a nineteenth century iron-smelting furnace in upstate New York.

Returning to the iron salt experiments, the colors we observed from iron salts appeared real and earthly, whereas the copper and chromium salts (in parts F and G) were not earthly. These colors cannot be penetrated with your feelings. Rather, they penetrate into you.

We discussed the equations of the reactions.

Part B: $2\ HCl + Fe \rightarrow FeIICl_2 + H_2(g)$ (yellowish-green color)

Part C: $HCl + 2\ FeIICl_2 + HNO_3 \rightarrow HNO_2 + 2\ FeIIICl_3 + H_2O$ (gold-orange)

Part D: $FeIIICl_3 + 2\ KSCN \rightarrow FeIIICl(SCN)_2 \cdot 4H_2O + 4KCl$ (orange-red)
aq

Part E: $4\ FeIIICl_3 + 3\ K_4[FeII(CN)_6] \rightarrow Fe_4[FeII(CN)_6]_3 + 12\ KCl$ (blue)

EXPERIMENT #4: IRON AND ITS RELATIONSHIP TO CYANIDE

Procedure and Observations: An old piece of cast iron was broken off with a hammer. As we observed the freshly exposed surface, we discovered that the fresh surface appeared more ceramic than metallic. The cast iron contained approximately 3% carbon.

A. A small piece of the cast iron was placed in a test tube and covered with concentrated HCl. The iron was almost fully dissolved as it formed a dark, olive green solution of $FeIICl_2$.
B. Some earth from under a spruce tree was collected and a small amount placed in a test tube. It was covered in concentrated HCl then boiled over a Bunsen burner. The yellowish-brown mixture was then poured into filter paper. The filtrate was collected in a new test tube.
C. KSCN solution in water was placed in a test tube. The filtrate from Part B was added. A deep reddish-orange color developed, as in Experiment 3, Part D.

$$FeIIICl_3 + 2\ KSCN \rightarrow FeIIICl(SCN)_2 \cdot 4H_2O + 4KCl \text{ (orange-red)}$$
aq

D. Brave participants then tasted this ferrous chloride ($FeIIICl_3$) in minute quantities. It was extremely hygroscopic and astringent, the taste lingering for many minutes.
E. We returned to the "iron sauce" formed in part A. We added drops of NaOH until a neutral pH was tested. Potassium cyanide (KCN) was then added very carefully to another test tube. **DANGER! Potassium cyanide is a deadly poison and can be absorbed through the skin or through dust inhalation. Also, potassium cyanide plus water forms cyanide gas, which has no odor and can rapidly cause death upon inhalation. This experiment should only be done very carefully and under a fume hood which does not vent anywhere near inhabited spaces or open windows. Under no circumstances should students handle potassium cyanide!** The KCN solution was then added to the "iron sauce" which had been previously neutralized. It turned brown, yet remained half clear, a bit like the atmosphere. It was diluted with water. Only at this point was HCl added. A light blue color developed. We then added ferric chloride, upon which the solution turned dark blue.

$$4\ FeIIICl_3 + 3\ K_4[FeII(CN)_6] \rightarrow Fe_4[FeII(CN)_6]_3 + 12\ KCl \text{ (blue)}$$

Discussion: Rudolf Steiner gives us indications that cyanide brings the will of man into the limbs. When the human being moves, cyanide appears—albeit briefly—then immediately disappears. Cyanide can actually be produced out of blood by boiling down the blood into crystals. Blood has the tendency to form cyanide. Iron (FeII) can absorb the cyanide and detoxify it, forming the $K_4[FeII(CN)_6]$ complex. Iron is a helper of life. A deficiency of iron leads to a running down of life. The blue color of blood indicates it is at work in detoxification. The deep blue color is restful, demonstrating its rejuvenating effect on the organism. An 8d (2") nail contains approximately the same amount of iron as is present in the blood of our body.

EXPERIMENT #5: IRON IN THE BLOOD

Procedure and Observations:

A. Five drops of blood were collected from a finger stick (using a lancet pen, available from a pharmacy) in a very small crucible. The crucible was then placed in a strong Bunsen burner flame for 10 minutes. At first, it burned and smoked, and then it began to glow through and through. The reddish-brown residue was barely visible, but formed a branching pattern at the bottom of the crucible.
B. We then added some drops of 10% HCl totaling about 1 ml. The residue turned brown. This was then heated over a mild Bunsen burner. The liquid turned a little bit yellow. It was kept hot, near boiling, for 5 minutes. The pattern on the bottom of the crucible disappeared.
C. The crucible was taken off the fire. We added 30% hydrogen peroxide then NaOH since this reaction could only take place in a basic solution. We then added 30% HCl until the pH tested acid for the next reaction to occur. The solution was clear.
D. We added KSCN. An intermediate red color emerged and immediately turned clear again. Dr. von Mackensen said this was a mistake owing to the addition of too much hydrogen peroxide, upon which he boiled it again to remove the excess hydrogen peroxide. More KSCN was then added. A deep red color developed reminding us of the color developed in Experiment 3, Part D.

$$FeIIICl_3 + 2\ KSCN \rightarrow FeIIICl(SCN)_2 \cdot 4H_2O + 4KCl \text{ (orange-red)}$$
$$\text{aq}$$

Discussion: In asking ourselves about the function of the iron in our blood, Dr. von Mackensen suggested developing the imagination, "I am an iron knight. I get my strength through iron." Returning to the quantity of iron in the human body (about the amount in an 8d nail), two-thirds is blood iron, while one-third is enzymatic iron. Mainstream scientific thinking tells us that enzymes all act independently, like little daemons. In fact, the motor forces of the body are driven by iron. It is the most active substance, followed by phosphorus, then sulfur.

The blood of human beings and mammals contains iron as the center of the hemoglobin molecule. In mollusks, copper serves an analogous purpose. Even lower organisms use vanadium. Plants utilize magnesium in the chlorophyll molecule to facilitate its respiratory functions.

The hemoglobin molecule follows the formula $[C_{738}H_{1166}FeIIN_2O_3O_{208}S_2]_4$and contains only 0.336% iron. This formula was developed in 1862 by Hoppe-Seiler and the molecule was given the name "crystallisats."

The blood contains 45% by weight of red corpuscles. Dr. von Mackensen gave indications for another experiment. To begin, one would collect a sample of blood and separate the red blood cells using a centrifuge. Once separated, these would be placed in water. After one or two hours, these red blood cells explode. The red substance that comes out is hemolyse, which contains 34% hemoglobin. From this, the hemoglobin can be crystallized. The shape of the crystals varies with different organisms. In humans, the crystals are rhombic; in squirrels, hexagonal; in doves, cubic. All vertebrates and other organisms with red blood have hemoglobin that crystallizes in unique geometric shapes.

Hemoglobin absorbs nine times more oxygen than plain water of a similar volume. All human activities are based on hemoglobin.

Carbon monoxide is extremely poisonous because of the affinity of the heme group for CO, which is 300 times greater than the affinity for oxygen. Carbon monoxide is a living substance, a living form of carbon whereas carbon dioxide is a dead form. This is shown through carbon monoxide poisoning.

Rudolf Steiner said in *The Foundations of Medicine* that the foundation of blood is the capability of crystallization. The activity of the "I" comes in through the blood and gives healing forces for the whole organism, especially to the nerves. Healing comes from the challenge to the ego overcoming the crystallizing effect of iron in the blood.

CONCLUDING THOUGHTS

Once the experiments with iron were carried out, Dr. von Mackensen pointed toward a deeper sense of how iron, carbon, and oxygen interact in the cosmos, in the Earth, and within the human being. Fossil records suggest the imagination of a time when the Earth's atmosphere was devoid of oxygen, and the iron compounds on the surface of the Earth existed primarily in reduced or partially oxidized forms. Minerals in these oxidization states often have a greenish or dull gray coloration. As photosynthesis "greened" the oceans and oxygenated the atmosphere, one can imagine the Earth's surface iron gradually "rusting" into the brown- and orange-hued minerals that dominate today.

We can also form an imagination of the ancient processes that make it possible for us to produce usable iron today. The carbon and oxygen compounds necessary for smelting are the products of plants—specifically, coal and air have gained the possibility of producing heat, light, and transformation from prehistoric plants' exposure to sunlight. In a certain sense, it is not the material substance of coal and air which is essential to the transformation of ore into iron, but only their capacity to carry and concentrate "imponderables" such as heat and light from the sun into the smelting furnace. One can experience the life-like qualities of iron—its flexibility, strength, and elasticity—as something gained only through the concentration and release of imponderables, much as living beings on Earth derive their capacity for life directly or indirectly from the light and warmth of the sun. There is something here akin to the structure of hemoglobin, where a kernel of iron brings the potential for crystallization processes into the blood, yet must be continually surrounded by oxidization/reduction processes.

Even after it is smelted, human-made iron remains intimately associated with plant products and their capacity to create change through oxidization. For example, we experience the power of iron in our automobiles where (as with the steamships) we use iron's strength and elasticity to carry out our physical intentions more rapidly and intensively, trading external distance for an inner experience of distance from the world. Iron can only give us this power, however, if we fill up at the pump with plant products imbued by the sun with the potential to produce heat and movement.

A picture may form in one's mind of the ponderable substance of mineral iron rising from the core of the Earth to meet the imponderable qualities of cosmic light at the surface. When these two are brought in concentrated association through smelting, the steely qualities of iron give human beings the ability to step into the "iron age." Ultimately, all human-made iron not continually maintained by human activity is "un-smelted" by oxidization processes, losing its capacity to behave in a life-like way.

Leading our thoughts and imaginations in profound and often unexpected directions, Dr. von Mackensen was able to bring an experience of iron that was unique for each individual teacher at the conference, yet pointed toward a "being of iron" that we could all perceive as vividly active in humanity's evolving relationship to the cosmos.

Fundamental Approach of the Mackensen Conference

by
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One of the key elements that impressed me from the von Mackensen Conference was the emphasis placed on understanding process. For example, one of his first demonstrations was to take a piece of Silver Steel (1% carbon), place it in a burner flame until it began to glow red, and then plunge it into a cold container of water. Prior to undergoing this process, the rod had been demonstrated as being somewhat bendable and it didn't leave a mark on a glass plate. After the rod had been put through the warming and cooling process described above, the rod snapped when bent and was able to leave a scratch mark on a glass plate. After reviewing this demonstration, von Mackensen went on to describe how in the past, much effort had been made to find just the right material in which to quench the steel (mud, oils, etc.), to achieve certain specific properties in the steel. One can quickly see that it is not necessarily the physical *material* that is important (it is not a chemical reaction between the oil and the steel). Instead, it is the interaction of the two materials in two different thermal states that brings about such a change in the steel. Instead of focusing only on the materials or only the thermal characteristics of the materials, *one is asked to look more deeply at the interaction (relationship) that takes place when these qualities are brought together.* Depending on the actual process of cooling that takes place in the steel due to the warming characteristics (in time) of the oil, different qualities and characteristics become present in the steel. While attention needs to be given to the trace materials added to the Iron and Carbon when steel is made, the above demonstration underscores the importance of considering the process by which the steel is formed if specific characteristics of the steel are desired. From this one can begin to see iron not only as a material but also as an intention that manifests in different forms and is affected as much by process as by material.

I can speak for this understanding through my present work both in terms of class teaching and actual research. Perhaps it is only a small step on the surface but I believe it has profound implications if we really take on this manner of seeing the world.

Formic Acid and Oxalic Acid

a topic for 12th Grade Chemistry

by

Reinhard Schoppmann

From the work of the "Pedagogical Research Office"
at the Association of Free Waldorf Schools, Kassel

translated from *Erziehungskunst*, June 1991

A Contribution to 12th grade Chemistry

For the chemistry teacher who wants to present a phenomenologically-based way of teaching, also in the 12th grade, the curriculum indications about the lesson plan given by Rudolf Steiner on 04/30/1924[1] have always posed an enormous challenge, which, as far as I know, has not been satisfactorily met to this day. This was finally expressed in these words: "There ought to be an inorganic, an organic, an animal, and a human chemistry." As examples for the students were mentioned: "hydrochloric acid, pepsin, juice of prunus spinosa resp. the "metamorphosis process formic acid-oxalic acid."[2] Previously Steiner had mentioned the difference between vegetal, animal and human protein, which would lead to the concept of "ascending protein." Human protein is supposed to be different from animal protein.

Analytically Oriented Chemistry or a Study of Vital Processes?

Such words will raise anyone's hackles who has been trained in conventional chemistry and who thinks along those lines. Because this kind of chemistry has registered the differences between different living beings only incidentally. It has focussed entirely on individual substances, which are largely severed from any connection with their origin, i.e. being "isolated." One could say that chemists have to a particular degree blurred distinctions, when they have ascertained, for instance, that the innumerable proteins of plants, animals and humans can be reduced to the same twenty "components," the so-called amino acids. It is in a way a matter of pride for the chemist to find a substance, once he has discovered it, again and again in the largest possible number of contexts. In this manner the tendency to simplify prevails in chemistry and not to make distinctions between substances according to their origin. Thinking in terms of chemical elements which are conceived as existing in all substances, even in living beings, exemplifies this tendency.

Chemistry can be experienced quite differently if one's attention is not directed analytically towards a small number of reproducible basic building blocks, which appear again and again and everywhere, but if one contemplates, what infinite plenitude of conditions of creation prevails in nature, causing a multitude of configurations—although the number of subsequently encountered substances is quite limited. Steiner must have meant these conditions of creation when he continuously urged that the teaching of chemistry should be developed not primarily based on chemical substances but on processes (e.g., Conferences of 06/21/1922[3]). Because in their vital processes the representatives of the various natural realms differ enormously, even if finally analytically identical compounds can be identified as fragments.

In the known publications by Waldorf teachers (Georg Ott,[4] F. Julius[5]) the curriculum for the 12th grade is only hinted at, and as far as I know there are no generally accessible reports regarding concrete attempts to create a curriculum based on the requirements mentioned above. Accordingly a general search is under way. For a start, the subject of formic acid and oxalic acid has been worked on for some time in the Kassel Section of the Association of Free Waldorf Schools. Initial results have been presented at various professional meetings and have been tested in my own teaching in the 12th grade. I hope the following contribution motivates others to undertake further investigations.

To Experience Processes of Metamorphosis in Matter

Processes relating to formic and oxalic acid have been mentioned repeatedly in lectures by Rudolf Steiner at the turn of 1923/24 and have been demonstrated in experimental detail. They were presented in

great detail in the morning of December 22, 1923 to the workers at the Goetheanum[6] and then in the evening of the same day, immediately before the so-called Christmas Meeting, to the members of the Anthroposophical Society.[7] But also in the first lecture of the "Christmas Course" for physicians on January 2, 1924[8] and in Chapter 17 of the book that was jointly published with Dr. Wegemann.[9] Anyone interested may read the full texts. It should be evident that such citations have no place in classroom instruction, but they could be valuable to the teacher for the preparation of the period and for the planning of the experiments to be demonstrated. After all, during classroom instruction everything should be derived from external observation and from the data themselves.

Before the teachers Rudolf Steiner speaks of a process of metamorphosis. How is this to be understood? To become aware of a metamorphosis, we must direct our attention not only to a given moment and something occurring at a given site, but we must internalize the observation and then compare the internalized observation with a renewed observation of the state that was originally perceived. If we are able through internal agility to transform the two states one into the other, we can consider this an experienced metamorphosis. Thereby something will always be perceived as continuing and something else as changed. One can relate this also to the postulated four-fold chemistry. Using the example of formic acid and oxalic acid one can develop an introduction to such conceptualization. Perhaps it is possible to demonstrate some of the principles of this way of seeing things.

In oxalic and formic acid the inorganic aspect shows up only to a slight degree, the relationship to the organic-vegetal and to the animal sphere being more obvious. The relationship to the human being still has to be investigated. In this connection it is not essential to develop and teach attributions based on concepts and ideas, but to present the substances themselves with their past and future possible states as clearly as possible, so that the phenomena accessible to experience can express themselves and reveal the naturally given order.

Tendencies of Oxalic Acid - its Role in the Organism of the Plant

Oxalic acid is described as an acid which is widely present in the vegetal sphere—with the exception of cruciferous plants. It betrays itself to us by the sour flavor of green plants: above all in rhubarb, spinach, the leaves of red beets and in wood-sorrel (oxalis acetosella, Fig.1) —to the latter it owes its name—its flavor is unmistakable.

Through a magnifying glass or a microscope its calcium salt can be observed in the leaves of many plants in the shape of transparent parallelepipeds—especially so in brown onion skins (Fig.2). When one chews the stems and leaves of arum (arum maculatum) the crystals actually sting one's tongue. For centuries the pressed juices of such plants have been used as mordants because of their content of oxalic acid. In 1769 Savary first isolated crystals of

Figure 1

Figure 2a

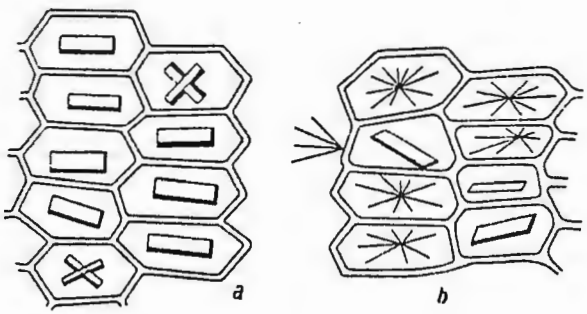


Figure 2b (left) Form of crystals of calcium oxalate in brown onion skin, (b) converted to gypsum crystals after treatment with sulfuric acid.
From Schmells Natural scientific experiments, biological workbook, Vol 3, Experimental Biology, *by F. Steinecke and R. Auge.*

the so-called sorrel salt from sorrel juice, which today is defined as the double salt of potassium hydrogen oxalate and oxalic acid. The first synthesis of the free acid is due to Scheele, who in 1776 obtained it by oxidation of cane sugar with nitric acid, and in 1810 Gay-Lussac obtained it in an alkali melt from sawdust. Both of these instructive synthesis methods should be demonstrated in the class room.[10]

Oxalic acid can appear in the first case (Scheele's nitric oxidation) as unusually large and beautiful crystals (Fig.3). In the second case (Gay-Lussac alkali method) its appearance can be recognized only after precipitation with a solution of calcium chloride. This precipitate of calcium oxalate cannot be decomposed by acetic acid, unlike calcium carbonate, and is therefore insoluble.

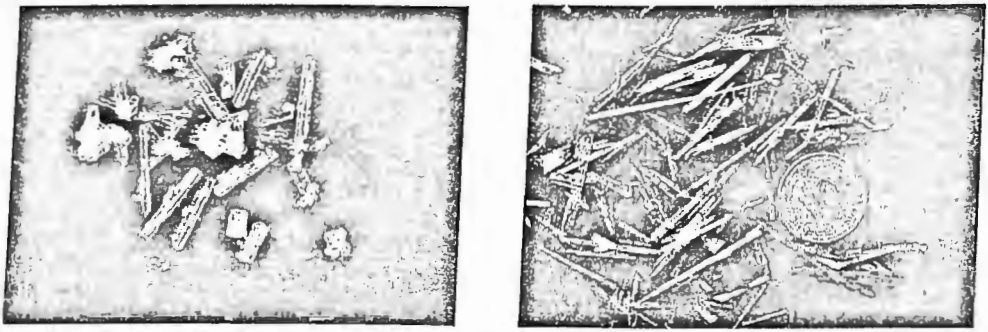


Figure 3: Oxalate crystals formed in Scheele's synthesis from oxalic acid, by oxidation of cane sugar with nitric acid.

TABLE I Oxalic Acid Content
according to published data (some as salts)

Wood sorrel	0.31% to 1.25% (data vary)
Rhubarb	0.5% to 2.4% (data vary)
Spinach	0.46% to 3.2% (data vary)
Mangel	0.69%
Parsley	0.19%
Red beets (root)	0.34%
Red beets (leaves)	0.92% (corresponds to 12% of dry weight)
Cocoa powder	0.45%
Tea (drug?)	3.7%
In human blood	0.0002% (as metabolism product)
In human urine	20mg per day are excreted

When we have the free acid in front of us it has the appearance of a salt: colorless monoclinic crystals, which are odorless, and which upon heating in a test tube give off large amounts of water vapor, initially forming a liquid and then again a solid (anhydrydous salt). Only above 157°C without melting again they sublimate, giving off smoke. Thereby they clearly demonstrate their acidic nature: the sublimating vapors irritate irresistibly and cause a deep racking cough. Only at this point will a flame form. We observe reddish-blue, transparent flames; the combustion gases of these can be inhaled without danger. The flames that have a cleansing effect seem to emanate directly from the solid white substance. Analytic chemists may teach us, however, that immediately preceding this event a decomposition to carbon monoxide, carbon dioxide and water vapor has taken place above the substance.

If we place a few small crystals of oxalic acid carefully on the tongue, we will be surprised by the strongly sour, cooling, and astringent flavor, although the solubility of the dihydrate crystals in water at room temperature is limited to 10%. The ingestion of about 5g of oxalic acid at a time can kill a person through the plugging of the kidney channels by calcium oxalate crystals! Experiments to increase the solubility of oxalic acid show that the relatively small amount of 9.5g in 100g water at 20°C can be increased 12-fold by heating the solution. Upon slow cooling we can observe well developed, large columnar crystals.

In non-aqueous solvents like ether, benzene or chloroform crystals of oxalic acid are barely soluble, but they are well soluble in ethanol.

A further experiment with the cooled-again concentrated aqueous solution of oxalic acid is also instructive: if one pours it while agitating into an identical volume of a saturated solution of sodium carbonate (soda), a dense precipitate of sodium oxalate will appear after carbon dioxide gas has effervesced away. This is also relatively poorly soluble—contrary to comparable sodium salts; it is actually almost the only poorly soluble sodium salt existing under normal conditions.

TABLE 2
Solubility of Oxalates in 100g Water

salt type	solubility #1	solubility #2
K-salt (monohydrate)	36.4g at 20°C	49.0g at 50°C
Oxalic acid, dihydrate	9.5g at 20°C	120.0g at 90°C
Na-salt	3.7g at 22°C	6.3g at 100°C
Acid K-salt	2.2g at 0°C	51.5g at 100°C
Acid Na-salt (monohydrate)	1.6g at 15°C	
Ca-salt	0.0006g at 18°C	0.0014g at 95°C

The observations described so far have presented us with the picture of a certain solidity and insolubility of the substances in question. We may ask ourselves: do plants have to overcome this tendency, i.e., must they secrete this substance in order to remain internally at least flexible (mobile?) enough to present themselves to us as soft, leafy, juice-suffused beings; do all plants have to battle against becoming rigidified, as is shown here by the example of oxalic acid ?

Formic Acid–An Opposite Picture

Let us now turn our attention to formic acid, where we will find a contrary picture. The source of formic acid is self-explaining; but beetles and certain caterpillars also produce this liquid. What is astonishing is the high concentration of up to 75% of acid in these insects and the quantity, which reaches up to 20% of the body weight. (For comparison: the quantity of blood in the human being amounts to 7% of the body weight.) In 1975 it was discovered by means of a radio telescope that formic acid was also widely present in the universe. Traces of it seem to be detectable in many regions.

Simply when one opens a bottle of this clear, thin liquid the nose gives warning: "it bites!" The tongue should be allowed to be in contact only with the highly diluted acid, and even so the fresh and acidic undertone surpasses all other flavors. As early as 1670 this product of the ant was described as an individual substance; in 1749 the Prussian beet-sugar chemist Andreas Sigmund Marggraf distilled it from crushed ants. In a 5% alcohol solution it became widely known under the name "ant spirits" as a remedy used for rubbing into rheumatic, gouty parts of the body. Nowadays synthetic formic acid is used under the designation "E236" for the preservation of foodstuffs.

In addition to the process based on carbon monoxide commonly applied today, air oxidation of methanol ("wood spirits") has long been considered as a production method giving good yields. While the cold liquid, free from water, will extinguish a burning match, the vapors of the acid when heated will soon ignite and will burn with a transparent, light-blue, wavy flame. Above the boiling point of 101°C liquid formic acid cannot exist at atmospheric pressure. It will then entirely volatilize—like water. Its freezing point (+8°C) also resembles the latter. But even with a hydrophobic substance like ether it is totally miscible. With bases it forms easily soluble salts; it can even dissolve limestone, which is the reason for using it for cleaning boilers and removing boiler scale.

TABLE 3:
Solubility of Formates in 100g Water

Na-salt	70.6g at 15°C	160.0 g at 100°C
K-salt	331.0 g at 18°C	657.0 g at 90°C
Ca-salt	16.0 g at 18°C	

While in oxalic acid we encounter solidity and low solubility, formic acid appears volatile and mobile (of low viscosity??). As a counterpoint to the solid crystals of calcium oxalate in the leaves of plants we find the free formic acid spreading out in the form of gas everywhere, even to the highest altitudes. With both acids secretion processes are involved, which can be considered in some manner to correspond to each other. One secretion occurs in the vegetal, the other one in the animal sphere. Rudolf Steiner describes, how this activity of secretion is responsible for making vegetal and animal life possible.

Possible Transformations of Both Substances

It becomes especially interesting to study and demonstrate the possible transformation of the two substances: free formic acid is an easily accessible source of carbon monoxide; one only has to "dehydrate" it with some concentrated sulfuric acid to obtain in a gentle stream a large volume of this toxic gas, which burns with a blue flame. But if we retain formic acid bonded in the shape of its calcium salt and heat it in this form, a flammable gas also evolves, but its flame seems to be much brighter than that of carbon monoxide, because hydrogen has also been formed. The residue of this process turns out later to be common calcium carbonate, which foams violently when acid is added to it. How is this to be explained? To identify heavily diluted formic acid, one makes use of its ability to reduce silver nitrate in ammonia solution to black metallic silver, which can be deposited as a mirror. The acid itself is completely converted to carbon dioxide. It acts as reducing agent, sharing this ability with many substances, such as sugars, taken from the living sphere. We can approach the question posed above more closely if we heat formic acid to more than 300°C with an excess of sodium hydroxide. Now the gas that is evolved is pure hydrogen and the solid residue is sodium oxalate, which in turn is converted only at 400°C to carbon monoxide and sodium carbonate. Thus it is possible to obtain oxalic acid from formic acid, while the lightest ("thinnest") substance known to us, hydrogen, hardly present in the terrestrial sphere, is formed as a by-product. The earlier described mobility and volatility of formic acid, however, is afterwards no longer encountered in the solid residue. Its possible transformations seem to lead only to even denser and more calcified spheres—namely those of carbonic acid and its salts. One may ask why carbonic acid—especially in the form of its gaseous anhydride, carbon dioxide—should be called "dense." Students should be familiar from the 11th grade with the comparison between the two gases hydrogen and carbon dioxide—where the latter was dealt with as a combustion product of the element carbon.

Hydrogen is the lightest gas, and is present in almost pure, although very dilute form at extreme altitudes (above 100km, found as almost 97% of the atmosphere there). On earth, it produces one of the hottest flames (oxy-hydrogen blowpipe), but it cannot easily be converted into a liquid on a technical scale, or even less into a solid. On the other hand, the behavior of carbon dioxide is just the opposite: more than 20 times heavier than hydrogen, it can be found in pure form in caves or crevices within or near post-volcanically active rocks; man uses it as a fire extinguishing medium or freezing agent after having liquefied it first under moderate pressure and then solidifying it by rapid pressure release (dry ice). Since their first chemistry lessons students know about its great importance on earth for the origin of plant forms, where during "photosynthesis" it undergoes a kind of condensation. In connection with the formation of hydrogen during the course of the "metamorphosis-process" formic/oxalic acid one could ask oneself: is a generally valid law of evolution evident here, according to which a densification step is possible only if simultaneously a step in the opposite direction takes place? In chemistry such a process is referred to as "disproportionation" in a different context.

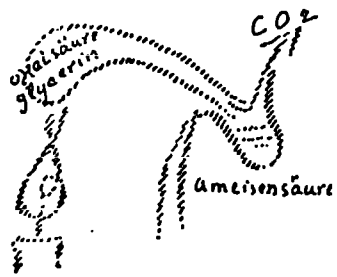


Figure 4a: Rudolf Steiner's instructions for an apparatus for the transformation of oxalic acid to formic acid (according to GA 232, p.194, lecture of December 22, 1923).

Having engaged in such considerations with the students, the question regarding the feasibility of the still unperformed transformation of oxalic acid into formic acid becomes an exciting undertaking. Rudolf Steiner describes it extensively—even including the description of an appropriate apparatus (Fig.4) in the earlier mentioned lectures (11 cf. footnote 7 and 8).

In the above-mentioned lectures Steiner describes this chemical reaction as a total mirror image of that "which exists alive and sentient in the human being," but not only in the human being but also "in the life and activity of nature" (in plants and insects).

In the laboratory it can be performed as follows: if one dissolves crystals of oxalic acid in an equal weight of glycerol and mildly heats the solution, the mixture soon starts to foam: carbon dioxide escapes.

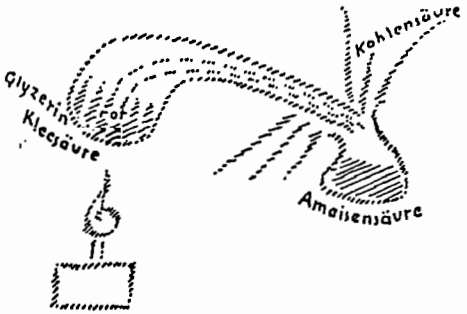


Figure 4b: Alternate drawing by Steiner for an aspparatus for transforming oxalic acid into formic (according to GA351, p252, lecture on the same day, December 22, 1923.)

At temperatures above 100°C one can then obtain a clear distillate, which undergoes all reactions of formic acid. The reverse metamorphosis, the "disproportionation" of the solid into the volatile acid has succeeded, where at the same time the dense, solid matter has been liberated in the form of carbon dioxide!

Conclusion

In summary, one can represent this schematically, and also write a chemical formula:

liquid-volitile
formic acid

carbon dioxide
as asphyxiating gas

hydrogen as
as easily flammable
gas upwards

solid crystalized
oxalic acid

ex: $2\ HCOOH \rightarrow \begin{matrix} COOH \\ | \\ COOH \end{matrix} + H_2$

$\begin{matrix} 2\ COOH \\ | \\ COOH \end{matrix} \rightarrow 2\ HCOOH + 2\ CO_2$

Could these considerations become a step on the unaccustomed path towards an inorganic, organic, animal and human chemistry? Certainly they will aid in practicing jointly with the students flexible and interrelated thinking, as a precondition for a deeper understanding of a kind of chemistry which does not primarily ask about resulting substances but about the conditions under which they have originated and been transformed.

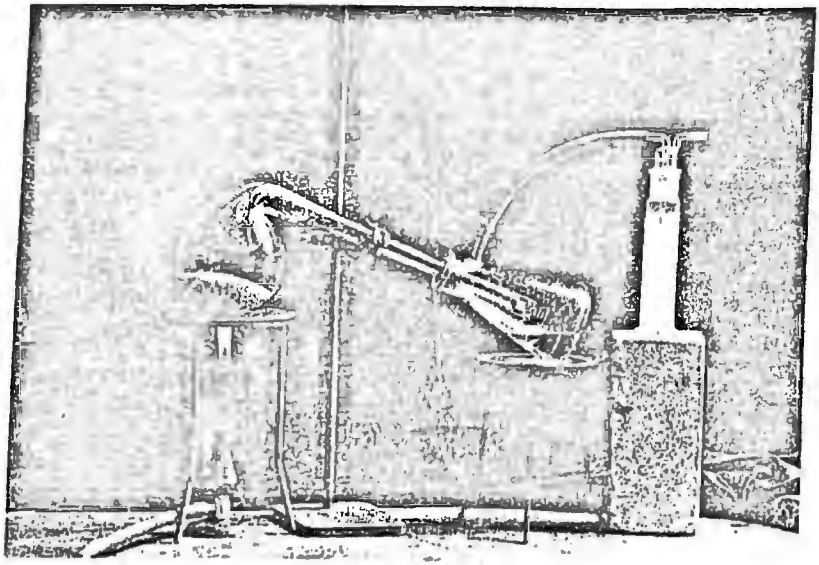


Figure 4c: Actusal version of the laboratory apparatus used for the transformation of oxalic acid into formic acid, based on the principles mentioned by Rudolf Steiner.

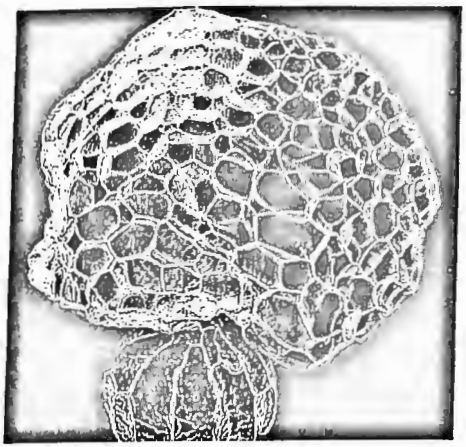
Endnotes and References

1. Rudolf Steiner, *Conferences with the Teachers of the Free Waldorf School in Stuttgart*, GA 300c, Dornach 1975.
2. The concept of metamorphosis is a key concept for the entire view of nature at the Waldorf School. It was developed by Goethe while contemplating the shape of plants, where Goethe was able to show that all their parts can be understood as mutations of the leaf-principle and the stem-principle. Cf. the essay by Gerhard Sturm "The Community of Blossom and Insect" in the preceding issue of *Erziehungskunst* (tr. Art of Education) and the re-issued booklet by Gerbert Grohmann: *Metamorphoses in the Realm of Plants* (publisher: Freies Geistesleben). For further details regarding the application of this concept to chemical processes see the following parts of this article.
3. *Faculty Meeting Conferences with Rudolf Steiner*; GA300b, Dornach 1975.
4. Georg Ott. *An Outline of Chemistry*, Zbinden Verlag, Basel.
5. Frits Julius. *Outlines of a Phenomenological Chemistry*, Stuttgart 1974; AWSNA Publications, 2000.
6. Rudolf Steiner. *Mensch und Welt . . .*, GA351, R. Steiner-Verlag, Dornach.
7. Rudolf Steiner. *Mystery Centers*, GA232, Steiner-Verlag, Dornach.
8. Rudolf Steiner. *Meditative Contemplation*, GA316, R. Steiner-Verlag, Dornach.
9. Rudolf Steiner/I. Wegmann. *Foundations of Anthroposophical Medicine*, GA27, R. Steiner-Verlag, Dornach.
10. The teacher will find many experimental details regarding the reactions of formic and oxalic acid mentioned here in the following books: Arendt-Doerner: *Technology of Experimental Chemistry*, Verlag Quelle & Meyer, Heidelberg; Flohr Floerke: *Methods and Techniques in Chemistry Teaching*, Verlag Quelle & Meyer, Heidelberg-Brandstaetter/Sternhagen: *Chemical Experiments for School*, Verlag Fr. Deuticke, Vienna; Gloeckner: *Experimental School-Chemistry*, Aulis-Verlag, Koeln Habith/Puff/Schmitz DuMont: *Chemistry Teaching*, Steinkoipf-Verlag, Darmstadt Keune et al.: *Chemical Experiments for School*, Verlag Harri Deutsch, Frankfurt AM complete summary can be ordered starting in the fall of 1991 from the Pedagogical Research Office in Kassel, in a booklet by von Mackensen: *Topics from the Chemistry Period of the 12th Grade: Formic Acid-Oxalic Acid.*

World of Wonder

Pinedrop Seeds

In Autumn, with the flowers gone and leaves disappearing, plant seeds become more conspicuous. There are many interesting mechanisms of seed dispersal, with wind being an important one. The tiny seeds of pinedrops, *Pterospora andromedea,* shown on the right in a Scanning Electron Micrograph, have a unique lacey transparent net-like cellular structure that provides buoyancy for efficient dispersal by the wind, hence the genus name Pterospora, derived from the Greek Winged Seeds.



Hydraulic Rams

A number of people have called me to ask how to build a demonstration hydraulic ram. The following web sites may prove helpful:

http://www.yin-yang.com/rampumps/ *I've made this one, it is super.*

http://www.bae.ncsu.edu/programs/extension/publicat/wqwm/ebae161_92.html

You can purchase one here. You will also find good drawings, method of operation, and relevant mathematics.

http://www.theramcompany.com/ *Here you will find a lot of history and good information; it has the only solar powered ram I've seen.*

http://www.lifewater.org/wfw/rws4/rws4d5.htm

— DSM

What the Water Spider Taught Me

by

Mick Follari
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Here are some very interesting effects that can be observed at the meeting of a gas, liquid, and solid, manifested in surface tension and capillary effects, that contradict what I have found on the subject in my Fluid Dynamics and Chemistry books. However, what is wonderful is that in these effects, we find that the behavior of the transition state (liquid) between solid and gas, also indicates something about our soul conditions, and this is in some ways a reminder of the alchemical aspect of scientific work.

In the 12th grade physics, addressing light, color, and epistemology, we begin with a trip to a nearby lake. In the crisp autumn morning we walk in silence to Wonderland Lake and spend about two hours studying the lake and surroundings for visual phenomena. This activity is nicely described in the book, *The Marriage of Sense and Thought* by Edelglass, Meier, Davy, and Gebert (pg. 81). Customarily, students will readily notice the reflections in the lake of the surrounding trees and mountain landscape, they will notice the lifting of objects seen in the lake, they will notice ripple effects (and their interaction with the previous scenes). And there is also a very special, rich observation that had eluded me until a recent journey with my 12th grade. Having made all the previous observations before, I had the time to be fascinated by one new, strikingly beautiful observation—having to do with a water spider.

I would like to suggest that this moment with the water spider has led me to restructure and reexamine the whole of this course, and even indicates work to be done in 9th or 10th grade that may be pertinent, to help set the stage for this discussion in 12th.

First: On Reflections

Though I will generally skim over the more everyday observations (which are nonetheless very important (these have been discussed in other writings). I would like to highlight several discussion points that are important for later use in the course.

Reflections are common observations, but the students should really make several key observations (perhaps with help). Remember that movement is important! This is partly what separates experiences in the world from those in the laboratory and helps develop a sense for holistic seeing. Children (think back to when you were one) often carry wonderful observations related to movement in the world. Students can think that the reflected image may be stretched vertically as compared with the tangible one, until they crouch (move vertically) down to the water level. From this viewpoint they will seem to be equally-sized, or nearly so. The reflection will be disturbed and distorted as ripples move through it; they may even point out that in the disturbance are patterns of light and dark and "pieces" of the sky appear. As they move sideways along the shore, they will notice that the reflected image remains always aligned between them and the object, constantly reorienting itself to their movements. This makes them a participant in the observed phenomenon. This sense of movement and smooth, constant adjustment will be crucial to later discussing the rainbow. Several students may comment on the relationship of the sun to the object, to its shadow, and the reflection. Notice that the shadow remains in place as I move, it is tied more closely to the tangible object, while the reflection is more related to me.

Where is the reflection? If it "exists" on the surface, why do we need to focus as though it is farther away (a mile or so in the case of a tree at the opposite shore)? Focussing on a floating leaf, then focussing on the reflection of a tree, your body tells you that the tree is much further than the leaf (surface). You must "spread" your eyes to see the tree in focus—your eye musculature responds as it does to distant objects. Note that Escher has a nice print called "Three Worlds" in which all three visual spaces are drawn in focus—something that could never happen at the lake. Also, closer objects (my feet at the shore) are larger than farther ones, as the familiar laws of perspective indicate. And a reflected space is established, in fact, with all the laws of perspective we would expect, one which appears to be the same size as the tangible space it reflects, can in fact almost be visually indistinguishable from the tangible world, and also is intimately connected to me (the observer) and the tangible object as verified through movement. Which is real? Is not the reflected space just as real? The tangible world has certain visual properties, material properties, chemical ones, etc. . . . I expect that a tangible tree (by definition) is one which I could reach out and feel with my hand. The reflected tree is just as real, but only possesses visual properties which are shared with and correspond to the familiar ones of the tangible world. My crouching friend next to me describes a similar but slightly different experience of the reflected space from me, standing up. However, as we move and continue to observe, we are able to sift out an understanding of reflection. Is there a lawfulness? Can we characterize all these observations in the statement of a law? In class, we will penetrate some of these observations more fully with the "cups" demonstration (see Edelglass, pg.83), and derive the law of reflection.

Lifting Stones

Twelfth graders are usually already aware of refractive lifting. They have stuck pencils into water or have reached for something under water which was not in the position they expected. What is subtle perhaps is that as ripples wash toward shore, the lifting effect is intensified, and the objects appear to shake or move, and are magnified for a moment as the ripples pass through. We believe that ripples are local gatherings of more water than their immediate surroundings, and so it seems that this lifting effect depends on the amount of water through which we are looking. How can we measure the visual depth to the stone to compare with the dry depth to the tangible stone? In the field this would be nearly impossible. However, in the lab we can set up a controlled pond (fish tank) and do a beautiful demonstration to solve this very problem. As the students are probably aware (or quickly determine), we cannot simply insert a ruler into the water to measure the depth to a quarter resting there. The ruler's inches will be compressed (lifted) so that they won't correspond to inches on dry land or out of the tank. Could we simply find a conversion factor for the underwater ruler? No, in fact, deeper inches appear more compressed than shallower ones. The whole visual scale of the submerged ruler is affected and cannot be easily related to a tangible one outside the water. This realization has a connection to Special Relativity, which we cover at the end of the block. Quite a dilemma—we would like to characterize the lifting effect by comparing the visual quarter to its tangible counterpart, but how? How do we carry the tangible measurements from out of the water into the visual, refracted space in a way that is usefully comparable?

Think back to something we already have determined: a reflected image is a visual copy of its tangible counterpart. Therefore, we have an extremely elegant way of seeing both a ruler with measurements that correspond exactly to those in dry space (air) and seeing the refracted quarter on the bottom of

the fish tank—we can reflect a ruler held just at the water's surface into the water and compare the two depths (we can measure the drained fish tank to determine its dry, visually unaltered depth, or insert a ruler and mark the water surface on it). What else will we need to know? If I move while observing the quarter, does it remain in the same place, or is it lifted different amounts? The students will figure out that we need to know one more measurement and to determine a way to mark that (distance to the "piercing point" through which we are looking). We used a framing square with a string-suspended nail set exactly to point to the water surface. The observer, would direct an assistant to position the square until it pointed to the place through which he was looking. This way (as opposed to simply using the edge of the tank) we were able to look through several different angles and compare results for the refractive index.

Here we have already made practical use of the first visual lawfulness of the block—the exact correspondence of the reflected space to the tangible one. The beauty of this solution can hardly be overstated. From the two depths it is possible to derive mathematical relationships—the familiar Snell's Law. Our measurements in the fish tank yielded results for water that are very close to those listed in textbooks. After a few examples, students will notice that the angle to the surface normal in the less-dense medium, is always greater than in the more-dense. Looking at a sketch, we might predict something unusual—that at some point the exterior angle will be 90° while the interior one is not. "Freddy the Fish" will not be able to see out of the lake! Some students may have experienced this while diving, and we can now discuss total internal reflection. From this, a discussion of fiber optics is a nice application.

What is the index of refraction really about? An optical phenomenon has indicated a material property of the medium into which we are looking. Each transparent medium into which we might look has a certain material property that we can quantify with the index of refraction. It may have to do with density, but regardless, it is an index assigned to various materials of an optical characteristic. It is a relative scale. Remember the triboelectric series from 11th grade? The temperature scale of 9th ? There is no absolute scale for indexing the refractive effect of various materials, it is simply arranged relative to air (the most common medium through which we look). Implied by our observations is the further conclusion that the amount of material through which we look is an important factor, in other words, the amount of visual lifting is both dependent on the material and on the amount of that material.

Note that both reflection and refraction indicate the presence of ripples—a disturbance in the reflection indicates surface disturbance, while an intensification of the lifting indicates changes in depth.

Finally, it is possible, though very difficult, to see colored fringes around the stones at the pond edge. Most students have a hard time experiencing this. Some students have commented that they can see "rainbows" at the light/dark edges of the ripples on the water under certain conditions (in certain positions relative to the sun). We will draw out the colors in a more effective way next.

Finally, What the Water Spider Taught Me

Another wonderfully intriguing and mysterious phenomenon can also be experienced at the lake. While quietly observing reflections and refraction, squatting at the water's edge, I noticed a water spider sail slowly past. As the water spider hovered for a moment in front of me, I noticed the shadows of his feet on the lake bottom. Four large ovular shadows ringed with an intense brightness. The four ovals were quite large relative to the actual size of the spider's feet. One could almost say that the brightness had been "gathered" to the outsides of these large ovals or circles. A blade of dry grass floated by slowly behind the spider, and here I was able to make some further assessments: portions of the grass that were above the water could be

related to a normal-looking shadow on the pond bottom, i.e., slightly blurred but showing no unusual brightness. Portions below the surface also showed no unusual brightness, but at the place where the grass met the surface, outrageous bulbous shadows appeared, with a bright ring at their edges. The grass is important, because just as we needed to move to uncover conditions for understanding reflection and refraction, we need to carefully assess the conditions under which the phenomena will appear. In this case, we can determine that the mysterious bright ring corresponds to something happening at the meeting of the object and the surface of the water. Upon closer inspection, we observe that the surface of the water is curved downward where it meets the object, and realize that the gathered light, or brightness, seems to be due to a focussing of the sunlight, as with a magnifying glass because of the changed shape of the surface.

Touching one's finger to the water surface, a curious effect is observed: the shadow of my finger is split by a bright line that spreads into lightning-like patterns farther up the finger. In this case, the light is "gathered" to the inside of the shadow—the complementary, or inverse effect to the water spider's leg effect. Remember that we are always concerned with studying carefully the conditions under which an effect can be observed. In this case, inspection of the water surface uncovers that the surface is curved up toward my finger, the opposite effect to the suspended needle, or water spider leg. Remember that Nature often offers herself and her secrets in complementary pairs (the appearance of both the dark and light color spectra are a wonderful example of this). The lesson is that when observing phenomena, be aware of the possibility of its complement.

Considerations on Surface Tension

What happens when a solid meets the interface of a liquid with gas, when there are all three states of matter together? One effect, not so unfamiliar, is surface tension. In fact, the grass and the water spider's legs both exhibit the effects of surface tension under the conditions described above; in other words, the surface appears 'dimpled' as thought there is a skin on it. Objects which are more dense than water are supported on the liquid surface in a most improbable way. In the classroom, a nice way to investigate these effects is to carefully suspend a sewing needle on the water surface. This can be done by placing a needle on tissue paper on the water, then carefully pushing down the tissue paper until the needle is supported. Once accomplished, the needle can remain fairly stable in this position, even be blown or pushed around somewhat without sinking. It is difficult, however, to get the needle into position, and is a great task for the students to try. My students were better at it than I was, and could get a 0.16g needle to be supported in a Petri dish of water. What is going on here? A sewing needle is made of steel that is about 8 times as dense as water, and cannot float!

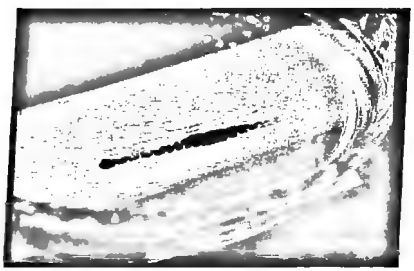
Needle supported on the surface of water showing enlarged shadow

Needle supported on the surface showing the curvature of surface water

A Solid is characterized by the fact that it creates its own boundaries, and supports shear stresses; a Gas is characterized as the state of matter which creates no boundaries of itself, and obviously supports no shear. A liquid is a state of transition between the two—it supports no shear (by definition) and creates only one boundary of itself. This appears to be a flat surface (as when I pour water into a Pyrex dish) normal to the gravitational force, but its essence is actually a response to

the presence of the gas. How do I know? A falling raindrop is a liquid/gas interface, and in fact the only thing preventing it from being perfectly spherical is gravity or air resistance while falling. Therefore it seems that independent of gravity, a liquid forms one boundary with a gas, and this is spherical–an effect verified by astronauts weightless in orbit.

We might be pressed to say that our transitional state, the liquid, when presented with a gas, responds by behaving more solid-like; it "withdraws," inducing forces which give it some form. There is no membrane to speak of under surface tension conditions, but only the apparent effects of forces. In our Pyrex dish, at the one self-induced surface-boundary, the liquid can actually support objects more dense than itself, such as the needle. There must be forces present in the liquid to accomplish this. A trip to our trusty Fluid Dynamics, Chemistry, or Materials Science texts will uncover a discussion of intermolecular forces, and the imbalance presented at the boundary with the gas, the result of which is surface tension behavior. Molecules deep within the liquid repel each other because of their close packing, molecules at the surface are less dense and attract each other. The absence of half their neighbors leads to the mechanical effect of a surface in tension.[1] Why then, does the water dimple under some solids, but come up to meet my finger? Or for that matter, why does water rise up the sides of a test tube, creating a meniscus? The explanation usually given is that the determination of surface tension effects or capillarity is determined by whether the cohesive forces of the liquid are greater or less than the adhesive forces between the liquid and solid. These forces are explained as cohesive forces between like molecules, and adhesive forces between unlike molecules. The contact angle between the liquid and solid, sensitive to the physiochemical conditions, indicates whether the liquid will be wetting or non-wetting, which in turn indicates the surface effects.[2]



Twisty-tab under water

In texts, it seems that, barring changes in chemistry, the appearance of surface tension or capillarity are properties of the materials—like water/glass vs. mercury/glass. One exhibits capillarity, one surface tension. So we can say that if the cohesive forces in the liquid are stronger than the attractive forces to the solid, then the liquid responds by withdrawing and establishing this membrane-like behavior (surface tension), more solid-like. If the attractive forces are greater, then the liquid exhibits capillarity effects, almost more gas-like by wanting to spread (balanced by weight of rising liquid). Either way, it seems that this state of tension—the liquid (transition) state between extremes of solid and gas—is forced into breaking the form that it had established in response to the gas by either becoming more solid, or more gas-like, and the force imbalances cause changes in surface shape which then refract the light like lenses, focussing it into brightness in the effects described above.

However, what do you expect would happen when the needle–which is supported on the water under surface tension—is touched to the surface like my finger (which exhibits capillarity)? Should it dimple the surface slightly, giving the large round shadow with bright ring? Wrong! It makes a beautiful diamond-shaped bright starburst! Further investigation reveals that the same materials that cause water to exhibit surface tension effects actually cause both (and vice versa). Here is the crux: slowly pushing an object (like a small thin steel screwdriver) into the water and then pulling it out,

Finger touching surface of water showing the contracted brightness

forms the bulging/bright ring on the way down, and narrow starburst on the way out. Obviously, the entire system of forces must be considered, or we must consider all the conditions under which the effects are observed. When the needle is resting on the surface, it is obviously pressing down (weight effects predominate), while held at the surface (like my finger), it is not pressing down ("levity" effects predominate). So the visual effects may have as much to do with force conditions as with material properties.

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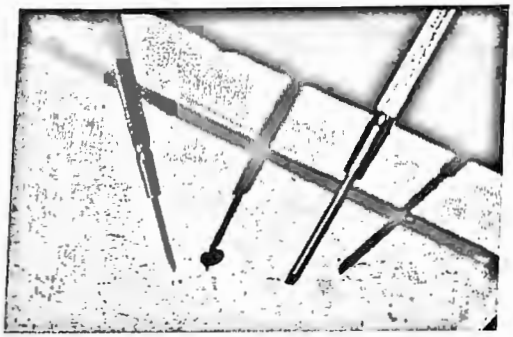
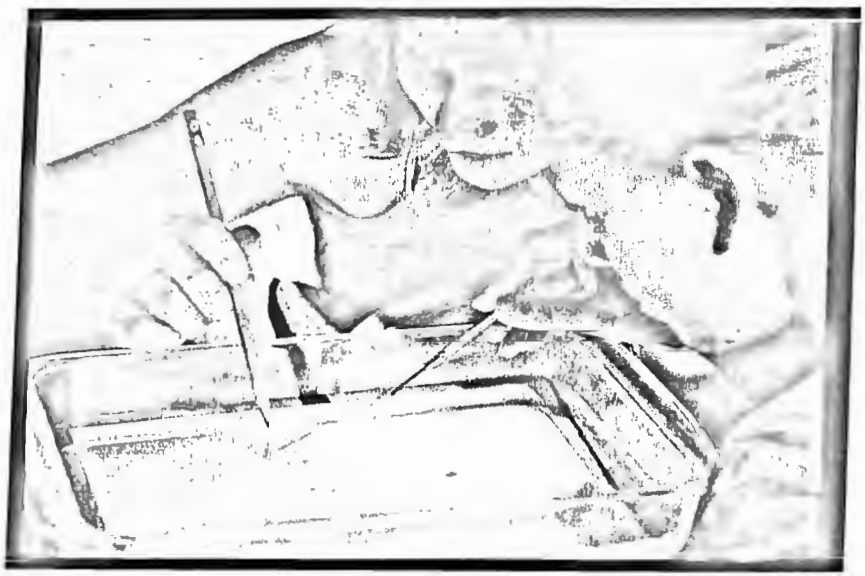
[1] White, Frank M., *Fluid Mechanics*, McGraw-Hill, 1986.

[2] Giancoli, Douglas C., *Physics: Principles with Applications*, Prentice-Hall, 1980.



Two similar steel screwdrivers. The left one is being gently pushed downward while the right one sits in place.



Students gently pushing tissue paper out from under a sewing needle

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Waldorf Science Newsletter: edited by David Mitchell & John Petering

This newsletter is published twice each year and is dedicated to developing science teaching in the Waldorf schools. Teachers are invited to pose questions, seek resource material, discuss experiments, write about their classes (successful and not very successful) and investigate phenomena. The editors also translate relevant science articles from Waldorf periodicals from around the world. The following past editions are available from:

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