CHAPTER 6

The Honeymoon: Lead and Alchemy: Decoding Chemistry Within the Imagery

*The first face of **Saturn** is black, the second is white, and the third is the color of smoke from **lead**....**Saturn** is the source of the agglutinating force: vision in the astrological occult sciences, i.e., the search for the causes of things, ... the force which mixes the **melancholic element** in all parts of the body....His minerals are **lead**....The force of **Saturn** is coldness and dryness and his essense is ominous and corrupt; it is sickening, disagreeable, artful and timorous. **Saturn** rules over ...fear, deep thought and preoccupations, conceptualization, verbosity and occult sciences and all other aspects.*

The Picatrix
an Islamic book of Astrological magic.

Alchemical literature "reeks" with allusions to lead. Alchemical literature is often deliberately obscure (why?) and framed in theoretical foundations substantially different from a modern understanding of chemical nature. Despite these differences, does the literature convey accurate information about lead as we now know it? And if so, does that tell us something about the relationship between science and humanity?

This chapter explores both the "science" and history of alchemy with respect to lead and the rise of patent law and commercialization of ideas. These concepts will be important when we examine the white lead industry of the 20th century.

We show that alchemical theory attempted to create a unified explanation for the age old philosophical dilemma of humanity - that we live in a world of constant change which ultimately ends with our death. Some things were less prone to change than others and therefore had special significance. Alchemical theory had to continuously adapt to new information obtained from metallurgy.

The Purity and Religious Significance of Gold

The fixedness of gold is important in defining purity. The earliest Indian references on gold (Rig Vedic times) draw explicity on the concept of the purity or fixedness of gold (Sarpotday and Subbarayappa, 1990):

In the beginning arose the Gold Womb (Hiranyagarbha). The earth's begetter who created heaven."

In the Atharva Veda the impregnable (fixed, non-destructible) city of the gods there exists a gold receptacle (*hiranyah kosah*) invested with light. In the Rig Veda, Agni is identified with gold and is called the Purifier (*pavak*) and is symbolized by a golden body. The Indo-European kings in their power displaying sacrifices of horses would use the symbolism of the fixed and constant life giving nature of gold. The Sataphatha Brahmana says:

In presenting (the gold vessel) to the brahmin, he imbues himself with immortal life; for gold is immortal life, and whatever benefit he desires, he thereby obtains for himself".

Pliny, the 50 A.D. Roman author, writes of the purity or unchangingness of gold:

The main reason for the popularity of gold is not, in my view, its colour; silver is lighter and more like daylight: that is why it is more commonly employed for military standards, since its sheen is visible from further away.

Gold is preferred to other metals not for its weight and malleability - since in respect of both properties it takes second place to lead - but because,

remaining unscathed in conflagrations and on funeral pyres, it is the only metal that loses nothing by contact with fire. Indeed, the opposite is the case: the quality of gold is enhanced the more it is subjected to fire. Fire also provides a test of quality, making the gold take on its own colour and glow red; this process is known as 'assaying'.

That gold is not easily affected by fire is the first proof of its quality. But it is also remarkable that, although gold is resistant to charcoal prepared from the hardest wood, it very quickly becomes red-hot when subjected to a fire of chaff and is cupelled with lead to purify it (Pliny, 1938-1963, XXXIII, 58, 59, 60).

Some two thousands years later Alexander Hamilton used this preference for gold to argue for a monometallic gold standard for U.S. currency which affected the profitability of the silver mining (and lead) industry (see Chapter 2).

Two Types of Knowledge

In Mesopotamia, India, China, and Greece people grappled with questions about the purity of gold. By experiment, by experience, by analogy, and by comparison with other people's thinking they refined their own thoughts about gold. At times these thoughts were merely "esoteric or philosophical" and at others, times of economic crisis, these thoughts were inspired by more material considerations, manufacture of wealth. Two distinct but interwoven strands must be followed to understand alchemy: thoughts about the process (natural philosophy) and thoughts about artesanal knowledge. Not all societies valued these thoughts equally, leading to a sometimes wide chasm between technical knowledge and theory, which affected the trajectory of thought.

This was particularly true in the west. One prime example is that expressed in the Hindu texts. The migration of the Indo-Europeans with the chariots into India brought them into contact with artisans (metallurgists, potters with their wheels) of the subcontinent. A systematization of value on "occupation" which accounted for the various groups was described in the late Vedic text dealing with the sacrifice of the mythical being Purusha and the creation of the universe and the four "varnas" or classes of people (Kulke and Rothermund, 1990, p. 41):

When they divided Purusha how many portions did they make?
What do they call his mouth, his arms? What do they call his thighs and feet?
The Brahman was his mouth, of both arms was the Rajanya [warrior] made
His thighs became the Vaishya, from his feet the Shudra was produced.

The brahman were the priests, the mouth of the god's sacrifice, the warriers/nobles were of the arms, the freeman were of his thighs, and the indigenous people, slaves, artisans, those of darker color, the shudra, were of the feet. The contempt that the Indo-European's had for the artisan class is in part due to their direct contact with the elements, as was true in other early cultures. This contact would bring them fear as well as impurity. Ritual vessels could not be made by the artisans:

It [the sthali, an earthern milpot] is made by an Arya, with perpendicular sides for the communion with the gods. In this way it is united with the gods. Demonical [asurya], indeed, is the vessel which is made by a potter on a potter's wheel .

A similar contempt for the artisan is expressed in Greek philosophy. Plato's *Philebus* has Socrates dividing knowledge into technical (arts and crafts) and pure (education and culture). The two types of knowledge are "not unlike two species of metals, one of which is pure, the other alloyed with base and foreign elements" (Procter, 1991, p. 17). The arts and crafts change, but the object of true science is eternal:

We find fixity, purity, truth, and what we have called perfect clarity, either in those things that are always, unchanged, unaltered, and free of all admixture, or in what is most akin to them; everything else must be called inferior and of secondary importance."

Heroditus says that:

Among the Greeks, but also among the Thracians, Scythians, Persians, Lydians and most other peoples, men who learn trades and their descendants are held in less regard than other citizens, whilst any who need not work with their hands are considered noble, especially if they devote themselves to war (Herodotus, 1998, p. 167).

Plutarch spells out the political context of knowledge, its purity and impurity:

Lycurgus is said to have banished the study of arithmetic from Sparta, as being democratic and

Figure 6.1: Seven chemical steps involved in alchemy originally from Steffan Michelspacher's 1616 work: *Cabala: Spiegel der Kunst und Natur in Alchymia*. From Gareth Roberts: *The Mirror of Alchemy*.

popular in its effect, and to have introduced geometry, as being better suited to a sober oligarchy and constitutional monarchy. For arithmetic, by its employment of number, distributes things equally; geometry, by the employment of proportion, distributes things according to merit. Geometry is therefore not a source of confusion in the State, but has in it a notable distinction between good men and bad, who are awarded their portions not by lot, but by the difference between vice and virtue. This, the geometrical, is the system of proportion which God applies to affairs. He protects and maintains the distribution of things according to merit, determining it geometrically, that is in accordance with proportion and law (Farrington, 1966, p. 29-30).

A story by Aristotle indirectly shows the contempt with which artisans and their crafts were held by the learned of the time:

For even in the study of animals unattractive to the sense, the nature that fashioned them offers immeasurable pleasures in the same way to those who can learn the causes and are naturally lovers of wisdom. It would be unreasonable, indeed absurd, to enjoy studying their representations on the grounds that we thereby study the art that fashioned them (painting or sculpture), but not to welcome still more the study of the actual things composed by nature, at least when we can survey their causes. Therefore we must avoid a childish distaste for examining the less valued animals. For in all natural things there is something wonderful. And just as Heraclitus is said to have spoken to the visitors, who were wanting to meet him but stopped as they were approaching when they saw him warming himself at the oven [tradesman's shop] - he kept telling them to come in and not worry, 'for there are gods here too' - so we should approach the inquiry without aversion, knowing that in all of them there is something natural and beautiful (Bennet, 1986).

Procter sums up the ideas of the ancients in the following passage (Procter, 1991, p. 21):

Pure knowledge- knowledge of the fixed and final forms of things-separated one from the filth of the furnaces...transcended the body, the feminine, the world of the slaves, the world of production and reproduction.

Already in our story, "Why lead?" we have encountered at least three instances in which technology flowed from one group to another via war booty, capture of slaves. Glassmaking flowed from Mesopotamia to Egypt during the 18th dynasty (1551-1524 B.C.) of Egypt when Amenhotep I expanded his empire to Palestine, and the conquest of Syria by Thutmose III. The art of glassmaking was again transferred from Egypt and the middle east to the Hellenistic empires and from there as slave booty to the Roman empire. We also noted that the skill of paper making was incorporated into the Islamic world by the capture of Chinese papermakers during war in the 751 A.D. in Samarkind.

These two main ideas (purity of gold) and the impurity of technical knowledge play a role in the development of alchemical theories. The role of the alchemist is to direct change in nature toward the fixed and pure gold.

Decoding The Chemistry in Alchemy

Figure 6.1 is an allegorical rendering of Western Alchemical thought taken from Steffan Michelspahcer's 1616 work *Cabala: Spiegel der Kunst und Natur in Alchymia* (Gareth, 1994, p. 44) . Seven chemical steps - calcination, sublimation, solution, putrefaction, distillation, coagulation, and tincture - lead upwards towards the pure metals, symbolized by the sun and the moon in the temple roof. The temple itself is within a mountain that has seven figures on top of it. The seven figures occupy different ledges on the outside of the mountain. The lowest ledge supports a figure of the planetary god Saturn. He is shown as lame. In one hand he holds an agricultural scythe; in the other, quite near his mouth, an infant. The next highest ledge is occupied by Venus, then Mars and Jupiter. The upper two side figures are the female Moon and the male Sun, over which runs the winged messenger Mercury. The planets are framed within the circle of the zodiac, which is itself framed within the corners of the Aristotelian four substances. At the lower frame are water at the left hand bottom corner and the earth at the right hand bottom corner. The upper left hand corner is fire which is symbolically related to and above water. Air is above earth.

Within the temple are seven windows, a naked king and queen, each holding a plant with two flowers. Over the king is a sun and over the queen is a moon.

Allegorical works also represented each individual chemical step. The first chemical step, calcination, is shown by Herbrandt Jamstahler, *Viatorium spagyricum*, 1625 (Figure 6.2) as a lion

Figure 6.2 Step one of seven: calcination by Herbrandt Jamstahler, 1625. From Gareth Roberts' *The Mirror of Alchemy.*

Figure 6.3 Jamstahler's Sublimation, 1625 From Gareth Roberts' *The Mirror of Alchemy.*

swallowing a snake and with the sun separated from the moon by a winged Figure (Gareth, 1994, p. 103). Sublimation, the conversion of solid to gas, Figure 6.3, is shown by Jamstahler with Saturn in the lower right hand corner laboring to grow metals in a tree. The king and queen are again separated this time by the distillation process. A similar picture is shown from the frontispiece to Joachim Becher's *Natur-Kundigung der Metallen*, 1661, in which Saturn with his symbol of a scythe (time) waters the tree of conception and with the help of the labor of alchemy grows the metals in the tree (Figure 6.4) (Smith, 1994, p. 220).

Jamstahler shows putrefaction (Figure 6.5) as the disintegration or decomposition of a metal into a powder, its killing, symbolized by the central figure of death, a skeleton. Death has come to the king or sun.

The killing motif is also represented by that of a king eating his son and awaiting rebirth. An example occurs in the Lambspring of *Dyas chemica* (1625)(Gareth, 1994, p. 89) (Figure 6.8).

Jamsthahler represents congelation, the conversion of liquid to solid, in Figure 6.9 with the crude furnace in the lower right hand corner.

As these pictures indicate, the alchemical steps involve phase changes: sublimation, distillation, evaporation, freezing. Along with these phase changes, color and its sequencing was important. The most expected color sequence in alchemy was black to white (Figure 6.9, the white rose) to red (Figure 6.10, the red rose) as represented in *The Booke of the Rosary of philosopher*, 1588 (Gareth, 1994, p. 88). The red substance would supposedly convert lead to gold. Notice that in Figure

Figure 6.4. Johann Becher's Front piece to *Natur-Kundigung der Metallein*, 1661, showing Saturn watering a tree of metals. From P. H. Smith, *The Business of Alchemy*

Figure 6.7 Jamstahler's alchemical step of congelation, 1625. From Gareth Roberts' *The Mirror of Alchemy*.

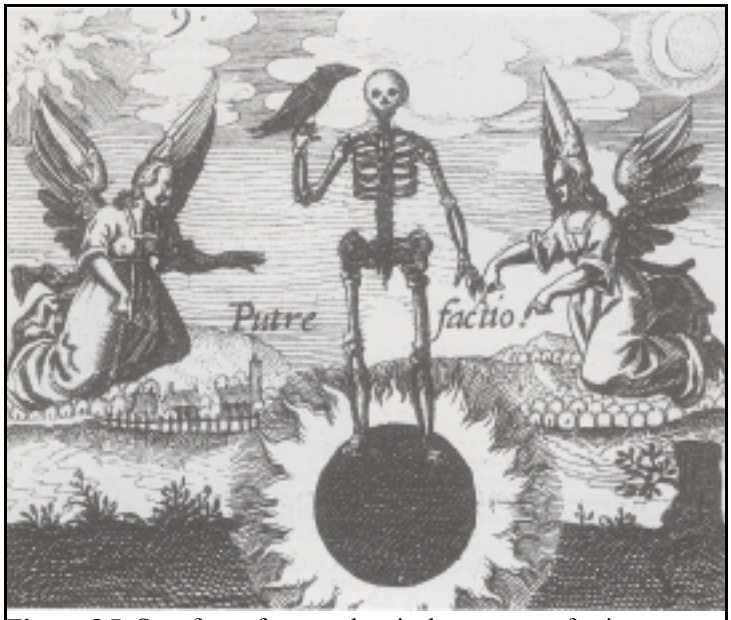


Figure 6.5 Step four of seven chemical steps: putrefaction as drawn by Jamstahler in 1625. From Gareth Roberts' *The Mirror of Alchemy*.

6.3 the queen offers the king a rose.

What chemical significance does the motif of seven steps and astronomical bodies have, especially the sequencing of the planets with the metals? What is the chemical foundation for the sequence of steps, the phase changes, and color transformations? What chemical basis might there be to the color sequences as described by alchemical stages?

As we begin to answer these questions please recall our discussion of the chemistry of metallurgy, glasses, and pigments. Lead undergoes phase changes and many numerous color changes, particularly involving black, white, red, and yellow.

The Days of the Week: Early Electrochemical Knowledge

The earliest known metals were gold and copper (used in ~5300 B.C.); lead (used ~3500 B.C.); tin (used ~2650 B.C.), silver (smelted ~2500 B.C.); iron (~1400 B.C); and mercury (known ~200 B.C.) (Time line J.1). They are grouped by approximate time of discovery in the Middle East. Different time lines can be established for metal discovery in Africa and the Americas. The metals fall

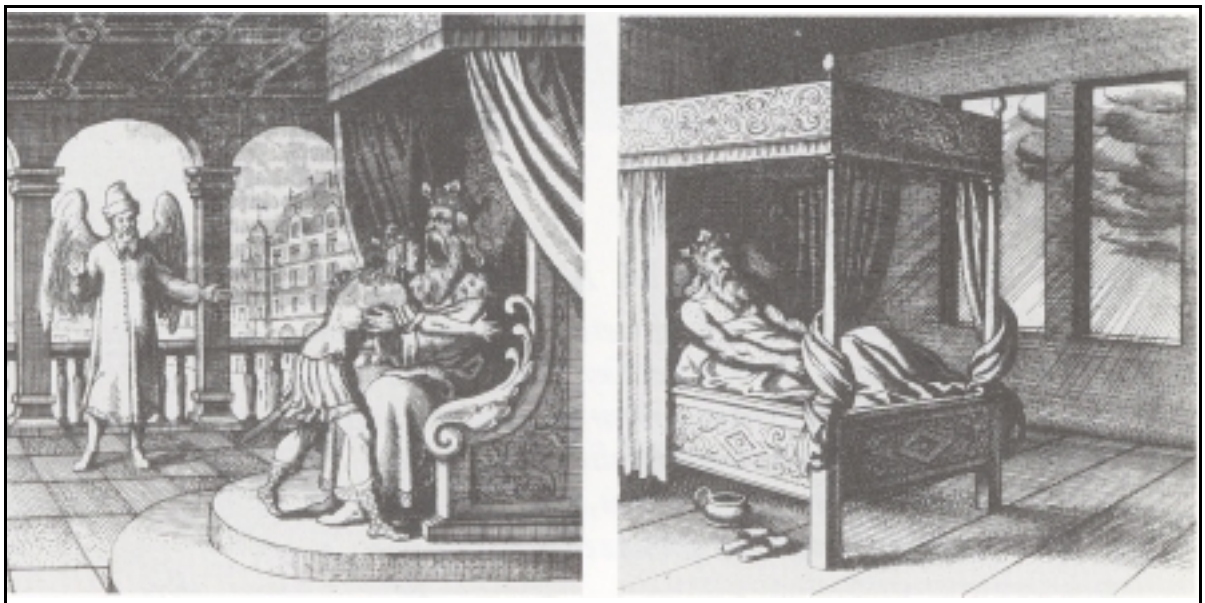


Figure 6.6.: The king consumes his child and awaits rebirth as depicted by Lambspring in *Dyas Chemica* from Gareth Roberts' *The Mirror of Alchemy.*

Figure 6.8 The White Rose in alchemical chemistry attributed to Arnold of Villanova (1240-1311). In Gareth Roberts' *The Mirror of Alchemy.*

Figure 6.9 The Red Rose in alchemy converts lead to gold. Attributed to Arnold of Villanova (1240-1311). In Gareth Roberts' *The Mirror of Alchemy.*

Table 6.2: Astronomical Wanderers, Orbits, and Metals

Wanderer	Week Day	Distance from Sun, km	Period	brightness	Planetary Symbol	Metal Sun
Sunday	-				☉	Au
Moon	Monday		27.3 days		☽	Ag
Mercury	Wednesday	58	88 days		☿	Hg
Venus	Friday	108	225 days	brightest	♀	Cu or Sn
Mars	Tuesday	228	687 days	red	♂	Alloy or Fe
Jupiter	Thursday	778	11.86 years	2nd brightest		Cu or Sn
Saturn	Saturday	1429	30 years		♄	Pb

Wednesday from Wodens day, Miercoles for Mercury in Spanish.
Friday from Fritags day, or Viernes for Venus in Spanish
Tuesday from Tewes day, or Martes for Mars in Spanish
Thursday from Thors day, or Jueves for Jove or Jupiter in Spanish

Table 6.1: Chemical Properties

Element Redox Couple	E^o(V)	m.p. (^{0}C)	b.p. (^{0}C)	d (g/cm^3)	physical state	color	refractive index, η	Mohr scale hardness (1 to 10)
$Au^{+/0}$	1.83	1064	2897	17.0	solid	gold		2.5-3
$Ag^{+/0}$	0.7991	962	2212	10.30	solid	silver	0.18-0.54	2.5-4
Bronze,brass		variable	variable	variable	solid	variable		3-4
$Hg_2^{2+/0}$	0.7960	-38.87	356.87	13.59	liquid	silver white	1.6-1.9	
$Cu^{2+/0}$	0.340	1083	2567	8.93	solid	reddish		2.5-3
$Pb^{2+/0}$	-0.126	327	1740	11.343	solid	silver blue	2.01	1.5
$Sn^{2+/0}$	-0.136	231.89	2260	6.52	solid	white/gray	2.1	1.5-1.8
$Fe^{2+/0}$	-0.410							
S	0.141	112-120	445	2.07	solid,	golden yellow	1.957	

E^0 (V) oxidation potential (negativities most easily oxidized)
m.p. Melting point
b.p. Boiling point
d density

roughly into two categories, the coinage metals (gold, silver, and copper) and the metals grouped near the end of the periodic table's d block (lead, tin, and mercury). In addition to these metals, sulfur was also known as a pure element by the time of the Greeks. Table 6.1 shows some of the chemical properties associated with these elements, properties easily observed in ancient times: color and brilliance, physical state, and chemical stability.

The coinage metals each show distinct colors: gold, silver, and red. Mercury, tin, and lead have color variations on white and gray.

The most important observable property is the physical state of the elements at room temperature and in easily achieved campfires (~600 ^{0}C) or kilns (~900-1000 ^{0}C). All of the metals, with the exception of mercury, are solid at room temperature. The liquification of gold and copper are just beyond the easy access of campfire and cruder kilns, while tin and lead melt easily. Mercury can be converted with ease

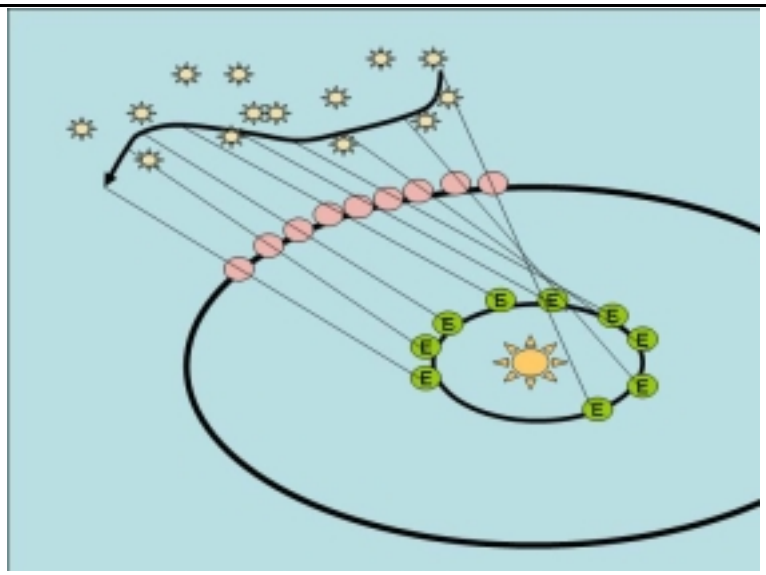


Figure 6.10 A person on earth viewing Mars sees the location of Mars against a backdrop of starts as wandering.

to a gaseous state due to its low boiling point (356 ^{o}C) and its distillation was described by the Romans. The easily accomplished phase changes of mercury were characterized by its name "quick silver".

Hardness played an important role in the use of the metals in manufacturing process. The Mohr hardness scale (talc =1 and diamond =10) places all of these metals relatively low in hardness (Table 6.1).

The reactivity of the elements is the most intriguing observable. Sulfur, tin, mercury, and lead have chemically reactive species. They are involved in a large number of oxidative transitions, as shown by the redox potentials listed in Table 6.1. The more negative the potential the more easily oxidized. The elements are organized within Table 6.1 by decreasing redox potential. Gold is the least reactive.

As often happened in chemistry the above mentioned chemistry was systematized by combining descriptive elements of both chemistry and astronomy. For example, Isaac Newton (1643-1727) is most commonly known as the father of physics, the inventor of calculus, and a prolific publisher on optics. He was also a committed alchemist. Over his life time he amassed a library of 109 alchemical texts and annotated them with a total of 650,000 words (Dobbs, 1975, p. 90). His annotations reveal that he was looking for an overall theory of matter, similar to his mathematical theory of physics. He referred to aspiration in his preface to *Principia*:

For if Nature be simple and pretty comformable to herself, causes will operate in the same kind of way in all phenomena, so that the motions of smaller bodies depend upon certain smaller forces just as the motions of larger bodies are ruled by the greaterforce of gravity. It remains therefore that we inquire by means of fitting experiments whether there are forces of this kind in nature, then what are their properties, quantities, and effects .

Astronomical and chemical phenomena were correlated early in human history. Several planetary parameters are observable to the naked eye - trajectory, color, and brightness. These can be used to systematize the seven visible "planets". The trajectory of each planet is a combination of the time it takes to orbit around the sun (Table 6.2) and the direction of observation from the earth. The changing frame of observation causes the interior planets, Venus and Mercury to have complete set of phases like those of the moon while the exterior planets exhibit an incomplete set of phase changes. The planets all exhibit retrograde motion (Figure 6.10) to varying extent. The retrograde motion takes place with respect to the various constellations that map out a belt of the sky known as the Zodiac (Figure 6.11). The apparent retrograde motion is the result of the relative speeds of the earth and planets. Of the seven visible "wanderers", Mercury has the most erratic and variable pathway in the sky. Venus and Mercury behave differently from Mars, Jupiter, or Saturn in that their celestial location always appears closer to the Sun. Historians have argued about the sequencing of the planets with respect to the days of the week based on the length of the orbit or observed period vs some other variable.

Most historians have concurred that the planets are sequenced with respect to their astronomical period, even though it is not immediately apparent that this should be so. We will argue that the sequence was first set by metallurgical knowledge, that the planets were then assigned to the metals based on some loose fit of non-periodic information. Once this association was set at the time of the Roman empire, new metallurgical knowledge required the alchemists to

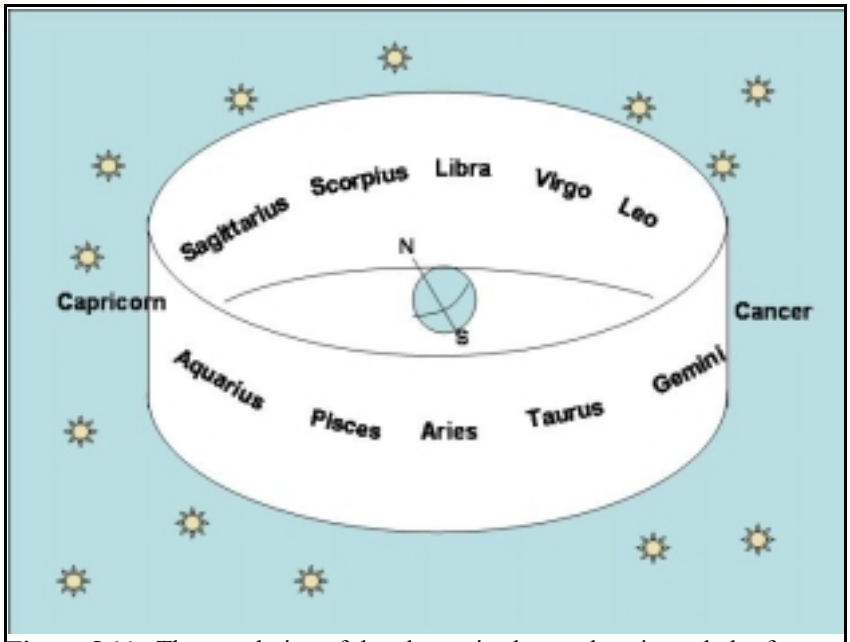


Figure 6.11. The wandering of the planets is observed against a belt of stars known as the Zodiac.

change the metal sequence. Since the planets were now fixed by custom, the assignment of metals to planets had to change.

We begin with the accepted rationale for planetary sequence based on period and then progress to the alternative hypothesis: planetary sequence set by metallurgical knowledge predating 200 A.D.

The astronomical period known today is a measure of the planetary orbit around the sun (Table 6.2). Because the sun was believed to orbit the earth the period systematized by early astronomers deviates from that in Table 6.2 (from longest to shortest) as Saturn, Jupiter, Mars, Sun (365 days), Venus, Mercury, and Moon. The sequence of the days of the week is theorized as deriving from counting out the hours of the day (Table 6.3) (Beck, 1972; Bickerman, 1968; Colson, 1974; Zerubavel, 1985) beginning with the furthest (most impure) to the closest (most pure) wanderer. Each hour is consecutively assigned a planet beginning with Saturn then Jupiter, Mars, Sun, Venus, Mercury, and finally the Moon for the 7th hour. The 8th hour begins again with Saturn and so forth (Table 6.3). The first day beginning with Saturn (Saturday) ends with the 24th hour of Mars so that the second day begins with the Sun (Sunday). Following this scheme results in a sequence of days associated with each of the planets: Saturday, Sunday, Monday, Tuesday (Tewes=Mars), Wednesday (Woden=Mercury), Thursday (Thor=Jupiter), and Friday (Fritag= Venus). In English the Germanic rendering of the Gods is used for the daily sequence.

Metals were then assigned to the planets based on a "force" fit of a variety of loose associations between the metal (heavy weight and long astronomical period) such that the final information content is presumed to be predominately astronomical.

Jensen, however, proposed in 1901 that the days of the week (planets) were associated with the metals. He suggested that the sequence was driven first by metallurgy and then astronomical information was cobbled onto the metal sequence (Jensen, 1901)This theory is supported by the manner in which Celsus writes of the planets. In his anti-Christian tract *On the True Doctrine* (~180 A.D.) Celsus writes (Hoffman, 1987, p. 95)

That their (Christian) system is based on very old teachings may be seen from similar beliefs in the old Persian mysteries associated with the cult of Mithras. In that system there is an orbit for the fixed stars, another for the planets and a diagram for the passage of the soul through the latter. They picture this as a ladder with seven gates, and at the very top an eighth gate: the first gate is lead, the second tin, the third bronze, the fourth iron, the fifth an alloy, the sixth silver, and the seventh gold. And they associate the metals with the gods as follows: the lead with Kronos, taking lead to symbolize his slowness; the second with Aphrodite, comparing the tin with her brightness and softness; the third with Zeus - the bronze symbolizing the firmness of the god,; the fourth with Hermes, for both iron and Hermes are reliable and hard-working; the fifth with Ares- the gate which is a result of mixture is uneven in quality; the sixth with the moon; and the seventh with the sun-the last two being symbolized by the colors of the metals.

In Celsus's rendition, the seventh element was an alloy while iron (a historical latecomer to the sequence) was given along with mercury to Mercury.

Celsus is quite explicit in setting the gate

Table 6.3 Assigning Planets to Days by Counting Out Hours

Day:	1	2	3	4	5	6	7
Hour							
1	***Saturn***	***Sun***	***Moon***	***Mars***	***Mercury***	***Jupiter***	***Venus***
2	Jupiter	Venus	Saturn	Sun	Moon	Mars	
3	Mars	Mercury	Jupiter	Venus	Saturn	Sun	
4	Sun	Moon	Mars	Mercury	Jupiter	Venus	
5	Venus	Saturn	Sun	Moon	Mars	Mercury	
6	Mercury	Jupiter	Venus	Saturn	Sun	Moon	
7	Moon	Mars	Mercury	Jupiter	Venus	Saturn	
8	Saturn	Sun	Moon	Mars	Mercury	Jupiter	
9	Jupiter	Venus	Saturn	Sun	Moon	Mars	
....							
21	Moon	Mars	Mercury	Jupiter	Venus	Saturn	
22	Saturn	Sun	Moon	Mars	Mercury	Jupiter	
23	Jupiter	Venus	Saturn	Sun	Moon	Mars	
24	Mars	Mercury	Jupiter	Venus	Saturn	Sun	

Table 6.4: Ordering of Metals to Planets (Weekdays)

Source	**Date**	**Sun**	**Mon**	**Tues**	**Wed**	**Thur**	**Fri**	**Sat**
Babylonian list	1600-1400 B.C.	Au	Ag				Pb	metal ?
Celsus	174-178 A.D.	Au	Ag	Mixed	Iron	Bronze*	Sn	Pb
Vettius Valens	200-300	Au	Ag	Fe	Electrum (Hg)	Sn	Cu	Pb
Odes of Alexandria	300-400 Au	Ag	Fe	Sn	Electrum**		Cu	Pb
Proklos & Olympiodoros	500-600 Au	Ag	Fe	Sn	Electrum/ mixed metal		Cu	Pb
The Venerable Bede	673-735	Au	Ag	Bronze*	Pb	Electrum**	Sn	Fe
Stephanos	600-700 Au	Ag	Fe	Hg	Sn	Cu	Pb	
Al-Dimashqi	900	Au	Ag	Fe	?	Sn	Cu	Pb
Syriac	1000-1100	Au	Ag	Fe	Electrum (Hg)	Sn	Cu	Pb
Monasses	1150	Au	Crystal	Fe	Bronze*	Ag	Sn	Pb
Agrippa	1533	Au	Ag	Fe	Hg	Sn	Cu	Pb
Chaucer	1380	Au	Ag	Fe	Hg	Sn	Cu	Pb
Lists by Kircher	1652	Au	Ag	Fe	Cu	Bronze*	Sn	Pb
Lists by Kircher	1652	Au	Ag	Fe	Hg	Sn	Cu	Pb
NASA corrosion potential in seawater	2001	Au	Ag	Steel 316 304	Bronze M & G	Cu	Sn	Pb

Electrum: a native alloy of Ag and Au with 5-50% silver content
Bronze: predominately Cu
Steel: 0.2-1.5%C remainder Fe
Steel 316: 0.08% C; 2% Mn; 0.045%P; 0.03%S; 1%Si, 17%Cr, 12%Ni; 2.5%Mo, remainder Fe
Source of compilation: Nriagu

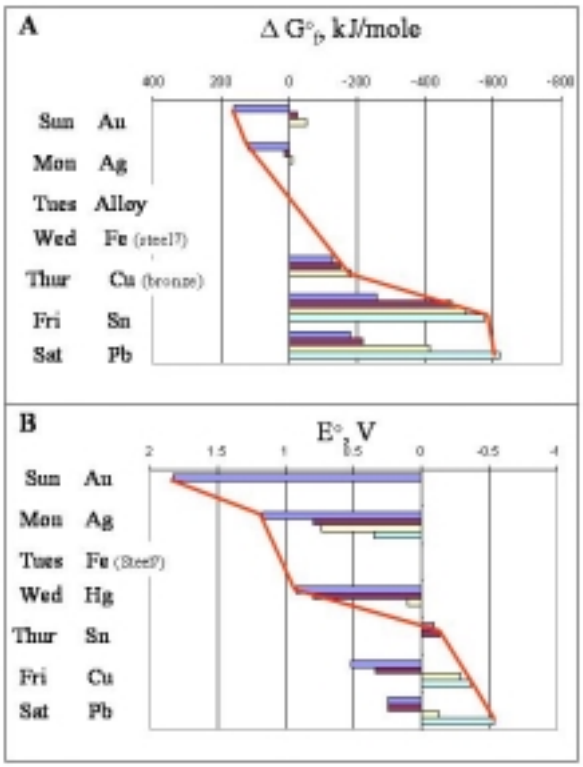


Figure 6.12 Cu is less reactive than Sn when oxidized in a fire (A) but more reactive than Sn when electrochemically (wet) oxidized (B). The switch in position results in a switch in metal position during the days of the week. (See Table 6.4)

sequence to the metals and then assigning the planets. The planets are subsequently forced to fit a sequence determined by the properties of the metals. Color rules the assignment of the sun to gold, the moon to silver, and Mars to alloys and/or Fe. Iron oxides on Mars give rise to its intense red color. The assignment of the alloy to Mars, the god of war, is consistent with the use of bronze materials, with their enhanced hardness, for warfare.

The brightness of the planet was also used to make planetary assignments. The observed brightness of a planet depends the amount of sunlight reflected from the planet to earth. The intensity of reflected light is a function of the planetary surface, the distance between the planet and earth, the planet and the sun, the surface area of the planet, and the angle of observation. Venus is close to the sun, close to earth and has a highly reflective surface due to its cloudy atmosphere. Because of these factors the relative brightness of Venus to Jupiter is 4.7. Because of its reflectivity Venus is assigned to tin, a material used extensively for mirror manufacture. Jupiter, the second brightest planet, is sometimes also assigned to tin. The metal Mercury (*argentvive* or live or quick silver) is associated with the planet of the same name because both have rapid motion.

Celsus' sequence was (Pb (Saturn)> Sn (Venus) > bronze > iron > Alloy > Ag (Moon) > Au (Sun). The end members of the sequence Pb>Sn....Ag>Au reflect the ease of metal oxidation by fire as shown in Figure 6.12A. The free energy (ΔG^0_f) associated with a number of reactions in which the metal acquires one or more oxygens is shown. The more negative the value the more easily fire oxidized the metal. Following the red line from bottom to top traces the reactivity sequence of metals in fire from the most reactive to the least reactive. Some metals have a large number of oxides (for example lead can form αPbO, βPbO, Pb_3O_4, βPbO_2, γPbO_2, and αPbO_2). This variation is indicated in the figure by the number of ΔG_f values for lead as well as other elements.

Although the sequence of the metals changed with time (Table 6.4) the assignment of Pb>Ag>Au is almost invariant. Why should the rest of the sequence change? One reason may be that each alchemist grappled with experimental data that varied based on the purity of the metal and/or the conditions of the fire. A second reason must be related to the change in the type of experiment performed. During the Arabic period the technology of stills was developed to the point that mineral acids could be manufactured and the reactivity sequence of the metals in the presence of minerals acids was explored. Depending upon the composition of the mineral acid the ability to oxidize the metal changes (Figure 6.12B). In Figure 6.12B following the red line from bottom to top traces the metals from most reactive to least reactive based on oxidation/reduction reactions taking place in a mineral acid. As for reactions in a fire to form an oxide, some metals have a wide range of possible reactions depending upon the mineral acid. Notice that copper and tin trade places in the reactivity sequence when subjected to fire vs a mineral acid. The sequence change is mirrored in the change in assignments of metals to planets (Figure 6.11) observed historically.

The data in Table 6.4 reflects this change particularly with respect to the inner elements in the sequence. By the time of Chaucer, however, the metal sequence again appears to stabilize around a sequence that closely reflects the 2001 sequence of oxidation (corrosion) of metals given by NASA. This assumes

Figure 6.13 The Green Lyon, mercury, forms an amalgam with gold, the Sun. *The Booke of the Rosary of philosophers'* as shown in Gareth Roberts *The Mirror of Alchemy. The image dates to 1588.* The Stadbibliothek Uadiana, St. Gallen

that alchemists loosely used the term iron to mean steel which is composed primarily of iron with an altered unreactive surface layer. Similarly bronze is predominately copper which as been altered by trace metal additives that harden and make the metal more stable.

Chaucer's rendition places Cu with Venus and Jupiter with Tin.

> *The bodies seven, eek, lo heer anon.*
> *Sol gold is, and Luna silver we declare;*
> *Mars yron, Mercurie is quyksilver;*
> *Saturnus leed, and Jubitar is tyn,*
> *And Venus coper, by my fathers kyn.*

Our argument to this point is that the seven day week was set rather early by the reactivity of the known metals so that the 7th day week is a system of electrochemical knowledge. The planets were then "force" fit to the metal reactivity sequence and by happy coincidence a mathematical manipulation of astronomical periods and their allegorical relation to purity confirmed the chemical sequence. As metallurgical (chemical) knowledge grew the sequence of metals was altered to accommodate changes due to a conversion from pyrotechnical (fire) driven reactivity to a mineral acid reactivity.

A Glaring Exception: Mercury

The sequence of metals and planets represented in Figure 6.1 differs from the reactivity sequence that the medieval alchemists were converging upon (Table 6.4). Mercury is depicted at the top of the mountain straddling a position between gold and silver. How might we explain this discrepancy? If you remember from Chapter 2 mercury forms alloys with various metals in which those metals are absorbed into the liquid mercury metal.

The Green Lion: Amalgamation

Mercury is very rarely found pure as an element nor as an oxide. It is most often found as as the bright red mineral cinnabar or vermillion, HgS, a charge transfer compound used in cosmetics throughout history. Cinnabar has a hardness of 2.5. It is easily converted by heat directly to pure mercury with the emission of SO_2 gas. As the pure metal it is liquid, and it can easily be distilled (b.p. 357 ^oC).

Mercury can "consume" or form alloys with other early known metals (Trotman-Dickenson, 1973, p. 283). The alloys may remain liquid or become pasty or solid like the common dental alloy $Ag_2Hg_3 + Ag_3Sn$ (Treptow, 1978). Gold and silver both can be purified by forming an amalgam with Hg. The purification of gold through amalgamation is described by the Roman Pliny (23-79 A.D.) In his *Natural History* (Healy, 1991, p. 99):

There is also a mineral found in these veins of silver that contains a distillation - always in liquid form - which is called mercury. It is universally poisonous and destroys any container, corroding it with an invasive process of disintegration. All substances float on its surface except gold, which is the only metal that it attracts to itself. Mercury is thus very good for refining gold, since, if the two are repeatedly shaken together in earthenware vessels, the mercury draws out all the impurities in the gold. After the impurities have been driven out, separation of the mercury from gold is achieved by pouring both on to well-dressed hides: the mercury is exuded through the hides like a kind of sweat and the gold is left pure.

Figure 6.14 *Saturn solensis* is depicted as a lame man, carrying the water or fertilization can and an agricultural scythe. The can shows his chemical symbol. From *Caveman to Chemist.*

The use of mercury to dissolve gold gave rise to its image as the king killer, the lion, as shown in the 1588 *Booke of the Rosary of Philosophers.* The image is captioned *Of Our Mercury which is the grene Lyon devouringe the Sonne* (Gareth, 1994) (Figure 6.15).

Although Agricola mentions amalgamation in his 1530 text *De Re Metallica* (Hoover and Hoover, 1950) as does Biringucio in his Pyrotechnia (1540) the use of mercury amalgamation for the purification of silver, its widespread adaptation, known as the Patio process, first took place in the New World. Amalgamation was introduced in the 1550s in Mexico by a Spanish immigrant, Bartolome de Medina, whom we met in Chapter 2. The estimated loss of mercury to the environment from Spanish colonial mining is 196,000 tons (de Lacerda and Salomons, 1998).

The use of mercury in gold and silver purification accounts for the placement of mercury between symbols depicting Ag and Au (Figure 6.1 and Figure 6.2). In Figure 6.4 the lion consumes a snake, where the snake is a symbol of the Ouroboros, the prime material (Rothernberg, 1993, p. 292).

Saturn and the Child: Solvation, Liquification, and Purification, **and Killing the Son (Sun)**

As noted above, Mercury (see Figure 6.1), occupies a unique role in the transformation or purification of gold from silver. He thus spans the top of the figure between the two planets that represent the two elements. The bottom rung of the planets is Saturn, where Saturn is depicted as a lame man who holds an agricultural scythe in one hand and in the other, quite near his mouth, an infant. How do these mythological motifs (scythe and infant) embody chemical concepts in the same way that the use of mercury (quicksilver) to purify gold from silver is represented by the fleet-footed winged God Mercury at the top of Figure 6.1?

The story begins with the unique "marriage" of silver to lead. Although silver can be found in its native state, it is also commonly found as argentite, Ag_2S, in conjunction with galena. As a consequence, lead was a by-product of silver mining. In addition, lead was a necessary component of the purification process for silver as we found out in Chapter 2. Lead and the silver to be purified are heated in a bone ash cup (*cupel*) in the presence of oxygen. Lead forms a melt of lead oxide chains (Figure 4.2) which solubilize metal impurities (Figure 2.4). The fluid is less dense than silver and is "wicked" into the cup. Analysis of Arctic ice (Figure 1.3) shows that until the advent of

Figure 6.16 An ancient Grecian vase depicting Rhea carrying an infant to Saturn to be consumed. C. 450 A.D. In T. H. Carpenter's *Art and Myth in Ancient Greece*, Thames and Hudson, 1991. Figure 94.

leaded gasoline cupellation was the single most important cause of lead dispersion throughout the world.

Not all lead was lost to the atmosphere through purification processes. Large amounts of lead were recovered from the slag heaps for use in the glassmaking industries. The high metal content of the slag accounted for many color variations in glass. Antimony found in yellow glasses (Figure 4.4) and pigments may have derived from silver mining PbO slags. This theory would account for the disappearance of antimonyl yellow around 400 A.D. when the Roman Spanish silver mine of Rio Tinto stopped production and a replacement yellow, Lead Tin II, was developed (Brill, 1968) (Figure 4.1).

The allegorical description of cupellation (Saturn with scythe and infant)

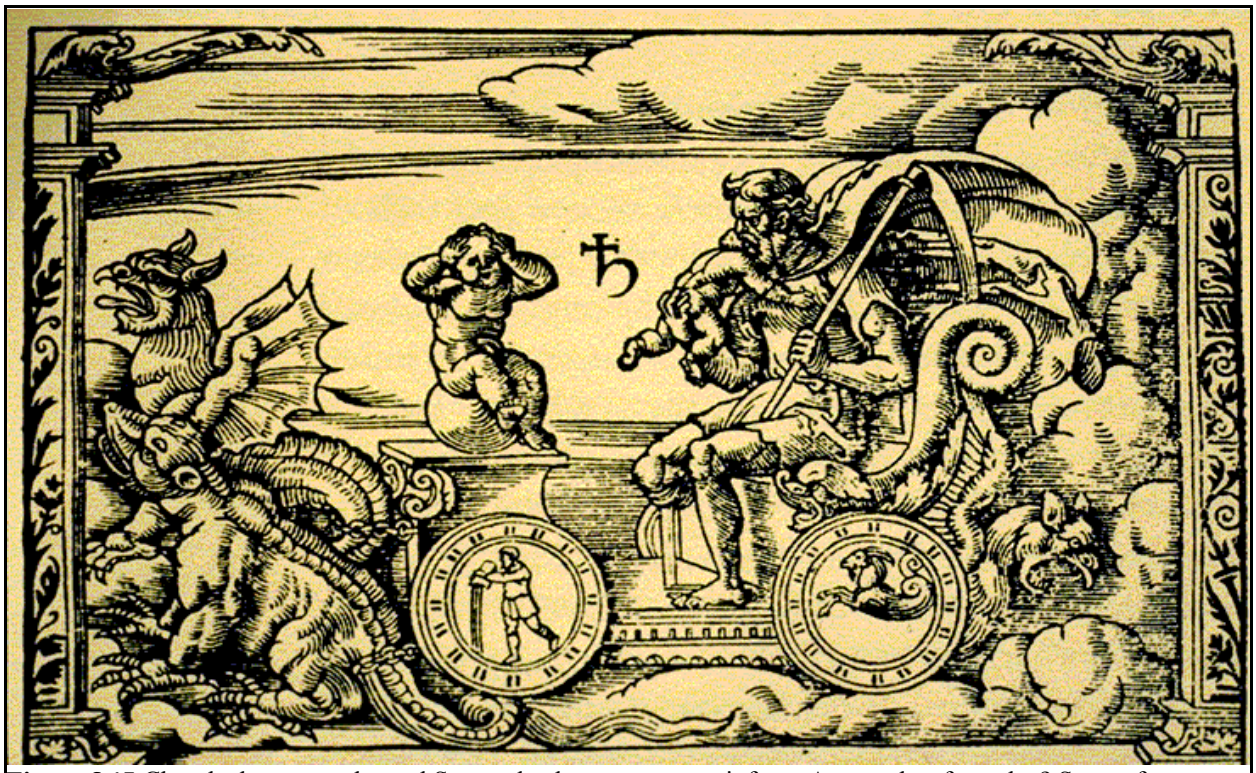


Figure 6.15 Cherubs lament as the god Saturn, lead, consumes, an infant. A metaphor for today? Saturn from Solensis Acatus *Phaenomena et Prognostica*, 1569, Cologne. Plate 135 in David Fontana's *The Secret Language of Symbols.*

Figure 6.17 Ruben's *Saturn* consumes his child. Prado Madrid. From Goya, *The Origins of Modern Temper in Art* by Fred Licht, Universe Books, N.Y.

shown in Figure 6.13 is based upon the mythology of Saturn/Kronos (Graves, 1960, p. 37-43). Lead is associated with Saturn, the Roman agricultural god, who was based upon the Greek agricultural god Kronos. Kronos was the son of Uranus and Earth. He and his brothers, the Titans, were, at the command of their father, hidden in the caves of earth. Earth, tiring of hiding her sons, encouraged the children to revolt. Kronos, the leader of the revolt, castrated his father and fertilized the earth with his blood. Kronos married his sister, Rhea. As children were borne of this union, Kronos, consumed them to prevent a repetition of history. Some vivid images are shown in Figures 6.15 and 6.17 (Fontana, 1993). Rhea, tired of infanticide, on the birth of Jupiter (Zeus) gave Kronos a stone wrapped in swaddling clothes and hid Jupiter away (Figure 6.16). When Zeus was full grown he battled with Kronos. Zeus made Kronos lame and cast him into the furthest reaches of the heavens. The distance or long period of the planet represents lead's density and its position as the most reactive of elements with respect to gold. Saturn (Kronos) is depicted as a lame man, often holding an agricultural scythe and consuming an infant.

This mythology embodies chemical information. Lead and his brothers are hidden in earth as ore. Lead consumes (PbO solvates metals) or kills with a scythe (in a bone ash cupel) all metals. He is given a stone to eat (Philosopher's stone or catalyst), which liberates Jupiter (tin in Chaucer's system). Tin is not solvated in cupellation. Saturn, in a battle for supremacy with tin, is lamed (densified) and cast into the farthest reaches of heaven (accounting for the dark color of PbS) and the slow orbit of Saturn. In so doing, lead gives birth (is reborn) as a more pure element, silver.

In Figure 6.1, lead occupies the lowest level of the black Earth from which pure gold is grown. It kills nearly all metals, and in rebirth gives forth silver. This allegorically describes the cupellation process.

The Four Aristotelian Elements

In Figure 6.1, the Earth temple of the elements, planets, and gods, is housed within a framework of the Aristotelian four substances: Earth (*Terrae*), Air (*Aeris*), Fire (*Ignis*), and Water (*aquae*).

The Arabic alchemist Jabir ibn Hayyan of Baghdad (720-780 A.D.) commenting on Aristotelian chemistry, incorporated the role of sulfur. Ibn Sina (980-1037A.D.), born near Bukhara was known in the Latin world as Avicenna. He sets forward Jabir's Aristotelian theory of the metals as combinations of liquid (female mercury) and earth (sulfate) and air (yellow combustible sulfur) (Grant, 1974, p. 571):

If the mercury be pure, and if it be commingled with and solidified by the virtue of a white sulphur which neither induces combustion nor is impure, but on the contrary is more excellent than that prepared by the adepts, then the product is silver. If the sulphur besides being pure is even better than that just described, and if in addition it posssesses a tinctorial, fiery, subtle and noncombustive virture- in short, if it is superior to which the adepts can prepare-it will solidify the mercury into gold.

Then again if the mercury is of good substance, but the sulphur which solidifies it is impure, possessing on the contrary a property of combustibility, the produce will be copper. If the mercury is corrupt, unclean, lacking in cohesion and earthy, and the sulphur is also impure, the product will be iron. As for tin, it is probable that its mercury is good, but that its sulphur is corrupt; and that the commingling (of the two) is not firm, but has taken place, so to speak, layer by layer, for which reason the metal shrieks. Lead, it seems likely, is formed from an impure, heavy, clayey mercury and an impure fetid and feeble sulfur for which reason its solidification has not been thorough.

The text indicates that a materials' colors and physical states were attributed to variable combinations of sulfur and mercury. Metals are various (impure) combinations of liquid (mercury) and air (sulfur). Some of the metals are too humid; others are too dry. Some are too cold and others too hot. Alchemy uses the four Aristotelian elements - earth, air, fire, water - to recombine materials into a greater purity:

[6.1] $\text{metal} = wS_{(\text{fixed or earth})} + xS_{(\text{air or gas})} + yHg_{(\text{liqiud})} + z(\text{fire})$

Alchemical Theory of Metals

Alchemical theory attempts to explain the phase and color changes observed during cupellation and amalgamation. It predicts a sequence for the purification steps of the metals required to achieve the appropriate balance of earth, gas, liquid and fire. Roger Bacon (1214-1294 A.D.) clearly described the necessary changes. Bacon had studied at Oxford and supported himself by writing various elementary treatises for students. He may have become a Franciscan to protect himself from papal displeasure over alchemy (Little, 1914). In writings attributed to him (*Speculum alchimiae*), alchemy is defined as (Muir, 1914):

.... the Art of Science teaching how to make or generate a certain kind of medicine, which is called the Elixir, and which, being projected upon Metals, or imperfect Bodies, by thoroughly tinging and fixing them, perfects them in the highest degree, even in the very moment of Projection.

Silver is present in lead with different degrees of impurities. It can be obtained from lead by alchemy (*de Preparatione Lunae ad Sulphur*) through a method of cupellation. Bacon writes about the transmutation of metals in *De Arte Chymiae*:

Let all workers in alchemy know that true species cannot be transmuted. For they say, and it is said also here, that lead is always lead, even granted that its impurities are purged away so that silver may be seen; thus they deceive men not understanding the words of Aristotle on solution. To whom it may be answered that it is not for us to be labouring about the transmutation of bodies in order to make some sort of being from non-being, and to make something from this mineral that is not of this mineral. But that we may reduce a corrupted mineral to an incorrupted mineral.... Since lead is a species of silver, the sicknesses of which mineral - to wit, softness, blackness, and foulness - have invaded it, when these are put aside, there is silver true and good; and so it is reduced to its true mineral, and in accordance with its first primary origin it is not translated nor transmuted from its own mineral. Similar iron is silver, but it is corrupted....by the power of its impure sulphur and of its impure quicksilver. From which source hurtful things enter it, to wit, blackness, hardness, dryness; which being removed, there is good silver. In like manner copper is the soul and sister of silver, in all its

dispositions, to wit, in softness, in hardness, in fusibility and malleability, but it is red; we take away from it its redness, and then there is genuine silver. Similarly tin has softness, the grating sound of teeth, and blackness, which being removed it is reduced to silver. In like manner silver is gold save in its colour, because the colour of gold was taken away from it, in its mineral state, by the power of quicksilver. But we give colour to it, and then there is good gold. This is in keeping with what is said by Aristotle. If the quicksilver be pure and bright and the sulphur be clean and red, and a temperate heat be used, mineral gold is made from these, in nature, after a long time. Similarly if the quicksilver be impure, and the sulphur be not clean, some other mineral body is made from these, in accordance with the inward disposition of that body. What nature does in a thousand years, we are able to accomplish artificially in a short time, perhaps in one day, or in some hours, with the proper medicine, that takes a long time to prepare, by the use of which bodies suffering from mineral corruptions are reduced to uncorrupted mineral substances.

In short, alchemy is a catalytic process that speeds up the purification process leading to gold. Lead is corrupt silver. Iron is corrupt silver with too much sulfur and mercury. Copper is red-colored silver. Tin is silver with too much quicksilver or mercury. Finally, silver is gold without color.

In his *Lexicon alchemiae sive dictionarium alchemistricum* (1612) Martinus Rulandus states that lead (Ruland, 1984):

....Is attributed to Saturn by chemists, and is so called. It is a Livid, Terrene, Heavy, Metallic Body, with very little Whiteness and much of Earthy Nature. It is converted into Tin by cleansing. Thus Tin is more perfect than Lead. And Lead has more of the substance of Fixed Sulphur in its composition than Juppiter, i.e., Tin. Lead is an Impure body, procreated from the copulation of Imperfect Living Silver [mercury], which is impure, unfixed, terrene, feculant.... It is wanting in purity, fixation, colour, and fire. In sum, Living Silver, which is of bad quality, gross, of bad taste, fetid, and of feeble power, like a menstrous mother, units with a livid or leprous Sulphur, and frigid Saturn, for a son, is the result; and this is Lead.

The above passages indicate that alchemists theorized that all matter was composed of various proportions of the four Aristotelian elements.

We should insert a comment here that some of the difficulty in reading these texts is due to differences in how the alchemists and modern chemists view the world (chemical theory) and some are deliberate attempts to obscure information. As we will see in the next chapter Roger Bacon encoded his recipe for gunpowder. Alchemical knowledge was neither protected by guilds nor by patent law so open exchange of information was not rewarded. Indeed, we have seen (and will see more) examples of individuals whose inventions brought no personal reward, such as Medina and his introduction of amalgamation to the silver mines of Mexico.

Returning to Figure 6.1, the seven chemical steps, the seven planets, the sequencing of planets, the specific placement of lead with an infant at the bottom of the rung, the framing of the planets, metals, gods against the zodiac and the Aristotelian four elements have been explained. What remains to be explained is the sequencing of the chemical steps: calcination, sublimation, solvation, putrefaction, distillation, coagulation, and tincture. If our hypothesis that alchemists were attempting to describe real phenomena rationally (within their chemical world view) we should be able to understand the sequence of steps that they proposed.

The Alchemical Sequence: Phase and Color Changes

The sequence of metal reactivity (purity) set was set in the days of the week by about 300 A.D. If the metal reactivity sequence gave clues as to the intermediate steps in transforming lead to gold then the color and physical phase of the intermediate steps can pre predicted. Lead , the least pure element, was solid, black, heavy, and had a low melting point. The next most reactive element, tin, was multicolored (white or grey), a solid, and also easily melted. Tin is followed by copper which is a red solid at room temperature. Mercury, the next most reactive element is a silver colored liquid. An alloy of copper or iron follows and has variable properties. The remaining, least reactive, elements are silver and gold. Thus an alchemist might predict that chemical changes accompanying conversion of lead to gold should be marked by color changes from black to white to red to silver and to gold. Phase changes should occur in a predictable sequence with a liquid state (mercury) preceding the formation of silver.

As Gareth Roberts' work shows, color was a significant observation that the alchemists tried to

Figure 6.18 The Peacock's tail represents color stages required in alchemy. From the *Splendor solis*, as shown in Gareth Roberts' *The Mirror of Alchemy.*

explain. White is symbolized by the white rose which produces silver and red is symbolized by the red rose which produces gold (silver with a reddish tint).The white and red roses appear in the allegorical figures explaining Calcination, Sublimation, and the overall alchemical sequence (Figure 6.1). Sometimes a gold color is mentioned.

George Riply in "*Recapitulation*" 1541 describes the true and false colors (Ripley, 1977):

Pale & black with false citrine, imperfect white & red,

The Peacocks feathers in colour gay, the Rainebowe which shall overgoe,

The spotted panther, the lyon green, the crowes bil blue as lead,

These shal apeare before thee perfect white, and manie other more,

And after the perfect white, gray, false citrine also,

And after these, then shall apeare the body red invariable,

Then hast thou a medicine of the thirde order of his owne kinde multiplicable.

Citrine is a kind of yellow. The Peacocks' feathers are shown in Figure 6.18.

Ripley's verse indicates that red is the prelude to silver and gold.

The metal reactivity sequence indicates that color should proceed from grey or black (lead) to light (tin) to red (copper) to liquid (mercury) to silver and gold.

The chemistry of lead during cupellation may have served to confirm alchemical theory, based on the color (black to white to yellow to red) and phase changes which can be observed on cupellation (Figures 6.19 and 6.20). As we discovered when examining lead's role in pigments (Chapter 5) lead oxides exhibit a range of colors based on semiconductor bandgaps, oxygen to metal charge transfer, and metal to metal charge transfer processes. Each of these oxides can be achieved by careful control of temperature and oxygen as shown in Figure 6.19 and Figure 5.17.

The color changes of lead oxides on heating were a source of hope to alchemists as the color sequence matched that predicted by the metal purity sequence. The color changes were also a source of difficulty because they could not always be well controlled. As we found out in a discussion of mining (Chapter 2), glasses (Chapter 4), and pigments (Chapter 5), lead oxide, litharge, concentrates a variety of trace metals. Some of these metals can form colored species with lead (such as lead antimonate). Unless the lead oxide source was well known we might expect that alchemists would obtain a variety of colors on heating of the lead oxide.

Alchemists like the False Geber tried to characterize impurities in lead. The False Geber is thought to be a Spanish Jew from the Islamic occupation, circa 1200 A.D. He appropriated the name of an earlier alchemist, Al-Jabir or Jabir ibn Hayyan of Baghdad (720-780 A.D.). The False Geber describes lead chemistry in four paragraphs:

Chapter X.
On the Nature of Saturn or Lead

It now remains, that We come to the Description of Saturn; of which We say it differs not from Tin, after repeating its Calcination, to the Reduction, thereof; except that it hath a more unclean Substance, commixed of the two more gross Substances, vis of Sulphur and Argentvive; and that the Sulphur in it is burning, and more adhesive to the Substance of its own Argentvive; and that it have more of the Substance of fixed Sulphur to its Composition, than Jupiter hath. The Probations of these We infer by manifest Experiences.

This first paragraph states that lead (Saturn) is different from tin (Jupiter) because it has more sulfur and mercury (*Argentvive* = live silver or quicksilver), and the sulfur is more strongly bound to lead (Saturn) than to tin (Jupiter), as the following paragraphs prove. The references to sulfur not only are literal (as in PbS) but may also symbolize color (such as the yellow of pure sulfur) and gas, while mercury symbolizes a phase change (solid to liquid). The K_{sp} of PbS equals 1.25×10^{-28}, that of Sn is 3×10^{-28}. From this it may be noted that lead is slightly more insoluble than tin sulfide, suggesting a stronger (more adhesive) binding of sulfur to lead than tin.

That it is of greater Earthy Feculency than Jupiter, is manifested by the Sight, and by the Washing of it with Argentvive, in this, viz. That more Feculency comes from it in the Washing than from Jupiter; and that it takes the first Degree of Calcination more easily than Tin, which is a sign of much Earthiness. For We find Bodies of more earthiness, of more easie Calcincation; and of less Earthiness of more difficult Calcination . The Probation of this is, the most difficult Calcination of Gold compleatly. And because

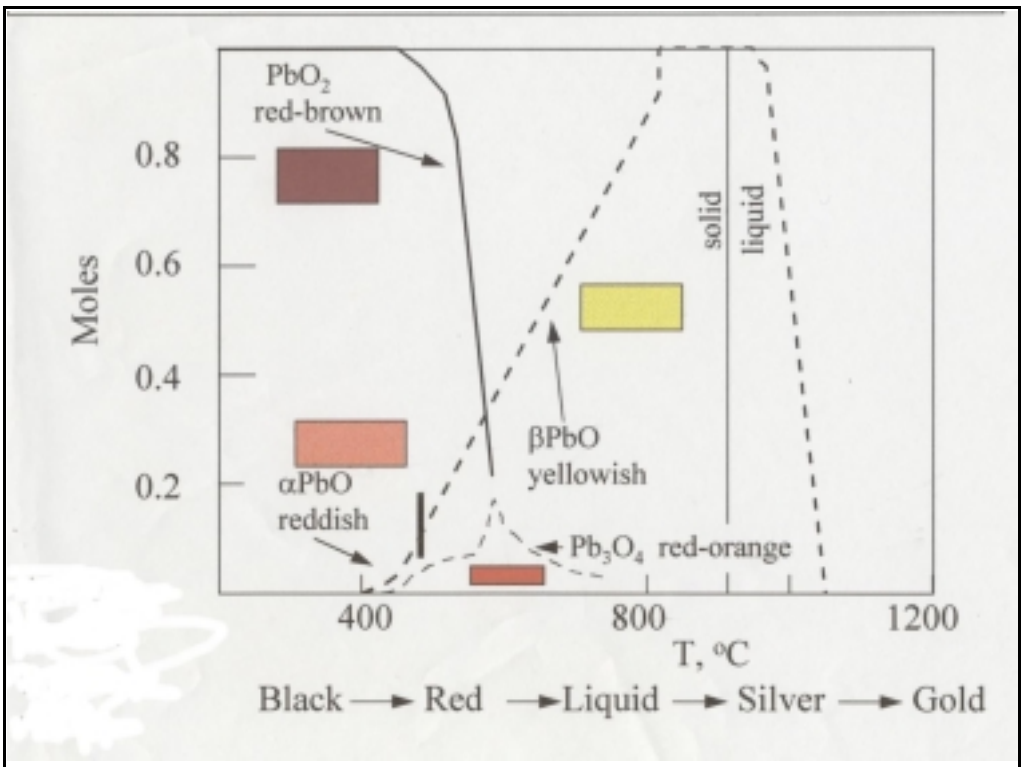


Figure 6.19 Lead oxide stability changes with temperature. As the oxide chemical changes form, so too does it color. At high temperatures a phase change occurs. In cupellation the liquid phase floats above silver so that silver is liberated.

Figure 6.20 The metal sequence is determined by reactivity toward fire. The most reactive is lead at left, the least reactive is gold at right. Powders of lead compounds shown in the approximate order they would be observed on heating (see Figure 6.19). All are oxides with the exception of the first, lead sulfide. (Author)

its Foulness is not rectified, as in Jupiter, by repeated Calcinations, that is a sign of greater Impurity in its Principles, in its own Nature, than in Tin, in its Nature.

This second paragraph indicates that lead is dirtier (darker) than tin (Pb = black, Sn = silver, see Table 6.1). It further indicates that Pb is more soluble in mercury than Sn (Table D.6). More importantly, lead is calcined (oxidized) more easily than tin, and the least calcinable element is the most heavenly one, gold (Table 6.1). Repeated calcining does not render lead perfect, but induces more color changes and hence must contain more "earth." The reference to containing more earth reflects the increase in weight that occurs on oxidation.

And that the Quantity of its Combustible Sulphur, is more adhesive to the substance of Argentvive in it, than in Tin; is manifest by this, vis. That the said Quantity is not separated from it in Fume, but it is of a Citrine Colour of much Yellowness, the like of which is remaining below with what is in the Bottom; which must necessarily be a sign of one of these three things; either that it hath none, or a very small Quantity of Combustible Sulphur in it; or that it hath much conjoyned in the nearness of its Principles, to the Radix of its Commixtion. But we are assured by the Odour thereof, that it hath some Quantity; and not a little, but much: because that Odour of Sulphureity is not removed from it in a short time. Therefore We have considered with a consideration, by which We are assured that burning Sulphur, approaching to the Nature of fixed not burning Sulphur, is uniformly commixt in the Substance of Argentvive. Therefore, when the Fume of it ascends, it must necessarily ascend with the Sulphur not burning, of the Property of which it is, viz, to create Citrinity..

This third paragraph interprets the binding of sulfur to lead based on color and formation of gases. On calcination, lead is yellow (β PbO). Alchemists thought this color was related to the amount of sulfur remaining indicating that sulfur was more adhesive to lead. Some sulfur must remain because the smell of it is present. The False Geber tells us that the remaining sulfur is mixed with mercury. This explains the low melting point of lead oxide and its mercury-like liquidity.

But that the Quantity of Sulphur not burning is grater in it, than in Tin, is affirmed by Us most truly; because we see the whole Colour of it to be changed into Citrine, but of Tin into White, in the Calcinations. Therefore in this, to us is open the Way of finding out the Cause of this Work, by which Jupiter (in Calcination) is more easily changed into an hard Body than Saturn' but not sooner into slowness of Liquefaction than Saturn. And that therefore is, because the Cause of the Hardness of Nature is Sulphur and Argentvive fixed: but the Cause of Liquefaction is twofold, viz Argentvive and combustible Sulphur. .....

This fourth and last paragraph cites reasons why the total amount of sulfur in the lead is not greater than the amount that would occur in tin. Rather, the lead is transformed to a different state (yellow) than that of tin (white). The yellow may be related to αPbO. Perhaps it is lead antimonate or a lead tin compound that can form if the lead oxide is not pure. It also refers to the melting point of Sn as being higher than that of lead but that that depends upon the degree of calcination. This is consistent with the melting point of SnO_2 > PbO, and the melting point of Sn < Pb.

In summary, The False Geber knew that lead ores would burn in oxygen (calcination), liberate various sulfur-containing gases (sublimation), and change color in the sequence black to white to red to yellow. This sequence is consistent with the expected color change of metals according to their oxidation potentials. The False Geber further knew that the lead oxides so formed would liquefy (solvate) according to an expected phase transition in the metal sequence (solid copper to liquid mercury). The liquefied lead would consume all metals (putrefaction), leaving behind or giving birth to silver which solidified (coagulation). The color of the lead oxide varied according to the exact amounts of metal impurities in the melt. The final step necessary was the formation of the tincture whose red/yellow color showed that it would complete the final step to gold.

The language of the alchemist was also used by those who were more interested in recording technical details for dissemination such as Vannoccio Biringuccio. Biringuccio, a contemporary of Agricola, wrote a comprehensive metallurgical text, *Pirotechnia.*

Biringuccio was born in 1480 in Siena. His political career was tied to the Petrucci family. At the age of he 27 traveled to Germany and northern Italy. In 1513 he was appointed to Armory of Siena Commune but a 1515 uprising caused him to flee the city. He was accused of having debased the coinage alloys, declared a rebel, and exiled. During his exile he traveled to Rome, Naples, and Sicily. In 1523, when Pope

Figure 6.22 Jacob's ladder connects the base world to the pure heavens, similar to the ladder of the elements. *Jacob's Ladder*, School of Avignon. C. 1490. Musee du Petit Palais, Avignon. P. 90 in *The Sky, Mystery, Magic, and Myth* by Jean-Pierre Verdet. Discoveries, Harry N. Abrams, Inc., N.Y.

Figure 6.21. Mayan temple with seven steps to represent the seven heavenly bodies. Photo: Al B. Benson, III.

Clement VII reinstated the Petrucci family he regained his post as Armor. In 1524 he was granted a monopoly on saltpeter production. A second rebellion in 1525 sent him into a second exile from which he returned in 1530, taking up the professions of architecture and arms caster. In 1538, he moved to Rome and became head of the papal foundry and papal munitions.

Biringuccio writes of lead (Smith and Gnudi, 1990)):

I shall proceed in this chapter to tell you about lead. Because this metal is overabundant in wateriness, and also because it has its other substances in poor elemental mixture, it is highly impure. It is called an imperfect, leprous, and little-fixed metal, which it clearly shows itself to be because of the ease of liquefying it and because it is easily converted largely into a dross that is almost earthy and also because of the stain that it leaves when it rubs against anything. Nevertheless, when we consider its effects, we judge it to be a metal that we are greatly indebted to. Even though Nature in creating us has put into our souls such a thirst and desire to possess gold and silver and precious gems in great quantities, we would neither have these things nor know them if we did not have lead and we tire ourselves in the vain effort to possess them. For without the aid of lead we would never have known how to extract gold and silver from copper, nor how to lift from precious gems the earthy and rocky veil that clouds and covers their beauty and clarity.

*The calcination of lead in a reverberatory furnace seems to me such a fine and important thing that I cannot pass it by in silence. For it is found in effect that the body of the metal increases in weight to 8 or perhaps 10 per hundred more than it was before it was calcined (** theoretically should be 7.7% more as PbO*). This is a remarkable thing when we consider that the nature of fire is to consume everything with a diminution of substance, and for this reason the quantity of weight ought to decrease, yet actually it is found to increase. After it has been in the fire so long it seems reasonable that the contrary should happen, because many of its parts have been consumed as well perhaps as those of the elemental fire. Deducing reasons for such an effect, it may be answered that all heaviness tends to the center and the denser a body is the heavier it is within its species. Since those watery*

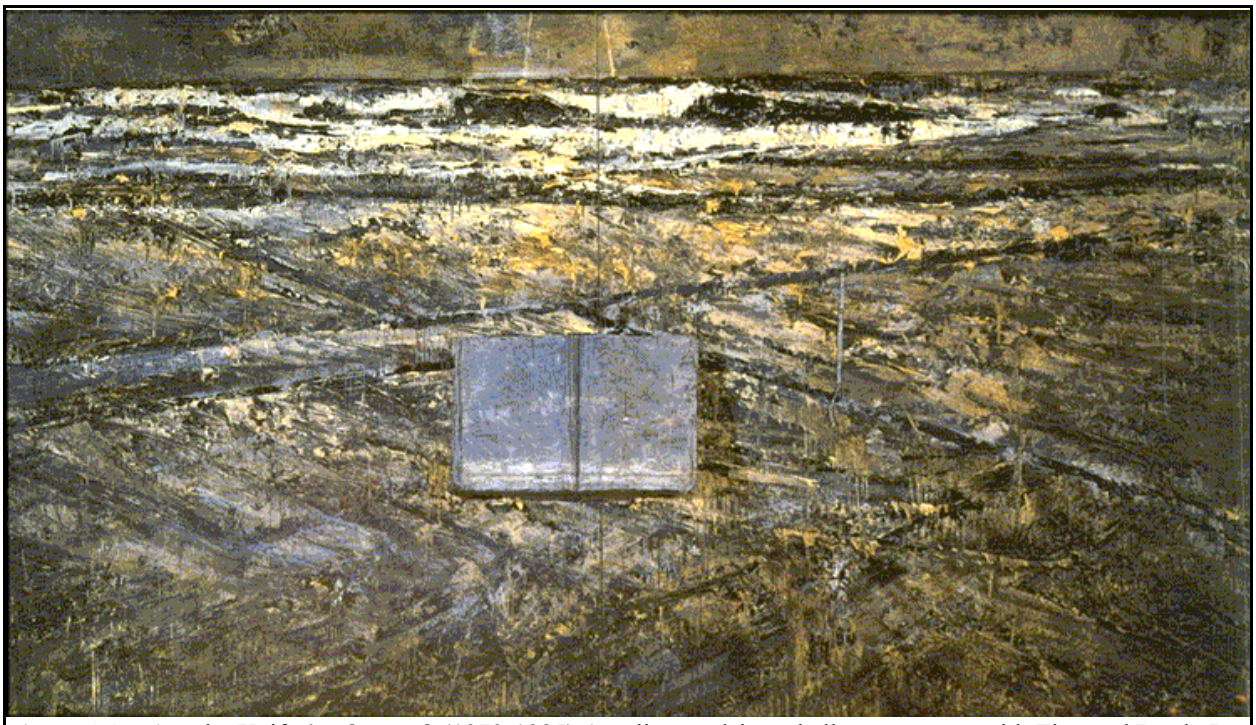


Figure 6.24 Anselm Keifer's *The Book* (1979-1985) Acrylic, emulsion, shellac on canvas with Zinc and Lead. In Mark Rosenthal's *Anselm Keifer*, 1987, Philadelphia Museum of Art.

and airy parts are removed by the fire from this composition of lead as from a poorly mixed metal, and since all its natural porosity is closed (through which the air is used to enter that by its nature and power held it suspended under its influence with a certain lightness), the lead, brought to this point, falls back into itself like a thing abandoned and lifeless. Thus it comes to retain more of its ponderosity in the same way that the body of a dead animal does, which actually weighs much more than when alive. For, as is evident, the spirits that sustain life are released and, since it is not possible to understand how these can be anything but substances with the qualities of air, the body remains without the aid of that which made it lighter by lifting it up toward the sky, and the heaviest part of the element has its natural force increased and is drawn toward the center. Thus the above difficulty is resolved by this explanation.

Alchemical Theory: Conclusion

Most of the elements in Figure 6.1 have been analyzed in terms of chemistry. The ores buried in Earth's temple are liberated through a sequence of seven steps. The number seven arises by coincidence of the seven earliest known pure elements and the seven visually observed heavenly bodies (planets) wandering across the region of sky known as the Zodiac. The seven observed planets were of ritual and religious significance (Figure 6.21) The seven metals are associated with seven planets and preserved within the seven-day week. The information content of the seven- day week closely approximates electrochemical information. The seven-day week represents a "ladder" (Figure 6.22) of purity from most reactive to least reactive metal. The ladder of purification applies to humans who are anchored to the dark Earth as well as to metals which must be liberated from the Earth. The purification of gold from silver involves a mercury amalgam hence Mercury's position at the top of the temple in Figure 6.1 The winged image of Mercury invokes its fleeting transitions between liquid and gas as well as its astronomical motion. The position of lead at the bottom of the temple results from its ease of oxidation and the fact that it is the foundation for industrial purification of silver, as well as the "host" or soil from which silver is mined or grown. (Silver is found within lead ore). Cupellation, the purification of silver from lead, involves color and phase changes of lead oxides consistent with the color and phase changes predicted by the oxidation sequence of the metals. Saturn both grows and kills metals (as the scythe implies) and consumes them (as the infant implies) to

Figure 6.24 Anselm Keifer's *Emanatin* (1984-1986). Oil, acrylic and emulsion, applied lead and photographs. Plate X in John C. gilman's *Anselm Keifer and the Postmodern World*. Temple Univ. Press. 1980.

await rebirth. This symbolism is consistent with the solvation of metals by molten lead oxides and the release of pure (uncorrupted infant) liquid silver. The dseven chemical steps were envisioned as a manipulation of the four Aristotelian components of matter (earth, air, fire, and water) that catalyzed the natural transformation of metal from readily oxidizable to heat resistant.

The last element of Figure 6.1 left unexplained are the two men, the ferret, and the rabbit at the bottom of the figure. One man is setting a ferret into a rabbit hole. The rabbit exits from a second hole. The second man is blindfolded. In medieval times domestic rabbits were retrieved from their dens by ferrets. The imagery may imply that the left hand figure has the means to unlock the productive secrets of earth while the right hand man does not. In short, the left hand man holds the patent rights to alchemical knowledge.

Alchemical imagery both reflected explicit technological and chemical information and offered compelling emotional content about the human condition. As a result it remains a richly explored material throughout the reformation, the modern, and post-modern worlds. It has inspired countless works on the bargain that humanity makes for knowledge These references have been extensively analyzed for their psychological meaning as mythological archetypes, as they were in Jung's *Psychology and Alchemy,* and for death and (re)creation symbolism (Dobbs, 1990). Alchemical myths have also been mined in literary works such as Goethe's *Faust* and Jonson's *The Alchemist*. Even postmodern visual artists have employed alchemical images as Anselm Keifer did in his *Immanation* and *The Book* (Figures 6.23 and 6.24) (Gilmour, 1990). Keifer's work is explicitly based on alchemical meaning deriving from his exploration of meaning in post Holocaust Germany. Rosenthal commenting on *Emanation* explains:

I the second Emanation, *an enormous canvas more than thirteen feet tall, the lead "ray" is altogether presnt, but instead of meeting land, it touches the water. While Emanation recalls the "pillar of cloud" discussed earlier, its narrative is more charged and active. Implicit is the idea that hot lead, descending from a devastated, flaming sky, will be cooled in the water. The cycle is rene4wed at the bottom where flames appear in a photograph. A continuum is thus established, perhaps based on the concept that God exists in everything, and all elements flow out from and back to him.*

Part II Alchemical Entrepreneurs and The Problem of Intellectual Property Rights.

We ended the first half of this chapter by speculating that the ferret in Figure 6.1 was an illusion to patent rights necessary for economic exploitation of knowledge outside of a guild system. Part II of this chapter will explore the transition of alchemical knowledge into an economic commodity.

Alchemists and Control of Information

Sale of alchemical expertise appears to have been related to fluctuations in economic times, some closely related to events in silver mining declines as analyzed by Smith (1994).

The first Western hothouse of alchemy was Alexandria. Alexander founded this metropolis at the delta of the Nile River in 331 B.C. by Alexander as a commercial town linking several trade routes. Its Museum and Library were founded by Demetrius of Phaleron (an Attican exile) at the request of Ptolemy (I) Soter. The Museum (a research institute named for the nine Muses) was part of the palace(Delia, 1992; Jones, 1949, p. 35; Marlowe, 1971, p. 57; Parsons, 1952, p. 160). Demetrius assembled about 200,000 rolls of manuscripts. He also invited Euclid (d. 270 B.C.) to start a mathematical school. Another major scholar at Alexandria was Eratosthenes, who calculated the circumference of the Earth to be 24,662 miles, quite close to the actual figure of 24,862.

Alexandria became absorbed into the Roman Empire with its library and school intact. The approximately 30 scholars continued to receive stipends, free living accomodations, communal meals, and exemptions from Roman poll taxes (Fraser, 1972, p. 415). Near the end of the Roman Empire, a significant amount of alchemical activity arose from Alexandria's chemical school. This coincided with the failure of the economic system in the western Roman Empire and a debasement of coinage (see Chapter 2, Figure 2.6). Because of deforestation, fuel became progressively less available for running Rio Tinto silver mines in Spain, and the silver content of the coins fell. If alchemical experimentation was prompted by the debasement of coinage, it is not surprising that the Emperor Diocletion banned it in Rome in 292 A.D.

One of the most important Alexandrian alchemists was Marie the Jewess, who lived around 200 A.D. (Figure 6.25) (Burland, 1967, p. 2). Marie the Jewess identified copper, lead, and zinc as corporeal and fixed. To be transformed, metals had to be volatilized (made incorporeal) as air (oxides), earth (sulfides), sea (chlorides), and be regenerated (condensed) into a new state. In addition to having a

Figure 6.25 Marie the Jewess as depicted in 1624. From Gareth Roberts' *The Mirror of Alchemy*.

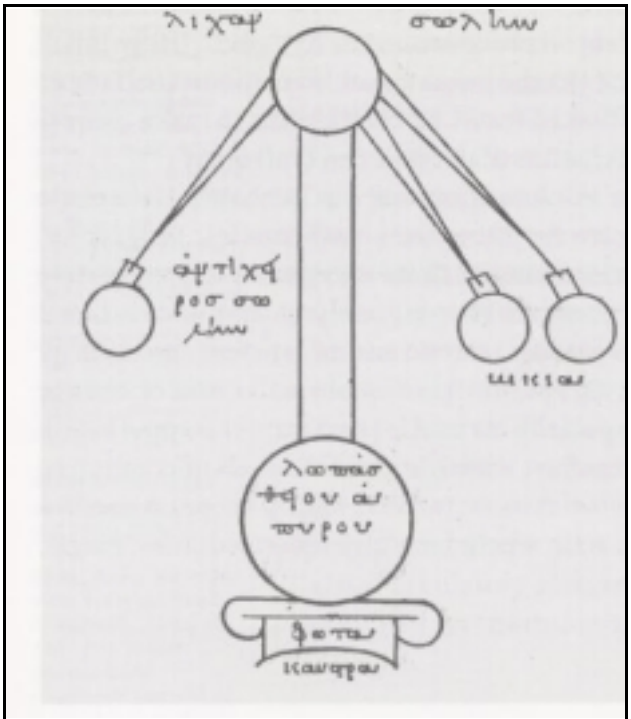


Figure 6.26 The Greek still as copied into the *codex Marcianus Graecus*, 11th century. In Gareth Roberts' *The Mirror of Alchemy*.

philosophical bent, Marie the Jewess actively experimented. She invented the *bainmarie* (double boiler) and the first real method of controlling distillation processes (Figure 6.26).

Islam and its learning was carried to Spain. By the ninth century, the Arabs were working Spanish mines again, and Cordoba had become a center of great learning and metallurgy. Universities were established in Cordova, Seville, Malaga, Toledo, and Granada. These institutions taught Aristotelian and humor-based medicine and chemistry. The libraries at Cordova, which contained 400,000 books were administered under a separate caliphate (Aitchison, 1960). Robert of Chester, an Englishman, studied alchemy and astrology in Spain and published the first Latin translation of alchemical texts (*Book of the Composition of Alchemy*) in 1144.

Great European interest in alchemy arose at this time because of access to the Arabic texts and because of the European economic expansion, the opening of the German mines, and finally, an economic downturn that stimulated new ideas about the making of coinage metals.

By the end of the 1300s, the Black Death had come and gone, leaving behind a decimated population that could not sustain the economic boom of the 1100-1200s. Silver mines in Germany lost production (Chapter 2) and the monetary system began to collapse. The crisis peaked between 1395 and 1415. Money was so lacking that in 1423-1425 many places were minting lead coins (see Chapter 2). It is not surprising that this time period shows a great increase in European alchemical output (Patai, 1994, p. 173).

During this transitional period, Raymond Lull (1234-1315) became active. Lull was a native of Majorca and the son of noble Catalan parents. He became a philosopher, logician, theologian, metaphysician, mystic, preacher and missionary. He visited Africa several times. He had a large output of alchemical literature, some of which was composed by others (false Lulls). A second Raymond Lull apparently was born about 1295 and became known by the name Raymund de Tarrega, a converted Jew, who traveled to Paris in 1319 and London in 1332 where he escaped from the Tower of London. Various sources state that Raymund was making gold for King Edward III to finance his wars on the continent (succession for the French crown),

Raymond Lull disciple of Arnaldus de Villanova, having been presented to Edward III, king of England, by an abbot of Westminster, who had brought him up from Milan to London, performed considerable transmutation for that prince, who had persuaded him that he was preparing himself for waging war against the Turks. After some time had passed, Raymund saw that Edward turned his arms against the king of France. He complained of the use which the king made of the gold which he had supplied with the sole object of fighting the infidels. For fear that Raymund would seek out the protection of his enemy, Edward commanded that he be seized. But later Raymund regained his liberty, trusting the vigilance of his physician, for the promise which Lull made to cast a golden bell which would be heard all over the world. While he was transmuting the imperfect metals for this work, he seduced the physician, promising him the secret of transmutation. The latter then made arrangements with the owner of a ship who took them to France, when the materials were near the point of being poured into the mold of the promised bell. Informed of the escape of Raymund, Edward gave orders to pursue him, but it was of no use. In order to record the memory of this event for posterity, Edward commanded that a coin be minted which is called rosa mobilis which the curious keep to this day as a

Figure 6.27 Emperor Rudolf, II, the alchemist. Portrait by Hans von Aachen (1552-1615). Mannerisim period. Vienna Kunsthistorisches Museum. Image source: http://www.vol.c2/RudolfII/umelcien.html

Figure 6.28 Emperor Rudolf II as vegetables by Giuseppe Arcimboldo, 1590 A.D. Image source: http://www.vol.c2/RudolfII/umelcien.html

precious medal, and on which can be seen a rose above a ship propelled by oars.

Several works attributed to Lull are from England and dedicated to King Edward. Some of these have a medical bent that suggests the influence of the Scottish physicians and alchemists Jacopo and Giovanni Macolo (McColl) who worked in the Medici Court (Pereira, 1994). Raymond wrote a much quoted alchemical text, *De secretis naturae sive quinta essentia (On the Secrets of Nature or the fifth Essence*). Unfortunately, he also wrote a text called *De invocatione demonum (On the Invocation of Demons)* which brought him to the attention of the Spanish Inquisition. Pope John XXII banned the work in 1317. Raymond made the mistake of returning to Spain and was incarcerated in 1368 because of the ban.

The pope wrote:

Alchemies are here prohibited and those who practise them or procure their being done are punished. They must forfeit the public treasury for the benefit of the poor as much genuine gold and silver as they have manufacture of the false or adulterated metal. If they have not sufficient means for this, penalty may be changed to another at the discretion of the judge, and they shall be considered criminals. If they are cleric, they shall be deprived of any benefices that they hold and be declared incapable of holding others.

In 1323, the General of the Dominican Friars in Barcelona excommunicated all friars studying alchemy. In 1380, the King of France banned alchemy, as did Henry IV in England in 1404. In 1418, the greater council of Venice directed an edict against the alchemists.

Another wave of alchemical literature arose at a time when the landed nobles were in economic crisis and the guilds were weakening. This time period

Figure 6.29 Portrait of Johann Becher, 1723. In Pamela H. Smith *The Business of Alchemy.* He is known as the father of Economics.

corresponds to the turbulent period of the Reformation (Timeline J.14). The influx of New World metals had resulted in a devaluation of money by 50%. *War led to a breakdown of the stable guild society through the cessation of trade, the levying of war taxes and influx of soldiers and refugees into what had been a closed society (Smith, 1994, p. 24).* Men who peddled their skills as alchemists attempted to capitalize on the lack of communication between the "learned" court men and the "vulgar" workers. The learned documents gave hints about the alchemical process, which was protected in the secrecy of the guild. The guild secrets helped protect the livelihood of guild towns from the encroachment of the lords, the masters and controllers of the arable land.

The earliest court craze for alchemy occurred around Emperor Rudolf II of The Holy Roman Empire (Figures 6.27 and 6.28) (Burland, 1967, p. 91). He was himself an alchemical adept (Evans, 1973; Federman, 1964, p. 146). Born in Vienna in 1552 A.D., he was the son of Emperor Maximilian II, and Maria, sister of the Spanish Philip II (Figure 2.35). Rudolf was crowned King of Hungary in 1572 and King of Bohemia three years later. He was elected ruler of the Holy Roman Empire in 1576, through a precarious bargain between Lutherans and Roman Catholics. Many notable alchemists were part of Rudolf's court including Michael Sendivoi, Sendivogius, who achieved a transmutation with the Emperor. Another alchemist in the court, Hieronymous Scotus, was noted for his poisons (useful for court politics) and exorcism. Rudolf appointed Sebald Schwaertzer prefect of mines. Schwaertzer fled to the court in Prague during 1592 when he was suspected of poisoning two successive Electors of Saxony. Schwaertzer was credited with the secret of transmutation and was appointed prefect of mines for the massive exploitation of silver in Joachimstal (Jachymov). A later occupant of that post was Nicolaus Maius, also an alchemist. Another alchemist to appear in Rudolf's court was John Dee, father of English navigation and lecturer on Euclidian math. Rudolf effectively retired from government to collect artists, philosophers, and perpetual motion machines. Johannes Kepler, who formulated the laws of planetary motion, was the court astronomy and astrological advisor. Manic depression incapacitated Rudolf between 1590 and 1601. He attempted suicide in 1599.

The role of Johann Joachim Becher is illustrative of alchemist's seeking to sell his knowledge (Figure 6.29) *(Smith, 1994, p. 24).*. Becher was born in 1635 in the free imperial city of Speyer. He was the son of a wandering Lutheran pastor in the Holy Roman Empire. He was tutored by his father in classical

languages. Becher learned this knowledge imperfectly, but put it to use at age 13 when he became the sole economic support of his mother and two brothers. His wanderings and tutoring brought him into contact with a wider social range than he could have encountered before the 30 Years War (1618-1648). In 1654, at age 19, he published an alchemical work under the name Solinus Saltzthal. At the age of 20, he became mathematician to Emperor Ferdinand III in Vienna and converted to Catholicism. In 1661, at age 25, he defended a thesis on epilepsy before the medical faculty at the University of Mains and was awarded a doctorate of medicine. In the same week as his defense, he married the daughter of a medical faculty member, who then stepped down in Becher's favor. He served as economic and technical advisor to nobility, and attempted to set out a grand theory of political and economic philosophy. Some consider him the founder of economics.

In his 1661 book *Natural Philosophy of Metals,* Becher sets out the principles of "conception" and "birth" of minerals by impregnation of the earth with vapors from mineral springs. A subtle, sulfurous, salty substance formed the nutriment that caused growth in the animal, vegetable, and mineral realms. In the books's front piece the figure of Saturn, the god of agriculture, waters the roots of a tree. The fruits of the tree are the six metals (Figure 6.4). The sun's rays "generate" the transformation (conception) of the six metals. In the frontspiece to another work a man with the sun for a head, a moon for a throat, head surrounded by the five other planets, and with a digestive system showing the chemical steps gives the allegorical correspondence between purity and man and metal. We all have the seed of purity within us. In his *Physica Subterranea* (1669) he described laboratory work as a:

natural history of metals, how to mature, improve, and transmut them; this is called studium mineralogia, spagyrica, or alchemy.

In 1676, Becher proposed the establishment of an alchemical laboratory in which the secrets of the artisanal class could be brought under control by the money-poor nobility. Royal support of alchemy was directed at not only the manufacture of gold, but knowledge about the nature of gold. Becher's proposed laboratory was to yield trade goods and thus revenue sources. It was also to integrate the territorial ruler in the productivity activity of artisans workshops.

In essence he was articulating a form of patent

Figure 6.30 Becher's silver medallion, 1675, transmutated from lead. In Pamela H. Smith, *The Business of Alchemy.* Front.

law. The earliest known patent is a 10 year monopoly granted in Venice to inventors of silk making devices in the 1200s. As we saw earlier (Chapter 4: Glasses), Venice also protected its glass making industry by prohibiting the immigration of foreign glassmakers in 1271. In 1306 and 1330, Venice further prohibited the import of Alum used in the glass making industry on the basis of quality.

The first "real" patent recorded is that of the English King Henry VI in 1449 who granted a 20 year monopoly to the Flemish born John of Utynam for his stained glass work. Venice established a formal patent ordinance in 1474. Queen Elizabeth I of England become the first prolific patent granter. In 1549 eight glassworkers were tempted from Murano to work in England. She granted patents for monopolies in glass work to Jean Carre and Anthony Becchu. Between 1561 and 1591 she issued at least 50 patents for monopolies. Her successor James I was so prolific at issuing patents that corruption became endemic. In 1610, he was forced to revoke all previous patents described in the *Book of Bounty*. A patent regulation at the time decreed that monopolies (patent rights) could be issued only for new inventions. The law was regularized in 1624.

To interest his various patrons in his projects, Becher demonstrated his skills by changing lead into

Figure 6.31 Becher's 1675 silver medallion transmuted from lead, reverse. In Pamela H. Smith, *The Business of Alchemy.*

silver (Figures 6.30 and 6.31). A commemorative medallion was made from the transmutated silver. The front of it is inscribed "In the year 1675, the month of July I, J. J. Becher, Doctor, transmuted this piece of the finest silver from lead by the art of alchemy (Vinna Kunssthistorisches Museum, (Smith, 1994, p. 173)." The opposite side shows a one-legged, bare-footed Saturn dressed in the clothes of a German peasant, carrying a scythe over one shoulder and his bare, struggling child slung over the other. This medallion was given to the king for display, an act that was considered very important (Smith, 1994). According to Pameal Smith:

Success in alchemical transmutation could be interpreted as confirming princely power and fitness to rule, for alchemical knowledge was revealed only to the most pious, and success in transmutation was granted only to individuals of exceptional moral probity. It was proof of the humility and piety of the Catholic emperor that God granted a transmutation at his court.

Metal Assays and the History of Mineral Acids

Why couldn't the alchemists simply carry out the appropriate experiments to determine the amount of gold that they created? Were they self-serving, or did they have other reasons? As we have already seen, gold can be purified only by appropriate use of sulfur-based metallurgy, cementation, or, mercury amalgamation. However, reaction of an unknown material with sulfur and recovery of a second material does not mean that the second unknown material is gold. That is, the sulfur test could provide "false positive" results.

To verify the purity of gold a "touchstone" was used. The stone was scraped with a control gold piece of known purity. A second "gold" piece of unknown purity was scraped along the black surface. The difference in color on the black could be judged by a trained eye and related to purity of gold.

True metal assays had to wait for the development around the 1300s of acids capable of reacting with gold (Time line J.16) (Multhauf, 1967, p. 162-163). Among these acids were sulfuric, nitric, and hydrochloric acids, which are capable of dissolving lead, and *aqua regio*, a mixture of nitric and hydrochloric acids capable of dissolving gold. These reagents could be used to prove that the gold content of lead did not change during an alchemical process.

Because controls were needed over temperature, gases and condensation of gases, the preparation of the mineral acids took some time to develop. The first written account of a mineral acid in Western Europe comes from the False Geber (1300 A.D.) (Time lines J.11 and J.16) (Stillman, 1960). His works included *Summa Perfectionis Magisterii, De Investigatione Perfectionis, De Inventione Veritatis, and Liber Fornacum*. The *Summa* contains a recipe for a mineral acid.

And first as to our solvent waters of which we have made mention in our Summa where we have spoken of solution by the sharpness of waters.

Take first one pound of vitriol of Cyprus and a half pound of saltpeter and a quarter pound of laminated alum and extract the water at the red heat of the alembic (retort), for the solvent power is great, and make use of it in the forementioned chapters: it will be made much sharper if you dissolve with that a fourth part of sal ammoniac, because it then dissolves gold, sulphur and silver.

The *vitriol of Cyprus* is either an iron or aluminum sulfate, saltpeter is KNO_3, and the laminated alum is an aluminum sulfate such as $AlNH_4SO_4$ or $AlKSO_4$. Heating sulfate releases sulfate gas which combines with water to produce sulfuric acid. Heating saltpeter gives of NO_x gas which combines with water to produce nitric acid (Figure 6.32). The addition of a chloride-containing species to this weak acid can produce hydrochloric acid. The three acids combined are capable of dissolving gold (*aqua regis*).

Djaber (Geber) gave nitric acid the name *aqua fortis (*strong water). Sulfuric acid was known as *oil of vitriol*, and the mixture of hydrochloric acid with nitric acid, capable of dissolving gold (the king) was known as *aqua regis* (king's water). Although it did not take very long (200 years) for these acids to enter routine production and use, production depended upon improvements in the alembic or still. The stills used by the alchemists were based on those designed by Marie the Jewess in 300 A.D. Because they were ceramic and shaped as they were, the "cooling" portion to condense the vapor was "cool" only during the initial portion of the reaction. The distillation process was singularly inefficient (Reichen, 1963, p. 11). Two major innovations on the still were the Rosenhutte, a better cooling arm, and the Moor's head, which allowed water to circulate for cooling). These changes allowed the first production of pure alcohol *(aqua ardens* or burning water) (Ihade, 1964) and of *oil of vitriol* by the distillation of green vitriol ($FeSO_4 7H_2O$). Once the reaction of *oil of vitriol* was established the it could be used to produce *aqua fortis* (strong water or nitric acid).

[6.2] H_2SO_4 + saltpeter (KNO_3) → aqua fortis

and *aqua regia*:

[6.3] H_2SO_4 + saltpeter + NaCl → aqua regia.

This latter reaction depends upon a well known method for the production of saltpeter. Vannuncio Biringuccio in 1540 wrote *Pyrotechnia* the first systematic text on the arts of mining and metallurgy. He gives the earliest complete account of preparing saltpeter (*sal nitro*).

The best salpeter is obtained from animal manure converted to earth in stable, or from latrines which have not been used for a long times and above all from pigpens. This manure must be converted to earth by time and entirely dried and powdered. Vats are then filled alternately by layers of this earth about four digits deep, and layers one digit deep of a mixture of two parts of quicklime and three parts of ashes from bitter oak. The vats are filled to about four digits or half an arm's length from the top and then filled with water. The water seeps through this earth, dissolves the saltpeter and trickles through holes in the bottom of the vats into conduits which carry it to other vats. This water is now tasted and if it is sharp and strongly salty it is good, otherwise it must again be passed over the same or other earths containing salpeter. This process is continued until practically all of the saltpeter is dissolved. The water is then placed in copper kettles on furnaces and slowly boiled to about one third of its original volume, then drawn off and put into a strong covered cask and allowed to settle until clear. The clear water is then drawn off and again evaporated by the same process as before. In order that water shall not foam and overflow and thus waste much good material, a measure is made of three quarts of soda or of ashes of bitter oak, or oak, or olive, and one quart of lime, and for every hundred pounds of water there is dissolved four pounds of alum of Rocca.

A glass or two of this water is added whenever you see that it threatens to rise and form a foam. The saltpeter solution is boiled until it becomes clear and of bluish color indicated that most of the water has been evaporated. It is then drawn off and placed in casks and allowed to solidify.

N. Lemery (1645-1715) of Paris and Joshua Ward (1685-1761) of England described large-scale oil of vitriol production. In this process a large glass globe (40-50 gallon container) had a small stoneware pot inside above a small amount of water. On the small pot rested a red-hot iron saucer of saltpeter and sulphur (Partington, 1961).

John Roebuck, M.D. patented the lead acid chamber process for the production of sulfuric acid. The substitution of lead chambers (either 10 ft square or if sealed up to 10x45 ft square) for glass jars stimulated sulfuric acid production and industries dependent upon it.

Figure 6.32 Ercher's representation of nitric acid distillation. In Biringuccio's *Pyrotechnia*.

Enough of the mineral acids were produced that they were noted by Francis Bacon. He was the lawyer, philosopher, statesman, and chemist (and, some say, the author of Shakespeare's works). He categorized the reaction of the various coinage metals experimentally with the mineral acids by the heat given off and by the color formed. He found that *aqua fortis* (nitric acid) produced no heat when it reacted with Hg and Pb, but gave off increasing amounts of heat when reacted with Ag, Cu, Sn, or Fe. *Aqua regia* (a mixture of nitric and hydrochloric acids) did not give off heat, but generated various colors (Partington, 1961).

Paracelsus (1493-1541), whom we met in his guise as chronicler of Miners, Diseases (Chapter 2, German mines) (Figure 6.33) performed similar experiments. He showed that a mixture of silver and gold heated in *aqua fortis* (nitric acid) left gold as a black powder. The silver-containing liquid could be recovered by placing a copper plate in the bath and reducing silver onto it. Paracelsus describes the separation of gold and silver with *aqua regia* (Partington, 1961, p. 312):

The separation of metals in aqua fortis, aqua regio and other similar strong corrosive waters is thus; that the metal which has another mixed with it is taken, and in thin sheets or small granules, placed in a parting flask and common aqua fortis poured on it in sufficient quantity. Let them then work upon one another until the metal is entirely dissolved to a clear water. If it is a silver which contains gold, the silver will then be all dissolved to a water and the gold be calcined and settle on the bottom like a black sand. And thus are the two metals gold and silver separated.

A very similar recipe is given by Agricola (1494-1555) who writes:

Beat the silver, in which you suppose gold to be contained, very thin, cut it in small pieces and lay it in strong water [aqua regia] and set it in a gentle fire until warm and as long as it gives off bubbles. Then take it and pour off the water into a copper dish and let

it stand and cool. The silver then settles in the copper dish. Let the silver dry on the copper dish after the water is poured off, and melt the silver in a crucible. Then take the gold from the glass flask and fuse that to a lump (De Re Metallica.)

Summary: Alchemy as a Rational Science?

At the time this author began studying chemistry (1970s) there seemed to be a common belief that modern (post-Reformation) science was substantially different, rationally based, as compared to the science that preceded it (alchemy). This world view further suggested that science, as practiced today, was rationale and "value-free". Based on the arguments made in this chapter we might, instead, infer that the science of the alchemist was well thought out within the confines of the world-view (basic theory), the lack of access to pure materials, and the lack of a system of intellectual property rights. This analysis coincides with that of Kuhn and Procter.

Kuhn (Kuhn, 1962) argues that scientists are slow to relinquish major philosophical arguments and that new ideas, like that of Darwin's Evolution, often require a generation of scientists to pass before acceptance. Procter (Procter, 1991) has argued the world view that a scientist brings to their work remains despite the scientists own perception of purely rationale discourse.

With respect to our biography of lead, the implications are that the use and misuse of lead does not begin solely with the advent of "modern" science, but lies in the social structure of both science and its commercial use.

Alchemy and Lead as Medicine

Proto-Medicine

From early times, the ability of mercury and lead to purify gold and transform silver was applied to medicine. Particularly in Chinese medicinal contexts metals were a stock feature of Taoist philosophy. Ko Hung (4th century A.D.) suggested that man is what he eats and the purest of men eats gold. Since most men could not afford gold, a substitute for potable gold was devised and based on based on cinnabar (mercury sulfide) and other raw materials (Goldwater, 1972, p. 23).

In *Tsan Thung Chii* (about 142 A.D.), Wei Po-Yang recommended the use of 15 oz. of lead and mercury in the preparation of "cyclically-transformed elixir" (Needham, 1976, p. 15). He notes:

Every day after eating, take three pills wrapped in jujubes. It cures epilepsy, melancholia, possession by goblins, and so forth. Taken over a long period of time, it hardens the bones and marrow, aids circulation of the blood, moistens the skin, brings out the color in the face, quiets the soul, and puts one in touch with the immortals (Sivin, 1968, p. 26).

Chinese medical chemists duly noted the toxicity of lead elixirs:

After taking the elixir, one feels an itch all over the body and the face, rather like having the sensation of an insect crawling over one. The body, the face, the hands and legs become swollen. One may experience a feeling of repulsion at the sight of food, and vomiting usually follows after meal. One feels rather weak in the four limbs. Other symptoms include frequent defaecation, vomiting, headache, and pains in the abdomen. No alarm should be caused by these effects, because they are due to the work of the elixir in dispelling all the inherent disorders in the human body (Sivin, 1968, p. 16).

Beginnings of Modern Western Medicine

Paracelsus, chronicler of Miners' Diseases and father of pharmacology, was one of the most articulate voices concerning alchemy and medicine (Figure 6.33). Born in 1493 and named Philippus Aureolus Theophrastus Bombastus von Hohenheim, he was the out-of-wedlock child of a Swiss nobleman physician and a bondswoman to a Benedictine abbey. His father intended for him to become a physician; hence his name Theophrastus indicating a follower of Aristotle. After his mother's death in 1500, he and his father began the first of many wanderings together (Jolandi, 1971). In the process, he attended a number of universities, including the University of Vienna. At the age of 25 (1515), he was awarded his doctor's hat from the University of Ferrara. He traveled from 1515-1522 across most of Europe (Spain, Portugal, France, England, Germany, Sweden, Moscow, Poland, Austria, Hungary, Croatia, Italy, Sicily, Rhodes, Crete, Constantinople, and Alexandria). In 1522, he took part in the Venetian wars. Later he became an army surgeon in the Netherlands and Denmark. In 1526, he was appointed city *physicus* of Basel, Switzerland after his semi-miraculous cure of a famous Basel printer, Johannes Froben, from an apoplectic stroke. This appointment also allowed him to be a professor at the university.

He alienated most of his medical contemporaries by eschewing the standard medical care of the time and suggesting that the physicians should be experimentalists:

It seems imperative to bring medicine back to its original laudable state, and, aside from striving to cleanse it of the dregs left by the barbarians, to purify it of the most serious errors. Not according to the rules of the ancients, but solely according to those which we have found proved by the nature of things through practice and experience....It is not title and eloquence, nor the knowledge of languages, nor the reading of many books, however ornamental, that are the requirements of a physician, but the deepest knowledge of things themselves and of nature's secrets, and this knowledge outweighs all else...

Elsewhere he wrote:

I am directing you, physicians, to alchemy for the preparation of the magnalia (god inspired medicine), for the production of the mysteria, for the preparation of the arcana (secret medicines), for the separation of the pure from the impure, to the end that you may obtain a flawless, pure remedy, God-given, perfect, and of certain efficacy, achieving the highest degree of

Figure 6.33 Paracelsus, the father of pharmacology, medicine, and chemistry. Painted by Jan van Scorel. The Louvre, Paris. Image 574 in Lyons and Petrucelli' *Medicine, An Illustrated History*, 1978.

virture and power. For it is not God's design that the remedies should exist for us ready-made, boiled, and salted, but that we should boil them ourselves, and it pleases Him that we boil them and learn in the process, that we train ourselves in this art and are not idle on earth, but labour in daily toil. (I/12,348-49).

He publically cast Avicenna's classical book on medicine into a bonfire on St. John's Day, so that, as he stated "all this misery may go in the air with the smoke". Not surprisingly, the medical establishment did not view him favorably. He soon came under vigorous attack, which he returned:

Avicenna, Galen, Rasis, Montagnana, Mesue, and other, after me, and not I after you! Ye of Paris, ye of Montpellier, ye of Swabia, ye of Meissen, ye of Cologne, ye of Vienna, and those who dwell on the Danube and the Rhine, ye islands on the sea, thou Italy, thou Dalmatia, thou Sarmatia, thou Athens, ye Greeks, ye Arabs, ye Israelites, after me, and not I after you! Even in the remotest corner there will be none of you on whom the dogs will not piss. But I shall be monarch and mine will be the monarchy, and I shall lead the monarchy; gird your loins! (Jolandi, 1971, p. Lv).

He denounced Aristotle's four elements while suggesting three: namely mercury, sulfur and salt.

By 1528 he had been forced from his chair. He went on the move again until his death in 1541 at the age of 48. During that period, he produced 134 works on religion and 500 pages of material on medicine. These texts were collected and published shortly after his death. Because of his far-ranging travels and writings he inspired many legends, including a Transylvanian one that he had made a pact with the devil for eternal youth. Many of the places where he wandered have been commemorated.

Paracelsus clearly expressed the concept of medicine and alchemy as searches for what is permanent, pure, or "fixed" in the material world:

God enjoined the physician to fight against the transience of things. This transience also characterizes the Great World in which God himself practises medicine. The physician, by following the instructions of the Great Physician, must act against accidents that befall things. For the Great Physician created ore but did not carry it to its perfect state. He has charged the miners with the task of refining it. In the same way, He enjoined the physician to purify man's body....from which purification man emerges as indestructible as gold....This is an action which -like that performed by fire on gold- frees man from the impurities that he himself does not know. And it is like such fire that the medicine should act.

Quicksilver manifests itself in three forms. In the first it is still unborn (ore); in the second it is as it is in itself (liquid mercury); in the third it appears such as it has been prepared by the alchemist's art. As for the first, you should know that you must take it with the ore...and refine it, according to the rules. As for the second, its body must be separated from the ore and purified by fire. It achieves its third form when it has gone through fire and is like a molten metal. Upon these three forms of manifestation of mercurius, or quicksilver, is based the cure of the French disease (syphilis). (Jolandi, 1971, p. 94).

This passage indicates that mercury had been found to be useful in the cure of syphilis.

Paracelsus defined the art of medicine as purification, to find the fixed and unchanging:

Let it be for you a great and high mystery in the light of nature that a thing can completely lose and forfeit its form and shape, only to arise subsequently out of nothing and become something whose potency and virtue is far nobler than what it was in the beginning.

Nothing has been created as ultima materia *- in its final state. Everything is at first created in its* prima materia, *its original stuff; whereupon Vulcan comes, and by the art of alchemy develops it into its final substance....For alchemy means: to carry to its end something that has not yet been completed. To obtain the lead from the ore and to transform it into what it is made for... Accordingly, you should understand that alchemy is nothing but the art which makes the impure into the pure through fire...It can separate the useful from the useless, and transmute it into its final substance and its ultimate essence.*

The transmutation of metals is a great mystery of nature. However laborious and difficult this take may be, whatever impediments and obstacles may lie in the way of its accomplishment, this transmutation does not go counter to nature, nor is it incompatible with the order of God, as is falsely asserted by many persons. But the base, impure five metals - that is, copper, tin, lead, iron, and quicksilver - cannot be transmuted into the nobler, pure, and perfect metals, namely, into gold and silver- without a tincture, or without the philosopher's stone.

Since ancient times philosophy has striven to separate the good from the evil, and the pure from the impure; this is the same as saying that all things die and that only the soul lives eternal. The soul endures while the body decays, and you may recall that correspondingly a seed must rot away if it is to bear fruit. But what does it mean, to rot? It means only this - that the body decays while its essence, the good, the soul, subsists. This should be known about decaying. And once we have understood this, we possess the pearl which contains all the virtues.

Decay is the beginning of all birth...It transforms shape and essence, the forces and virtues of nature. Just as the decay of all foods in the stomach transforms them and makes them into a pulp, so it happens outside the stomach....Decay is the midwife of very great things! It causes many things to rot, that a noble fruit may be born; for it is the reversal, the death and destruction of the original essence of all natural things. It brings about the birth and rebirth of forms a thousand times improved. ....

As mentioned previously, Paracelsus rejected Aristotelianism. He actively presented his work in a Christian light, using the metaphor of resurrection to describe the purification of metals. He prescribed lead (Saturn) as a medicine based on its alchemical properties:

When ... Sol and Luna have to be purified and proved, Saturn is added to them, and this has the effect of thoroughly purging them. Nevertheless, it is of that nature that it takes away their [malleability?]. It has the same effect on men, with great pains, as Jupiter and Mars. Being mixed with cold, it cannot act mildly. It has the very greatest powers and virtues, whereby it cures fistulas, cancer, and similar ulcers which come under its own degree and nature. It drives the same kind of disease from man as it expels impurities from Luna. But if it does not go out altogether at the same time, it brings more harm than good. Consequently, whoever would use it must know what diseases it cures....and what effects Nature has assigned to it. If this we consider, it can do no harm (Reisman, 1932, p. 9).

Paracelsus was not alone in prescribing lead for fistulas. When topically applied to sores and eye infections, lead worked well for symptomatic relief. Many ancient Egyptian medicinal recipes involved application of lead. Pliny also notes some of the medicinal uses of lead externally applied:

*It is used in preparing a particular emollient plaster for soothing and cooling ulcers and in plasters which are not applied with bandages, but which they use as a liniment to promote cicatrization (*scarring*) on the*

odies of delicate persons and on the more tender parts.

Homeopathy

Paracelsus formulated the "Doctrine of Signatures" which postulated that herbs that looked like the affected organ had a pharmacological effect on that organ. Paracelsus also articulated the idea that like cures like. This also can be taken to mean that the disease can be cured by the agent of the disease, a form of inoculation:

Thus is the microcosm, that is the matrix or the Little World, and it contains within itself all the minerals. it follows that the body can take its medicine from the world and thus it also follows that all minerals may have some benefit for man, each one according to the mineral in the microcosm or body. These things are revealed by philosophy, on which medicine is based. When the physician says that marcasite [bismuth] is good for this, then he must know beforehand that marcasite is in the world and that it is in the human microcosm. This is how the philosopher speaks. If he wants to speak as a physician, however, he must say, this marcasite is the man's disease, hence it will cure him. A hole rotting in the skin and eating into the body, what else is it but a mineral? Then follows: colcathar mends the hole. Why? Because colcathar is the salt that makes the hole. Thus Mercury cures the holes which it has provoked and other Arsenicals do likewise

Homeopathy in its earliest form teaches that "like cures like" so the cure for the disease should produce the symptoms of the disease in a sound person. (Modern homeopathy, on the other hand, is defined as the process of dilutions by which the pharmacologic effective range is found.)

Transition Between Paracelsian and Modern Medical Ideas on Lead

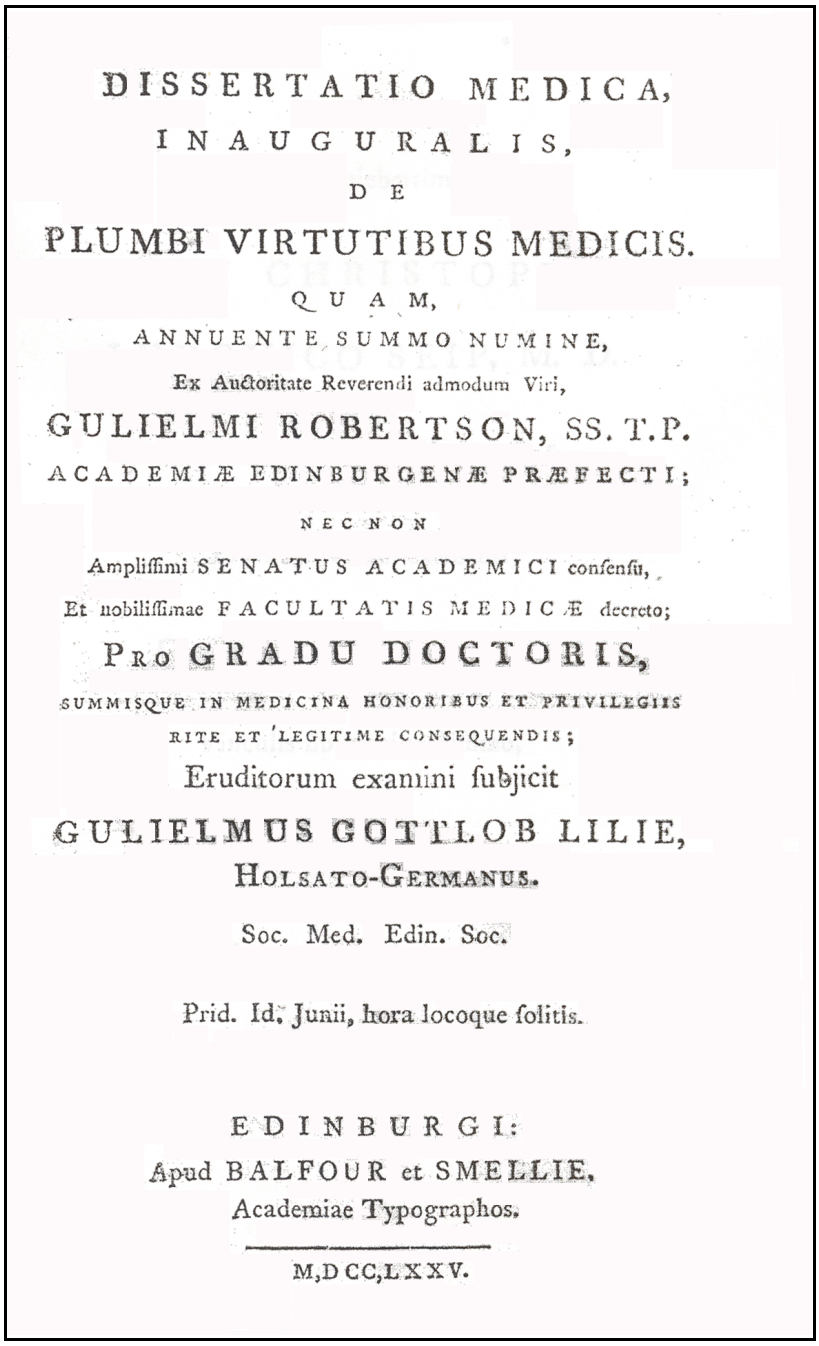
In 1775 William Lilie wrote his medical dissertation for the faculty of the University of Edinburough on the beneficial effects of lead used in medicine. (Lilie, 1775) Lilie reviews the state of current knowledge making reference to the works of Drs. White, Sproegel, Hoffman, Percival, Baker, Boerhaave, Warren, Goulard, Aiken, Cullen, and Hundeertmark. The full translated dissertation (courtesy of D. Scott Van Horn) appears in Appendix K. A synopsis is discussed here because the dissertation represents a transitional state in our understanding of lead and helps explain some of the used to which lead is put in modern folk or alternative medicines (see below).

The central dilemma of the dissertation is to find a coherent explanation for the differences in action of lead in its various forms both internal and external within the context of the prevailing theories of medicine (pre molecular biology and pre-germ theory) and chemistry (pre-atomic theory) at the waning of the Aristotelian theory of four primary materials: earth, air, fire, and water and also at the waning of Paracelsian medical theory.

Inflammation was believed due to the obstruction of vessel which allowed blood to be blocked and, therefore, accumulate. Three types of inflammation are elucidated. The first is due to external violence which completely destroys blood vessels. The second results from irritative stimuli which debilitate the vessels preventing them from having the strength to contract sufficient to expel the obstruction. The third was the result of habitual stimuli in which the vessels were overly aroused such that more fluids could rush into the vessels than could be accommodated resulting in flooding.

In order to relieve the inflammation the vessels needed to be able to contract with sufficient force to expel the obstruction. Lead, as lead acetate, or as a lead saline solution applied externally, was proven to have an astringent effect, causing wrinkling of the skin and was so thought to cause the vessels to contract which resulted in expulsion of the blocking and reduction of the inflammation. Lead was also thought to diminish the spasming of vessels which resulted in the habitual stimuli of over aroused vessels allowing too much fluid.

These observations were the basis for theories for the mode of action of lead used externally for eye inflammation, testicular tumors, cancer, acne, pimples and crusts, vaginal problems, and gonorrhea. As an organ the eye is very "nervous" with much spasming which could be reduced by lead acetate. Inflammatory tumors of the testicles which occur in gonorrhea were due to compressed ducts and lead, by its astringent action, could increase the pressure on the ducts to expel the blockage and allow relief of inflammation. Lead was also believed to be useful for open and long standing ulcers where relief was known to occur by expulsion of pus. The same reasoning explained the beneficial use of saline lead or lead acetate for facial eruptions and crusts (acne and pox), only in this case a caution is given for the sparing use of lead as these eruptions were believed to be the external manifestation of similar internal problems. Changes to



DISSERTATIO MEDICA,
INAUGURALIS,
DE
PLUMBI VIRTUTIBUS MEDICIS.
QUAM,
ANNUENTE SUMMO NUMINE,
Ex Auctoritate Reverendi admodum Viri,
GULIELMI ROBERTSON, SS. T.P.
ACADEMIÆ EDINBURGENÆ PRÆFECTI;
NEC NON
Ampliſſimi SENATUS ACADEMICI conſenſu,
Et nobiliſſimae FACULTATIS MEDICÆ decreto;
PRO GRADU DOCTORIS,
SUMMISQUE IN MEDICINA HONORIBUS ET PRIVILEGIIS
RITE ET LEGITIME CONSEQUENDIS;
Eruditorum examini ſubjicit
GULIELMUS GOTTLOB LILIE,
HOLSATO-GERMANUS.
Soc. Med. Edin. Soc.
Prid. Id. Junii, hora locoque ſolitis.
EDINBURGI:
Apud BALFOUR et SMELLIE,
Academiae Typographos.
M,DCC,LXXV.

the external manifestation would be paralleled by internal changes such that the lead would have an internal effect and it was known that lead was not to be used internally (see below). A too rapid relief of external symptoms could lead to adverse rapid effects internally. On the beneficial side, lead would aid in the expulsion of the pus by its astringent action causing contractions. Open cancers could find relief from the application of lead as it ended the putrefaction of the cancer, mitigated the inflammation, and gave a sensation of coolness bringing help to the desperate. Saline solutions of lead or lead acetate could be used for a variety of vaginal disorders depending upon the source of the ailment, presumably being useful for inducing contractions and expulsion of unwanted vaginal material.

On the basis of a review of then current understanding of lead, the author disagreed with Dr. Hundertmark's article "Dissertation of the Healthful Internal Use of Lead Acetate" in *Acts of Natures Curiosities*, Vol. 7, which endorsed internal use of lead. The common internal use of lead was for inducing vomiting which was caused by a similar astringent effect of lead as when applied externally causing contractions of the ventricle tissue. Lead was also used to induce diarrhea, again as part of its ability to "unblock" constricted vessels.

He notes the well known adverse effects of lead exposure to pure lead fumes (typesetters), and the adverse effects of lead exposure by various workers with calcined lead, and the greater toxicity of finely ground lead preparations. In attempting to explain these variable actions of lead (beneficial use of external lead acetate vs toxicity of pure lead vapor and ground lead) he proposes that pure lead is most potent and that preparations affect the purity of lead. Subtle (minute) calcination leads to the cleanest form of lead and is most potent. The action of a mineral acid on lead leads to separation of phlogiston (gas or air) and also heats the solution which affects the "inflammable" part of lead, resulting in weight changes. When lead is used without sacrifice of this "inflammable" principle it is not as "potent" (e.g. lead acetate or saline lead). However, even lead treated with acid, which affects its inflammable principle, is not as potent as calcined lead because of the effect of the acid itself which is similar

to the action of bile. Further, the acid is thought to, in some way, surround or coat the pure lead making it less potent.

He notes the fatal consequences of administering lead acetate directly to the jugular veins of dogs, and the adverse effect of oral use of lead acetate on dogs. He particularly notes the recent work of Dr. White who noted that the action of heart pulse and frequency diminished on the internal use of lead acetate. The author supposes that lead may have been the active ingredient of the slow poisons of the Italians.

Modern Toxic "Folk" or "Alternative" Remedies

Many of the medicinal remedies noted during the medieval and ancient times survive today (Simkiss, 2003).

Kohl, which we encountered as a mascara in ancient Egypt (Chapter 5), and as a topical ointment for eyes (just described) is still used as a traditional Egyptian remedy. Kohl also goes by the name *surma*. Similarly *kajal* is used as an eye medicine in India, Pakistan, Asia, and the Middle East. A case of severe lead poisoning (490 µg Pb/dL blood) was reported in Brussels in 2002 for a Moroccan woman using kohl (lead sulfide) (Bruyneel et al., 2002). Other clinical cases of lead poisoning from kohl have been reported (Mojdehl and Gurton, 1996).

Andrew Jackson, 7th President of the United States, whom we met at the beginning of our lead journey, was medicated with lead by his physician for similar astringent or drying properties. He was also prescribed Dr. Rush's *Thunderbolt* for stomach ache. *Thunderbolt* contained 10 grams of jalep and 10 grams of calomel (mercury).

.... Dr. Francis May, Jackson's physician, regularly swabbed him with sugar of lead. It was widely believed at the time that sugar of lead, in addition to its astringent powers, could reduce inflammation. So Jackson both drank it and bathed in it. He took it internally to combat his supposed tuberculosis and chronic stomachaches, and externally for its antiphlogistic action. He even squirted it into his eyes when his sight began to falter. (Remini, R. V.: Andrew Jackson)

In a similar vein, lead is used to cure children of rashes or fevers (acting as a coolant) in the Hmong community. It is known as *Pay-loo-ah*, and is a bright red or orange powder, suggesting that the main ingredient is either lead chromate or minium.

Homeopathic ideas may lie behind some folk remedies which prescribe lead for stomach aches. In Asian Indian communities lead containing stomachache remedies go by the names of *Ghasard, Bala Goli,* and *Kandu.* ####. One 35 year old woman was a frequent visitor to the emergency room with abdominal pain, vomiting, obstipation, and weight loss. She had severe pain in the extremities, loss of concentration, and loss of short-term memory. Her blood lead level was 140 ug/dL. She had used a traditional Ayurvedic medicine (van Vonderen et al., 2000). The lead content in some Ayurvedic preparations can range from 12 to 72% (Dunbabin et al., 1992; Kew et al., 1993; Pontifex and Gary, 1985; Prpic-JMajic et al., 1996; Smitherman and Harbes, 1991).

Numerous cases of lead poisoning are reported in the Mexican-American community as a result of the use of *Azarcon* for indigestion, diarrhea, and stomachache (*empacho*) (Bose et al., 1983). In the calendar year 1992, 40 cases of pediatric lead poisoning through traditional medines were reported. 36 of the 40 reports were related to the use of *azarcon* ####. Some samples of *azarcon* were found to contain 86% to 93.5% lead tetroxide (Levitt et al., 1984).

A number of Chinese herbal remedies have also be indicated as a source of lead poisoning (Anyeng et al., 2002).

Summary

The sub-selection of alchemical theories presented here theorize about the colors and phase changes associated with lead on heating during cupellation. The color and phase changes coincidentally parallel the color and phase sequence obtained by the metals ordered by their reactivity to oxygen. Each element contains within it the four Aristotelian elements, earth, air, fire and water. Each of the elements has corresponding qualities of dryness and coolness, heat, and liquidity.

Many modern toxic folk remedies involving lead are paralleled by early western medicinal practices based on the concepts of the four elements and homeopathic notions and the observation of leads astringent effects on biological tissue.

Chapter 6. Part II: Chemistry of Metal Color and Mineral Acids

Color of Metals

In ordinary reflected light, the observed color represents the light not absorbed. On the other hand, metals absorb nearly all light into their surfaces and re-radiate it: the reflected light thus represents light absorbed. Copper's $3d^{10}4s^1$ configuration results in 11 valence electrons occupying the d orbital and half of the s orbital. Occupancy of the 1s orbital implies low energy photons are absorbed and re-emitted, giving rise to the red color of copper (Figure 6.20) (Nassau, 1983; Slater, 1951). Gold, with it's lanthenide contraction providing a permutation on the energy of the s and d orbitals, reflects over a wider wavelength than copper, but still is biased toward longer wavelengths (red + white resulting in gold).

Chemistry of Mineral Acids

Unlike HCl, HNO_3 can be involved in both acid digestion (use of the proton) and a redox reaction. A comparison of the different possible oxidation states for N and Cl indicates that the nitrate can be easily involved in a redox reaction (Table 6.5). Nitric acid has nitrogen in the most positive oxidation state. Consequently, nitric acid can attack metals and acquire electrons to lower its oxidation state. HCl, on the other hand, has chloride in the most negative oxidation state. It can release electrons during a conversion from HCl to Cl_2.

To what form of nitrogen will the nitric acid convert? Nitrogen's final form is likely nitrogen gas, N_2, the most stable form of nitrogen. However, this prediction is wrong. A look at the molecule will help us (Figure 6.35). Notice the O group on the left-hand side of the molecule. This can be removed with only a single bond breakage. To form N_2 3 N-O bonds must be broken on two separate molecules (a total of six N-O bonds), and closely enough that the two N atoms can find each other. Thus the product of an HNO3 reduction is predicted to be:

[6.4] $4HNO_3 \rightarrow 4NO_2 + O_2 + 2H_2O$

The free energy of this reaction can be computed from the enthalpies of formation (Table D.7):

[6.5] $H_f = [2x(-286) + 1x(0) + 4(+34)] - [1x(-176)] = -262$ kJ/mol

Table 6.5 : Oxidation States of Cl and N

Oxidation State	Nitrogen	Chlorine
-3	NH_3	
-2	N_2H_4	
-1	NH_2OH	HCl
0	N_2	Cl_2
+1	N_2O	HOCl
+2	NO	
+3	N_2O_3	HOClO
+4	NO_2	
+5	HNO_3	$HOClO_2$
+6		
+7		$HOCl_3$

The reaction of nitric acid to NO_2 should be spontaneous. In fact the yellowish color that you note in a bottle of concentrated nitric acid is due to the presence of NO_2.

The nitric acid thus participates in several reduction reactions:

[6,6]	$NO_3^- + +3H^+ + 2e \rightleftharpoons HNO_2 + H_2O$	0.94 vs NHE	-2F(.94)
[6.7]	$HNO_2 + H^+ + e \rightleftharpoons NO(g) + H_2O$	1.00 vs NHE	-1F(1)
[6.8]	$NO_3- + 4H^+ + 3e \rightleftharpoons NO(g) + 2H_2O$	(1.88+1)/3	-F(1.88+1)

The combined reaction potential is +0.96 V for the conversion of nitrate to NO.

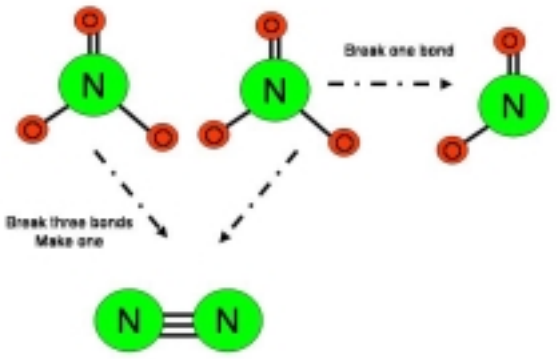


Figure 6.35 Nitrate decomposes easily to NO_2. The gaseous product is lost from the reaction.

Once the sample is digested, the metal is present in a matrix that is high in either nitrates (NO_3^-) or chlorides. Nitrate is not a particularly strong complexing or precipitating reagent, unlike the chloride ion. Chlorides can be good complexing agents for the heavier elements (soft metals). First row transition metals (Cu, Ni, Co, Zn) and first and second column alkali (Li, Na) and alkali earth metals (Be, Mg, Ca) are known as hard metals. These metals prefer smaller more compact ions that can have a high density, efficient energy, and packing via electrostatic means, like the lone electron pair on oxygen. Anions of choice are correspondingly small and dense: CO_3^{2-}, SO_4^{2-}, F^-. These anions are preferred in the following sequence : O^{2-} >> S^{2-} >Se^{2-} ,Te^{2-} and F>>Cl^- >Br^- <I^-. The larger, softer cations (Cd^{2+}, Hg^{2+} and Pb^{2+}) prefer larger softer, polarizable anions (I^-> Br^-> Cl^- >> Fl^-; Te^{2-} , Se^{2-} > S^{2-} >> O^{2-}. These preferences manifest in the equilibrium reactions of cations with chloride and carbonates and oxygen (TableD.9 and D.2).

The presence of such chlorides complexes can affect subsequent analysis. For example, lead in sea water is difficult to measure by methods that require heating because the lead chlorides are volatile, a fact that is exploited in leaded gasoline chemistry. An example calculation of the α fractions for Pb chloride in ocean water is given in Figure 1.22

Gold can be detected by reaction with *aqua regis* to form a colored transition metal complex (Puddlephatt, 1978) :

[6.9] $Au + HNO_3 \rightleftharpoons Au^+ + NO_2 + 1/2O_2 + H^+$

[6.10] $Au^+ + 4HCl \rightleftharpoons AuCl_4^{3-} + 4H^+$

The gold can be recovered and quantified by a gravimetric measurement:

[6.11] $AuCl_4^{3-} + NaS_2 \rightleftharpoons Au$

In summary, the ability of mineral acids to dissolve metals for subsequent analysis allowed verification of alchemical experiments not only by color and density but by alternative (chemical) assays.

Why didn't alchemists just go down to the neighborhood store and purchase these acids? The modern production of acids offers a clue about why mineral acids were unavailable in the past. Current production of hydrochloric acid follows one of two reactions:

[6.12] $H_{2(g)} + Cl_{2(g)} \rightarrow 2\ HCl_{(g)}$

[6.13] $2NaCl_{(s)} + H_2SO_{4(aq)} \rightarrow Na_2SO_{4(s)} + 2HCl_{(g)}$

The first reaction requires the handling and separation (distillation) of three gases, none of which were known to alchemists. The second reaction upon sulfuric acid which was also not known.

The production of nitric acid is similarly based on unknown materials and upon the handling of gases. The process is known as the Ostwald process:

[6.14] $4NH_3 + 5O_2 \rightarrow 4NO_{(g)} + 6H_2O_{(g)}$

[6.15] $2NO_{(g)} + O_{2(g)} \rightarrow 2NO_{2(g)}$

[6.16] $3NO_{2(g)} + H_2O_{(l)} \rightarrow 2HNO_{3(aq)} + NO_{(g)}$

Some source of ammonia is required, and again good distillation practices are necessary.

Sulfuric acid is currently the most important chemical produced. It is created through the process

[6.17] $S(s) + O_{2(g)} \rightarrow SO_{2(g)}$

[6.18] $$SO_{2(g)} + \frac{1}{2}O_{2(g)} \xrightarrow{slow} SO_{3(g)}$$

[6.19] $SO_{3(g)} + H_2O(l)$ violently $\rightarrow H_2SO_{4(aq)}$

The slow reaction can be catalyzed if the process is

carried out in the presence of nitrates:

$$NO_3 \rightarrow NO_x$$

$$NO_{(g)} + \frac{1}{2}O_2 \rightarrow NO_{2(g)}$$

$$NO_{2(g)} + SO_{2(g)} \rightarrow SO_{3(g)} + NO_{(g)}$$

The final product of these last three reactions NO feeds back to the second step to start the reaction again. As a consequence the reaction involves the burning of sulfur and saltpeter together over a vat of water. To protect the containment still the reaction is carried out in a lead chamber. A relatively impervious lead sulfur compound is formed under these acidic conditions which prevents the chamber from corroding.

Chapter 6: Problems

1. Why is gold valued?
2. How was technology transmitted in the premodern age?
3. A. In 1500-1700 Europe was land ownership economically viable to the Royalty of the courts of Europe?
   B. If not, what other resources were available to the royalty?
   C. Was European currency stable in these 200 years?
   D. Did the universities teach explicit metallurgical skills?
   E. How do questions a through d help explain why alchemy became a court interest?
4. Who is Johann Joachim Becher and what is he known for?
5. Describe the Aristotelian theory of matter. In this theory how are phase transformations understood?
6. According to ancient theory are metals living?
7. What metals are associated with the seven wanderers?
8. Who was Marie the Jewess? In what center of learning did she work?
9. What is the theme of birth and death in alchemy? What is the chemistry associated with "death"?
10. What are the seven steps of chemical transformations in alchemy?
11. In the False Geber's work, what major parts of lead chemistry are described by earthiness, difficulty of calcination, and liquefication?
12. Given the Aristotelian theory of matter why is mercury so important in alchemical transformations?
13. Describe the chemistry of putrefaction.
14. Describe the chemistry of Basil Valentinus black to white, white to red, until the glorious color of the triumphant King has been obtained.
15. When were mineral acids first described in Western literature?
16. When did mineral acids first become well known for gold assaying?
17. What technology did mineral assays replace?
18. What technology prevented mineral acids from being "discovered" sooner than they were?
19. What is *aqua fortis*? *Aqua regis*? *Oil of vitriol*? Green vitriol?
20. Who is Paracelsus? Why was he expelled from the university?

Questions Suitable for Chemistry Students

21. Why is gold so unreactive?
22. Why is nitric acid better than hydrochloric acid in oxidizing most metals?
23. Why does hydrochloric acid have to be added to nitric acid to be able to dissolve gold?

Chapter 6: Literature Cited

Aitchison L (1960) A History of Metals. New York: Interscience Publishers.

Anyeng TW, Chang KK, To CH, Mak A, and Szeto ML (2002) Three patients with lead poisoning following use of a Chinese herbal pill. Hong Kong Medical Journal *8:*60-62.

Beck CH (1972) Greek and Roman Chronology. Geneva: Druck.

Bennet JA (1986) "The Mechanics" Philosophy and the Mechanical Philophy. History of Science *24:*22.

Bickerman EF (1968) Chronology of the Ancient World. Ithaca, N.Y.: Cornell University Press.

Bose A, Vashistna K, and O'Loughlin BJ (1983) Azarcon por empacho - another cause of lead toxicity. Pediatrics *72:*106-8.

Brill RH (1968) The Scientific Investigation of Ancient Glasses. International Congress on Glass Technical Papers *8:*47-68.

Burland CA (1967) The Arts of the Alchemists. London: Weidenfeld and Nicholason.

Colson FH (1974) The Week: An essay on the origina and devloopment of the seven-day cycle. Westport, Connecticut: Greenwood Press.

de Lacerda L, and Salomons W (1998) Mercury from Gold and Silver Mining: A Chemical Time Bomb? Berlin: Springer.

Delia D (1992) From romance to rhetoric: The Alexandria library in classical and Islamic Traditions. The American History Review *97:*1449.

Dobbs BJT (1975) The Foundations of Newton's Alchemy, or: The Hunting of the Greene Lyon. Cambridge: Cambridge University Press.

Dobbs BJT (1990) Alchemical death and resurrection: the significance of alchemy in the age of Newton. Washington D.C.: Smithsonian Insitution.

Dunbabin DW, Tallis GA, and Popplewell PY (1992) Lead poisoning from Indian herbal medicine (Ayurveda). Medical Journal Aust. *157:*835-6.

Evans RJW (1973) Rudolf II and His World: A Study in Intellectual Hisotry, 1576-1612. Oxford: Oxford University Press.

Farrington B (1966) Science and Politics in the Ancient World. London: Barnes and Noble.

Federman R (1964) The Royal Art ofAlchemy. London: Chilton Book Co.

Fontana D (1993) The Secret Language of Symbols, A Visual Key to Symbols and Their Meanings. San Francisco: Chronicle Books.

Fraser PM (1972) Ptolemaic Alexandria. Oxford: Clarendon Press.

Gareth R (1994) The Mirror of Alchemy, Alchemical Ideas and Images in Manuscripts and Books from Antiquity to the Seventeenth Century. Toronto: The University of Toronto Press.

Gilmour JC (1990) Fire on the earth, Anselm Kiefer and the postmodern world. Philadelphia: Temple University Press.

Goldwater IJ (1972) Mercury, A History of Quicksilver. Baltimore: York Press.

Grant E (1974) A source book in medieval Science. Cambridge: Harvard University Press.

Graves R (1960) The Greek Myths. N.Y.: Penguin Press.

Healy JF, ed. (1991) Pliny the Elder: Natural History; A selection. St. Ives: Penguin Books.

Herodotus (1998) The histories. Oxford: Oxford University Press.

Hoffman RJ, ed. (1987) Celsus: On the true doctrince, a discourse against the Christians. Oxford: Oxford University Press.

Hoover HC, and Hoover LH (1950) Agricola's De Re Metallica. N.Y.

Ihade AJ (1964) The development of modern chemistry. N.Y.: Harper and Row.

Jensen V (1901) Zeitschrift fur Deutsche Wortforschung *157*.

Jolandi J (1971) Paracelsus, selected Writings. Princeton: Princeton University Press.

Jones HL, ed. (1949) Strabo, The Geography of Strabo. Cambridge: Harvard University Press.

Kew J, Morris C, and Aihie A (1993) Arsenic and mercury intoxication due to Indian Ethnic Remedies. British Medical Journal *306:*506-507.

Kulke H, and Rothermund D (1990) A History of India. London: Routledge.

Levitt C, Eberhardt M, Ing R, and Simpson J (1984) Sources Of Lead Poisoning. Journal of the American Medical Association *252:*22.

Lilie GG (1775) Plumbi Virtutibus Medicis. Medical dissertation, Juniversity of Edinbug, Edinburg.
Little AG (1914). In AG Little (ed.): Roger Bacon, Essays. Oxford: Clarendon Press.
Marlowe J (1971) The Golden Age of Alexandria. London: Victor Gollancz.
Muir MMP (1914). In AG Little (ed.): Roger Bacon, Essays. Oxford: Clarendon Press.
Multhauf RP (1967) Origins of Chemistry. N.Y.: Franklin and Watts.
Nassau K (1983) The Physics and Chemistry of Color (The 15 Causes of Color). N.Y.: Wiley-Interscience.
Needham J (1976) Science and Civilization in Ancient China. Cambridge: Cambridge University Press.
Parsons EA (1952) The Alexandrian Library. London: Cleaver, Homer Press.
Partington JR (1961) History of Chemistry. London: MacMillan and Co.
Patai R (1994) The Jewish Alchemists, A history and source book. Princeton: Princeton University Press.
Pereira M (1994) Medicina in the Alchemical Writings Attributed to Raimond Lull (14th-17th centuries). In P Rattani and A Clericusio (eds.): Alchemy and Chemistry in the 16th and 17th centuries: Kluwer Academic Press.
Pliny tE (1938-1963) Natural History. Cambridge, Ma.: Harvard University Press.
Pontifex AH, and Gary AK (1985) Lead poisoning from an Asian Indian fold remedy. Can. Med. Asso. J. *133:*1227-8.
Procter RN (1991) Value Free science: purity and power in modern knowledge. Boston: Harvard University Press.
Prpic-JMajic D, Pizent A, and Jurasovic J (1996) Lead poisonging associated witht he use of Ayurvedic Metal-mineral tonics. Clinical Toxicology *34:*417-23.
Puddlephatt RJ (1978) The chemistry of Au. N.Y.: Elsevier.
Reichen C-A (1963) A History of Chemistry. N.Y.: Hawthorne Books.
Reisman D (1932) The Story of medicine in the middle ages. N.Y.: Paul B. Hoeber.
Ripley G (1977) The compound of alchymy. Amsterdam: Theatrum Orbis Terrarum.
Rothernberg A (1993) Creative homospatial and Janusian Process. In JH Wotiz (ed.): The Kekule Riddle. Clearwater, Fl.: Cache River Press.
Ruland M (1984) A Lexicon of Alchemy. York Beach, Maine: S. Weiseer.
Sarpotday M, and Subbarayappa BV (1990) Gold in Vedic Society. In G Kuppuram and K Kumadamani (eds.): History of Science and Technology in India. Delhi: Sundeep Prakasahan.
Sivin N (1968) Chinese Alchemy: Preliminary Studies. Cambridge, Ma.: Harvard University Press.
Slater J (1951) Quantum Theory of Matter. N.Y.: McGraw-Hill.
Smith CS, and Gnudi MT, eds. (1990) The Pirotechnia of Vannoccio Biringuccio: The Classic 16th Century Treatise on Metals and Metallurgy. New York: Dover.
Smith PH (1994) The Business of Alchemy, Science and Culture in the Holy Roman Empire. Princeton: Princeton University Press.
Smitherman J, and Harbes P (1991) A Case of mistaken identity: herbal medicine as a cause of lead toxicity. American J. Indian Med. *20:*795-8.
Stillman JM (1960) The Story of Alchemy and Early Chemistry. London: Dover.
Treptow RS (1978) Amalgam Dental fillings, part I: Their sometimes outrageous hisotry. Chemistry *51:*17-20.
Trotman-Dickenson AF (1973) Comprehensive Inorganic Chemistry. London: Pergamon Press.
van Vonderen MGA, Klinkenberg-Knol EC, Craanen ME, Touw DJ, Meuwissen S, G. M., and de Smet P, A. G. M. (2000) Severe gastrointestingal symptoms due to lead poisoning from Indian traditional medicine. American Journal of Gastroenterology *95:*1591.
Zerubavel E (1985) The Seven Day Circle: The History and Meaning of the Week. Chicago: The University of Chicago Press.