The Days of the Week: An Oxidation/Reduction Algorithm

by Alanah Fitch

Historians have nearly uniformly suggested that the sequence of days of the week has its reference base in planetary information. One notable exception is Jensen who suggested in 1910 that the reference base for the order of the days of the week were the elements.[1] The "Astronomical Hypothesis" requires that, instead, elemental information was subsequently arbitrarily attached to the planetary sequence. In this article we pick up Jensen's suggestion and demonstrate that a compelling argument can be made that the underlying reference sequence for the days of the week is the oxidative reactivity of metals known at the time the days of the week were codified. Once the oxidative order of the metals was set, planets and days were attached and subsequently codified. This hypothesis will be referred to as the "Oxidation/Reduction Hypothesis."

The "Astronomical Hypothesis"

There are seven heavenly bodies that, to an observer on Earth, move "freely" through the stars (Fig. 1): the Sun, the Moon, Mars, Mercury, Jupiter, Venus, and Saturn. The seven wanderers (planet = wanderer in Greek) do not circumscribe the entire sky. They move through an elliptic portion of space containing the constellations that make up the Zodiac. Based on the relative orbit of the earth the planets may also appear to change directions or to actually regress rather than progress (hence the name "wanderer"). The time it takes for them to reappear in the same region of space relative to the stars as observed from earth is the synodic period. The planet/day sequence is clearly not based on the synodic period (Table I; Fig. 2).

A sidereal period is the time required for the planet to orbit the sun. A sidereal day is the time it takes for the Earth to rotate 360 degrees. One way of sequencing the wanderers involves their sidereal periods. Planets can be ordered from longest to shortest period [Saturn (29.45 yrs), Jupiter (11.86 yrs), Mars (1.88 years), Venus (0.615 years), Mercury (0.24 years), and the Moon (0.0748 yrs)]. The Sun has the shortest period, if the sidereal day (23.94 hours) is substituted for the sidereal period. This ordering is called the "Egyptian" sequence. Another common ordering is the Chaldean sequence, which utilizes the sidereal periods of the planets and

Editor's Note: We are running a bonus feature article in this issue on an intriguing topic; we hope you enjoy the ideas that follow below and we thank Johna Leddy for bringing them to our attention.

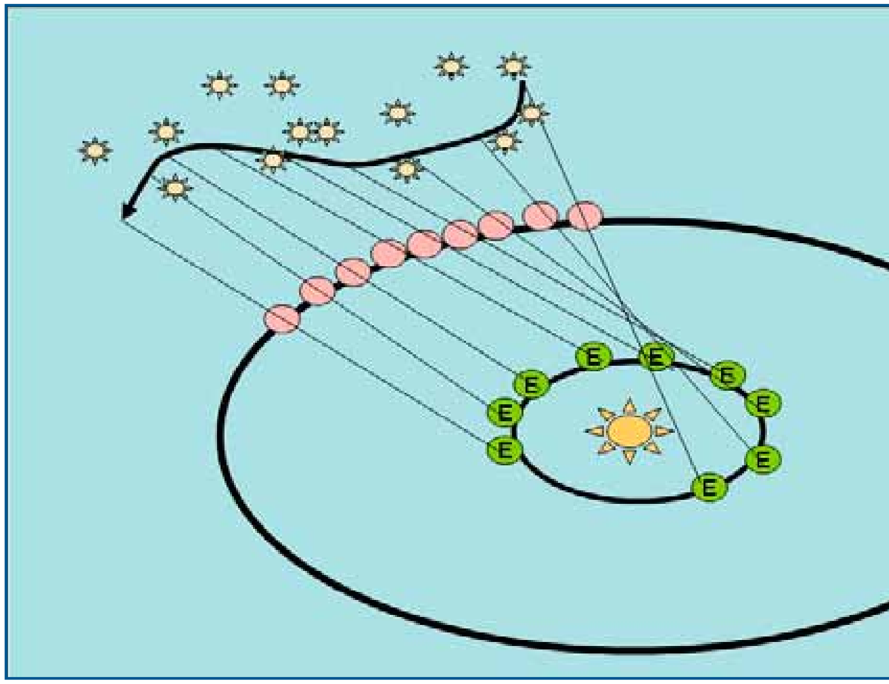

Fig. 1. *A cartoon illustrating how a planet is observed by a viewer from Earth. The pattern obtained may "wander" and may include retrograde (backwards) motion.*

Table I: Various astronomical observations.

"Planet"	Planet/Day	Distance from Sun (km)	Synodic Period * (days)	Sidereal Period** (yr)	Sidereal Day (hr)	Observations
Sun	Sunday					
Moon	Monday		29.53	0.049		
Mercury	Wednesday	57.9	115.8	0.24		Fastest moving, East then West
Venus	Friday	108.2	583.9	0.615		Brightest, East then West
Earth		149.6		1	23.94	
Mars	Tuesday	227.9	779.9	1.88		Red, retrograde motion
Jupiter	Thursday	778.3	398.9	11.86		2^{nd} brightest, retrograde motion
Saturn	Saturday	1427	378.1	29.45		Retrograde motion

**Synodic period is the time required for object to reappear in same position with respect to the Sun/stars as observed from Earth.*
***Sidereal period is the time required to make one full orbit.*

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Moon and the apparent sidereal period of the Earth as a descriptor of the Sun's period [Saturn (29.45 yrs), Jupiter (11.86 yrs), Mars (1.88 yrs), Sun (1 yr), Venus (0.615 yrs), Mercury (0.24 yrs), and Moon (0.0748 yrs)]. The Chaldean sequence was identified by Babylonian astronomers of the 8th century BCE.[1-3] Neither of these series correctly describes the planet/day sequence (Fig. 2).

In order to obtain an astronomical basis for the planet/sequence a further manipulation is required. The Chaldean sequence is repeated throughout a 24 hour period (Fig. 3). The first hour of the first day begins with Saturn and ends with Mars for the 24th hour. The first hour of the second day thus begins with the Sun and ends with Mercury for the 24th hour. Repetition of the sequence results in a seven day sequence: Saturn's Day (Saturday), Sun's Day (Sunday), Moon's Day (Monday), Mars' Day (Tuesday from Tiwes' Day), Mercury's Day (Wednesday from Woden's Day), Jupiter's Day (Thursday from Thor's Day), and Venus' Day (Friday from Fritag's Day). The week obtained by this manipulation begins with the Saturday and ends with Friday. This seven-day sequence was common in Mesopotamia and supplanted the 8 day week of the Romans about the time of Julius Caesar and subsequently codified into law by the Emperor Constantine in 312 AD.

In addition to requiring further manipulations to achieve the planet/day sequence adoption of the "Astronomical Hypothesis" requires that then known elements (Pb, Cu, Au, Ag, Fe, Hg, Sn, S, and C[4]) assigned to the planets are (a.) assigned to the planets in reverse order and (b.) justified by relatively arbitrary means. One possibility is that the metals are assigned to the planets primarily on the basis of color (see Tables I and II). This seems to be an obvious conclusion for some of the metals but not others. For example, the coinage metals (gold, silver, and copper) have particular colors that are a function of the density and energy level of electrons states in the metal. Gold, with its lanthanide contraction providing a permutation on the energy of the s and d orbitals, reflects over a wider wavelength than copper being biased toward longer wavelengths (red + white resulting in gold). The larger wavelength range of reflection would be consistent with the wider wavelength range of radiation from the sun. Similarly, the assignment of silver to the moon can be easily rationalized on the basis of color.

Copper represents an interesting anomaly. The $2d^{10}4s^1$ configuration of copper results in eleven 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.[5-6] Copper should, therefore, be associated with Mars which has a red color deriving from the abundance of iron oxides on the planet. Copper, however, is most commonly associated with Venus (Table III), the brightest and "lightest" of the "planets." The color scheme fails to predict any of the planetary associations of copper and fails to predict the changes in copper/planet assignments that have been made over the last 2,000 years (Table III).[7-8] In addition, the color basis for assignment of metals to planet/days appears to fail for the remainder of the metals.

The clearest description we have of the early assignment of metals to planets comes from Origen who quotes Celsus in his anti-Christian tract *On the True Doctrine* (~180 AD).[9] In this account color is used only twice for the assignments of metals to planet/days

> *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*

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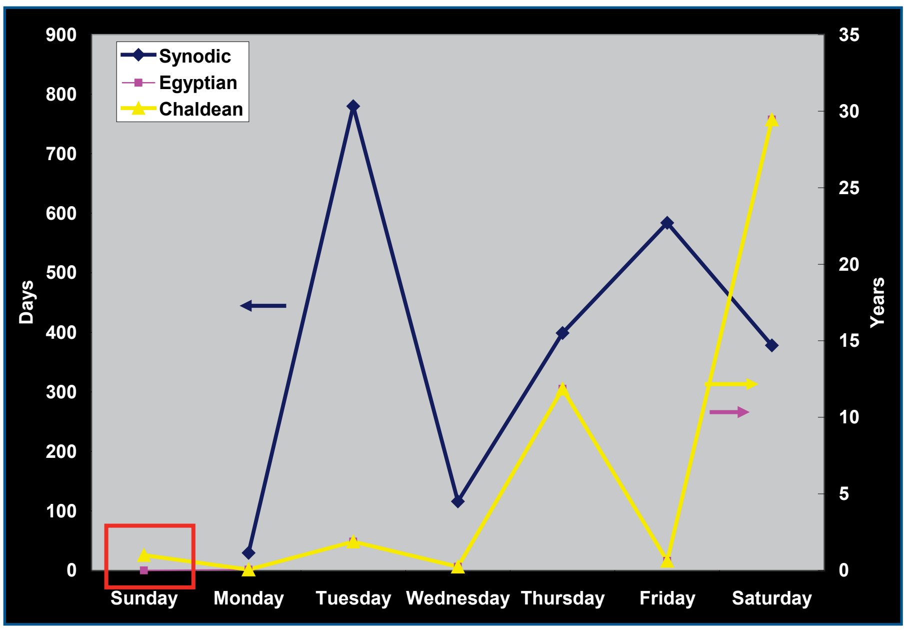

Fig. 2. *Plot of planetary/day sequence as a function of various astronomical periods. The red box highlights the difference between the Egyptian and Chaldean sequences. See text for explanation of synodic, Egyptian, and Chaldean Sequences.*

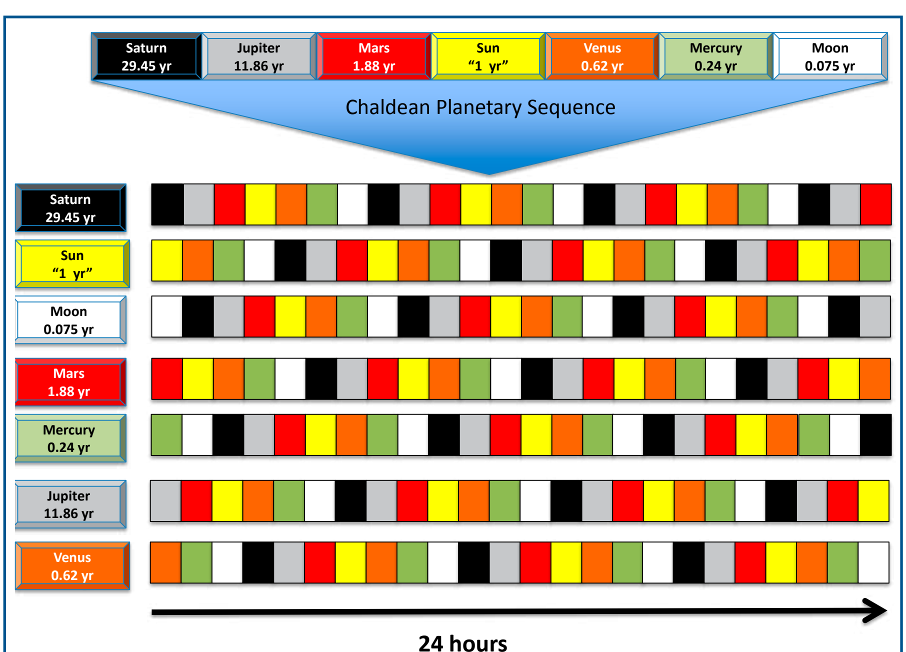

Fig. 3. *A diagram of the sequence of planets to a 24 hour day that results in the present day order if the sequence is presumed to begin on Saturday as the first day of the week.*

Table II. Ordering of metals to planets. (Source of planetary/metal compilation: Nriagu; see Ref. 8.)

Source	Date	Sun	Moon	Mars	Mercury	Jupiter	Venus	Saturn
Babylonian list	1600-1400 BCE	Au	Ag				Pb	metal?
Celsus	174-178 AD	Au	Ag	Mixed	Iron	Bronze	Sn	Pb
Vettius Valens	200-300	Au	Ag	Fe	Electrum[2] (Hg)	Sn	Cu	Pb
Odes of Alexandria	300-400	Au	Ag	Fe	Sn	Electrum	Cu	Fe
Proklos & Olympiodoros	500-600	Au	Ag	Fe	Sn	Electrum (mixed metal)	Cu	Pb
The Venerable Bede	673-735	Au	Ag		Pb	Electrum	Sn	Pb
Stephanos	600-700	Au	Ag	Fe	Hg	Sn	Cu	Pb
Al-Dimashqi	900	Au	Ag	Fe	?	Sn	Cu	Pb
Syriac	1000-1000	Au	Ag	Fe	Electrum (Hg)	Sn	Cu	Pb
Monasses	1150	Au	Crystal	Fe	Bronze	Ag	Sn	Pb
Chaucer	1380	Au	Ag	Fe	Hg	Sn	Cu	Pb
Agrippa	1533	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
				Corrosion Potential				
NASA corrosion potential in seawater	2001	Au	Ag	Steel[3] (304 & 316)[4, 5]	Bronze (G)[6]	Cu	Sn	Pb

http://corrosion.ksc.nasa.gov/html/galcorr.htm

1. Bronze: predominately Cu
2. Electrum: a native alloy of Ag and Au with 5-50% silver content
3. Steel: 0.2-1.5%C remainder Fe
4. Steel 304: 0.08% C; 2% Mn; 18-20% Cr; 0% Mo; 8-10.5% Ni; Balance Fe; 1% Si; 0.045% P; 0.03% S
5. Steel 316: 0.08% C; 2% Mn; 16-18% Cr; 2-3% Mo; 10-14% Ni; Balance Fe; 1% Si; 0.045% P; 0.03% S
6. Bronze G: 88% Cu; 10% Sn; 2% Zn

Table III: Properties of elements.

Element	mp °C	bp °C	d (g/cm3)	Physical state, RT	Color	Refractive index, η	Mohr hardness scale (1 to 10)
Au	1064	2897	17.0	Solid	Gold		2.5-3
Ag	962	2212	10.30	Solid	Silver	0.18-0.54	2.5-4
Steel (0.2% C)	Variable	Variable	7.75	Solid	Variable		5-8.5
Fe	1535	2750	7.87	Solid	Gray		2.75
Hg	-38.87	356.87	13.59	Liquid	Silver/white	1.6-1.9	
Bronze, Brass	Variable	Variable	Variable	Solid	Variable		3-4
Cu	1083	2567	8.93	Solid	Reddish		2.5-3
Sn	231.89	2260	6.52	Solid	White/gray	2.1	1.5-1.8
Pb	327	1740	11.343	Solid	Silver/blue	2.01	1.5

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> *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 [Saturn], taking lead to symbolize his slowness; the second with Aphrodite [Venus], comparing the tin with her brightness and softness; the third with Zeus [Jupiter], the bronze symbolizing the firmness of the god; the fourth with Hermes [Mercury], for both iron and Hermes are reliable and hardworking; the fifth with Ares [Mars], 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 this text color is the basis of assignment for only silver and gold. Density, hardness or softness, and reflectivity serve as the basis for the remainder of the metals. Lead is correctly identified as the densest of the metals (Table II). Density, however, is only used for sorting lead. Hardness/softness is mentioned for two assignments: tin and bronze (the major component of which is copper). Hardness is a function of the electron configuration and played an important role in the use of the metals and in their manufacture. The Mohr hardness scale (talc = 1 and diamond = 10) places all the metals relatively low in hardness. The brightness of mirrors (the major component is tin) derives from the optically active Cu_3Sn_8 δ phase of a Cu/Sn alloy which is, in Celsus' account, the factor for sorting the metal.

Taking Celsus' 2nd paragraph at face value suggests a rather arbitrary sorting of metals to the planets based on a hodge-podge of chemical observables (Table III). The arbitrariness of the sorting seems to be re-enforced by the fact that some of the assignments change with time (Table II, Fig. 4). We find bronze disappearing and copper appearing, the mixed material Celsus quotes as assigned to Mars replaced with iron, and competitive planetary assignments for Cu and Sn. We also have mercury making selected appearances and disappearances. By the time of Chaucer we have:

> *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.*

The "Oxidative/Reductive" Sequence, A Superior Hypothesis?

The data above give us three separate clues pointing toward the metals as the basis for the sequence of the days (metal/days as opposed to planet/days). Those clues are: the exact text of Celsus, the historical timing of major alterations in metal/days, and the sporadic appearance of mercury. First we consider Celsus' text. The first part of the text refers explicitly to the purification of the soul through a series of metal gates. Only after this is established does Celsus make the assignments of the planets to the metals. This suggests that the metal sequence is fixed by purity (reactivity) of the elements and independent of the planets. The justification for the assignment of the metal to the planets is therefore contrived to fit the purity sequence of the metals and the established Chaldean hourly sequence of the metals. In fact, the astronomical sequence, according to Celsus, may be entirely contrived to fit the chemical purity sequence.

Second, we note that the sequence of the metals with respect to the days is relatively fixed from BCE to ~700 AD (Fig. 4). From ~700 AD to 1400 AD, multiple metals swap assignments until a "final" sequence is obtained. This suggests that (a.) the order was important enough to require change and a record of the change and (b.) that some historical event occurred around 700 AD that altered the philosophical basis for the ordering of the metals. Why is the order of metals significant? The answer to this question can be approached by asking, why assign metals to days/planets at all? The answer must lie in the importance of those metals in society. We note that Celsus does not, strictly speaking, order the pure metals. He includes bronze (Cu/Sn alloy) and in the 5th purity stage he uses an unnamed alloy. We also note that some pure elements known at that time were not placed in the sequence (*e.g.* S and C). We conclude that the assignments made were of materials of metallurgical importance. We predict that the sequence of metal/days should track the accumulated knowledge of metallurgy.

At the time of Celsus metallurgy was based primarily on manipulations by fire. Consequently we may assume that the "purity" index is more appropriately thought of as an inertness to fire oxidation. The inertness or reactivity of the metal with respect to oxidation by thermal treatment can be described by the oxidation reaction

$$xM + \left(\frac{y}{2}\right)O_2 \xrightarrow{heat} M_xO_y \qquad (1)$$

Table IV. Metallurgical reactions.

Metal	M_xO_y	ΔG_f^o (kJ/mole)	Reaction	E°,V
Au	Au_2O_3	+163	$Au^+ + e \leftrightarrows Au$	1.83
	AuO_3	-24.26	$Au^{3+} + 3e \leftrightarrows Au$	1. 52
	AuO_3^{2-}	-51.9	$AuCl^{-2} + e \leftrightarrows Au + 2Cl$	1.154
			$AuCl^{-4} + 3e \leftrightarrows Au + 4Cl$	1.002
Ag	Ag_2O_3	+120.58	$AgO^- + 2H^+ + e \leftrightarrows Ag + H_2O$	2.220
	AgO	+13.5	$Ag_2O + 2H^+ + 2e \leftrightarrows 2Ag + H_2O$	1.173
	Ag_2O	-11	$Ag^+ + e \leftrightarrows Ag$	0.7991
			$AgCl + e \leftrightarrows Ag + Cl$	0.2223
Hg	Hg_2O	-53.5	$HgO(c,red) + 2H^+ + 2e \leftrightarrows Hg_{(l)} + H_2O\ (l)$	0.9256
	HgO	-59	$Hg_2^{2+} + 2e \leftrightarrows 2Hg$	0.8535
			$Hg_2Cl_2(c) + 2e \leftrightarrows 2Hg(l) + 2Cl-$	0.268
Cu	CuO	-128	$Cu^+ + e \leftrightarrows Cu$	0.52
	Cu_2O	-148	$Cu^{2+} + e \leftrightarrows Cu$	0.34
	CuO_2^{2-}	-183.9	$CuO + 2H^+ + 2e \leftrightarrows Cu + H_2O$	0.536
			$Cu_2O + 2H^+ + 2e \leftrightarrows Cu + 2H_2O$	0.46
			$CuCl + e \leftrightarrows Cu + Cl$	0.121
Sn	SnO	-257	$Sn(OH)_2 + 2H^+ + 2e \leftrightarrows Sn + 2H_2O$	-0.091
	SnO_2(hydr.)	-477.2	$SnO(black) + 2H^+ + 2e \leftrightarrows Sn + H_2O$	-0.104
	SnO_2	-520	$Sn^{2+} + 2e \leftrightarrows Sn$	-0.136
	SnO_3^{2-}	-574.9		
Pb	PbO	-180	$Pb(OH)_2 + 2H^+ + 2e \leftrightarrows Pb + 2H_2O$	0.242
	PbO_2	-217	$Pb^{2+} + 2e \leftrightarrows Pb$	-0.126
	Pb_2O_3	-411.78	$Pb(Cl)_2 + 2e \leftrightarrows Pb + 2Cl^-$	-0.268
	Pb_3O_4 (minium)	-617		
Fe	$Fe_{0.95}O$	-245	$Fe^{3+} + 3e \leftrightarrows Fe$	-0.030
	FeO	-251	$Fe^{2+} + 2e \leftrightarrows Fe$	-0.44
	Fe_2O_3	-742		

Reactions of this type can be sorted by the standard free energy of formation, ΔG_f^o (Table IV).[10-12]

The standard free energies of formation are entirely consistent with the purity rank of the assigned metals in the first important account of the metal/planetary sequence (Celsus) (Fig. 5). Figure 5 represents all of the free energy values of the relevant metal reactions (Table IV) associated with the five metal/day assignments plotted against the purity rank in the Celsus sequence. (Figure 5 contains data for the metal copper, although the purity sequence specified by Celsus specifies the alloy bronze. The data for copper (small circles) is included for comparison with Fig. 5). As can be observed, the most reactive metals are lead and tin and the least reactive metals are gold and silver, consistent with the assignment of these metals in the purity sequence of Celsus. Rather surprisingly, given the arbitrary distance in the purity steps, a correlation can be derived between the purity rank and the free energies of oxide formation (data for copper excluded). This correlation was obtained by removing the one data point for iron (Fe_2O_3) which is substantially off the trend. It is interesting to note that the only time that lead is displaced from the bottom of the purity sequence [The Venerable Bede (673-735 AD) (Table II, Fig. 4)], it is displaced by iron.

What is the historical event that set off centuries (700-1400 AD) of reordering of the metals? The major changes observed in Fig. 4 occurring at ~750 AD relate to the discovery and manipulation of mineral acids, in particular that of nitric acid, as described by Jabir (720-815 AD). By this time in history the planet/day sequence had become permanent and any subsequent changes in metal purity require shuffling of the metals to names of days rather than a re-shuffling of sequence of the days of the week.

Nitric acid oxidizes metals to a variety of products via the reactions

$$M^{m+} + me \Leftrightarrow M \quad (2)$$

$$M^{m+}_{\frac{2y}{m}} O_y + 2yH^+ + 2ye \Leftrightarrow \frac{2y}{m} M + yH_2O \quad (3)$$

For oxidations occurring in solution, the apparent formal potential, $E^{o\prime}$, applies. Figure 6 gives the metal/day sequence corresponding to Chaucer, which appears to track the redox potentials of Reactions 2-3 (Table IV). The correlation with the purity sequence is, however, not as good as the sequence for oxidation by fire. The relatively poorer correlation can be explained by the simultaneous introduction of aqua regia (HNO_3/HCl) allowing oxidation to be boosted by chloride complexation (see Fig. 6, triangles; Table IV). Jabir is also associated with the advent of aqua regia (mixture of nitric and hydrochloric acids) which opens up reactions in which the metal is oxidized to a chloride complex.

$$MCl_z^{(m-z)+} + me \Leftrightarrow M + zCl^- \quad (4)$$

Even allowing for chloride complexation the correlation is poorer than for fire oxidation (omitting low lying points for iron R^2 = 0.56). The poorer correlation may explain the oscillations in assignments between 700-1400 AD.

The poor fit is most likely related to the rates of reactions in nitric acid and the presence of ions which accelerate passivation. It is known that Fe, Ni,[13-16] Sn,[17-19] Pb,[20,21] and Cu[22,23] dissolve in dilute nitric acid more rapidly than in concentrated due to the formation of a passivating layer that forms on the electrode surface in concentrated nitric acid. Thus while the formal potential for the oxidation of iron (two data points outlined in white, Fig. 6) predicts a high reactivity, the kinetics of the reaction shift it into a higher "purity" rank.

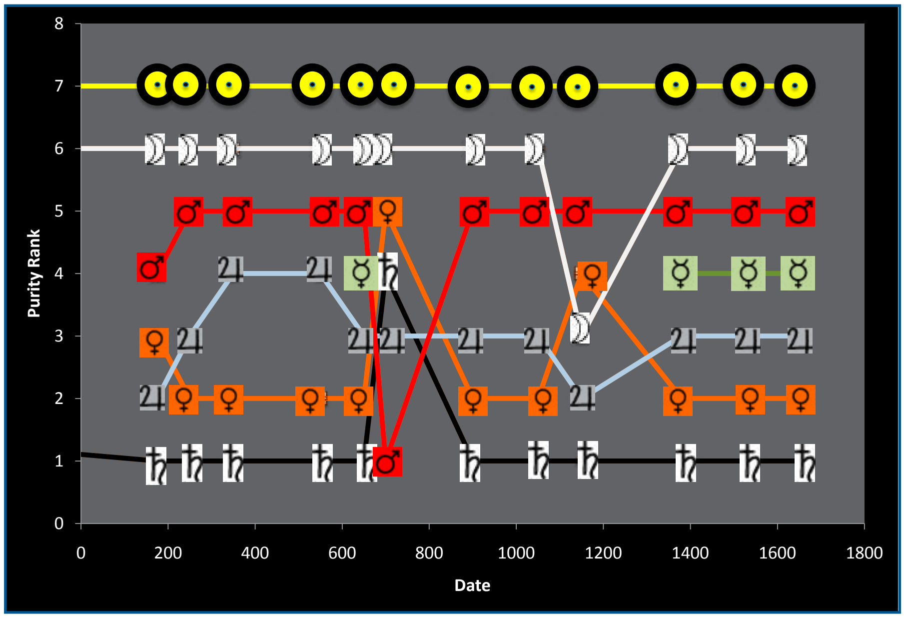

Fig. 4. *A plot of element/metal assignments to purity rank over history. Alchemical symbols are used for the various metals. The final (1700s) sequence is from bottom to top: lead, copper, tin, mercury, iron, silver, gold. The compilation of assignments can be found in Table III and is derived from Nriagu.*

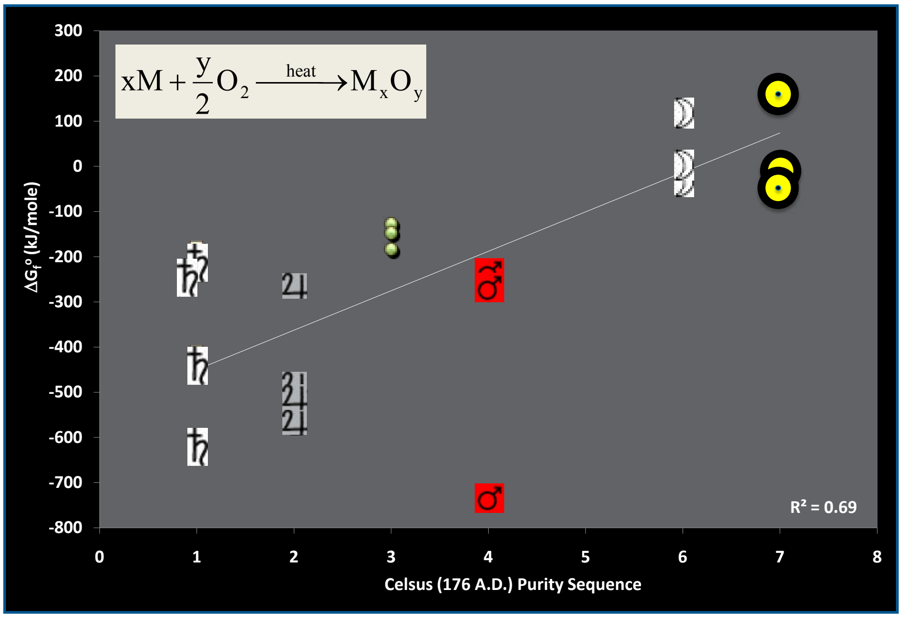

Fig. 5. *A plot of Celsus' (176 AD) purity rank vs. the free energy of formation of a variety of oxides. Reactions are shown in Table IV. The symbols for the metals are the same as in Fig. 4. The three circles at purity rank 3 (bronze) represent reactions involving metallic copper.*

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In homogeneous solution an autocatalytic decomposition sequence for nitric acid has been proposed[24]

$$NO_3^- + 2H^+ + 2e \rightarrow NO_2^- + H_2O \quad (5)$$

$$NO_2^- + H^+ \rightarrow HNO_2 \quad (6)$$

$$HNO_2 + H^+ \rightarrow NO^+ + H_2O \quad (7)$$

$$NO^+ + e \rightarrow NO \quad (8)$$

$$2NO + NO_3^- + H^+ + H_2O \rightarrow 3HNO_2 \quad (9)$$

The variability in the reactivity of the nitric acid based on concentration is derived from control of Reactions 6, 7, and 8 which drive the catalytic Reaction 9. Passivation may occur through adsorption of NO_2^- to the metal surface.[25] With time the adsorbate layer may convert to more stable species diffusion blocking layers.[26] In the process zero valent iron can be converted to Fe_2O_3.[27] In Fig. 6, the three data points which fall directly on the regression are for Fe_2O_3 pH2-4. The formation of the initial film may be disrupted by chloride ions. It is interesting to speculate that the variability of the acid (nitric *vs.* aqua regia) and the complexity of the nitric acid reaction may account for the 700-year lag in stabilizing the sequence of metals to the planet/days.

Clue 3, the sporadic appearance of mercury as a metal/day, supports the idea that the sequence of metal/days should reflect metallurgical knowledge. Mercury was known as a pure element by about 500 BCE but does not show up as a metal/day in the Babylonia list (1600-1400 BCE). In Roman times while mercury was used to recover gold from embroidery it was not used in ore refinement. Mercury's first unambiguous appearance is in ~650 AD but it does not become embedded in the days until Chaucer's list. At that period in history mercury was used in metal ore recovery.[4] By the time of Agrippa (1533 AD), Hg had become well used in metallurgy in the processing of silver ores in Mexico, accounting for its subsequent "permanent" inclusion in the metal/day sequence.[28]

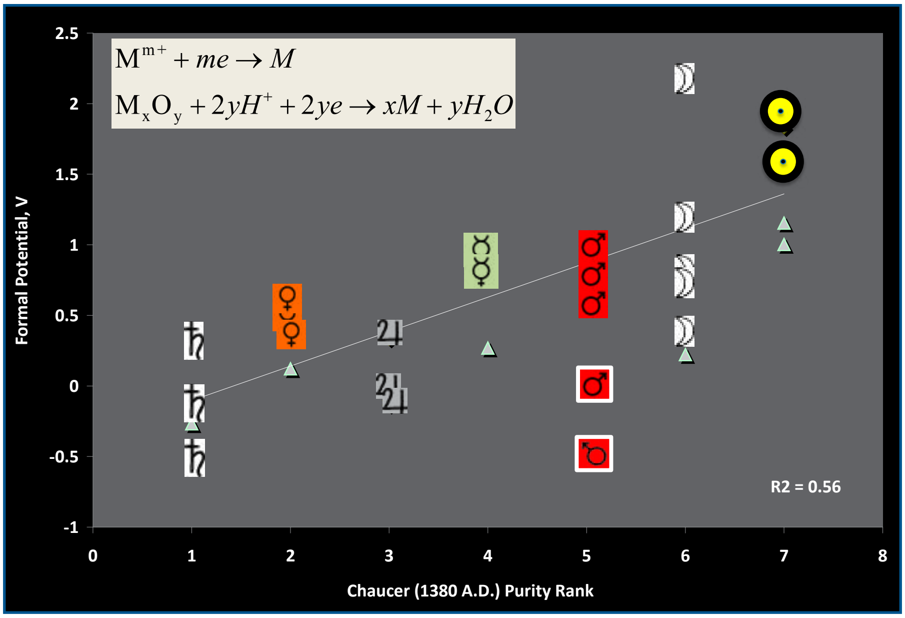

Fig. 6. *A plot of Chaucer's (1380 AD) metal sequence vs. the standard electrochemical voltage (vs. NHE) of relevant half reactions. The symbols for the metals are the same as in Fig. 4. Reactions are shown in Table IV. Triangular symbols represent reactions taking place in a chloride matrix such as aqua regia. The three normal data points for iron correspond to Fe_3O_2 between pH 2-4. The low lying white boxed data points for iron correspond to Fe/Fe^{3+} and Fe/Fe^{2+}. See text for a discussion.*

Conclusion

The two hypotheses outlined above seek to explain the codified sequence of the seven-day week. The "Astronomical Hypothesis" is based on an approximately accurate sidereal period of the planets counted to fit seven 24-hour days, resulting in a week that begins on Saturday. Metals are then arbitrarily force-fit to that planet/day sequence to achieve a metal purity sequence by counting the days backwards from Saturday to Sunday. The "Oxidation/Reduction" sequence is based on accurate metallurgical knowledge of the reactivity of metals to air oxidation. The resulting metal/days subsequently have planets attached to them in an arbitrary force-fit. Occam's Razor test, (the simplest hypothesis should be most accurate) suggests that the "Oxidation/Reduction" sequence is superior. The "Oxidation/Reduction" hypothesis requires only seven data points (reactivity of the metals) to define the days of the week, while the "Astronomical Hypothesis" requires seven astronomical observations to then be "sorted" by a relatively complicated scheme in which the metals are attached to the days of the week counting backwards from Saturday toward Sunday. The "Oxidation/Reduction" hypothesis also accounts for variations in the metal/day assignments prior to codification (see the Babylonian list, Celsus' list, and the list of Vettius Valens).

About the Author

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