



From telluric helix to telluric remix

Philip J. Stewart¹

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Abstract

The first attempt to represent the Periodic system graphically was the Telluric Helix (*Vis Tellurique*) presented in 1862 by Alexandre-Emile Béguyer de Chancourtois, in which the sequence of elements was wound round a cylinder. This has hardly been attempted since, because the intervals between periodic returns vary in length from 2 to 32 elements, but Charles Janet presented a model wound round four nested cylinders. The rows in Janet's table are defined by a constant sum of the first two quantum numbers, n and l , so that they end with the s-block, headed by hydrogen and helium. By combining Janet's table, Edward Mazurs' version, in which each row represents an electron shell and Valery Tsimmerman's use of a half square for each element, I have produced a representation that can be printed out and wound round to make a cylinder with manageable dimensions. In the unwound version, I have placed the s-block in the middle, to emphasise its pivotal nature, since it both ends each $(n + l)$ row and contributes electrons to the valence of elements in the next $(n + l)$ row; it thus does not necessarily belong either on the left or the right side of a table. The downward arrows that link subshells within each $(n + l)$ series graphically illustrate the Janet Effect (or Madelung Rule). To acknowledge my debt to Chancourtois, Janet, Mazurs and Tsimmerman, I call my design the 'Telluric Remix'.

Keywords Periodic system · Continuous sequence · Helix · Spiral · Left-step table · Charles Janet · Quantum numbers

History of helical versions

The Telluric Helix (*La Vis Tellurique*) was the first graphic representation of the periodic system of the elements, conceived as a spiral wound round a cylinder. It was designed by Alexandre-Émile Béguyer de Chancourtois (1862), a French mineralogist. He published his idea without an illustration, and it was little noticed until much later, as described by van Spronsen (1969) pp. 97–102. 'Telluric', from Latin tellus, telluris, earth, recalls the 'earths'—oxides—in which many elements had been discovered. In English it is often referred to as the 'Telluric Screw', though a screw usually tapers to a point, suggesting a

✉ Philip J. Stewart
philip.stewart@plants.ox.ac.uk

¹ University of Oxford, Oxford, UK

conical outline, so ‘helix’ is more appropriate, although Archimedes’ helix (κοχλίας–kochlias, cf. cockle) is called his ‘screw’.

In fact, a helix with constant diameter could not work for the periodic system without gaps in all except the longest sequences, because the intervals between periodic returns vary in length from 2 to 32 elements. Chancourtois divided his cylinder into 32 vertical columns, but this was simply the effect of halving the circle five times; for the groups of elements to line up, there would have been big gaps. Subsequent efforts to represent the periodic system as a helix with cylindrical outline recognised the need to vary the size of the coils; a successful attempt to draw this in two dimensions was that of Georg Schaltenbrand (1920). Charles Janet (1928b), plate 3, improved on it by winding his helix round four nested cylinders. His drawing is too big to reproduce here but may be seen in van Spronsen (1969) p. 175. It would be very difficult to realise physically, and there is no evidence that he ever constructed it.

A cone would have been a possible alternative to a cylinder, but the projection of a cone on to its base is a spiral, and indeed spirals have been popular since the version produced by Baumhauer (1969). Mendeleev himself never represented the system as a spiral, though he wrote ‘In reality the series of elements is uninterrupted and corresponds, to a certain degree, to a spiral function’—translated in Jensen (2002), p. 56. Janet (1930) himself drew a periodic spiral (Fig. 1)—notice ‘element zero’—2 protons with 2 ‘nuclear electrons’; in effect 2 neutrons before their discovery! Other examples include those of John D Clark, (1933, 1949), and Edgar Longman (1951)—a graphics artist whose mural transformed Clark’s ‘Circus Maximus’ design into an elegant ellipse with a dynamic upward slope, on which I based my own ‘Chemical Galaxy’—Stewart (2004). Spirals and helices have a number of advantages: they can give an impression of the overall shape of the periodic system; they show the proximity of neighbouring elements, which are separated when the sequence is broken up; they have aesthetic appeal for our eyes which evolved in a world of curved forms. However, the direction of reading necessarily changes between the upper and lower halves of the chart. Tables have the advantage of utility and convenience, especially for eyes used to pages in the Roman, Cyrillic or similar alphabets.

Periods or rows?

Any arrangement of the elements in order of atomic number is, of course, a purely human construct; even the concept of elements is the result of a long evolution—Paneth (1962), Scerri (2006a). If the uninterrupted series is to be cut into strips to make a table, there is a variety of ways of placing the cuts. The resulting rows are commonly referred to as ‘periods’, but there is no one correct way of delimiting these. A period (Greek *περίοδος*) is literally a coming round again. When properties repeat after a definable interval, their return is periodic, so from carbon to silicon is just as much a period as from fluorine to chlorine. The division into rows needs to be based on something more fundamental than personal choice. Most chemists probably think it self-evident that rows should begin with hydrogen and the alkali metals and end with the noble gases, but it has not always been so.

Mendeleev (1869) in his *Tabelle I* showed six columns, not rows, and their limits now look strange: (1) hydrogen and lithium; (2) beryllium to sodium; (3) magnesium to indium; (4) titanium to thorium (atomic weight 118!); (5) zirconium to barium; (6) unknown of atomic weight 180? to lead. *Tabelle II*, Mendeleev (1871), looks more familiar, with ten rows (*ряды*). For Mendeleev, two rows made a ‘period’ (1) hydrogen to fluorine, (2)

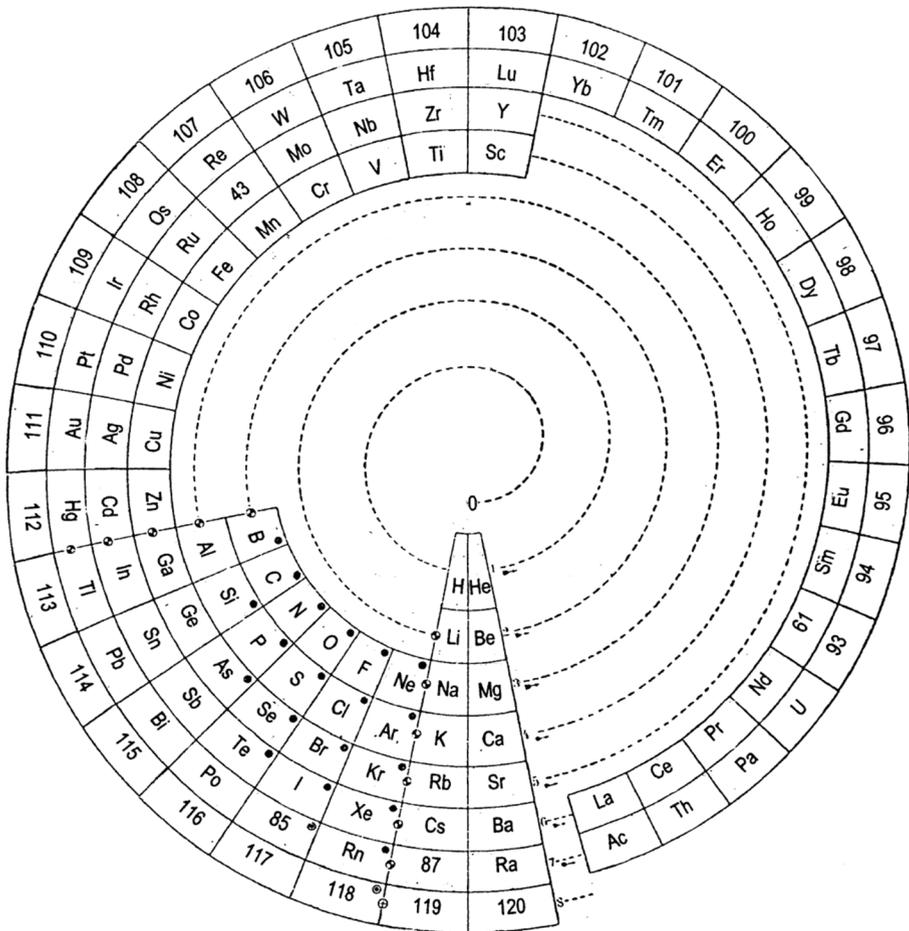


Fig. 1 Periodic spiral by Charles Janet

sodium to copper, (3) [copper]/zinc to silver, (4) [silver]/cadmium to eka-silver (in the middle of what should be the lanthanides), (5) [eka-silver] to gold, (6) [gold]/mercury to eka-gold (in the middle of what should be the actinides). The system worked, with its alternating rows of seven and of eleven elements, as $7 + 11 = 18$, the combined number of electrons in *s* plus *p* plus *d* orbitals; (there was double counting, which compensated for the missing group of noble gases: the ‘coinage metals’ were placed both at the end of the elevens and—tentatively—at the beginning of the sevens.) His system broke down after barium, where the lanthanides should be, but seemed to resume after tantalum—Stewart (2018b). He called this pattern the ‘Periodic Law’, although he was unable to define it mathematically. His organizing principle was the highest oxidation state, indicated at the top of each column, though this was largely notional in his group VIII.

When the noble gases were discovered, Mendeleev placed them very logically on the left of his revised version as group zero—their highest oxidation state—so that his ‘typical’ row and the first of his sevens began with helium and neon respectively. From argon onwards, they stood at the beginning of the rows of eleven, now with the ‘coinage metals’

in parentheses in group VIII. With the addition of ‘aether’ and ‘coronium’, his ten rows became twelve, (Mendeleev 1904). Eventually the inert gases were moved to the right-hand side, but it is only since then that it has been generally accepted that they close the rows. It makes sense intuitively to see a break here, since the electrons added up to this point play no further part in bonding, but the decision to count rows from alkali metals to noble gases is not forced; it is an option, as is the numbering of groups from 1 to 18 on this basis. For an unusual choice, see the version of Scerri (2006c), apparently since abandoned (in fact an adaptation of an LST of Janet 1928a, already inadvertently reinvented by Simmons 1947), in which the rows begin with the halogens (including hydrogen) and end with the chalcogens.

Charles Janet’s table

Charles Janet, an engineer, geologist and biologist, came to the study of the periodic system in 1927, at the age of 78. By November 1928, he had produced the definitive version of his left-step table (LST), which he always referred to as ‘helical (*helicoidal*)’, relating it to his representation on nested cylinders—Janet (1928b). Figure 2 shows this, drawn with a half-square per element as suggested by Valery Tsimmerman (2006). For the sake of symmetry, Janet moved the alkali and alkaline earth metals to the right-hand side with hydrogen and helium as the first row, and lithium and beryllium as the second, and hypothesised the existence of transuranian elements. Taking the differences between the atomic numbers of the alkaline earth elements plus helium, he found the perfectly regular series 2–2–8–8–18–18–32–32, instead of the incomplete 2–8–8–18–18–32, obtained by Rydberg (1914), who took the differences between those of the noble gases including helium. Two years later, he demonstrated that his table was structured by the quantum numbers—Janet (1930). It has been relaunched by Katz (2001), and extensively examined by Bent (2006), and Weinhold and Bent (2007); see also Schwartz (2007).

Janet’s rows all end with the ns^2 elements—helium and the alkaline earth metals—but begin with ns^1 , np^1 , nd^1 and nf^1 elements respectively. This made the order of filling (*‘l’ordre de capture des electrons*) regular, with ℓ (he used Bohr’s k , equal to $\ell + 1$) decreasing as n increases, so that $(n + \ell)$ remains constant along each row—Janet (1930). This gave him an objective basis for dividing the sequence of elements into rows, which, for clarity, I shall refer to as ‘ $(n + \ell)$ series’. Janet thought it might be an absolute rule, but it has exceptions, so I shall call it the Janet Effect, rather than his ‘rule’. How many exceptions there are depends on how they are defined—at most 20 out of 118 elements. It is an idealization, like any scientific model.

Erwin Madelung (1936), said the same thing six years later, again without exceptions; his *Aufbau* is Janet’s *ordre de capture*. Because Janet was unrecognised—Stewart (2010)—it came to be called ‘Madelung’s Rule’. This effect has not been deduced from first principles; Per-Olov Löwdin (1969) proclaimed the derivation of the $n + \ell$ rule to be a major unsolved problem in quantum chemistry—Wong (1979), Allen and Knight (2002), Scerri (2006b), Schwarz (2004). An explanation was proposed by Klechkovsky (1962). See also Ostrovsky (2001), Schwarz (2007), Scerri (2019).

In most of his writings Janet referred to ‘*nappes*—layers’, meaning the four nested cylinders of his helical model, but he may be at the origin of the term ‘block’ in English. Near the end of his only English article, Janet (1929)—or rather his translator—wrote ‘the vertical groups are 32 families in four blocks, corresponding with four surfaces

LEFT-STEP PERIODIC TABLE

By Charles Janet, November 1928

Block s: $\beta=0$																																					
Block p: $\beta=1$																																					
Block d: $\beta=2$																																					
Block f: $\beta=3$																																					
57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88						
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	Fr	Ra						
89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120						
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og	?							
(227)	(232)	(231)	(238)	(237)	(244)	(243)	(227)	(232)	(231)	(238)	(237)	(244)	(243)	(286)	(287)	(288)	(289)	(270)	(270)	(278)	(281)	(282)	(285)	(286)	(280)	(289)	(283)	(283)	(284)	(284)							
1	2	3		4		5		6		7		8		9		10		11		12		13		14		15		16		17		18		19		20	
H	He	Li	Be	B	C	N	O	F	Ne	Na	Mg	Al	Si	P	S	Cl	Ar	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	Rb	Sr
1.008	4.003	6.94	9.012	10.81	12.01	14.01	16.00	18.99	20.18	22.91	24.31	26.98	28.09	30.97	32.06	35.45	39.97	39.10	40.08	44.96	47.87	50.94	51.99	54.84	55.85	58.93	58.89	63.55	65.38	69.72	72.63	74.92	78.97	83.79	85.47	87.62	

Fig. 2 Charles Janet's Table, redrawn with added elements

of cylinders, two dyads of blocks of families corresponding with the surfaces of two cylinders.' Simmons (1947) inadvertently presented as new an LST from Janet (1928a), with hydrogen and helium over fluorine and neon (he almost certainly never read the paper as it was scarce and in French). He wrote 'The new long chart displays the elements in integral zones (solid blocks) of related elements.' This was his only reference to 'blocks'; elsewhere he used 'zones', and he regarded the metals and non-metals of the p-block as separate zones. He ungenerously said of Janet (1929) 'Janet's insistence on coiling the chart, together with the paucity of explanation, cause Janet's table to be regarded as only touching the fringe of the present arrangement.' Janet was thus the victim of his own extraordinary ability to see things in three dimensions and to transform them into a range of beautiful 2-D curves. Simmons (1948) came back with a copy of Janet's definitive LST—Janet (1928b) and (1929)—but with no reference to its author. This time he used the word 'block' all over the place and very exactly in the modern way—s-block (including H and He), p-block etc.

Janet's blocks are not just graphic artefacts; they have distinctive characters. The s-block is radically different from the others, looking back to the $(n + \ell)$ series that it completes, and forward to the following $(n + \ell)$ series, to the bonding of which it contributes, until ns^2 combines with np^6 to make the octet of a noble gas ('nobility' decreasing as atomic weight increases), at which point all eight electrons retreat into the atomic core (the first time with helium, where there is no np^6). The p-block comprises non-metals and metals, roughly forming two triangles and separated by metalloids; they include many of the commonest elements and of those essential to life. The d-block consists entirely of metals, with multiple oxidation states except in its extremities (the scandium and zinc columns); withdrawal of d electrons into the core increases as its orbitals fill up; the preceding lanthanide contraction makes the third row of the block very similar chemically to the second. The 4f elements are predominantly trivalent metals, with the f electrons withdrawing into the core almost from the beginning; those of 5f are more varied with electrons less tightly bound and valences from 3 to 6. The nf orbitals are energetically close to those of $(n + 1)d$, with consequent substitutions, especially in 5f. Within each block there is a marked difference between the elements in the first half of each subshell, with half-filled orbitals, and those in the second half, where increasing numbers of orbitals are fully occupied.

There are still arguments about where the f-block begins and ends. A traditional approach is to place lanthanum under yttrium in a conventional table, at the price of dividing the d-block, which looks tolerable if the lanthan/actinides are footnoted but is unacceptable in the LST. It is surprising that people who place helium above neon because of its (lack of) chemical behaviour, want to locate lanthanum instead of lutecium beneath yttrium in spite of its chemical behaviour. Consider the simple fact that lanthanum was discovered in ceria, along with six other light lanthanides (cerium to gadolinium, without promethium) and that lutecium was discovered, along with scandium and yttrium and six heavy lanthanides (terbium to ytterbium) in yttria. The reason for this is that lutecium inherits the lanthanide contraction and lanthanum doesn't, which means that the Lu^{3+} ion is very similar in size to the Y^{3+} ion, and its chemistry resembles that of yttrium, just as that of hafnium resembles that of zirconium. This, plus the fact that the f shell is full in ytterbium, should be decisive. One may add that nobody advocates placing thorium in the d-block, although it has no f electrons in the ground state. A radical solution. In a continuous representation it is to group all the elements from lanthanum/actinium to lutecium/lawrencium with scandium and yttrium, as done by Clark (1949) and Longman (1951).

My telluric remix

Practically all tables, including Janet's, have rows that represent sections of the sequence of atomic numbers. The one serious exception is in two little-noticed versions by Mazurs (1974), Figs. 136 and 137, p. 134, (dated 1965), in which the rows represent the shells defined by the principal quantum number. The first and clearest of these tables is shown here as Fig. 3. This arrangement has the advantage of showing graphically the Janet Effect, which causes the $(n + \ell)$ series to snake up, along or (mostly) down between subshells.

Reproducing Mazurs' table using a half-square per element, following Valery Tsimmerman, I saw that, with width and height of 16 and 8 units (or 20 and 10, with spaces added), it would fit on to the surface of a sphere, with the s-block running from 'pole to pole' and shells 4 and 5 running around the 'equator' (Stewart 2018a). This can also be represented on the surface of a cylinder, which, with rearrangement of the blocks, I have called my 'Telluric Remix' in honour of Chancourtois' original cylinder and the contributions of Mazurs and Tsimmerman. It is both a table, before it is rolled up, and a representation of the continuous sequence, with the help of some arrows, when it becomes a cylinder; Fig. 4.

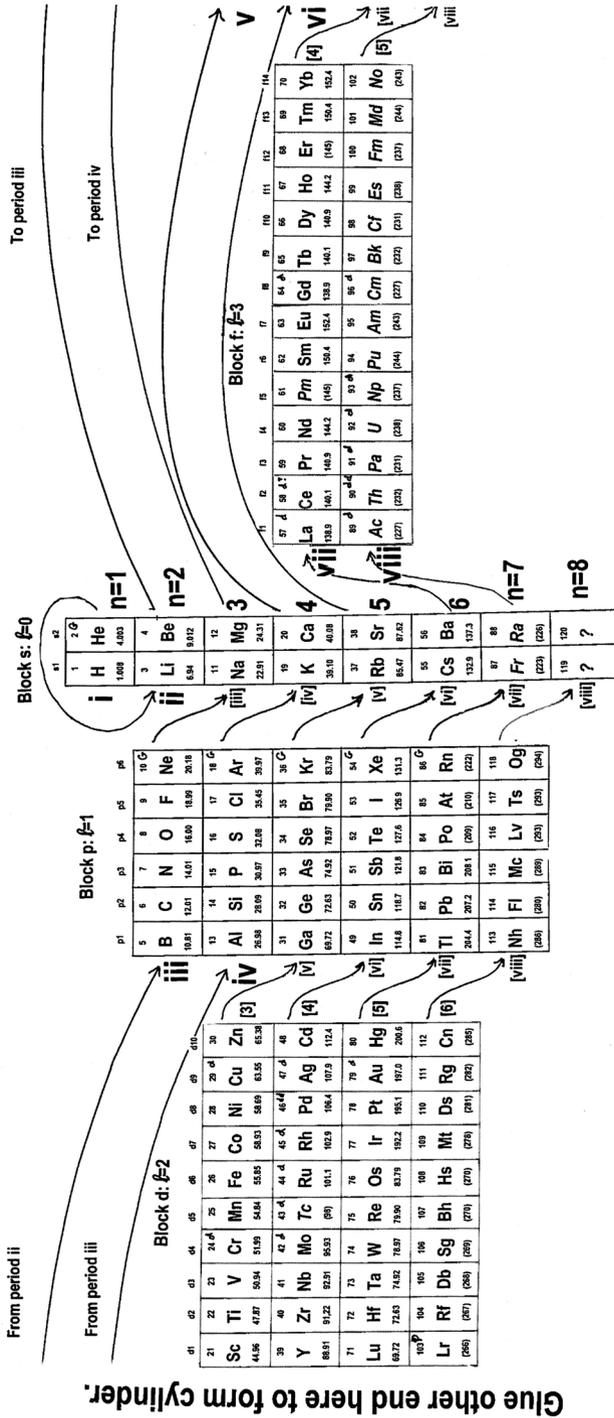
I could have placed the s-block either on the left or on the right. Instead I have planted it in the centre of my design to emphasise its pivotal nature and because there are no sides in a continuous representation. It is very different from the other blocks, each of which is confined to its sector of the table, apart from intrusions of d orbitals into f and s. Once the d orbitals are full—and even before that—they are drawn into the core and play no further part in bonding. The f orbitals are drawn in even sooner. The p orbitals withdraw definitively in the noble gases. The s pair behaves quite differently, joining with the f, d and p electrons of the next $(n + \ell)$ series to form their valence shell. This declines in the heavier members of the p-block (sometimes called the 'inert-pair effect'), and ceases completely when the next s subshell begins.

Janet placed hydrogen and helium at the head of the s-block, though both are non-metals and the rest of the block consists of strongly electropositive metals. This position for hydrogen is generally accepted as there is no obvious alternative, though some have treated it as a halogen. The similar case of helium is more controversial, as it clearly behaves as a noble gas. However, the explanation for this is that it completes the first shell and the first $(n + \ell)$ series and its electrons are very strongly drawn to the nucleus. The behaviour of hydrogen can be explained in a similar way: it is half way to a full shell and is reluctant either to lose or gain an electron, so it is only superficially like lithium or fluorine. It is more like a 'univalent carbon', with intermediate electronegativity and mainly covalent bonding, as advocated by Cronyn (2003). It seems appropriate too that hydrogen and helium stand side by side at the top of the s pillar—the two primeval elements, from which all others derive and which make up most of the non-dark matter in the universe.

The rows are marked with Arabic numerals, which indicate the values of the principal quantum number, and Janet's $(n + \ell)$ series are indicated by Roman numerals. Groups are numbered sequentially within each block, and in general the xth member of each subshell has x electrons in that subshell. Exceptions are shown by a small d (or two) in the corner, signifying that a d electron replaces an s electron in the d-block or an f electron in the f-block (note also p in lawrencium). This makes it easy to determine the electronic configuration of each element: starting from the last noble gas, note the number of electrons in the subshell[s] up to the element in question. Noble gases are marked with a letter G in the corner.

Blocks:		Inner transition elements.										Transition elements.										Representative elem.											
Subshells:		f										d										p								s			
Electrons:		1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	1	2

TELLURIC REMIX by Phiilip J Stewart



Critics may suggest that this layout makes it harder to see things such as diagonal relationships and the ‘knight’s move’, but these are not an essential feature of the periodic system. As regards the similarity of highest oxidation state between elements in the p and d-blocks, which caused Mendeleev to put them in the same Roman-numbered groups, these can be deduced as far as his group VII by matching up the number of their outer p or d electrons, to which should be added 2 for the s electrons. General trends such as electronegativity or the division between metals and non-metals can be read in much the same way as in the traditional table.

Another criticism is that half squares are not big enough to contain much information, but I believe this is a myopic view of the purpose of a periodic chart. As an end-paper table, it should mainly suffice to remind one of the position of individual elements in relation to their neighbours and analogues, or to recall the values of the atomic number and the atomic weight. As a wall chart, it should give an overall view of the system, conveying its harmony and its beauty. Detailed information about specific elements is best conveyed by a website or book and not by nose-to-wall scrutiny of a square on a big chart.

I claim six advantages for my ‘Remix’:

1. It can be printed out on a sheet of paper in standard size, to be displayed as a chart or rolled up to form a cylinder.
2. With the help of arrows, it shows the continuity of the series of elements.
3. It shows clearly the shells defined by the principal quantum number.
4. It illustrates graphically the overall form of the system, summed up by the Janet Effect (Madelung Rule).
5. It emphasises the pivotal position of the s-block.
6. It provides an easy way to work out electronic configurations.

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