Mendeleev and the Periodic Table

The periodic table was originally based on experimental observations of the chemical and physical properties of the elements. The Russian chemist Dmitri Ivanovich Mendeleev, who was professor of chemistry at the University of St. Petersburg, was the most important contributor to the early development of the periodic table. Mendeleev could not find a textbook that suited him and decided to write his own. In the course of writing his book, Mendeleev examined relationships between the properties of the elements and their compounds trying to find a system of organization that would help his students to learn chemistry. He discovered the periodic law, which he published in 1869, and constructed a periodic table soon afterward.

According to Mendeleev's periodic law, "the properties of the elements are a periodic function of their atomic weights." Mendeleev realized that, when placed according to their atomic weights (masses), several elements were out of place. He concluded that the atomic weights must be wrong and put the elements where they belonged on the basis of their properties. Figure 8.16 shows Mendeleev's periodic table of 1871.

Because a number of elements had not yet been discovered, there were several blank spaces (for

Reihen	Gruppe I. — R^2O	Gruppe II. — RO	Gruppe III. — R^2O^3	Gruppe IV. RH^4 RO^2	Gruppe V. RH^3 R^2O^5	Gruppe VI. RH^2 RO^3	Gruppe VII. RH R^2O^7	Gruppe VIII. — RO^4
1	H=1							
2	Li=7	Be=9,4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27,3	Si=28	P=31	S=32	Cl=35,5	
4	K=39	Ca=40	—=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56, Co=59, Ni=59, Cu=63.
5	(Cu=63)	Zn=65	—=68	—=72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	—=100	Ru=104, Rh=104, Pd=106, Ag=108.
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140	—	—	—	— — — —
9	(—)	—	—	—	—	—	—	
10	—	—	?Er=178	?La=180	Ta=182	W=184	—	Os=195, Ir=197, Pt=198, Au=199.
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	—	—	
12	—	—	—	Th=231	—	U=240	—	— — — —

MENDELEEF'S PERIODIC TABLE FROM HIS PAPER IN LIEBIG'S ANNALEN SUPP. 8, 133.

Figure 8.16 Mendeleev's periodic table was published in a German journal in 1872. In German, "Reihen" means row, "Gruppe" means group, and "J" is the symbol for iodine. In the formulas for oxides and hydrides at the tops of the columns, the letter "R" is used to represent any of the elements in a group. Notice that the numbers that are now subscripts in formulas were superscripts in Mendeleev's day. The numbers after the equal signs in the body of the table are the atomic masses of the elements; the elements are arranged in order of increasing atomic mass. Mendeleev placed elements with similar properties in the same group leaving spaces for elements that were not known such as the elements with atomic masses 44, 68, and 72.

example at 44, 68, and 72) in Mendeleev's table. On the basis of the properties of neighboring elements, Mendeleev predicted the properties of these unknown elements. Three of these missing elements were discovered within the next 15 years. The fact that the properties of the newly discovered elements were very similar to the properties predicted by Mendeleev (see Table 8.2) provided convincing evidence for both the correctness and the usefulness of the periodic table. The last missing element to be found was francium, which was not discovered until 1939.

Table 8.2 Some Properties of Germanium

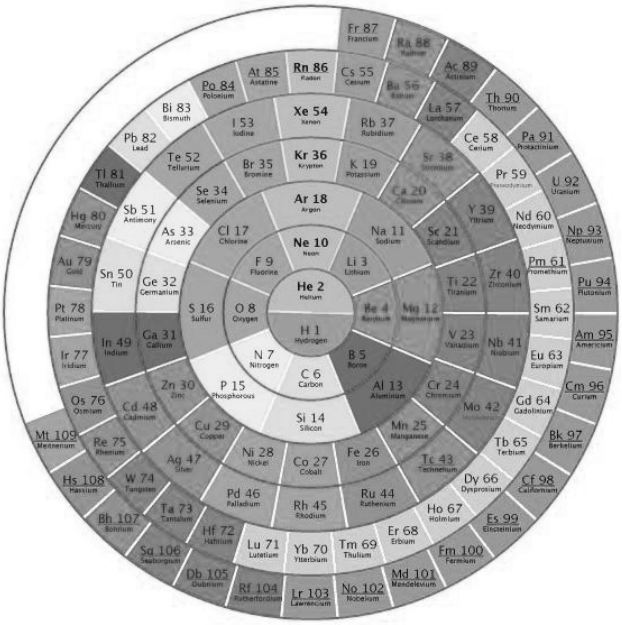
Property	Predicted by Mendeleev in 1871	Found by Winkler in 1886
Atomic mass	72	72.32
Density, g/cm^3	5.5	5.47
Molar volume, cm^3/mol	13.1	13.22
Color	Dirty gray	Grayish white
Heating in air gives	EO_2	GeO_2
Properties of EO_2	High melting point, density = 4.7 g/cm^3	Melting point, 1086 °C* density = 4.703 g/cm^3
Properties of chloride	Formula, ECl_4, boiling point a little under 100 °C and density = 1.9 g/cm^3	Formula, $GeCl_4$, boiling point, 86 °C, density = 1.887 g/cm^3

* Modern value

A number of changes have been made in the periodic table since 1871. When the noble gases helium and argon were isolated from air in 1894, another column was added. The existence of neon, krypton, xenon, and radon was then predicted from the periodic law, and these gases were soon discovered. The position of the lanthanides, an early problem, was worked out by Bohr in 1913. American chemist Glenn Seaborg realized in 1944 that the elements beginning with actinium (atomic number 89) form a second *f*-block series like the lanthanides. Chemists had previously thought that these elements were transition elements. The ability to predict the properties of the transuranium elements (the elements with atomic number greater than 92) was of great help in working with these elements when they were synthesized. All the transuranium elements are radioactive and some have only been made in minute amounts (a few atoms).

The problem of the elements that were out of order according to their masses (Ar and K, Co and Ni, Te and I, and Th and Pa) was solved in 1913 when Moseley discovered atomic numbers. According to the modern periodic law, the properties of the elements are a periodic function of their *atomic numbers*, not of their atomic masses. The atomic number of an element describes the number of electrons outside the nucleus. The arrangement of the electrons in shells and subshells, the electron configuration of the elements, determines the properties of the elements. Why did atomic mass work so well as a basis for organizing the properties of the elements? The answer to this question lies in the aufbau process—as protons are added to the nucleus, the mass of the atom increases. As protons are added to the nucleus, neutrons must also be added, and mass increases faster than atomic number. However, the order according to atomic number is about the same as the order according to atomic mass. A few elements are out of order when arranged according to atomic mass because naturally occurring samples of these elements contain unusually high proportions of heavy isotopes.

Mendeleev was a very practical man, who used his scientific knowledge to improve the yields and quality of Russian crops and contributed to the development of the chemical and petroleum industries. However, his forward-looking political views were not popular with the Czar. In 1890 he carried a request for the relief of unjust conditions from the students at the university to the administration and was retired early.



IUPAC Periodic Table of the Elements

Key: atomic number, Symbol, name, standard atomic weight

1																	18
1 H hydrogen [1.007, 1.009]	2											13	14	15	16	17	2 He helium 4.003
3 Li lithium [6.938, 6.997]	4 Be beryllium 9.012											5 B boron [10.80, 10.83]	6 C carbon [12.00, 12.02]	7 N nitrogen [14.00, 14.01]	8 O oxygen [15.99, 16.00]	9 F fluorine 19.00	10 Ne neon 20.18
11 Na sodium 22.99	12 Mg magnesium [24.30, 24.31]	3	4	5	6	7	8	9	10	11	12	13 Al aluminium 26.98	14 Si silicon [28.08, 28.09]	15 P phosphorus 30.97	16 S sulfur [32.05, 32.08]	17 Cl chlorine [35.44, 35.46]	18 Ar argon 39.95
19 K potassium 39.10	20 Ca calcium 40.08	21 Sc scandium 44.96	22 Ti titanium 47.87	23 V vanadium 50.94	24 Cr chromium 52.00	25 Mn manganese 54.94	26 Fe iron 55.85	27 Co cobalt 58.93	28 Ni nickel 58.69	29 Cu copper 63.55	30 Zn zinc 65.38(2)	31 Ga gallium 69.72	32 Ge germanium 72.63	33 As arsenic 74.92	34 Se selenium 78.96(3)	35 Br bromine [79.90, 79.91]	36 Kr krypton 83.80
37 Rb rubidium 85.47	38 Sr strontium 87.62	39 Y yttrium 88.91	40 Zr zirconium 91.22	41 Nb niobium 92.91	42 Mo molybdenum 95.96(2)	43 Tc technetium	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3
55 Cs caesium 132.9	56 Ba barium 137.3	57-71 lanthanoids	72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.8	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.6	81 Tl thallium [204.3, 204.4]	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium	85 At astatine	86 Rn radon
87 Fr francium	88 Ra radium	89-103 actinoids	104 Rf rutherfordium	105 Db dubnium	106 Sg seaborgium	107 Bh bohrium	108 Hs hassium	109 Mt meitnerium	110 Ds darmstadtium	111 Rg roentgenium	112 Cn copernicium		114 Fl flerovium		116 Lv livermorium		

57 La lanthanum 138.9	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd neodymium 144.2	61 Pm promethium	62 Sm samarium 150.4	63 Eu europium 152.0	64 Gd gadolinium 157.3	65 Tb terbium 158.9	66 Dy dysprosium 162.5	67 Ho holmium 164.9	68 Er erbium 167.3	69 Tm thulium 168.9	70 Yb ytterbium 173.1	71 Lu lutetium 175.0
89 Ac actinium	90 Th thorium 232.0	91 Pa protactinium 231.0	92 U uranium 238.0	93 Np neptunium	94 Pu plutonium	95 Am americium	96 Cm curium	97 Bk berkelium	98 Cf californium	99 Es einsteinium	100 Fm fermium	101 Md mendelevium	102 No nobelium	103 Lr lawrencium

Mendele've's Dream

In 1869, Mendele'ev made up a pack of cards and wrote an element and its atomic weight on each card. He began laying out the cards to see if there was a pattern of properties in the elements. The cards were incomplete because only half of the elements had been discovered. He stayed up for 3 days and 3 days working on the problem without sleeping. He became exhausted and fell asleep. While he slept, he had an extraordinary dream in which he saw all of the 63 elements arranged in a table. When he woke up he knew he had made an incredible discovery.

Discussion

1) In what was is scientific knowledge the result of human inference, imagination, and creativity? Use an example from this story.

2) In what sense is scientific knowledge invented? In what was is it discovered? Use examples from this story.