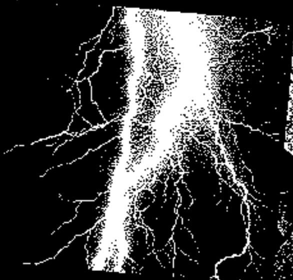
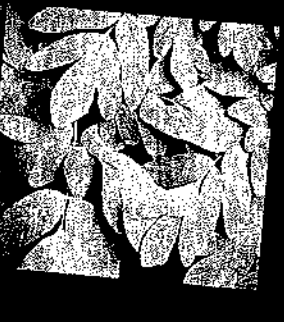
OXFORD

A GUIDE TO THE ELEMENTS

SECOND EDITION

ALBERT STWERTKA





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PERIODIC TABLE OF THE ELEMENTS

1 ◄ Atomic number
H ◄ Chemical symbol
1.00794 ◄ Atomic weight

Periods	1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8	9 VIIIB	10	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	1 **H** 1.00794																	2 **He** 4.00260
2	3 **Li** 6.941	4 **Be** 9.01218											5 **B** 10.811	6 **C** 12.011	7 **N** 14.00674	8 **O** 15.9994	9 **F** 18.99840	10 **Ne** 20.1797
3	11 **Na** 22.98977	12 **Mg** 24.3050											13 **Al** 26.98154	14 **Si** 28.0855	15 **P** 30.97376	16 **S** 32.066	17 **Cl** 35.4527	18 **Ar** 39.948
4	19 **K** 39.0983	20 **Ca** 40.078	21 **Sc** 44.95591	22 **Ti** 47.88	23 **V** 50.9415	24 **Cr** 51.9961	25 **Mn** 54.9380	26 **Fe** 55.847	27 **Co** 58.93320	28 **Ni** 58.6934	29 **Cu** 63.546	30 **Zn** 65.39	31 **Ga** 69.723	32 **Ge** 72.61	33 **As** 74.92159	34 **Se** 78.96	35 **Br** 79.904	36 **Kr** 83.80
5	37 **Rb** 85.4678	38 **Sr** 87.62	39 **Y** 88.90585	40 **Zr** 91.224	41 **Nb** 92.90638	42 **Mo** 95.94	43 **Tc**** 98.9072	44 **Ru** 101.07	45 **Rh** 102.90550	46 **Pd** 106.42	47 **Ag** 107.8682	48 **Cd** 112.411	49 **In** 114.82	50 **Sn** 118.710	51 **Sb** 121.76	52 **Te** 121.757	53 **I** 126.90447	54 **Xe** 131.29
6	55 **Cs** 132.90543	56 **Ba** 137.327	57 ***La** 138.9055	72 **Hf** 178.49	73 **Ta** 180.9479	74 **W** 183.85	75 **Re** 186.207	76 **Os** 190.2	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.96654	80 **Hg** 200.59	81 **Tl** 204.3833	82 **Pb** 207.2	83 **Bi** 208.98037	84 **Po**** 208.9824	85 **At**** 209.9871	86 **Rn**** 222.0176
7	87 **Fr**** 223.0197	88 **Ra**** 226.0254	89 **†Ac**** 227.0278	104 **Rf**** 261.11	105 **Db**** 262.114	106 **Sg**** 263.118	107 **Bh**** 262.12	108 **Hs**** (265)	109 **Mt**** (266)	110 **Uun**** (269)	111 **Uuu**** (272)	112 **Uub**** (277)		114 **Uuq**** (285)				

*	58 **Ce** 140.115	59 **Pr** 140.90765	60 **Nd** 144.24	61 **Pm**** 144.9127	62 **Sm** 150.36	63 **Eu** 151.965	64 **Gd** 157.25	65 **Tb** 158.92534	66 **Dy** 162.50	67 **Ho** 164.93032	68 **Er** 167.26	69 **Tm** 168.93421	70 **Yb** 173.04	71 **Lu** 174.967
†	90 **Th**** 232.0381	91 **Pa**** 231.0359	92 **U**** 238.0289	93 **Np**** 237.0482	94 **Pu**** 244.0642	95 **Am**** 243.0614	96 **Cm**** 247.0703	97 **Bk**** 247.0703	98 **Cf**** 251.0796	99 **Es**** 252.083	100 **Fm**** 257.0951	101 **Md**** 258.10	102 **No**** 259.1009	103 **Lr**** 262.11

**All the isotopes of this element are radioactive. With the exception of uranium and thorium, the atomic weight shown represents the relative atomic weight of the longest-lived isotope. The numbers in parentheses are the mass numbers of the longest-lived isotope.

THE PERIODIC TABLE

Although the world is varied and complex, everything in it—air, water, rocks, living tissue, and the almost infinite number of other objects and materials around us—is actually made up of only a limited number of chemical elements. We know today that only 91 such elements exist naturally on the Earth. They range from hydrogen, the lightest element, to uranium, the heaviest. Actually, several more elements do exist, but these have to be made artificially in laboratories.

The basic components of each chemical element are atoms. The atoms of an element consist of three kinds of particles: protons, neutrons, and electrons. Protons and neutrons exist at the core, or nucleus, of the atom. One of the important ways in which these two kinds of particles differ from one another is that each proton carries a single, positive electric charge, whereas a neutron carries no electric charge. Electrons, which are much smaller than either protons or neutrons, each carry a single negative electric charge. Electrons are present at some distance away from the nucleus of the atom and travel rapidly around it in complex paths known as orbits. Under normal circumstances, the number of electrons orbiting around the nucleus of a particular atom is exactly equal to the number of protons in the nucleus of the atom, so that the overall positive electric charge provided by its protons is exactly balanced by the overall negative charge provided by the electrons orbiting its nucleus.

The unique properties of each of the chemical elements are determined by their number of neutrons, protons, and electrons. Besides determining the properties of a pure chemical element, the neutron, proton, and electron content of its atoms also determines its behavior in relation to other chemical elements. Although each element behaves differently and has different properties from all of the others, the atoms of different elements can combine with one another to form clusters of atoms called molecules. It is this combination of atoms that accounts for the enormous variety of chemical substances that can be found in nature and created by modern technology.

When scientists first tried to describe the physical and chemical properties of the elements and chemical compounds, which are formed by the combination of atoms of different elements, they soon became buried under a mountain of seemingly unconnected facts. Many early scientists recognized the need to organize this information, and they attempted to discover some sort of order or pattern that could simplify what seemed to them an overwhelming array of chemical facts. The solution to the

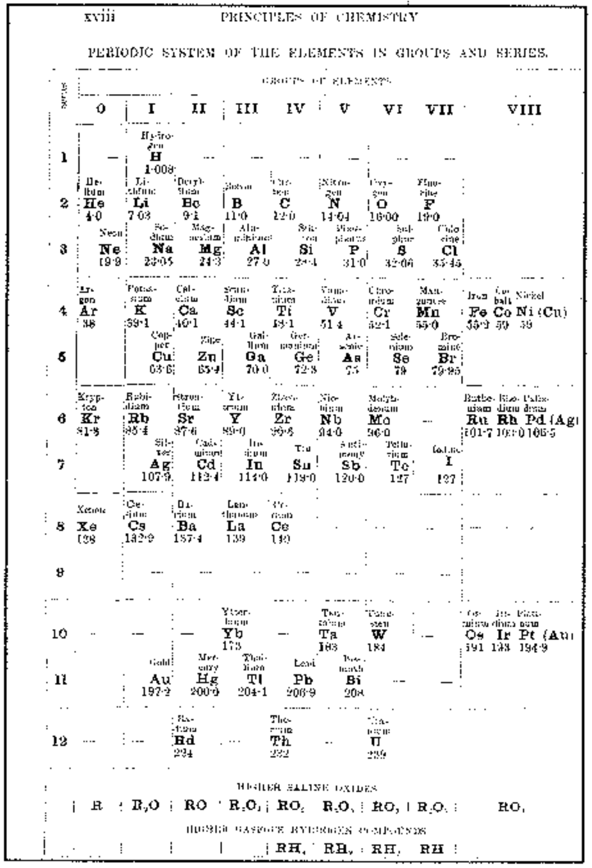
The Russian chemist Dmitry Mendeleyev created his periodic table (below) in 1869 while preparing a chemistry textbook for his students.

problem was the so-called periodic table of the chemical elements.

The modern periodic table is based primarily on the work of the Russian chemist Dmitry Ivanovich Mendeleyev (1834–1907) and the German physicist Julius Lothar Meyer (1830–1895). Working independently, both of these scientists developed similar periodic tables within a few months of each other in 1869. Mendeleyev, however, is usually given the credit for having developed the periodic table because he managed to publish his work first.

Mendeleyev, who was a professor of chemistry at the University of St. Petersburg, developed the periodic table while preparing a chemistry textbook for his students. As part of this project, he had written down the properties of the elements on cards. While sorting through these cards he noticed that when the elements were arranged in order of their weight, similar chemical properties occurred repeatedly at regular intervals. Mendeleyev used this observation to construct his periodic table. He placed the elements in horizontal rows, according to their weight, with the lightest in each row at the left end of the row and the heaviest at the right, and with one row beneath the other, so that all elements with similar properties fell into vertical columns.

Much of Mendeleyev's success depended on his placing elements with similar properties in the same group, even though this left occasional gaps in the table. He reasoned, correctly, that the elements that belonged in the gaps had not yet been discovered. The locations of the gaps enabled Mendeleyev to predict with remarkable accuracy the properties of these yet-to-be found elements.



xviii PRINCIPLES OF CHEMISTRY

PERIODIC SYSTEM OF THE ELEMENTS IN GROUPS AND SERIES.

GROUPS OF ELEMENTS

Series	0	I	II	III	IV	V	VI	VII	VIII
1	—	H 1·008	—	—	—	—	—	—	
2	He 4·0	Li 7·03	Be 9·1	B 11·0	C 12·0	N 14·04	O 16·00	F 19·0	
3	Ne 19·9	Na 23·05	Mg 24·3	Al 27·0	Si 28·4	P 31·0	S 32·06	Cl 35·45	
4	Ar 38	K 39·1	Ca 40·1	Sc 44·1	Ti 48·1	V 51·4	Cr 52·1	Mn 55·0	Fe Co Ni (Cu) 55·9 59 59
5		Cu 63·6	Zn 65·4	Ga 70·0	Ge 72·3	As 75	Se 79	Br 79·95	
6	Kr 81·8	Rb 85·4	Sr 87·6	Y 89·0	Zr 90·6	Nb 94·0	Mo 96·0	—	Ru Rh Pd (Ag) 101·7 103·0 106·5
7		Ag 107·9	Cd 112·4	In 114·0	Sn 119·0	Sb 120·0	Te 127	I 127	
8	Xe 128	Cs 132·9	Ba 137·4	La 139	Ce 140	—	—	—	—
9		—	—	—	—	—	—	—	
10	—	—	—	Yb 173	—	Ta 183	W 184	—	Os Ir Pt (Au) 191 193 194·9
11		Au 197·2	Hg 200·0	Tl 204·1	Pb 206·9	Bi 208	—	—	
12	—	—	Rd 224	—	Th 232	—	U 239		

HIGHER SALINE OXIDES

R	R_2O	RO	R_2O_3	RO_2	R_2O_5	RO_3	R_2O_7	RO_4

HIGHER GASEOUS HYDROGEN COMPOUNDS

				RH_4	RH_3	RH_2	RH

The table that Mendeleyev developed is in many ways similar to the one we use today. One of the main differences is that Mendeleyev's table lacks the column containing the elements helium through radon. In Mendeleyev's time none of the elements in this column had yet been found because they are relatively rare and because they show no tendency to undergo chemical reactions. Occasionally, Mendeleyev was forced to switch the order of his elements to make the table come out right, placing elements with greater atomic weights ahead of those with smaller weights. The atomic weight of an element is the average weight of all the atoms that form the element. It is mostly determined by the total number of protons and neutrons the atoms contain. Electrons are so much lighter than these nuclear particles that they contribute very little to the weight of an atom. Apparently, listing elements in order of their atomic weights did not always work. It was not until the beginning of the 20th century, with the knowledge gained about the structure of the atom, that the correct way of ordering the elements was discovered and the present periodic table was formulated.

THE NUCLEAR ATOM

The key event that led to the modern understanding of the atom was the discovery that atoms are made up of electrons, protons, and neutrons. Thus, despite its name, which derives from the Greek word for "indivisible," the atom could indeed be divided into smaller components.

In April 1897, Joseph John Thompson, professor of physics and director of the Cavendish Laboratory at Cambridge University in England, announced the discovery of the electron. Thompson reported that this tiny particle had a negative electric charge and a mass of about one two-thousandth of that of the lightest atom. Thompson's momentous discovery of a particle of matter smaller than the atom so startled his colleagues that many thought he had been "pulling their legs." It was no joke, however, and in Thompson's own words: "The production of electrons essentially involves the splitting up of the atom, [with] a part of the mass of the atom getting free and becoming detached from the original atom—that part being one or more electrons."

Ernest Rutherford, the distinguished New Zealand physicist who had been a pupil of Thompson's and who was a professor of physics at Cambridge University, supplied the next step toward the modern understanding of the atom in 1911. He discovered that the atom had a nucleus and that one of the important particles that occupied the nucleus was the positively charged proton.

As a probe for his study of the atom, Rutherford used the newly discovered phenomenon of radioactivity. Radioactive atoms, like uranium and radium, are unstable, and their nuclei spontaneously disintegrate. One of the products of this disintegration is a massive, positively charged particle called an alpha particle. At the time of its discovery, Rutherford did not know that the alpha particle was the nucleus of a helium atom, consisting of two protons and two neutrons. He therefore used the first letter of the Greek alphabet, *alpha,* to identify this particle and distinguish it from the other products given off by radioactive atoms.

Because the atom was too small to observe directly, Rutherford's brilliant idea was to use alpha particles as projectiles, firing them at atoms and observing how they scattered. This was like firing bullets at a sealed box and deducing the contents of the box by seeing how the bullets bounced. His target atoms were at first gold atoms contained in very thin sheets of gold foil. Gold was used because it is possible to make gold foil that is very thin, often thinner than fine paper. Rutherford observed that although most of the alpha particles passed right through the target, many were deflected at very large angles. Some were even deflected backward, as if they had hit a stone wall. Rutherford was so astonished by this that he compared it to "firing a 15-inch shell at a piece of tissue paper and having it come back and hit the gunner." Because most of the alpha particles went right through the foil, he reasoned that the atom was mainly empty space but that it must contain a small, heavy, positively charged core that was capable of repelling and scattering the projectiles fired at it. Rutherford called this massive core the nucleus of the atom.

After Rutherford's discovery of the nucleus, it became obvious that the nucleus of hydrogen, the lightest of the atoms, must play a fundamental role in the structure of all atoms. In 1920, he proposed to call this particle the proton, the name by which it has been known ever since.

Finally, in 1932, the British physicist Sir James Chadwick, who also worked at the Cavendish Laboratory in Cambridge, discovered that yet another particle existed in the nucleus of atoms. This new particle was the neutron. It has a mass close to the mass of the proton, but it has no electric charge.

These fundamental discoveries, coupled with the work of a brilliant young English physicist named Henry Moseley, ultimately led to the reason for Mendeleyev's success with the periodic table. Moseley, just before World War I, had been investigating the X rays given off by various elements. X rays are a very penetrating form of radiation usually produced by accelerating electrons to high speeds and then abruptly stopping them by having them smash into a metal target. The collision causes the target to give off X rays. When different elements are used as targets, the X rays have different properties. Each element has its own set of characteristic X rays. They are almost like a fingerprint of the element. Moseley was able to relate the properties of the X rays to the number of protons contained in the element. He discovered that every element had a different number of protons in the nucleus. The number of protons came to be called the atomic number of the element, represented by the letter Z, and it was always a whole number.

Atoms are normally electrically neutral, with an equal number of electrons and protons. This means, for example, that carbon, with an atomic number of 6, has six protons in its nucleus and six electrons outside the nucleus.

ISOTOPES

Moseley's experiments demonstrated that what distinguishes one element from another is its atomic number, the number of protons in the nucleus of its atoms, not its atomic weight, which is a measure of the total number of protons and neutrons in the nucleus. The correct way of ordering the elements in the periodic table was, therefore, by their atomic number, and not, as Mendeleyev had thought, by their atomic weight.

Although all the atoms of a given element have the same number of protons, they can have different numbers of neutrons. This explains, for example, why there are three different species of the element hydrogen. Ordinarily, a hydrogen atom has a lone proton in its nucleus and no neutrons. A heavier form of hydrogen, called deuterium, also has a single proton in the nucleus but contains a neutron as well. A still heavier form of hydrogen, known as tritium, has two neutrons in addition to the proton. These three species are called isotopes of the element hydrogen. Yet even though a deuterium atom, because of its extra neutron, weighs twice as much as an ordinary hydrogen atom, its chemical behavior is similar to that of hydrogen, indicating that the number of protons in the nucleus is what determines the behavior of each element.

Like hydrogen, the majority of the elements have isotopes. Some elements have only two isotopes, while others can have as many as eight or nine. It is a remarkable fact that the relative percentage, or abundance, of each of the various isotopes of any element is the same all over the Earth.

The existence of isotopes also explains why the atomic weight is an unreliable indicator of the position of an element in the periodic table. For any element, the atomic weight really measures the average weight of a mixture of its different isotopes. On this basis, it is possible for an element like argon, which has an atomic number of 18, to exist in a mixture of isotopes that have a greater average atomic weight than that of potassium, whose atomic number is 19. The atomic weight in the periodic table is often a number with a decimal fraction. The atomic weight of calcium, Ca, for example, is 40.08. The nucleus of the calcium atom cannot