

## BIOELEMENTS; THE CHEMICAL ELEMENTS OF LIVING MATTER.

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Among the 87 known elements less than one-half (namely 34) have been found to enter into living matter. Of these only 17 seem to be essential to life, and of these 17 not more than 4 elements form from 97 to 99 per cent of the living organism.

In order to illustrate the importance of the different elements Fig. 1 and Tables I and II have been prepared, showing that some elements occur invariably, others frequently, and still others are of such rare occurrence that their presence in living matter seems adventitious.

In Fig. 1 the new periodic system<sup>1</sup> has been utilized to show that all the bioelements occupy neighboring places and that the majority of them possess low atomic weights, belonging to the first two periods of the system.

An approximation to the ultimate composition of man is given in Column 2 of Table I, while Column 3 shows the elementary composition of long leaf pine, calculated from the data of Little.<sup>2</sup> The chemical character of the mammal in comparison with the gymnosperm is evident, the latter containing 99 per cent of C, H, and O and only very small amounts of other elements, of which Al and Si are the predominant ones (due to the abundance of these two elements in the soil).

With the exception of oxygen, no element enters into the living organism as a free element, but only in the form of compounds, the majority of these being non-polar; that is, organic compounds. For

<sup>1</sup> Hackh, I. W. D., *J. Am. Chem. Soc.*, 1918, xl, 1023; *Am. J. Sc.*, 1918, xlvi, 481.

<sup>2</sup> Little, A. D., *J. Ind. and Eng. Chem.*, 1916, viii, 102.

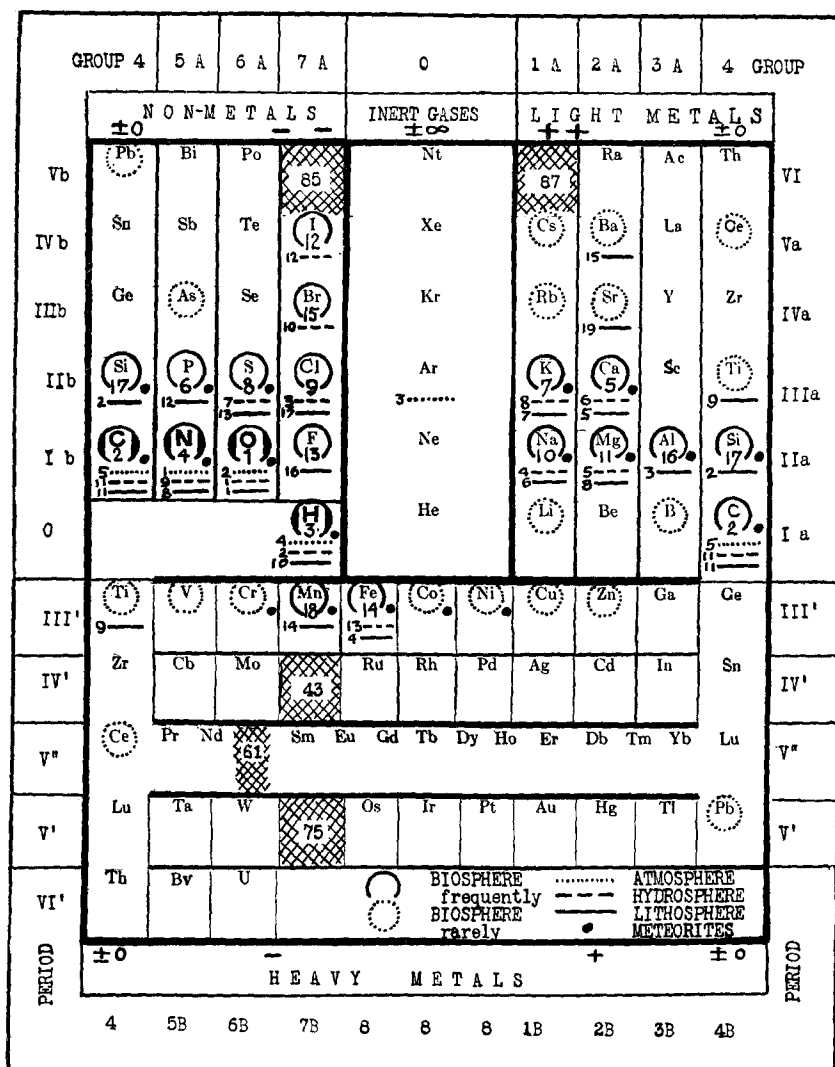


FIG. 1. Bioelements and the periodic system. Bioelements invariably or frequently present in living organisms are indicated by a continuous arc; those which occur variably and rarely by a broken circle. The numbers indicate the order of their relative percentage. The elements of the lithosphere, hydrosphere, and atmosphere are also indicated by a continuous, broken, or dotted line. The elements occurring in meteorites are shown by a dot. The numbers indicate their relative abundance. This chart of the periodic system divides the elements into non-metals, light metals, and heavy metals. Missing elements are those of atomic numbers 43, 61, 75, 85, and 87, while Po = polonium, Ac = actinium, and Bv = brevium are radioactive substances, of which so far no long lived isotope is known. (See Hackh, I. W. D., *Am. J. Sc.*, 1918, xlvi, 481; *J. Am. Chem. Soc.*, 1908, xl, 1023.)

comparison the average composition of these compounds or foods is given in Columns 4, 5, 6, and 7 of Table I.

Regarding the distribution of the elements in the biosphere, there are the nine essential elements which are invariably present in the cell: C, H, O, N, P, S, Mg, Fe, and K, while eight more seem also to be important, for they are always present in small amounts in plant

TABLE I.  
*Distribution of Bioelements.*

Order.	Mammals.		Gymnosperms.		Average composition of foods.			
	(2) per cent	(3) per cent	(4) per cent	(5) per cent	(6) per cent	(7) per cent	(8) per cent	(9) per cent
1	O 62.43	C 53.96	O 49.38	C 69.05	C 51.3	O 88.80		
2	C 21.15	O 38.65	C 44.44	O 17.90	O 22.4	H 11.16		
3	H 9.86	H 7.13	H 6.18	H 10.00	N 17.8	S 0.018		
4	N 3.10	Al 0.065	—	P 2.13	H 6.9	C 0.005		
5	Ca 1.90	Si 0.057	—	N 0.61	S 0.8	Ca 0.004		
6	P 0.95	S 0.052	—	S 0.31	P 0.7	Mg 0.003		
7	K 0.23	Fe 0.030	—	—	Fe 0.1	N 0.002		
8	S 0.16	N 0.030	—	—	—	Fe 0.002		
9	Cl 0.08	Ca 0.007	—	—	—	P 0.001		
10	Na 0.080	K 0.006	—	—	—	Na 0.001		
11	Mg 0.027	P 0.005	—	—	—	K 0.001		
12	I 0.014	Mg 0.003	—	—	—	Remainder 0.003		
13	F 0.009	Cl 0.002	—	—	—	—		
14	Fe 0.005	Na 0.001	—	—	—	—		
15	Br 0.002	F 0.001	—	—	—	—		
16	Al 0.001	Mn 0.001	—	—	—	—		
17	Si 0.001	—	—	—	—	—		
18	Mn 0.001	—	—	—	—	—		
	100.00	100.00	100.00	100.00	100.00	100.00		

Column 2 represents, in per cent, the elementary composition of man; Columns 4, 5, 6, and 7 give the average composition of common foods. The data of Column 3 are calculated from the results of Little and represent the elementary composition of the long leaf pine.

and animal organisms; namely, F, Cl, Br, I, Si, Na, Ca, and Mn. These seventeen bioelements are shown in their relative order in Fig. 1, all of them occupying neighboring places.

In addition to these elements there are some apparently essential to certain species of plants and animals, such as Al, Cu, Cs, B, Ba,

TABLE II.  
*Distribution of Chemical Elements.*

Order.	Lithosphere.	Hydrosphere.	Atmosphere.	Meteorites.
(1)	(2) per cent	(3) per cent	(4) per cent	(5) per cent
1	O 47.33	O 85.79	N 75.53	Fe 72.06
2	Si 27.74	H 10.67	O 23.02	O 10.10
3	Al 7.85	Cl 2.07	Ar 1.40	Ni 6.50
4	Fe 4.50	Na 1.14	H 0.02	Si 5.20
5	Ca 3.47	Mg 0.14	C 0.01	Mg 3.80
6	Na 2.46	Ca 0.05	Kr 0.01	S 0.49
7	K 2.46	S 0.05	Xe 0.005	Ca 0.46
8	Mg 2.24	K 0.04	Remainder 0.005	Co 0.44
9	Ti 0.46	N 0.02	—	Al 0.39
10	H 0.22	Br 0.01	—	Na 0.17
11	C 0.19	C 0.01	—	P 0.14
12	P 0.12	I 0.006	—	Cr 0.09
13	S 0.12	Fe 0.002	—	C 0.04
14	Mn 0.08	Remainder 0.002	—	K 0.04
15	Ba 0.08	—	—	Mn 0.03
16	F 0.07	—	—	Ti 0.01
17	Cl 0.06	—	—	Cu 0.01
18	N 0.02	—	—	Remainder 0.03
19	Sr 0.02	—	—	—
	Remainder 0.51	—	—	—
	100.00	100.00	100.00	100.00

The data of Columns 2, 3, and 4 are taken from Clarke,<sup>4</sup> those of Column 5 from Farrington, O. C., (*Field Museum Nat. History, Publication 120, 1907; Publication 151, 1911*), whose report contains analyses of 318 iron and 125 stone meteorites.

Li, Rb, and Zn, while traces of As, Ce, Co, Cr, Mo, Ni, Pb, Ra, Sr, and Ti, have also been reported in specific instances. These elements are marked by a broken circle in Fig. 1 and are also situated close together, with two exceptions.<sup>3</sup>

This summary would be incomplete without a consideration of the abundance of the elements upon our earth. In Table II the data calculated by Clarke<sup>4</sup> are systematically arranged and the order of occurrence in the three spheres (gaseous, liquid, and solid) has been embodied in Fig. 1. It is significant that only the four elements C, N, O, and H occur in all three spheres, while only seven, S, Cl, K, Na, Mg, Ca, and Fe, are predominant in two spheres. Thus the elements of living matter are also the common elements of the earth surface.

Plant organisms contain relatively more of the elements of the soil. Titanium seems to be an exception; although it occurs in traces in nearly all plants,<sup>5</sup> we know little of its physiological functions. Its abundance in celestial bodies, revealed by the spectrum of titanium oxide, would indicate a more important rôle of this element than is known at present.

In conclusion, only 5 per cent of the known elements (namely, C, N, O, and H) forms from 96 to 99 per cent of the biosphere,<sup>6</sup> while about 15 per cent of the elements is invariably or frequently present, another 20 per cent sometimes occurs in traces in certain organisms, and the remaining 60 per cent of the elements is absent under normal conditions; thus from 60 to 80 per cent of the elements (absent and rarely encountered) are of a more or less poisonous character.

<sup>3</sup> These two exceptions, Ce and Pb, would indicate that other members of the carbon group, Zr and Sn, should be found in organisms.

<sup>4</sup> Clarke, F. W., *U. S. Geol. Survey, Bull. 616*, 3rd edition, 1916.

<sup>5</sup> Robinson, W. O., Steinkoenig, L. A., and Miller, C. F., *U. S. Dept. Agric., Bureau of Soils, Bull. 600*, 1917.

<sup>6</sup> These four elements have also been utilized for a system of structure symbols of organic compounds (see Hackh, I. W. D., *Canadian Chem. J.*, 1918, ii, 135; *Science*, 1918, xlviii, 333).