79. *The Periodic System of the Chemical Elements in Three Dimensions. (The "Five–Five System.")*

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A new classification of the chemical elements is presented. It is based on an arrangement of the elements in three dimensions, and has the following advantages : (1) Elements of related chemical properties but with different typical valency are collected into "planes". (2) Elements with same typical valency are collected into "groups". (3) Several weaknesses of the present forms of the periodic system are overcome. (4) It has a bearing on the geochemical distribution of elements.

The Periodic System of the chemical elements has not yet reached a definite form generally acceptable to chemists and physicists. In textbooks and other literature one will hardly find two forms alike : the differences apply particularly to the composition of the homologous series.

Research on atomic constitution has had the Periodic System as its starting point and guide. Such research, however, was not satisfied with the Periodic System in its earlier forms, and this led to a new form relation—that of Thomson and Bohr. This new form consists mainly in that all homologous series are placed side by side, without any mutual relation. It does not seem probable that this form will be generally accepted. It is of little value to have all the series put side by side, and it is difficult to have the picture of the series in mind, when no practical connection or relation between them is established.

In the following a new classification of the chemical elements is described. It is characterised by an arrangement of the elements in all three dimensions, *i.e.*, in space and not in one "plane" as in the present forms. In the new form the elements fall into five different "planes" and five different "groups". It is proposed to designate the new form as the "five–five system"—5–5-S for short.

The Homologous Series.—A new rule according to which the homologous series may be determined more definitely than heretofore is proposed : *The Periodic System of elements consists of long and short homologous series. The short homologous series are composed of the typical heavy metals.* Accordingly, the series are :

Long series.

He–Ne–Ar–Kr–X–Rn
Li–Na–K–Rb–Cs–87
Be–Mg–Ca–Sr–Ba–Ra
B–Al–Sc–Y–La–Ac
C–Si–Ti–Zr–Hf–(Th)
N–P–As–Sb–Bi
O–S–Se–Te–Po
F–Cl–Br–I–85

Short series.

Cu–Ag–Au
Zn–Cd–Hg
Ga–In–Tl
Ge–Sn–Pb
V–Nb–Ta–(Pa)
Cr–Mo–W–(U)
Mn–43–Re
Fe–Ru–Os
Co–Rh–Ir
Ni–Pd–Pt

It will be seen that in the long series the basic properties of the elements will generally increase—and in the short series they will generally decrease—with increasing atomic weight. (Thallium is a paradox in its univalent state.)

One should perhaps consider antimony and bismuth as "heavy" metals, but usually they are not regarded as typical metals. In mineralogy they are more or less regarded as non-metals or metalloids.

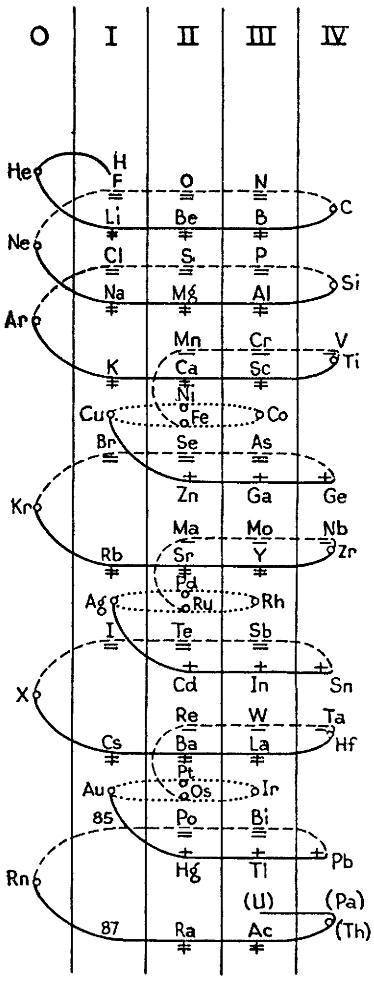
In the new system it is not proposed to classify the rare earths in any further detail than in present systems : they all fall into the place of lanthanum. Thorium, protoactinium, uranium and subsequent "synthetic" elements are regarded as belonging to a new series of rare earths.

The Five–Five System.—A total picture of the 5–5-S is given in Fig. 1. Horizontal projections through the position of the inert-gas elements are seen in Fig. 2. All elements are connected to a curve in the order of the atomic number. The elements fall into 5 different groups, having the number 0, I, II, III, IV. A plane through the elements in each group will be at a right angle to the five planes :

Major positive plane (indicated by ǂ)
Minor ,, ,, (,, ,, +)
Neutral ,, (,, ,, 0)
Minor negative plane (,, ,, —)
Major ,, ,, (,, ,, =)

FIG. 1.

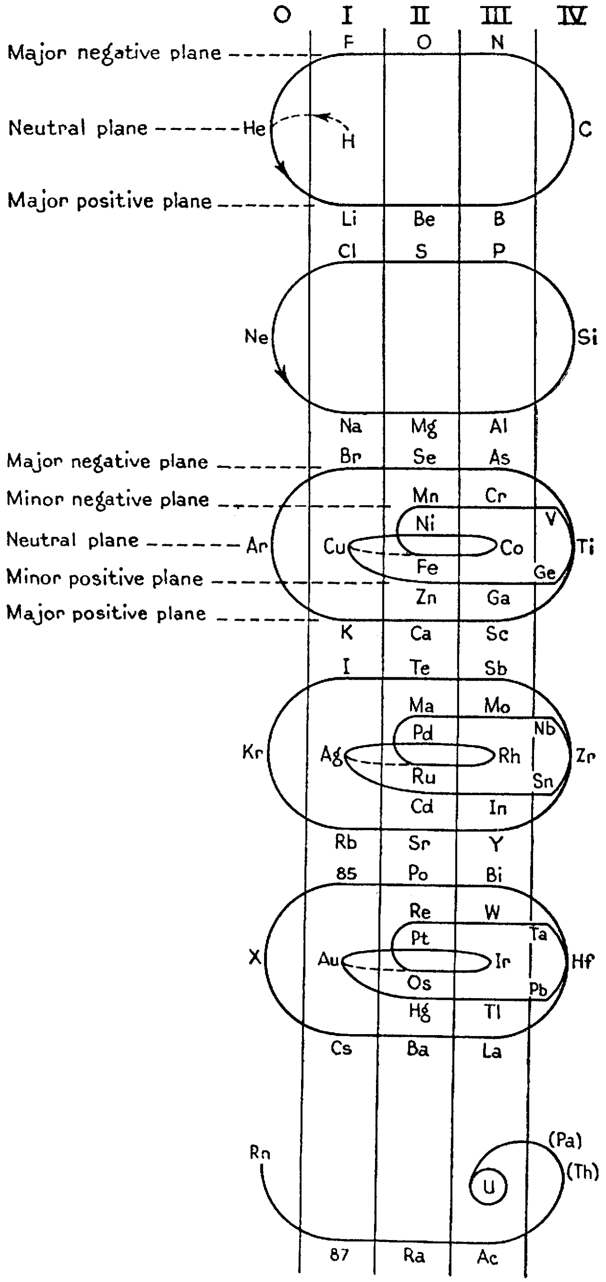
Group No.



Total Picture
of 5-5-S

FIG. 2.

Group No.



Horizontal Projections

Every element (except a few rare elements) has now come into a group whose number corresponds to one of its typical valencies, and the valency corresponding to the group number is just the one in which most of the elements usually occur in Nature.

Hydrogen will form a top element of all three homologous series of Group I. A picture of the five planes and five groups is given in the table.

		Group number:			
	0.	I.	II.	III.	IV.
Major positive plane		Li	Be	B	
		Na	Mg	Al	
		K	Ca	Sc	
		Rb	Sr	Y	
		Cs	Ba	La	
		87	Ra	Ac	
Minor positive plane			Zn	Ga	Ge
			Cd	In	Sn
			Hg	Tl	Pb
Neutral plane	He				C
	Ne				Si
	Ar	Cu	Fe–Ni	Co	Ti
	Kr	Ag	Ru–Pd	Rh	Zr
	X	Au	Os–Pt	Ir	Hf
	Rn				(Th)
Minor negative plane			Mn	Cr	V
			Ma	Mo	Nb
			Re	W	Ta
				(U)	(Pa)
Major negative plane		F	O	N	
		Cl	S	P	
		Br	Se	As	
		I	Te	Sb	
		85	Po	Bi	

			Plane :		
	Major positive.	Minor positive.	Neutral.	Minor negative.	Major negative.
Group 0			He		
			Ne		
			Ar		
			Kr		
			X		
			Rn		
Group I	———	———	H	———	———
	Li				F
	Na				Cl
	K		Cu		Br
	Rb		Ag		I
	Cs		Au		85
	87				
Group II	Be				O
	Mg				S
	Ca	Zn	Fe–Ni	Mn	Se
	Sr	Cd	Ru–Pd	Ma	Te
	Ba	Hg	Os–Pt	Re	Po
	Ra				
Group III	B				N
	Al				P
	Sc	Ga	Co	Cr	As
	Y	In	Rh	Mo	Sb
	La	Tl	Ir	W	Bi
	Ac			(U)	
Group IV			C		
			Si		
		Ge	Ti	V	
		Sn	Zr	Nb	
		Pb	Hf	Ta	
			(Th)	(Pa)	

The major positive plane comprises the alkali metals, the alkaline-earth metals, and the earth metals. In the terminology of mineralogy, the " rock-forming " base elements are all found in this plane.

The " ore "-forming elements, *i.e.*, the heavy metals, are found in the three middle planes, namely :

The minor positive plane, comprising the heavy metals which form weakly positive components in chemical compounds, and which have a low melting point.

The neutral plane, comprising the inert-gas series, the precious-metal series, and the C–Th series : they lie between positive and negative elements in the sense of 5–5-S.

The minor negative plane, comprising the typical heavy metals, which, as oxides, form weakly negative radicals in chemical compounds; these have a high melting point.

In the major negative plane those elements are found which form strongly negative components in chemical compounds. The plane comprises the typical acid-forming elements. The elements of this plane are non-metals and " metalloids ".

From a petrographic and mineralogical point of view the 5–5-S has certain advantages.

Goldschmidt and his co-workers, in their famous treatises " Laws on the Geochemical Distribution of Elements " (particularly in Treatise No. VIII, Oslo, 1927, pp. 77—80), have pointed out the difference of " state " of the atoms in crystals of NaCl-type, as compared with crystals of wurtzite–zinc blende–diamond type. The conclusion is based upon exact measurements of atom distance in these simple crystals. There are, however, certain exceptions to the rule which the authors point out (TiC, ZrC, MgTe, AlSb).

Seen from the standpoint of the 5–5-S, it may be concluded that the crystals whose atom distance follows what the authors call the rule of the NaCl type (decreasing distance with increasing valency) have their positive component in the *major positive* plane. The crystals whose atom distance follows what the authors call the rule of wurtzite–zinc blende–diamond type (constant distance, independent of valency) have their positive component in the *minor positive* or the *neutral* plane.

The apparent exceptions to the rule which the authors point out, basing their conclusion on the crystal form, are not exceptions when seen from the standpoint of the 5–5-S. The main consideration is not the crystal form, but the plane to which the positive atom belongs.

This conclusion is of considerable practical importance. As in these simple crystals the elements are in different " state ", one cannot expect that elements of the major positive plane and elements of the heavy metals planes will be associated in crystals of this type. Taking, for instance, zinc blende (ZnS), one finds scarcely any elements of the major positive plane in this mineral. Many other heavy metals of the minor positive plane (Cd, Hg, In, Ga, Tl, Sn, Pb) and of the neutral plane (Fe, Ag, Au) are, however, found in zinc blende.

Similarly, in sodium chloride one rarely finds elements of the heavy metal planes, but very often other elements of the major positive plane : K, Ca, etc.

In more complicated minerals, like compounds of two or more oxides (as MgO,SiO_2 and FeO,SiO_2), the " state " of the positive element (Mg and Fe) appears to be the same. In very many minerals one finds isomorphous mixtures and replacements of elements having the same valency and belonging to identical group of 5–5-S, but to different planes. This fact can usually be traced back to similarity in ionic (or atomic) radii.

Isomorphous mixtures and replacements in minerals are well known of the following groups of elements.

Bivalent elements (of Group II of 5–5-S), as Mg, Ca, Ba, Zn, Cd, Fe, Ni, Mn.

Tervalent elements (of Group III of 5–5-S) as Al, Sc, Y, La (and other rare earths), Ga, In, Tl, Cr, U.

Quadrivalent elements (of Group IV of 5–5-S) as Si, Ti, Zr, Hf, Th, Sn, V, Nb, Ta.

Vanadium in minerals is usually regarded as being in the ter- or quinque-valent state. It is, however, probable that it enters many minerals in the quadrivalent state, in view of the simultaneous presence of bi- and ter-valent iron in many vanadium-containing minerals (particularly titanium minerals). The quadrivalency of vanadium is so strong that some compounds of V_2O_5 spontaneously lose oxygen to form compounds containing V_2O_4. Niobium and tantalum are usually regarded as typical quinquevalent elements, but they have also a distinct quadrivalency.

The natural parageneses of elements of the planes are interesting.

Elements of the *major positive* plane are associated in very many rock-forming minerals. In sea-water salts elements of this plane form typical positive components.

The parageneses of metals of the *minor positive* plane (Zn, Cd, Hg, Ga, In, Tl, Ge, Sn, Pb) are well known.

The heavy metals of the *neutral* plane (Fe, Co, Ni, Cu, Ru, Rh, Pd, Ag, Os, Ir, Pt, and Au) are a typical family. In precious metals found in Nature, one has always a good chance of finding all heavy metals of the neutral plane. Likewise, in certain FeS ores containing nickel one finds practically all other heavy metals of the neutral plane.

Elements of the *minor negative* plane (V, Nb, Ta, Mo, W, Mn, Re) show a distinct paragenesis. In columbite, for instance, one usually finds all these elements—and further some of the elements of 4th *group* of 5–5-S, namely, Ti and Sn besides Nb, V, and Ta.

Elements of the *major negative* plane form negative components in minerals, and are often associated. In sea-water salts elements of this plane form the typical negative components.

The above facts suggest the following conclusion : Elements associated in Nature will usually belong to the same group, or to the same plane of the 5-5-S. When they belong to the same plane, the natural parageneses are a consequence of similarity in chemical behaviour. When they belong to the same group the parageneses follow from similarity in ionic (or atomic) radii. In many minerals both types of relationship are expressed simultaneously.

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