

atmosphere, have probably been misled by the close proximity of the brilliant yellow line of krypton to the helium line.

On the assumption of the truth of Dr. Johnstone Stoney's hypothesis that gases of a higher density than ammonia will be found in our atmosphere, it is by no means improbable that a gas lighter than nitrogen will also be found in air. We have already spent several months in preparation for a search for it, and will be able to state ere long whether the supposition is well founded.

“On the Position of Helium, Argon, and Krypton in the Scheme of Elements.” By SIR WILLIAM CROOKES, F.R.S.
Received and Read June 9, 1898.

It has been found difficult to give the elements argon and helium (and I think the same difficulty will exist in respect to the gas krypton) their proper place in the scheme of arrangement of the elements which we owe to the ingenuity and scientific acumen of Newlands, Mendeléef and others. Some years ago, carrying a little further Professor Emerson Reynold's idea of representing the scheme of elements by a zigzag line, I thought of projecting a scheme in three dimensional space, and exhibited at one of the meetings of the Chemical Society* a model illustrating my views. Since that time, I have re-arranged the positions then assigned to some of the less known elements in accordance with later atomic weight determinations, and thereby made the curve more symmetrical.

Many of the elemental facts can be well explained by supposing the space projection of the scheme of elements to be a spiral. This curve is, however, inadmissible, inasmuch as the curve has to pass through a point neutral as to electricity and chemical energy twice in each cycle. We must therefore adopt some other figure. A figure-of-eight will foreshorten into a zigzag as well as a spiral, and it fulfils every condition of the problem. Such a figure will result from three very simple simultaneous motions. First, an oscillation to and fro (suppose east and west); secondly, an oscillation at right angles to the former (suppose north and south), and thirdly, a motion at right angles to these two (suppose downwards), which, in its simplest form, would be with unvarying velocity.

I take any arbitrary and convenient figure-of-eight, without reference to its exact nature; I divide each of the loops into eight equal parts, and then drop from these points ordinates corresponding to the atomic weights of the first cycle of elements. I have here a model representing this figure projected in space; in it the elements are

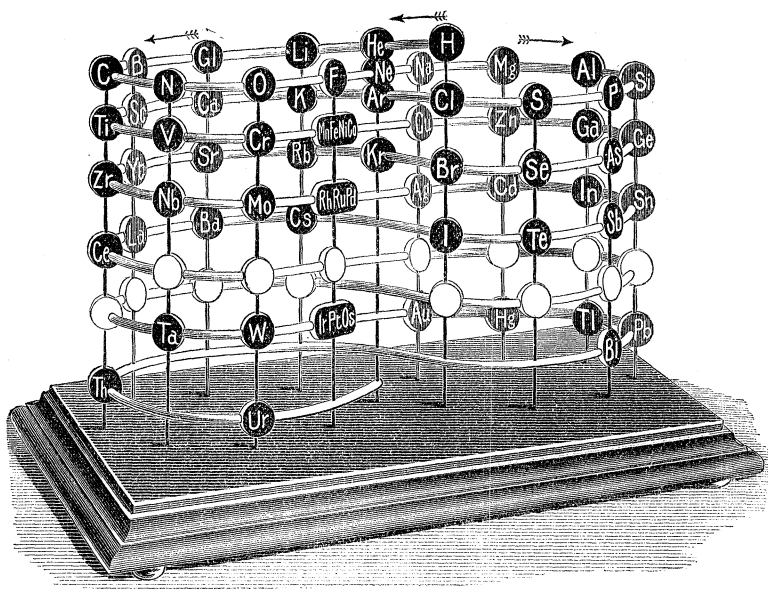
* Presidential Address to the Chemical Society, March 28, 1888.

supposed to follow one another at equal distances along the figure-of-eight spiral, a gap of one division being left at the point of crossing. The vertical height is divided into 240 equal parts on which the atomic weights are plotted, from H = 1 to Ur = 239.59. Each black disc represents an element, and is accurately on a level with its atomic weight on the vertical scale.

The accompanying figure, photographed from the solid model, illustrates the proposed arrangement. The elements falling one under the other along each of the vertical ordinates, are

H	He	Li	Gl	B	C	N	O	F	Na	Mg	Al	Si	P	S
Cl	Ar	K	Ca	Sc	Ti	V	Cr	Mn·Fe·Ni·Co	Cu	Zn	Ga	Ge	As	Se
Br	Kr	Rb	Sr	Yt	Zr	Nb	Mo	Rh·Ru·Pd	Ag	Cd	In	Sn	Sb	Te
I	—	Cs	Ba	La	Ce	()	()	()	()	()	()	()	()	()
()	—	()	()	()	()	Ta	W	Ir·Pt·Os	Au	Hg	Tl	Pb	Bi	—
—	—	—	—	—	Th	—	Ur	—	—	—	—	—	—	—

The bracketed spaces between cerium and tantalum are probably occupied by elements of the didymium and erbium groups. Their chemical properties are not known with sufficient accuracy to enable their positions to be well defined. They all give coloured absorption spectra and have atomic weights between these limits. Positions marked by a dash (—) are waiting for future discoverers to fill up.



Let me suppose that at the birth of the elements, as we now know them, the action of the *vis generatrix* might be diagrammatically represented by a journey to and fro in cycles along a figure-of-eight

path, while simultaneously time is flowing on, and some circumstance by which the element-forming cause is conditioned (*e.g.*, temperature) is declining; (variations which I have endeavoured to represent by the downward slope.) The result of the first cycle may be represented in the diagram by supposing that the unknown formative cause has scattered along its journey the groupings now called hydrogen, lithium, glucinum, boron, carbon, nitrogen, oxygen, fluorine, sodium, magnesium, aluminium, silicon, phosphorus, sulphur, and chlorine. But the swing of the pendulum is not arrested at the end of the first round. It still proceeds on its journey, and had the conditions remained constant, the next elementary grouping generated would again be lithium, and the original cycle would eternally reappear, producing again and again the same fourteen elements. But the conditions are not quite the same. Those represented by the two mutually rectangular horizontal components of the motion (say chemical and electrical energy) are not materially modified; that to which the vertical component corresponds has lessened, and so, instead of lithium being repeated by lithium, the groupings which form the commencement of the second cycle, are not lithium, but its lineal descendant, potassium.

It is seen that each coil of the lemniscate track crosses the neutral line at lower and lower points. This line is neutral as to electricity, and neutral as to chemical action. Electro-positive elements are generated on the northerly or retreating half of the swing, and electro-negative elements on the southerly or approaching half. Chemical atomicity is governed by distance from the central point of neutrality; monatomic elements being one remove from it, diatomic elements two removes, and so on. Paramagnetic elements congregate to the left of the neutral line, and diamagnetic elements to the right. With few exceptions, all the most metallic elements lie on the north.

Till recently chemists knew no element which had not more or less marked chemical properties, but now by the researches of Lord Rayleigh and Professor Ramsay, we are brought face to face with a group of bodies with apparently no chemical properties, forming an exception to the other chemical elements. I venture to suggest that these elements, helium, argon, and krypton in this scheme naturally fall into their places as they stand on the neutral line. Helium, with an atomic weight of 4, fits into the neutral position between hydrogen and lithium. Argon, with an atomic weight of about 40, as naturally falls into the neutral position between chlorine and potassium. While krypton with an atomic weight of about 80, will find a place between bromine and rubidium.

See how well the analogous elements follow one another in order: C, Ti, and Zr; N and V; Gl, Ca, Sr, and Ba; Li, K, Rb, and Cs; Cl, Br and I; S, Se, and Te; Mg, Zn, Cd, and Hg; P, As, Sb, and Bi; Al, Ga, In, and Tl. The symmetry of these series shows that we are

on the right track. It also shows how many missing elements are waiting for discovery, and it would not now be impossible to emulate the brilliant feat of Mendeléef in the celebrated cases of Eka-silicon and Eka-aluminium. Along the neutral line alone are places for many more bodies, which will probably increase in density and atomic weight until we come to inert bodies in the solid form.

Four groups are seen under one another, each consisting of closely allied elements which Professor Mendeléef has relegated to his 8th family. They congregate round the atomic weight 57, manganese, iron, nickel and cobalt; round the atomic weight 103, ruthenium, rhodium, and palladium; while lower down round atomic weight 195 are congregated osmium, iridium and platinum. These groups are interperiodic because their atomic weights exclude them from the small periods into which the other elements fall; and because their chemical relations with some members of the neighbouring groups show that they are interperiodic in the sense of being formed in transition stages.

[Note, June 22nd, 1898.

Since the above was written, Professor Ramsay and Mr. Travers have discovered two other inert gases accompanying argon in the atmosphere. These are called Neon and Metargon. From data supplied me by Professor Ramsay, it is probable that neon has an atomic weight of about 22, which would bring it into the neutral position between fluorine and sodium. Metargon is said to have an atomic weight of about 40; if so, it shares the third neutral position with argon. I have marked the positions of these new elements on the diagram.]

