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Strange, in this age when music blares at us day and night, that nobody seems to have noticed the close connection between music and the development of our ideas of the chemical elements. For the last century and a half, each major breakthrough in the understanding of atoms and their relationships has been a musical one.

In 1808, John Dalton suggested a scheme that took quite seriously the philosophical atoms of the ancient Greeks. Dalton's atoms were physical objects with definite shapes and weights (especially weights). The scheme provided a beginning of order in theoretical chemistry. The elements could be cataloged like words in a dictionary and, like words, they could be put together in meaningful ways. The chaotic world of compounds could be reduced to the relative simplicity of their constituent atoms. Yet, in a sense, the atoms themselves remained chaotic—almost ugly in their unrelatedness.

As far as we know, the first man to group the lonely atoms in a meaningful way was Johann Doebereiner. In 1829, he pointed out that certain elements could be collected in groups of three. The elements within any one group had similar properties—smell, chemical activity, or hardness. Also, the weight of the middle atom of the group was very close to the average of the other two.

Lithium, sodium, and potassium make up one such group; all are very soft metals and all will burn if they are dropped into water. In addition, the weight of the middle one, sodium, is 23—halfway between lithium's 7 and potassium's 39. Some half a dozen of these groups were known and were called triads by

Doebereiner. Although the word triad can simply mean a group of three, it is also used universally by musicians to mean a chord of three notes having a particularly pleasing relationship, such as A-C-E, or do-mi-sol. Triads form the basis for most of the chords in any musical composition.

Pleasing as they were, Doebereiner's triads provided very little insight into relationships among most of the other elements. But, in the early 1860's, J. A. R. Newlands read a paper before the London Chemical Society, showing that when the atoms were listed in order of increasing weight and compared to the white keys on a piano, there was a repetition of similarities when one moved up an octave from any one element. He used the term octave in its musical sense, where the first key is number one and the octave is number eight (actually the seventh key away from number one). If we start the musical scale with lithium, and continue with beryllium, boron, carbon, nitrogen, oxygen, and fluorine, the first octave is completed with sodium. (Neon, which we now place between fluorine and sodium, had not yet been discovered.)

Lithium and sodium, members of one of Doebereiner's triads, resemble musical octaves, two notes that are different, but sound like one if they are played together. Sodium is followed by magnesium, a good octave for the second note, beryllium. Aluminum, which comes next, is the octave for boron. The boron-aluminum combination is less pleasing, but can be made to sound right. And so it goes. With some straining of ear and imagination, a fair number of the lighter atoms can be lined up musically.

The trouble with Newlands' scheme is that it didn't go very far. After calcium, for instance, it takes 17 keys to reach its clearly similar octave, strontium. And the situation becomes progressively less harmonious. The Chemical Society was distinctly unimpressed by Newlands' scheme. In fact, one of its members is said to have risen gravely and asked if Newlands had, perhaps, tried to find regularities in an alphabetical arrangement of atoms.

Less than 10 years after Newlands, the Russian, Dmitri Mendeleev, published a paper which not only grouped all the known elements, but also predicted the existence of several previously unsuspected ones. Every chemistry student today has studied Mendeleev's periodic table. It has been the cornerstone of chemical progress for a hundred years, yet I have never seen in print any mention of how Mendeleev came upon it.



Mendeleev was sitting on a sofa. . . . Suddenly, during the Quintet, everything fell logically into place

When I was in college, I was fortunate enough to become acquainted with Frau Theodor Boveri. Professor Boveri (he was Herr Professor Doktor Geheimrat!) had worked closely with Mendeleev and the Boveri's had heard the story directly from him.

It happened that the Mendeleev family was a rather musical one. There were a number of children who, with their mother, could muster a string quartet, along with a pianist. One evening, this group was playing together, working on Schumann's Piano Quintet. I can

easily picture the scene, especially since I myself have played this same piece in amateur ensembles. There are the peaceful passages, interspersed with rough spots, sudden stops, and endless repetitions.

Mendeleev was sitting on a sofa. Apparently, he had been mulling over Doebereiner's and Newlands' problem. Suddenly, during the Quintet, everything fell logically into place. According to the Boveri's story, he sat down immediately at his desk and arranged the elements. Just like that!

If the story is allowed to end here it could be mistaken for a kind of hero-worshipping fairy tale. But, as I said, I have played that particular Quintet and I know the periodic table well. To me the connection is fantastically clear.

The second theme of the Quintet's first movement is presented first by the piano in a fragmentary seven-note melody. It breaks off and, then, is repeated in the same way. Next, piano and cello take up the same melody a third time but, this time, the viola continues with an inversion—a development—of the original melody. This pattern is repeated and, finally, there is an extensive development of the theme.

I certainly do not think that Mendeleev counted the notes on his fingers as his family started work on that theme. But it does seem very likely that the "dum, dah-ta-dah-dah-dah-dah," going round and round, followed first by a simple and then by a more complicated development, provided precisely the pattern that he was looking for. Where Newlarids had searched for simple, slavish repetitions, Mendeleev saw free, expanding creation. It is quite conceivable that, given this idea and with his knowledge of the elements, he could have dashed off the entire periodic table in a matter of hours.

The story seems even less far-fetched when compared with similar accounts of the genesis of other scientific ideas. For instance, Archimedes and his bathtub, Kekule with his dream of little dancing elves, Julius Mayer "walking up a gentle slope," and William Rowan Hamilton noticing the inscription scratched on the bridge. Creation often happens in this way.

Modern Atomic Theory

Then for more than half a century the musical development seems to have been muted. Ramsay, with his noble gases, merely added a note to the main theme. Thompson, Ruther-

ford, and Moseley provided the physical basis for the numbers which Mendeleev had so confidently assigned to the atoms. But finally, in the 1920's and 1930's, the modern atom was born—sonorous, musical, and orchestrated.

Rutherford had first tried to set the electrons of his atom in orbits, revolving around the nucleus like planets around a sun. But, if these electrons were treated as moving electric charges, they showed disastrous inconsistencies. Such an atom would quickly collapse. In 1925, De Broglie tried the crazy scheme of treating an electron as a wave and found, to his surprise, that it worked. Starting from here, Schroedinger and Heisenberg showed that the electrical-mechanical paradox of the collapsing atom could be resolved only if an ultimate paradox were accepted; that each electron within an atom behave like a standing wave. The modes of vibration of such a wave are vastly more complicated than those of a piano string or the air column in a French horn. But the basic conception and the mathematics come directly from the physics of musical sounds.

Within the atom each electron can exist only as a fundamental vibration, the wave motion of which can properly be compared with that of a violin string. When excited it can exist as the octave, or a higher overtone, of this fundamental. Hence, a heavy atom like uranium will have more than 90 of these electrons, each capable of its own harmonies, and the entire ensemble, resounding in the inner spaces of the atom, will produce a vibration pattern remarkably like that of a full symphony orchestra. This is inaudible to any human ear, of course, but can be recorded by the spectroscopist as music is recorded on tape.

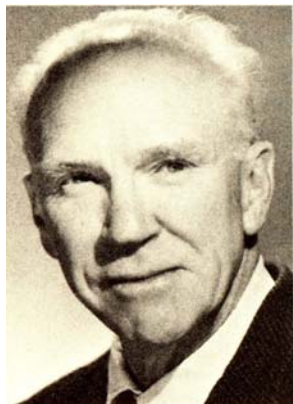
Today's mathematics treats the immeasurably complex vibration patterns of atom and orchestra in exactly the same way. Each, in its wholeness, defies precise mathematical description. But the trained physicist can single out one group of electrons, just as the trained musician can hear the viola section. He can treat their vibrations as a relatively simple and understandable unit, even though their full significance can be grasped only in the context of the whole.

I am now waiting with interest for the next musical step. The vibrations of the nucleus of the atom are known to be as complicated as those of its electrons. If the electronic makeup of an atom can be comprehended as a single chord played by an orchestra, who is going to show us how to treat the nucleus as a whole composition?

8g
11
/7./6
F=41
1a=wz

$\lambda = 22$
 $\mu = 24$
 $\nu = 27$
 $\xi = 28$
 $\rho = 31$
 $\sigma = 32$
 $\alpha = 35$
 $\kappa = 39$
 $\zeta = 40$

Part of Mendeleev's first draft stating the periodic table



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