Tetrahedron Letters No.26, pp. 1725-1731, 1964. Pergamon Press Ltd.
Printed in Great Britain.

ELEMENT-MAPPING, A NEW APPROACH TO THE INTERPRETATION OF HIGH RESOLUTION MASS SPECTRA[1] *

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(Received 24 April 1964)

In the past double-focusing, high resolution mass spectrometers have been used[2] to resolve peaks of same nominal mass but differing in elemental composition, or to determine the mass of ions with an accuracy permitting the determination of its elemental composition. Beynon[2a] had first shown that it is possible to determine the empirical formula of a compound, or to corroborate postulated fragmentation processes. At present, this approach involves mass spectra obtained with low resolution (up to 1 part in 1000) followed by the determination of the accurate mass of a few selected peaks of interest. In only very few cases the entire mass spectrum of a compound has been recorded with high resolution, limited to small molecules[3] because of the slowness of recording with high resolving power.

[1] Application of Mass Spectrometry to Structure Problems. Part XXI. Part XX: W. Richter and K. Biemann, Monatsh. Chem., 1964, in press.

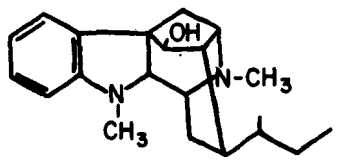
[2] For a review see (a) R. A. Saunders and A. E. Williams in "Mass Spectrometry of Organic Ions," F. W. McLafferty, ed., Academic Press, 1963. (b) R. D. Craig, B. N. Green and J. D. Waldron, Chimia, 17, 33 (1963)

[3] For example, esters up to mol. wt. 144: J. H. Beynon, R. A. Saunders and A. E. Williams, Anal. Chem., 33, 221 (1961).

* Supported by grants from the National Science Foundation (G-21037) and the National Institutes of Health (GM-09352). This work was done in part at the MIT Computation Center, Cambridge, Massachusetts.

DEOXYDIHYDRO-N_b-METHYLAJMALINE

	CH	CHO	CHN	CHNO	CHN2	CHN2O
94			6/ 8 0••••			
95	7/11 0••		8/10-0•••			
98				5/ 8 1••••••		
103	8/ 7-0•••					
106			7/ 8 0••			
107			7/ 9-0•			
108			7/10-0•••			
110			7/12-0••••			
115	9/ 7-0•••					
117			8/ 7 0••			
118			8/ 8 0•			
120			8/10 1••			
122			8/12 2•			
123			8/13 2•			
124				7/10 0•••		
126				7/12-0••		
127	10/ 7-0••					
129			9/ 7 1•			
130			9/ 8 0•••			
131			9/ 9-0••••			
132			9/10-1•••			
142			10/ 8-0•			
143			10/ 9-0••			
144			10/10-0••••			
145			10/11-0•••			
152			10/18-0••••			
154			10/20-0••			
156			11/10-0•			
157			11/11-0•••			
158			11/12 0•••	10/ 8-0••		
159				10/ 9-0•		
160				10/10-0•••		
167			12/ 9-0•			
168				10/18 0••		
170			12/12 0••			
173				11/11 0••		
181			13/11-0•••			
182			13/12-0••••	11/20 0••••••		
183					12/11 2••	
197					13/13 0••••	
213					14/17-0•••	
269						17/21 1•
336						21/30-0••



In contrast to previous work[2] we have been using a spectrometer of the Mattauch-Herzog type (CEC 21-110), which permits simultaneous recording of the entire mass spectrum with high resolution on a photographic plate, which therefore contains information regarding the exact mass of all the ions formed. We have developed a semi-automatic technique to measure the distances of all lines and to convert these with the aid of an IBM 7094 computer via their accurate masses to the elemental composition of all the ions produced from organic compounds, presently up to mol. wt. 900. It was immediately realized that the vast amount of data(composition of a few hundred ions), while difficult to comprehend, represents very valuable information concerning the distribution of the heteroelements within the molecule. Finally a comprehensible output-format was devised which we call an "element map" (see Figs. 1-3).

The element map contains all the species arranged in separate columns according to their heteroatom content. In Fig. 1 the first column shows the nominal mass; the second column, all the ions containing C and H; the third column, those containing C, H and O, etc. The 7th column lists species containing C, H, N_2, and O. The entry for each ion represents the number of C and H, deviation in m.m.u. from theoretical mass (limit $\pm$ 3 m.m.u.) and relative intensity (logarithmic scale) represented by 1-9 asterisks.

Such an arrangement of the data reveals much about the interrelationship of the heteroatoms within the molecule. The lower right-hand corner contains the heaviest ions with the highest number of heteroatoms, therefore the molecular ion ($C_{21}H_{30}N_2O$ in Fig. 1, the element map of deoxydihydro-N_b-methylajmaline). On the other hand, the very few entries in the CH-column, particularly the lack at higher masses, shows that the heteroatoms are intimately built into the carbon skeleton, making it impossible to produce ions without heteroatoms to any appreciable extent; the complete absence of

CHO-species, at least above mass 94, implies that the oxygen atom is not easily retained (i. e., an aliphatic and not aromatic oxygen).

On the other hand, the CHN-column is heavily populated, implying that the nitrogen atoms are not part of small substituents but rather built into the ring system. The ratio of carbon vs. hydrogen shows that the hydrogen rich CHN-series has at the most 10 carbon atoms, i.e., the aliphatic or alicyclic system is of about that size. The ions of low hydrogen:carbon ratio contain up to 13 carbon atoms, which means that the aromatic system can retain that many C-atoms with 1 N-atom. Similar conclusions can be reached from the CHNO-column as the entry 11/20 requires that the alicyclic system can retain 1 N-atom and 1 O-atom within 11 C-atoms; and the small but abundant fragment of mass 98 requires that 1 N-atom and 1 O-atom are within 5 C-atoms. In the CHN_2-column we find only a few ions with 12, 13, and 14 C-atoms, respectively, demonstrating that the loss of oxygen is accompanied by the loss of at least 7 C-atoms. The only fragment ion produced without loss of a heteroatom is due to the elimination of C_4H_9 from the molecular ion requiring the presence of a fully saturated C_4 side chain. All these conclusions are in agreement with the known structure of deoxydihydro-N_b-methylajmaline,[4] and the interpretation of the formation of most ions follows conventional lines.[5]

In contrast to the element map of an indole alkaloid (Fig. 1), that of a steroid is of very different appearance (Fig. 2). First, the CH-column is highly populated up to 17 C-atoms, implying that the molecule ($C_{19}H_{26}O_3$) can lose all 3 O-atoms with only 2 C-atoms, easily possible in such a polycyclic hydroxy diketone (loss of H_2O + 2 CO). The smallest fragment still containing 3 oxygen atoms has 17 carbon atoms, indicating that the heteroatoms are

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[4] R. Robinson, Angew. Chem., 69, 40 (1957).

[5] A. L. Burlingame, Ph.D. Thesis, MIT, 1963

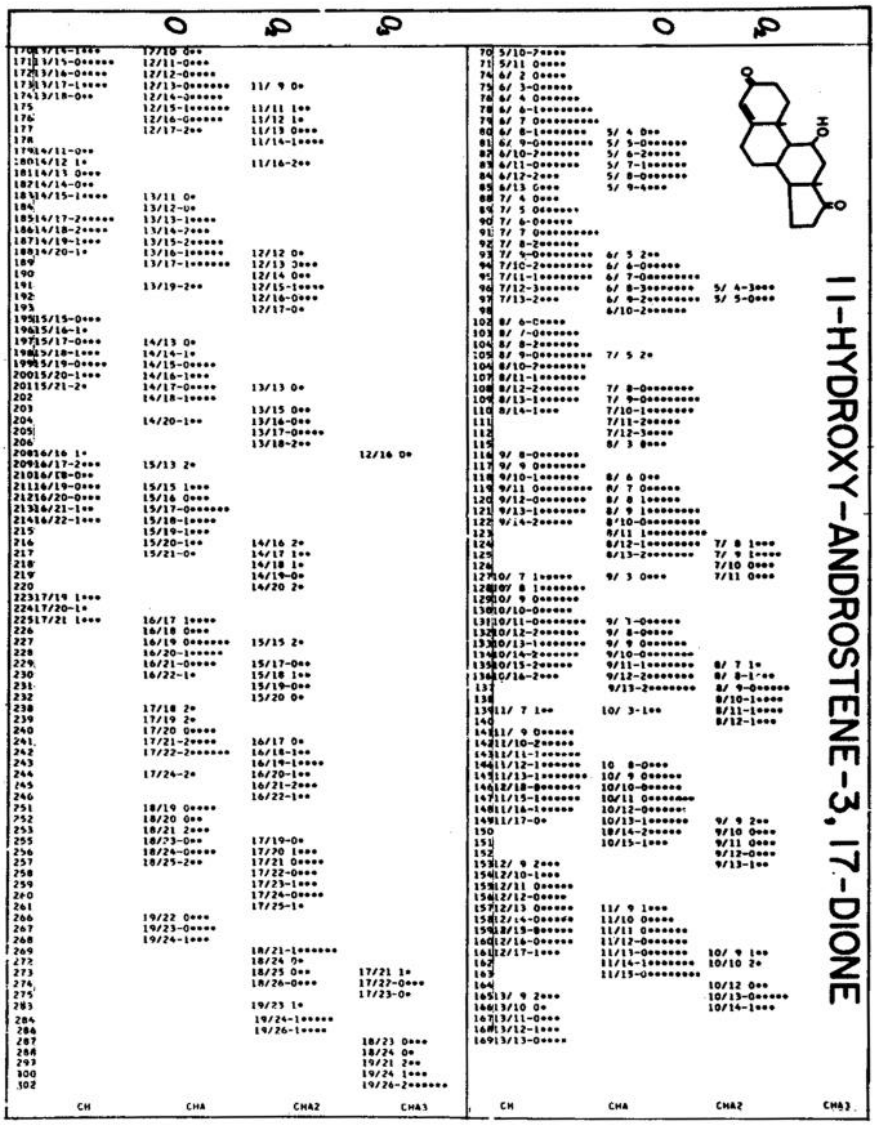

Figure 2. Element Map of 11-Hydroxy-Δ^{5}-Androstene-3,17-dione

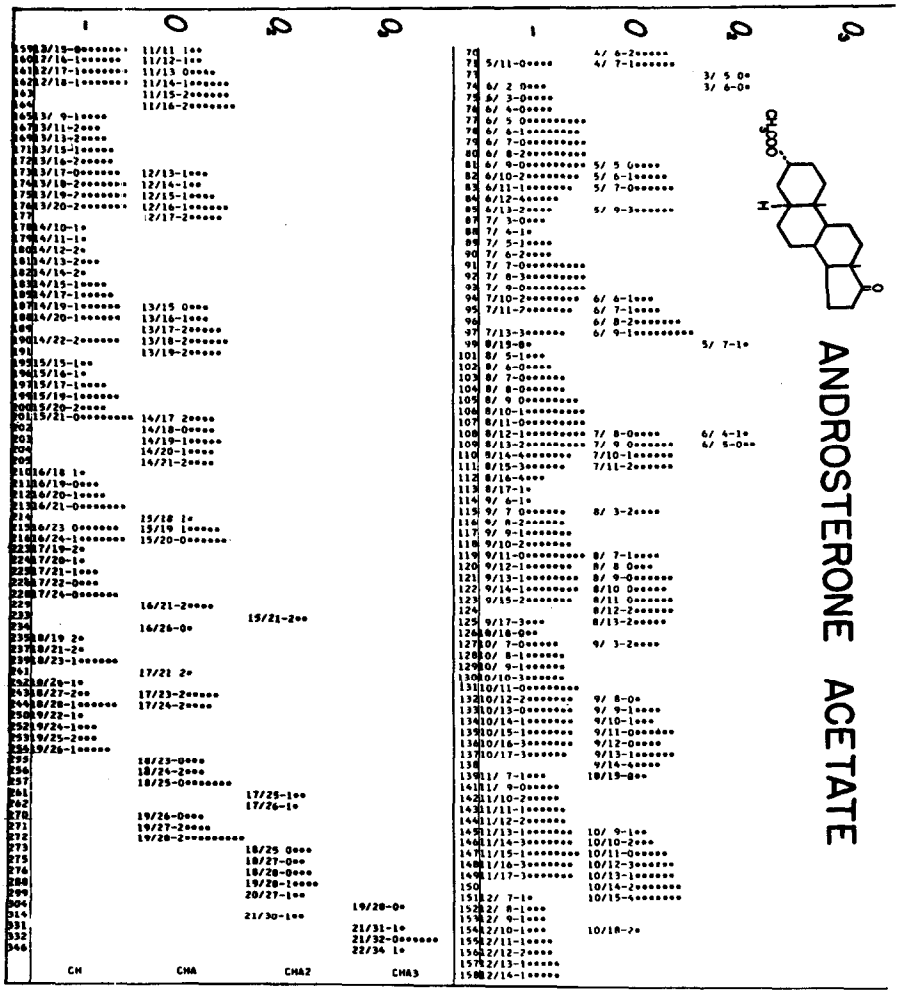

Figure 3. Element Map of Androsterone Acetate.

not bunched together in one corner of the molecule and that only 2 carbon atoms can be lost without involving the loss of oxygen. The CHO_2-column is much better represented, and it is of interest to note that the smallest fragment of this type contains 5 carbon atoms, the shortest connection between 2 O-atoms (C-11, 12, 13, 17, 18). The next larger such ion contains 7 C-atoms, probably ring D with C-11 and 12, but not C-18.

Another steroid of about the same size containing 3 O-atoms, androsterone acetate, has a rather different distribution of the oxygen atoms within the molecule, which is clearly pointed out by the element map of this compound (Fig. 3). This molecule can retain all 19 carbon atoms without oxygen due to elimination of acetic acid and of water from the carbonyl moiety, a process frequently found with cyclic ketones. Retention of all the oxygen atoms is very rare as two of them are part of an easily eliminated substituent and the loss of C_2H_4 is the only significant process not involving loss of oxygen. In contrast to Fig. 2, the CHO_2-ions are very rare for the same reason, while the CHO-ions are abundant, the largest ($C_{19}H_{28}O$) requiring the association of 2 oxygens within 2 carbon atoms. Scrutinizing the lower right-hand corner of Fig. 3 reveals that most of the fragmentation processes involve loss of CH_3COOH, CO, H_2O, CH_3, C_2H_4, C_2H_4O, etc.

From the above discussion it is clear that "element mapping" represents a valuable new approach in the interpretation of high resolution mass spectra, making use of the information conveyed by the elemental composition of all the species rather than their mass, the usual approach in mass spectrometry. It should be realized that in this representation even ions of very low abundance, which in conventional mass spectra are mostly disregarded, become very meaningful. As the element map contains also relative intensity ratios, the conventional lines of interpretation of mass spectra are, of course, used in conjunction with the approach outlined above.