

ELEMENT-MAPPING, A NEW APPROACH TO THE INTERPRETATION
OF HIGH RESOLUTION MASS SPECTRA¹ *

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In the past double-focusing, high resolution mass spectrometers have been used² 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 molecules³ because of the slowness of recording with high resolving power.

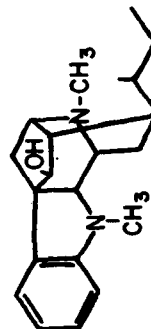
Application of Mass Spectrometry to Structure Problems. Part XXI.
Part XX: W. Richter and K. Biemann, Monatsh.Chem., 1964, in press.

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).

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DEOXYDIHYDRO-N ₁ -METHYLALMALINE						
	CH	CHO	CHN	CHNO	CHN ₂	CHN ₂ O
94						
95	7/11 0**		6/ 8 0*** 6/10-0***			
103				5/ 8 1****		
106	6/ 7-0***					
107			7/ 8 0** 7/ 9-0*			
108			7/10-0*** 7/12-0***			
110						
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*** 7/12-0**		
126						
127	10/ 7-0**					
129						
130			9/ 7 1*			
131			9/ 8 0***			
132			9/ 9-0***			
133			9/10-1**			
142			10/ 8-0*			
143			10/ 9-0**			
144			10/10-0***			
145			10/11-0***			
152			10/18-0***			
154			10/25-0**			
156			11/10-0*			
157			11/11-0**			
158			11/12 0***			
159				10/ 8-0** 10/ 9-0*10/10-0**		
160						
167			12/ 9-0*			
168				10/18 0**		
170			12/12 0**			
173				11/11 0**		
181			13/11-0***			
182			13/12-0***			
183				11/20 0****		
197						12/11 2**
213						13/13 0***
269						14/17-0***
272						17/21 1*



17/21 1*
21/26-2-

In contrast to previous work² 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, N₂, and O. The entry for each ion represents the number of C and H, deviation in m.m.u. from theoretical mass (limit ± 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 (C₂₁H₃₀N₂O 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).

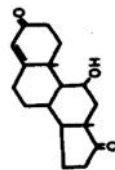
On the other hand, the CHN-column is heavily populated, implying that the nitrogen atoms are not part of small substituents but rather built into the ring system. The ratio of carbon vs. hydrogen shows that the hydrogen rich CHN-series has at the most 10 carbon atoms, i.e., the aliphatic or alicyclic 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 deoxy-dihydro- 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 ($\text{C}_{19}\text{H}_{26}\text{O}_3$) can lose all 3 O-atoms with only 2 C-atoms, easily possible in such a polycyclic hydroxy diketone (loss of $\text{H}_2\text{O} + 2 \text{CO}$). The smallest fragment still containing 3 oxygen atoms has 17 carbon atoms, indicating that the heteroatoms are

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

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

O				O			
1706/14-1000	1710 000			70 5/10-20000			
1712/17-00000	1711-0000			71 5/11 00000			
1720/14-00000	1712-00000			74 6/ 2 00000			
1733/17-10000	1713-000000	11/ 9 00		75 6/ 3-00000			
1763/18-000	1714-300000			76 6/ 4 00000			
175	1715-1000000	11/11 100		78 6/ 6-1000000			
176	1716-000000	11/12 10		79 6/ 7 0000000			
177	1717-200	11/13 0000		80 6/ 8-1000000	5/ 4 000		
178		11/14-10000		81 6/ 9-0000000	5/ 5-000000		
1794/11-000				82 6/10-000000	5/ 6-200000		
1801/12 10				83 6/11-000000	5/ 7-100000		
1811/13 0000				84 6/12-2000	5/ 8-000000		
1821/14-000				85 6/13 0000	5/ 9-00000		
1831/15-10000	13/11 00			88 7/ 4 0000			
184	13/12-00			89 7/ 5 000000			
1851/17-20000	13/13-10000			90 7/ 6-00000			
1861/18-20000	13/14-2000			91 7/ 7 00000000			
1871/19-1000	13/15-200000			92 7/ 8-200000			
1881/20-10	13/16-100000	12/12 00		93 7/ 9-0000000	6/ 5 200		
189	13/17-1000000	12/13 200		94 7/10-2000000	6/ 6-000000		
190		12/14 000		95 7/11-1000000	6/ 7-0000000		
192	13/19-200	12/15-10000		96 7/12-300000	6/ 8-3000000	5/ 4-3000	
193		12/16-0000		97 7/13-2000	6/ 9-2000000	5/ 5-0000	
19515/15-0000		12/17-00		98			
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19815/18-1000	14/14-10			104 8/ 8-200000			
19915/19-00000	14/15-00000			105 8/ 9-0000000	7/ 5 20		
20015/20-1000	14/16-1000			106 8/10-7000000			
20115/21-20	14/17-00000	13/13 00		107 8/11-1000000			
202	14/18-10000			108 8/12-200000	7/ 8-0000000		
203		13/15 000		109 8/13-100000	7/ 9-0000000		
204	14/20-100	13/16-000		110 8/14-1000	7/10-1000000		
205		13/17-00000		111	7/11-20000		
206		13/18-200		112	7/12-30000		
20916/16 10			12/16 00	115	8/ 3 0000		
20916/17-2000	15/13 20			116 9/ 8-000000			
21016/18-000	15/15 1000			117 9/ 9 0000000			
21116/19-0000	15/16 0000			118 9/10-100000	8/ 6 000		
21216/20-0000	15/17-000000			119 9/11 0000000	8/ 7 00000		
21316/21-100	15/18-10000			120 9/12-0000000	8/ 8 10000		
21416/22-1000	15/19-10000			121 9/13-1000000	8/ 9 1000000		
215	15/20-100	14/16 20		122 9/14-20000	8/10-0000000		
216	15/21-00	14/17 100		123	8/11 10000000		
217		14/18 10		124	8/12-10000000	7/ 8 1000	
218		14/19-00		125	8/13-2000000	7/ 9 10000	
219		14/20 20		126		7/10 0000	
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22317/14 1000				12807 8 1000000			
22417/20-10				12907 9 0000000			
22517/21 1000	16/17 10000			13010/10-00000			
226	16/18 0000			13110/11-000000	9/ 1-00000		
227	16/19 0000000	15/15 20		13210/12-200000	9/ 8-00000		
228	16/20-100000			13310/13-1000000	9/ 9 000000		
229	16/21-00000	15/17-000		13410/14-200000	9/10-0000000		
230	16/22-10	15/18 100		13510/15-200000	9/11-1000000	8/ 7 10	
231		15/19-000		1360/16-2000	9/12-2000000	8/ 8-1000	
232		15/20 00		137	9/13-2000000	8/ 9-000000	
233	17/18 20	15/20 00		138		8/10-10000	
234	17/19 20			13911/ 7 100	10/ 3-100	8/11-10000	
235	17/20 00000			140		8/12-1000	
236	17/21-20000	16/17 00		1411/ 9 00000			
237	17/22-200000	16/18-100		14211/10-20000			
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240		16/21-1000		14511/13-1000000	10/ 9 000000		
241		16/22-100		14612/18-8000000	10/10-000000		
242		16/22-100		14711/15-100000	10/11 0000000		
243				14811/16-10000	10/12-0000000		
244				14911/17-00	10/13-1000000	9/ 9 200	
245				150	18/14-20000	9/10 0000	
246				151	10/15-1000	9/11 0000	
247				152		9/12-0000	
248				15312/ 9 2000		9/13-100	
249				15412/10-1000			
250				15512/11 00000			
251				15612/12-00000			
252				15712/13 00000	11/ 9 1000		
253				15812/14-000000	11/10 0000		
254				15912/15-8000000	11/11 000000		
255				16012/16-000000	11/12-0000000		
256				16112/17-1000	11/13-0000000	10/ 9 100	
257				162	11/14-1000000	10/10 20	
258				163	11/15-0000000		
259				164		10/12 000	
260				16511/ 9 2000		10/13-000000	
261				16613/10 00		10/14-1000	
262				16713/11-0000			
263				16813/12-1000			
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11-HYDROXY- Δ^4 -ANDROSTENE-3,17-DIONEFigure 2. Element Map of 11-Hydroxy- Δ^4 -Androstene-3,17-dione

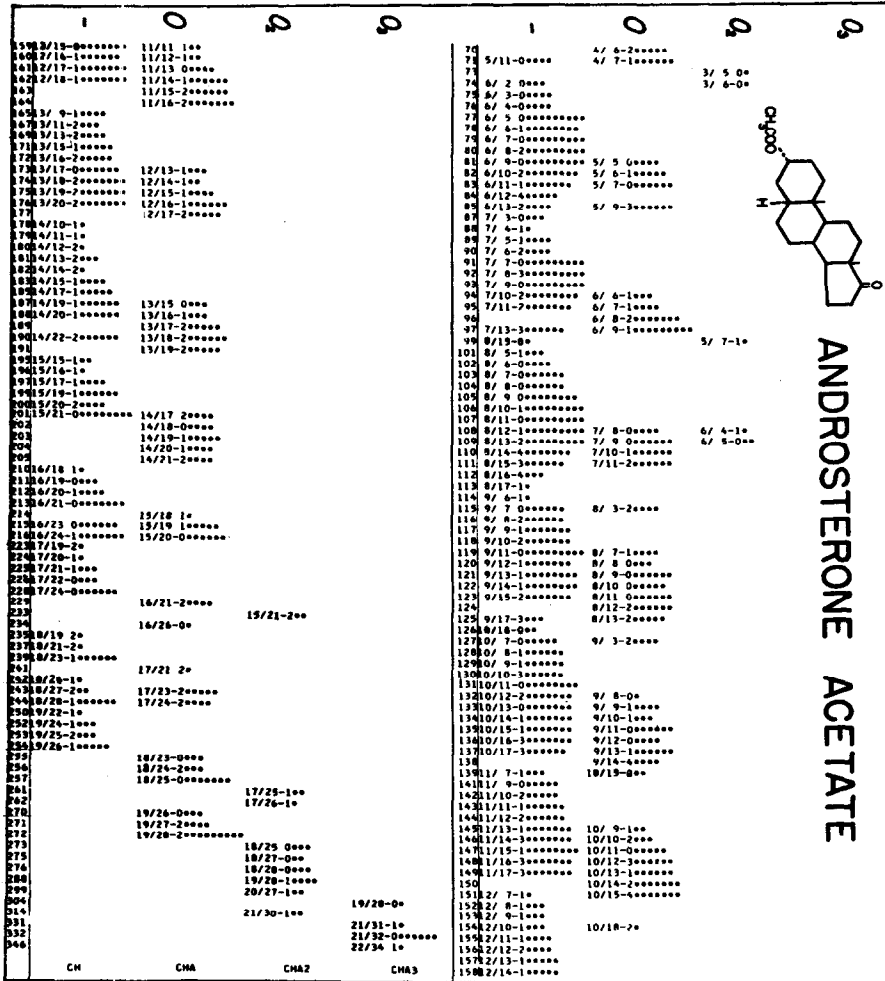


Figure 3. Element Map of Androsterone Acetate.

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 ($\text{C}_{19}\text{H}_{28}\text{O}$) 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 , $\text{C}_2\text{H}_4\text{O}$, 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.