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Fragmentations in Doubly Charged Ion Mass Spectra of Aromatic Carbonyl Compounds

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2E Doubly charged ion mass spectra of forty-six aromatic carbonyl compounds were determined. The spectra are quite different from those of singly charged ions. Several characteristic fragmentations including a novel [M−CO] peak are discussed. It is suggested that certain isomer pairs can be differentiated by comparing these spectra even when their conventional spectra are almost identical.

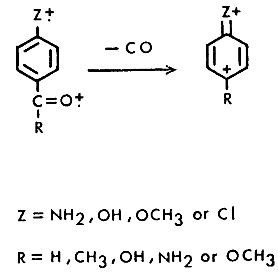
In a recent communication,[1] we have reported a novel rearrangement reaction in 2E doubly charged ion mass spectra[2] of acetophenone derivatives. A driving force for the reaction has also been briefly discussed. As an extension of this work, various aromatic carbonyl compounds were examined by the same technique[3] to elucidate any possible structural correlation in fragmentations, and to illustrate the potential usefulness of this spectra for the structural identification purposes.

Results and Discussion

The $[M-28]^{2+}$ *Peaks.* The doubly charged ion mass spectra of forty-six aromatic carbonyl compounds are summarized in Table 1 and Figs. 1 and 2. The characteristic [M−28] peak[1] was observed in most of the *p*-substituted compounds and in some of the *m*-substituted ones.

In order to determine the elemental compositions of the ion, the accurate masses were measured at half mass units of the peak in the conventional spectrum. The results were shown in Table 2. For the six compounds examined, the compositions of the [M−28] peak were unambiguously established as [M−CO]. These results indicate that the [M−28] peak has been produced, as previously suggested,[1] by the fragmentation reaction accompanying a rearrangement that involves a carbonyl side chain.

As is seen from Table 1, the carbonyl compounds whose spectra exhibited the intense [M−CO] peaks have electron-donating substituents such as an amino, a hydroxyl, or a methoxyl group. On the contrary, the spectra of *p*-tolualdehyde (**42**), *p*-methylacetophenone (**43**), and *p*-toluic acid (**44**) did not show the corresponding peak. On the other hand, when an electron-withdrawing, but lone pair electron-containing chlorine atom was introduced, the [M−CO] peak appeared as in the case of *p*-chlorobenzoic acid (**20**) or *p*-chlorobenzamide (**21**). These results suggest that the conjugative stabilization due to the lone pair electrons of the substituents in the product ion plays an important role in this fragmentation reaction [Scheme 1].



Scheme 1.

The intensity of the [M−CO] peak varies with the substituents. Because the molecular ion peaks were absent in most of the spectra, the height of the commonly observed peak at 62 mass units ($C_5H_2^{2+}$ ion)[3] was taken as an internal standard for intensity correlations. It is evident from Table 3 that the intensities of the [M−CO] peak in *p*-substituted compounds are in the decreasing order of $NH_2 > OH > OCH_3$. This is the same order as Hammett's substituent constants,[4] and these findings confirm the significance of the product ion stabilities in this fragmentation reaction. The methoxyl group seems to be not very effective to stabilize the [M−CO] ion. This is also evidenced from the fact that for *meta* substituted compounds the [M−CO] peak appeared only from benzoic acids and benzamides that have an amino, a hydroxyl, or a chloro substituent.

The nature of the carbonyl group also affects these intensity ratios. For the series of compounds with the same substituent, the ratios are in the following decreasing order: aldehydes>methyl ketones>carboxylic acids>acid amides>methyl esters.

Although the spectra of methyl esters of *p*-amino, *p*-hydroxy, and *p*-methoxybenzoic acids (**12**—**14**) showed the [M−CO] peak, the corresponding ethyl esters (**15**—**17**) did not afford this peak. In order to compare the behavior of ester alkyl groups, the conventional mass spectrum of ethyl methyl phthalate was measured. It was found that $[M-OC_2H_5]$ peak was much stronger than $[M-OCH_3]$ peak, and therefore, ethoxyl group appeared to be much better leaving group. If we assume that the elimination reactions of CO and of alkoxyl group from the molecular ion are competitive in the doubly charged ion mass spectrum, the absence of the [M−CO] peak in ethyl benzoates seems to be explicable because a simple cleavage reaction with elimination of the ethoxyl group could be much faster than the elimination of CO, when compared to the case of methyl benzoates. In fact, the $[M-OC_2H_5]$ peak was very prominent in these ethyl esters (**15**, **16**).

TABLE 1. 2E DOUBLY CHARGED ION MASS SPECTRA OF AROMATIC CARBONYL COMPOUNDS (RELATIVE INTENSITIES IN PARENTHESES)[a)]

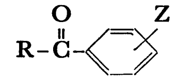
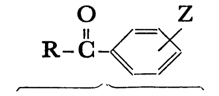
 Compd.	R	Z	[M-CO]	[M-R]	[M-R-CO]	[M-R -CO-H]	[M-18]	$[C_nH_2]$ (n=1,2,⋯)	Other fragment ions
(**2**)	H	*p*-OCH_3	108 (100)					62, 74 (49) (14)	63, 75, 76 (12) (8) (13)
(**3**)	CH_3	*p*-NH_2	107 (100)	120 (74)	92 (39)	91 (16)	117 (9)		89, 104, 105, 106, 108, 121 (11) (5) (18) (8) (9) (7)
(**4**)	CH_3	*p*-OH	108 (36)	121 (100)	93 (10)	92 (33)	118 (5)	62, 86 (14) (16)	63, 64, 90, 105, 106, 120, 122 (12) (5) (5) (5) (5) (7) (9)
(**5**)[b)]	CH_3	*p*-OCH_3	122 (74)	135 (22)				62, 74, 86 (100) (29) (29)	63, 64, 75, 76, 77, 78, 87, 92, 123 (38) (16) (17) (48) (5) (13) (5) (7) (7)
(**6**)	OH	*p*-NH_2	109 (36)		92 (19)	91 (22)		62 (5)	89, 93, 94, 120 (17) (100) (7) (6)
(**7**)	OH	*p*-OH	110 (100)	121 (24)		92 (18)		62, 74 (63) (19)	63, 64, 75, 94, 111 (20) (7) (7) (41) (8)
(**8**)	OH	*p*-OCH_3	124 (46)	135 (19)	109 (5)			62, 74 (100) (31)	63, 64, 75, 76, 78, 92, 104 (34) (13) (16) (22) (7) (14) (5)
(**9**)	NH_2	*p*-NH_2	108 (94)	120 (40)	92 (74)	91 (23)	118 (100)	62, 74 (21) (14)	63, 65, 76, 87, 88, 89, 90, 109, 119 (6) (10) (5) (5) (5) (25) (6) (10) (13)
(**10**)	NH_2	*p*-OH	109 (17)	121 (10)		92 (6)	119 (100)	62, 74 (13) (5)	63, 89, 91, 94, 120 (9) (8) (7) (8) (10)
(**11**)	NH_2	*p*-OCH_3	123 (28)	135 (12)		106 (7)		62, 74 (100) (38)	63, 64, 75, 76, 77, 78, 80, 89, 91, 92, 100, 104 (44)(18)(18)(44) (7)(19) (8) (8) (7)(16) (5) (13)
(**12**)	OCH_3	*p*-NH_2	123 (16)	120 (29)	92 (100)	91 (32)		62 (8)	65, 88, 89, 90, 93 (6) (5) (28) (7) (15)
(**13**)	OCH_3	*p*-OH	124 (63)	121 (65)	93 (15)	92 (62)	134 (18)	62, 74 (100) (17)	63, 64, 65, 75, 76, 90, 94, 122, 152 (33) (18) (11) (9) (6) (5) (6) (6) (5)
(**14**)	OCH_3	*p*-OCH_3	138 (43)	135 (7)				62, 74 (100) (23)	63, 64, 75, 76, 77, 78, 92, 104 (37) (20) (12) (38) (6) (24) (10) (8)
(**15**)	OC_2H_5	*p*-NH_2		120 (100)	92 (68)	91 (19)			89, 93, 121 (9) (7) (10)
(**16**)	OC_2H_5	*p*-OH		121 (100)	93 (18)	92 (86)		62, 74 (62) (23)	63, 64, 65, 75, 90, 91, 94, 110, 120, 122, 130, 132 (23)(26)(14) (5) (6) (5)(10) (5) (8) (9) (14) (14)
(**17**)	OC_2H_5	*p*-OCH_3						62, 74 (100) (14)	61, 63, 64, 65, 75, 76, 78, 92 (21) (57) (20) (8) (6) (26) (29) (8)
(**19**)	CH_3	*p*-Cl	126 (6)	139 (100)	111 (88)	110 (7)		74, 86, 98 (24) (49) (20)	75, 76, 85, 87, 88, 89, 90, 99, 102, 104, 112 (68) (50) (5) (11) (11) (38) (38) (5) (10) (8) (12)
				141 (36)	113 (32)				125, 140 (12) (12)
(**20**)	OH	*p*-Cl	128 (100)	139 (44)	111 (46)	110 (8)		74 (26)	73, 75, 76, 92, 102, 104, 108, 112, 129, 140 (6)(36)(17) (6) (5) (5) (5) (7) (11) (6)
			130 (43)	141 (17)	113 (20)				
(**21**)	NH_2	*p*-Cl	127 (100)	139 (12)	111 (26)	110 (6)	137 (6)	74 (31)	75, 76, 91, 100, 101, 128 (48) (32) (22) (6) (6) (9)
			129 (35)		113 (9)				
(**22**)	OCH_3	*p*-Cl	142 (9)	139 (14)	111 (42)	110 (9)		62, 74 (5) (68)	75, 76, 112, 134 (100) (50) (6) (28)
				141 (6)	113 (11)				
(**24**)	H	*m*-OCH_3						62, 74, 86 (100) (38) (11)	63, 64, 75, 76, 78, 136 (28) (9) (14) (21) (11) (7)
(**25**)	CH_3	*m*-NH_2		120 (8)	92 (100)	91 (35)		74, 86 (6) (7)	77, 80, 89, 90, 93 (5) (11) (20) (5) (12)

Table 1 (Continued)

 Compd.	R	Z	[M-CO]	[M-R]	[M-R-CO]	[M-R -CO-H]	[M-18]	$[C_nH_2]$ (n=1,2,⋯)	Other fragment ions
(**26**)	CH_3	*m*-OH		121	93	92	118	62, 74, 86	63,64,65,75,76,77,78,79,85,87,89,90
				(87)	(24)	(100)	(8)	(67) (26) (42)	(25)(23)(28)(23) (8) (6) (9)(17) (5)(10) (8)(12)
									98,99,107,120,122
									(13) (6) (13) (7) (8)
(**27**)	CH_3	*m*-OCH_3		135				62, 74, 86	63,64,75,76,77,78,85,87,88,89,90,91,92,
				(30)				(100) (31) (51)	(35)(17)(22)(52)(12)(63) (5)(10) (5) (5)(14) (5)(12)
									98,102,104
									(8) (6) (8)
(**28**)	OH	*m*-NH_2	109	120	92	91		62, 74	63,64,65,75,76,81,87,88,89,90,93
			(60)	(13)	(100)	(28)		(46) (25)	(10) (6) (6) (7) (7) (7) (6)(15)(47)(13)(23)
(**29**)	OH	*m*-OH	110			92		62, 74	63, 64, 65
			(25)			(12)		(100) (12)	(30) (16) (9)
(**30**)	OH	*m*-OCH_3		135				62, 74	63, 64, 75, 76, 78, 92
				(10)				(100) (25)	(31) (11) (12) (14) (9) (6)
(**31**)	NH_2	*m*-NH_2	108		92	91	118	62	89, 119
			(8)		(14)	(11)	(100)	(6)	(10) (12)
(**32**)	NH_2	*m*-OH	109	121	93	92	119	62, 74	63,64,65,87,88,89,91,100,110,120
			(9)	(7)	(6)	(16)	(100)	(85) (17)	(39)(19)(14)(10) (8)(13)(26) (6) (6) (7)
(**33**)	NH_2	*m*-OCH_3		135		106		62, 74	63,64,73,75,76,77,78,79,80,88,89,91
				(24)		(6)		(100) (44)	(41)(12) (5)(15)(42) (9)(25) (5)(11) (5) (9) (5)
									92,100
									(13) (7)
(**34**)	OCH_3	*m*-NH_2		120	92	91			88, 89, 93
				(40)	(100)	(29)			(5) (15) (15)
(**35**)	OCH_3	*m*-OH				92		62, 74	61, 63, 64, 65, 75
						(8)		(100) (8)	(9) (40) (18) (12) (5)
(**36**)	OCH_3	*m*-OCH_3		135				62, 74	61, 63, 64, 75, 76, 78, 92
				(16)				(100) (20)	(10) (47) (18) (9) (27) (22) (9)
(**38**)	CH_3	*m*-Cl		139	111	110		74, 86	75,76,87,88,89,90,98,102,104,112,125
				(75)	(100)	(5)		(22) (51)	(100)(59)(14)(14)(47) (6)(24) (13) (5) (6) (6)
				141	113				
				(14)	(27)				
(**39**)	OH	*m*-Cl	128	139	111	110		74	73, 75,76,77,92,101,102,108,109,112
			(80)	(40)	(75)	(15)		(70)	(11)(100)(56) (7)(20) (5) (9) (7) (5) (11)
			130	141	113				120,129
			(21)	(11)	(24)				(17) (6)
(**40**)	NH_2	*m*-Cl	127	139	111	110	137	74	73, 75,76,77,89,91,92,100,101,102,103,
			(78)	(24)	(78)	(11)	(9)	(70)	(7)(100)(70) (5)(11)(57) (6) (20) (15) (6) (7)
			129	141	113				104,108,112,119,120,128
			(25)	(7)	(25)				(6) (6) (10) (5) (5) (5)
(**41**)	OCH_3	*m*-Cl			111			74	73, 75, 76, 134
					(17)			(60)	(5)(100) (49) (17)
(**42**)	H	*p*-CH_3		119	91	90		62, 74, 86	85, 87, 88, 89, 98, 118
				(6)	(59)	(93)		(7) (5)(100)	(5) (17) (16) (26) (8) (44)
(**43**)	CH_3	*p*-CH_3		119	91	90		86	87, 89, 92, 102, 104, 118, 132
				(8)	(100)	(18)		(19)	(5) (11) (6) (22) (7) (9) (6)
(**44**)	OH	*p*-CH_3	108	119	91	90	118	62, 86	85, 87, 88, 89, 92
			(6)	(16)	(92)	(100)	(62)	(6) (88)	(5) (30) (35) (41) (12)
(**45**)	CH_3	*m*-CH_3		119	91	90		86	87, 88, 89, 92, 102, 103, 115, 118
				(25)	(100)	(34)		(20)	(5) (5) (20) (9) (25) (5) (5) (31)
(**46**)	OH	*m*-CH_3		119	91	90	118	62, 74, 86	85, 87, 88, 89, 92
				(18)	(85)	(72)	(41)	(5) (5)(100)	(8) (27) (29) (36) (11)

a) Spectra of compounds **1**,**18**, **23**, and **37** are shown in Figs. 1 and 2. b) Due to the operating conditions of the mass spectrometer, relative intensities of this compound is differeent from those previously reported.[1]

TABLE 2. OBSERVED AND CALCULATED MASSES OF $[M\text{-}28]^{2+}$ PEAKS IN amu.

Compound	Obsd. masses of the peak	Calcd. for $[M\text{-}CO]^{2+}$
p-Anisaldehyde (**2**) $(C_8H_8O_2)$	54.0281	54.0288 $[C_7H_8O]^{2+}$
p-Aminoacetophenone (**3**) (C_8H_9NO)	53.5358	53.5367 $[C_7H_9N]^{2+}$
p-Methoxyacetophenone (**5**) $(C_9H_{10}O_2)$	61.0362	61.0366 $[C_8H_{10}O]^{2+}$
p-Aminobenzoic acid (**6**) $(C_7H_7NO_2)$	54.5256	54.5264 $[C_6H_7NO]^{2+}$
Methyl *p*-aminobenzoate (**12**) $(C_8H_9NO_2)$	61.5352	61.5342 $[C_7H_9NO]^{2+}$
Methyl *p*-hydroxybenzoate (**13**) $(C_8H_8O_3)$	62.0260	62.0262 $[C_7H_8O_2]^{2+}$

TABLE 3. THE PEAK INTENSITY RATIOS OF $[M\text{-}CO]^{2+}/[62]^{2+}$

	p-NH_2	*p*-OH	*p*-OCH_3
Ar-CHO	—	2.7	2.0
Ar-$COCH_3$	*ca.* 200	2.6	0.7
Ar-COOH	7.3	1.6	0.5
Ar-$CONH_2$	4.5	1.3	0.3
Ar-$COOCH_3$	2.0	0.6	0.4

Other Characteristic Fragment Ion Peaks. Fragment peaks at 62 and 74 mass units were commonly observed. These ions are expected to have the compositions of C_5H_2 and C_6H_2, respectively, and would probably be the same ions as appeared in aromatic hydrocarbons.[3] Particularly for compounds with a hydroxyl or a methoxyl group at *para* or *meta* positions, the 62 peak was very strong and often accompanied by intense peaks at 63 and 64 mass units, whereas these peaks were relatively weak in amino, methyl, or chloro derivatives. On the other hand, a group of intense peaks at 74, 75, and 76 mass units was observed in *p*- or *m*-methoxy and chloro compounds.

A peak at 86 mass units was observed in all acetophenones except for *p*-amino compound, and in methyl substituted benzaldehydes and benzoic acids. This ion would be also a hydrocarbon fragment of C_7H_2.[3] These compounds also exhibited moderately intense peaks at 87, 88, 89, and in some cases at 90 mass units.

The [M−R] peak, resulting from a simple α-cleavage of the carbonyl group, was observed for most of the compounds. Expulsion of carbon monoxide from this ion afforded the [M−R−CO] peak as in ordinary spectra. However, methoxy compounds did not show this [M−R−CO] peak in any appreciable amount. It is of interest that for hydroxy compounds the corresponding peak appeared at 92 mass units rather than at 93. The composition of this 92 ion from methyl *p*-hydroxybenzoate (**13**) was established as C_6H_4O ([M−R−CO−H]), but the structure of the ion is unknown at present. This [M−R−CO−H] peak was also observed in amino and methyl compounds.

Besides these peaks, some other fragmentations are also characteristic of the substituent. For example, amino compounds showed a peak of intermediate intensity at 89 mass units, while methyl compounds afforded a peak at 118 and methoxy derivatives at 78 mass units.

Finally, it is worth noting that the [M−18] peak was the base peak in the spectra of both *p*- and *m*-amino or hydroxybenzamides (**9**, **10**, **31**, **32**), and that the [M−44] peak was significant for *p*-amino or *p*-hydroxybenzoic acid (**6**, **7**).

Discrimination of Isomers. As was discussed in the previous section, the [M−28] peak was characteristic of the compounds that have strong electron-donating substituents. It is, therefore, possible to differentiate the isomer pairs of certain compounds by observing this peak. For example, the conventional spectra of *p*- and *m*-hydroxybenzaldehydes (**1**, **23**) are essentially the same, but in their 2E doubly charged ion spectra only the *p*-compound exhibited a strong [M−28] peak, whereas the peak was negligibly small in the *m*-compound [Fig. 1]. The similar situation was encountered in several other cases, *e.g.*, in *para* and *meta* isomer

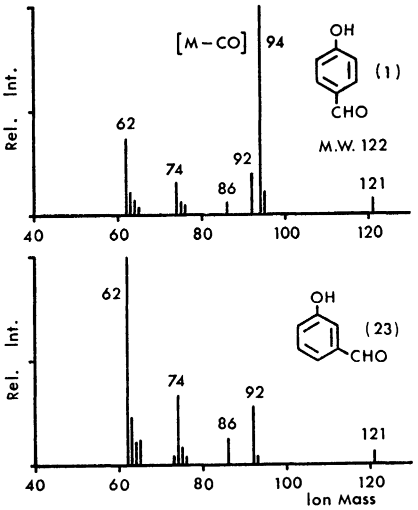


Fig. 1. 2E Doubly charged ion mass spectra of *p*- and *m*-hydroxybenzaldehydes (**1**, **23**).

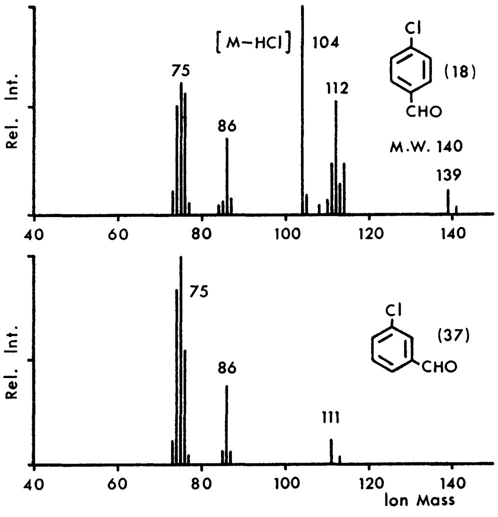


Fig. 2. 2E Doubly charged ion mass spectra of *p*- and *m*-chlorobenzaldehydes (**18**, **37**).

pairs of methoxybenzaldehydes (**2**, **24**), aminoacetophenones (**3**, **25**), and hydroxybenzoic acids (**7**, **29**).

Other characteristic peaks can also be used. Thus, an [M−HCl] peak was very prominent only in *p*-chlorobenzaldehyde (**18**) in doubly charged ion spectra [Fig. 2], while both *p*- and *m*-isomers afforded almost identical spectra in ordinary measurement (singly charged ion spectra).

Conclusion

It is evident from the above results that in doubly charged ion spectra of aromatic carbonyl compounds several different fragmentations were observed from those in conventional spectra. One of the most characteristic peaks of these compounds is the [M−CO] peak. Examination of the substituent effects revealed that the product ion stabilities are the most important factor in this fragmentation reaction.

Although several other structure-spectral pattern-correlations are obtained, the detailed structure of each fragment ion and the precise mechanism of its formation are not elucidated at this stage, and apparently further work is awaited.

On the empirical ground, however, it was found possible to distinguish the isomer pairs of certain compounds by using this spectra. This is of course very limited at present, but it is our hope that after accumulation of many data the 2E doubly charged ion spectrum will be one of the useful diagnostic tools for isomer discrimination and for structural identification of organic compounds.

Experimental

Materials. The most of the compounds were commercial samples of extra pure or guaranteed grade. The following compounds were prepared and characterized by standard procedures: *p*-aminoacetophenone (**3**), *p*-hydroxyacetophenone (**4**), methyl *p*-anisate (**14**), *p*-chloroacetophenone (**19**), *p*-chlorobenzamide (**21**), methyl *p*-chlorobenzoate (**22**), *m*-aminoacetophenone (**25**), *m*-hydroxyacetophenone (**26**), *m*-hydroxybenzoic acid (**29**), *m*-aminobenzamide (**31**), *m*-hydroxybenzamide (**32**), *m*-anisamide (**33**), methyl *m*-aminobenzoate (**34**), methyl *m*-hydroxybenzoate (**35**), methyl *m*-anisate (**36**), *m*-chloroacetophenone (**38**), *m*-chlorobenzamide (**40**), and methyl *m*-chlorobenzoate (**41**).

Doubly Charged Ion Mass Spectra. The spectra were determined with a Hitachi RMU-7 double focusing mass spectrometer by using the previously described method.[3] After the range of mass to charge ratio in ion source was set at *m/e* 600 and the electrostatic sector at 300, the accelerating voltage was adjusted for the desired peak to be observed. Standard operating conditions were as follows: ionizing energy 70 eV, ionizing current 80 μA, source temperature 250 °C, sample pressure $1—5\times10^{-6}$ Torr, and accelerating voltage 1.8 kV.

Accurate Mass Measurements. The accurate mass measurements were carried out on a Hitachi RMH-1 double focusing mass spectrometer. Operating conditions were ionizing energy 70 eV, ionizing current 0.6 mA, source temperature 200 °C, accelerating voltage 6.7 kV and resolution about 30000 (10% valley). Accurate masses of most peaks were determined by using doublets which were made by introducing appropriate reference samples into the spectrometer. In the case of nitrogen containing fragments, the peak appeared between nominal integer masses and, therefore, calculation by using Lagrange's interpolation formula gave reliable results. Data on Table 2 indicate the agreement between the calculated and observed values was satisfactory.

For the peak at 92 mass units from methyl *p*-hydroxybenzoate (**13**), the following result was obtained. Obsd: 46.0133, calcd for $(C_6H_4O)^{2+}$: 46.0131.

References

1) H. Sakurai, A. Tatematsu, and H. Nakata, *Org. Mass Spectrometry*, **7**, 1109 (1973).

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