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RECENT DEVELOPMENTS IN MASS SPECTROMETRY FOR THE ANALYSIS OF COMPLEX MIXTURES

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INTRODUCTION

Several new mass spectrometry techniques are being applied to the analysis of substances in a wide range of complex matrices including air, water, soils/sediments, commercial products, biological fluids and tissues. These new techniques include negative chemical ionization mass spectrometry (NCIMS), tandem mass spectrometry (MS/MS), desorption chemical ionization (DCI), and fast atom bombardment mass spectrometry (FAB). This review briefly discusses some of these developments which may help significantly in contaminant analysis. A much broader and more detailed review of recent advances and applications in mass spectrometry was published in *Analytical Chemistry Fundamental Reviews* (1).

NEGATIVE CHEMICAL IONIZATION MASS SPECTROMETRY

Within the last three years, an international conference was held on negative chemical ionization mass spectrometry (2). This relatively new form of mass spectrometry, originally developed by Dougherty et al (3), has the selectivity and sensitivity of electron capture detection, plus the advantage of providing confirmatory identification of the analyte (4–16).

Under NCIMS conditions there are five anion-producing reactions that are important (3, 17, 18). They are:

1. resonance capture of a thermalized electron:

$$M + e^- \rightarrow M^{-\cdot *} \xrightarrow{N} M^{-\cdot}$$

2. disassociative capture of a thermalized electron;

$$A - B \overset{e^-}{\leftarrow} A^- + B\cdot$$

3. anion association;

$$M + X^- \rightarrow MX^-$$

4. proton abstraction; and

$$AH + B^- \rightarrow A^- + BH$$

5. oxygen exchange for either halides or hydrogen atoms

$$AY^- + O_2 \rightarrow AO^- + YO\cdot.$$

The selectivity of NCIMS is strongly dependent upon the reagent gas mixture, construction of the ion source and the mass analyzer (1, 3). In NCIMS a reagent gas is present in the source at 10^4 to 10^5 times the concentration of the substrate. Under these conditions the ion-forming reactions are controlled by the nature of the reagent gas and the substrate (3, 19, 20, 21). Control of ion source pressure and temperature are critical parameters for obtaining reproducible sensitivities and mass spectra (1, 3, 18, 21). Table 1 is a list of ion-forming reactions for several different reagent gas mixtures, published by Dougherty (3). Table 2, compiled by Budzikiewicz (18), is a summary of possible uses of NCIMS including classes of compounds, reagent gases to be used, and special comments about spectra expected.

Negative chemical ionization mass spectrometry has been used successfully in the analysis of a broad range of contaminants using various mass spectrometry techniques, including GC-MS (11, 13, 16, 19–24), desorptive chemical ionization (8, 25), tandem mass spectrometry (26, 27), and laser mass spectrometry (28).

Dougherty and coworkers have applied NCIMS to screening samples for toxic residues including chlorinated aromatic pesticides (17, 22), pentachlorophenol, and 2,4,5-T (5). Figures 1 and 2 represent results of NCIMS analysis of fish samples for chlorinated aromatics. Figure 3 is a NCIMS analysis of human adipose tissue for chlorinated residues.

Numerous scientists have investigated the behavior of polychlorinated dibenzo-p-dioxins using NCIMS (4, 7, 15, 19, 20, 29). Hass and coworkers (6) have shown that oxygen-rich NCIMS is a sensitive and specific probe for polychlorinated dibenzo-p-dioxins. Hass et al (23) employed NCIMS techniques for measuring polychlorinated dibenzo-p-dioxins in biological

Table 1 Ion-forming reactions in NCIMS[a]

Reactions common to all systems.

$$M + e_s^- \quad [M]^{\cdot -} \cdot \overset{N}{} M^{-}\cdot$$
$$AB + e_s^- \quad A^- + B^\cdot$$

Hydrocarbon (93%), methylene chloride or methyl chloride (5%), oxygen (2%). Chloride/oxygen reagent.

$$RCl + e_s^- \rightarrow R^\cdot + Cl^-$$
$$ZH + Cl^- \rightarrow [ZH\cdots Cl]^-$$
$$RCl + Cl^- \rightarrow RCl_2^-$$
$$ZH + Cl^- \rightarrow Z^- + HCl$$
$$ACl^{-}\cdot + O_2 \rightarrow AO^- + ClO^\cdot$$

This gas mixture has the same high sensitivity for electron-capturing molecules as pure hydrocarbon or hydrocarbon/oxygen mistures, and it also has high sensitivity for alkylating agents such as aliphatic polyhalides, phosphate esters, and carbamates. The selectivity of the gas mixture is very high—neutral lipids are virtually transparent.

Hydrocarbon (95%), water (5%). Hydroxide reagent.

$$H_2O + e_s^- \rightarrow OH^- + H^\cdot$$
$$AH + OH^- \rightarrow A^- + H_2O$$
$$M + OH^- \rightarrow MOH^-$$

Hydroxide can also be generated by the following reactions:

$$N_2O + e_s^- \rightarrow N_2 + O^{-}\cdot$$
$$O^{-}\cdot + RH \rightarrow OH^- + R^\cdot$$

Reactions of hydroxide are mimicked by methoxide

$$CH_3ONO + e_s^- \rightarrow CH_3O^- + NO$$
$$NH_3 + e_s^- \rightarrow NH_2^- + H^\cdot$$

All these reagents give high sensitivity for many structural classes of compounds. The selectivity for toxic substances or electron-capturing molecules is low, because these reagents all react with neutral lipid esters and alcohols and can even produce intense spectra with saturated hydrocarbons.

Fluorocarbon, CHF_3, $C_2F_3Cl_3$, etc. Fluoride or chloride reagent.

$$CHF_3 + e_s^- \rightarrow F^- + 2F^\cdot + CH$$
$$AH + F^- \rightarrow A^- + HF$$
$$M + F^- \rightarrow MF^-$$
$$M^{-}\cdot + F^\cdot \rightarrow M + F^-$$

Fluorocarbons will produce either F^- or Cl^- as the reactive reagent, depending on their structure. CHF_3 gives F^-, CF_2Cl_2 and $CFCl_2CF_2Cl$ give Cl^- with some $Cl_2^{-}\cdot$. Fluoride is an exceptionally strong gas phase base, and mimics OH^- in reactivity and low selectivity. All of the fluorocarbon reagents appear to have decreased sensitivity for electron-capturing substances because of reactions like these:

$$M^- + F^\cdot \rightarrow M + F^-$$
$$Cl_2^{-}\cdot \rightarrow Cl^- + Cl^\cdot$$
$$M^{-}\cdot + Cl^\cdot \rightarrow M + Cl^-$$
$$Z^- + Cl^\cdot \rightarrow Z^\cdot + Cl^-$$

Similar reactions can occur with other radicals with high electron affinities in the source.

[a] From (3) with permission.

Table 2 Summary of the possible uses of NCI[a]

Reactant gas	Reagent ions	Class of compound	Ions in the M region
Ar, N_2	—	various	M^-, $[M-H]^-$
CH_4, $i\text{-}C_4H_{10}$	—	various	M^-, $[M-H]^-$
NH_3, (CH_2Cl_2)			$[M+CH_3]^-$, $[M-H+CH_3]^-$, $[M+C_2H_5]^-$
CH_3ONO	CH_3O^-	compounds with acidic H	$[M-H]^-$
H_2 (CH_4, $i\text{-}C_4H_{10}$)	H^-	compounds with acidic H	$[M-H]^-$
		nitroarenes	M^-
		compounds without acidic	$[M+H]^-$
CF_2Cl_2	Cl^-	RCOOH, $RCONH_2$, ArOH, $ArNH_2$, perchloro compounds, polyols	$[M+Cl]^-$, $[M-H]^-$ (little)
	(HCl_2^-)		
CH_2Cl_2	$(CH_2Cl_3^-)$	ROH, RNH_2, carbonyl compounds	$[M+Cl]^-$, $[M+HCl_2]^-$
		nitroarenes	M^-, $[M+HCl]^-$
		RBr(1)	$Br^-(I^-)$
		multifunctional natural products	$[M+Cl]^-$, $[M-H]^-$
		hydrocarbons, tert-amines, nitriles	no $[M+Cl]^-$
CHF_3	F^-	alcohols	$[M+F]^-$, $[M-H]^-$
CF_4	(CF_3^-)	$RSi(CH_3)_3$	R^-

N_2O	O^-	unsaturated hydrocarbons, acetone, nitriles	$[M-H]^-$, $[M-2H]^-$ $[M-H+O]^-$	
		RCOCl	$[M-Cl+O]^-$, $[M-H_2Cl+O]^-$	
		phenothiazines	hardly any ions	
		ROH	$[M-H]^-$, $[M-3H]^-$	
		alkylarenes	$[M-H]^-$, $[M-H+O]^-$, $[M-H+N_2O]^-$, $[M-H+N_2O$	
O_2	O^-, O_2^-	ROH, RCOOH	$[M-H]^-$, $[M+O_2]^-$	
		polycyclic arenes	M^-, $[M-H+O]^-$	
		S-arenes	$[M+O_2]^-$	
		chlorinated arenes	M^-, $[M-Cl+O]^-$, $[M-H+O]^-$	
N_2O+	OH^-	alkanes	$[M+OH]^-$, $[M-3H]^-$ (little)	
H_2, CH_4, i–C_4H_1 others		alkenes	$[M+NO]^-$, $[M+N_2O]^-$ $[M-H]^-$, $[M-3H]^-$ (little) "M + 25", "M + 43"	0 and
		alkylarenes	$[M-H]^-$ "M + 25", "M + 43"	
		ROH, RCOOH, ketones, esters	$[M-H]^-$, also $[M-3H]^-$	
		esters	$[M-3H]^-$	
		amines	scarcely ions	
		RCOCl	$[M-Cl+O]^-$, $[M-H_2Cl+O]^-$	
S	S_x^-	alkylarenes	$[M-H+S_x]^-$	
		dinitriles	$[M-H]^-$, $[M+S_x]^-$,	
		ferrocene	$C_5H_5S_x^-$	

[a] From (18) with permission.

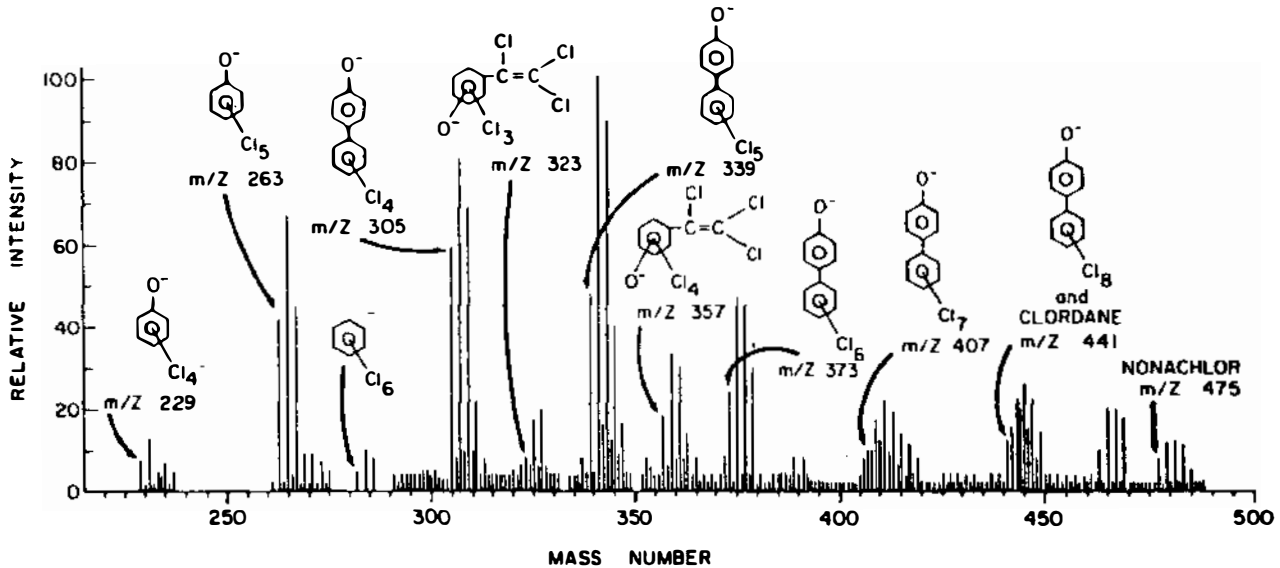


Figure 1 Negative chemical ionization mass spectrum of a stream distillate of 150 mg of Lake Ontario trout. Source temperature, 150°C; pressure, 0.45 torr; reagent gas, isobutane oxygen, 10:1. [From (17) with permission.]

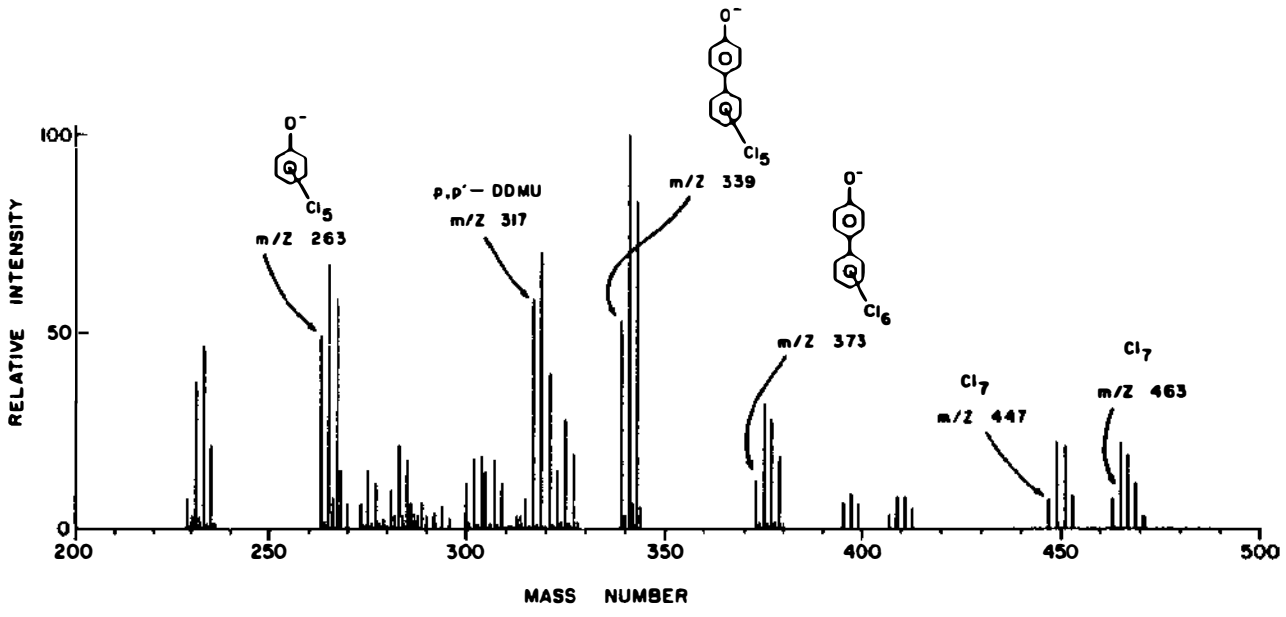


Figure 2 Negative chemical ionization mass spectrum of planar molecules in composite samples of Tittabawassee River carp, Emerson Park, Midland, Michigan, 1977. Source temp. 150°C; pressure, 0.46 torr; reagent gas isobutane/oxygen 10:1. [From (17) with permission.]

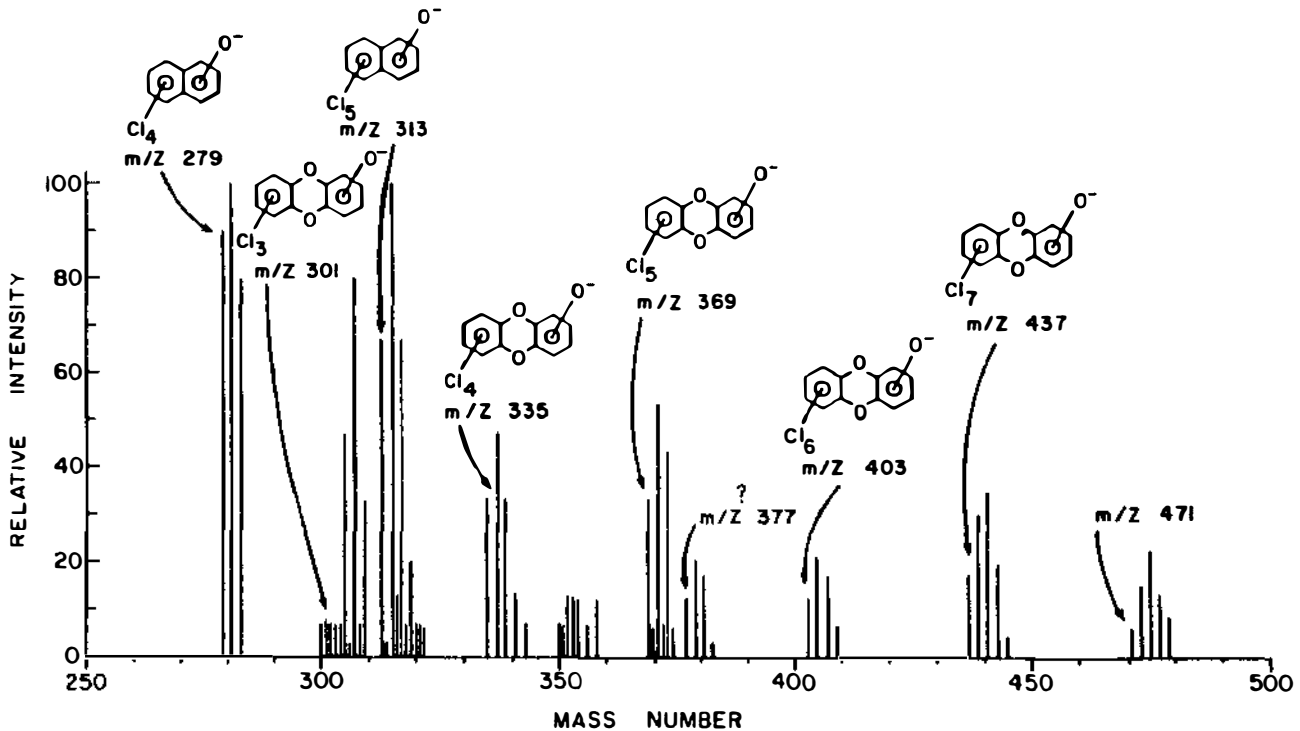


Figure 3 Negative chemical ionization mass spectrum of a steam distillate of human adipose tissue. Source conditions equal to those in Figure 2. [From (17) with permission.]

samples. Picogram and subpicogram detection limits have been reported for various polychlorinated dibenzo-p-dioxins including TCDD using atmospheric pressure NCIMS with oxygen-rich reagent gas mixtures (19, 20, 29, 32).

Roboz et al (16) determined individual polybrominated biphenyls (PBBs) in human serum using NCIMS. This technique allowed a 20-fold improvement over GC-ECD quantitation of individual PBBs with detection limits as low as 10 pg/ml serum.

Brumley et al (8) have demonstrated the feasibility of confirming the presence of aflatoxin-B1 in peanut butter, corn, and other foodstuffs, and aflatoxin-M1 in milk using NCIMS. Table 3 lists aflatoxins and related mycotoxins identified by Brumley et al (8) using NCIMS.

Negative chemical ionization mass spectrometry is not limited to organic analysis. Thomson et al (30) have demonstrated that atmospheric pressure NCIMS is extremely selective and sensitive to various contaminants in ambient air, including SO_2, SO_3, SO_4, HSO_4, Cl, and NO_3. NCIMS has also been successfully used in the analysis of trace metals from various matrices (31) and in stable isotope tracer studies (31).

Although negative chemical ionization mass spectrometry is still in its infancy, it has proven to be a powerful new method for the analysis of complex samples for trace levels of many toxic compounds. The sensitivity and selectivity of the technique is partially due to the fact that NCIMS is a "soft" ionization technique that gives few fragments. (1–5). Unfortunately there is not a large amount of data available to aid in interpreting unknown spectra. Also, numerous ion-molecule reactions may lead to several different quasimolecular ions; some experience is required for interpretation.

Research is needed to increase the number of reference spectra available and to provide a comparison of spectra under various NCIMS conditions.

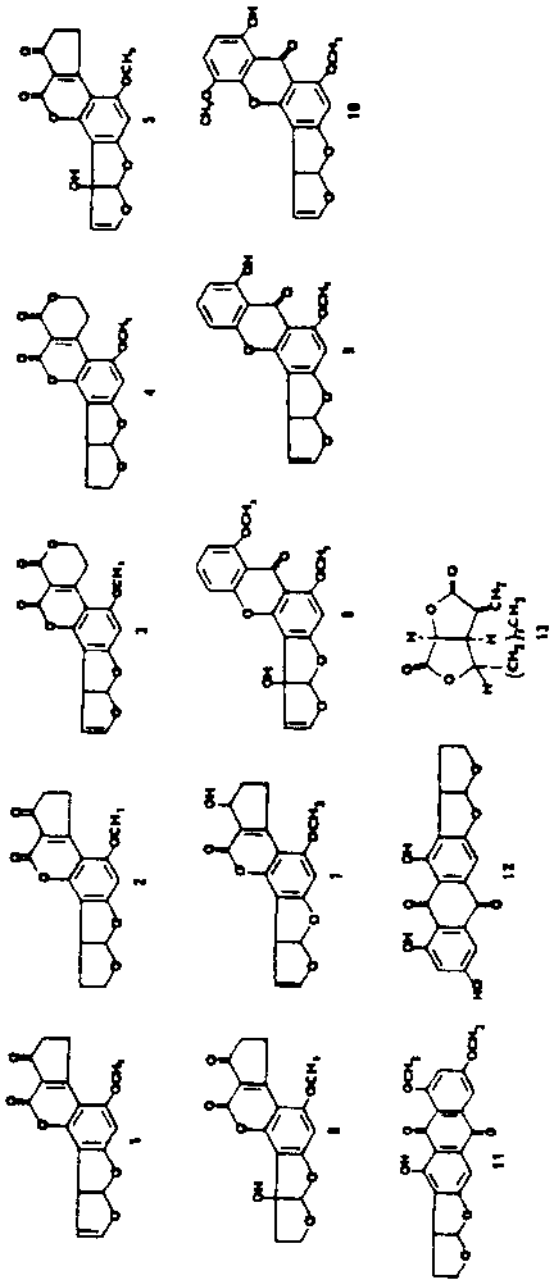
TANDEM MASS SPECTROMETRY

Tandem mass spectrometry is known by a number of names (1, 33, 39) including mass spectrometry/mass spectrometry (MS/MS), direct analysis of daughter ions (DADI), mass-analyzed ion kinetic energy spectrometry (MIKES), collision induced spectrometry (CID), and collision activated mass spectrometry (CAMS). Tandem mass spectrometry (MS/MS) is emerging as a significant technique for the identification and quantitation of organic compounds in complex mixtures (33–40). This method combines low detection limits with minimal sample preparation (33–39) for *specific compound identification* in complex samples. At this time, complete characterization of complex samples by MS/MS is impractical (1, 33, 39).

MS/MS is analogous to gas and liquid chromatography with mass spec-

Table 3 Methane negative ion chamical ionization mass spectra of aflatoxins and related mycotoxins (8)

Compound	No.	Mol wt	Source temp, °C	Percentage of rel abundance			Other, *m/z* (% rel abundance)
				M^-	$(M-H\cdot)^-$	$(M-CH_3)^-$	
aflatoxin B_1	1	312	130	100	47.9	82.0	313 (16.4), 314 (6.6), 298 (15.2)
aflatoxin B_2	2	314	130	100	60.2	98.9	315 (19.2), 300 (16.1)
aflatoxin G_1	3	328	130	100	27.6	45.9	329 (19.9), 330 (6.0), 314 (19.1), 315 (4.5), 312 (27.8), 284 (13.0)
aflatoxin G_2	4	330	130	100	33.7	97.7	331 (16.0), 332 (10.4), 316 (22.5), 328 (7.7), 286 (20.9)
aflatoxin M_1	5	328	130	56.9	27.8	100	329 (10.1), 330 (6.2), 314 (16.1, 315 (8.1)
aflatoxin M_2	6	330	130	61.5	40.8	100	331 (10.7), 316 (13.2), 317 (4.6) [impurity 345, 359, 360]
aflatoxicol	7	314	130	8.7	9.4	100	330 (16.3), 295 (40.0), 296 (9.6), 281 (18.9)
aspertoxin	8	354	150	100	23.8	35.8	355 (23.5), 352 (8.7), 340 (15.7), 338 (5.4) [impurities 386, 326, 311, 300, 299, 285, 284]
sterigmatocystin	9	324	120	100	51.4	16.1	325 (24.1), 326 (6.1), 310 (4.3) [impurity 354, 339]
5-methoxysterigmatocystin	10	354	90	100	78.5	6.6	340 (1.2), 351 (1.3), 355 (20.4), 356 (2.9), 369 (6.0), 370 (1.1)
aversin	11	368	100	100	3.1		366 (5.0), 369 (22.0), 370 (3.5)
versicolorin	12	340	100	100			341 (20.5), 352 (5.7), 343 (1.1), 338 (3.6)
avenaciolide	13	266	150	100			267 (15.0), 268 (2.3)



trometry (GC-MS, LC-MS) in which the sample is separated chromatographically, then identified by the mass spectrometer. In MS/MS one mass spectrometer (analyzer) ionizes and separates the components of the mixture. The second mass spectrometer (analyzer) produces a mass spectrum of each component (33, 34, 39). Thus there are three fundamental control parameters in MS/MS. These are (*a*) mass(es) selected by the first mass spectrometer, (*b*) mass(es) selected by the second mass spectrometer, and (*c*) absence or presence of a collision gas. These parameters can be varied independently or in combination.

McLafferty (33, 39) and Burlingame et al (1) have reviewed various instrumental configurations used in MS/MS and their advantages and limitations. Instrumentation development in MS/MS is very active; many improvements in instrumentation, with, it is hoped, a corresponding decrease in price, should be forthcoming.

Tandem mass spectrometry has been applied to a number of problems. McLafferty (39) lists over forty applications of MS/MS. Cooks and coworkers were able to map the distribution of natural products in whole plant tissue by cutting out plant sections, crushing them under liquid nitrogen, and introducing them directly into the MS/MS. Natural products identified by this study (41) included cocaine, morphine, papaverine, coniine, and atrophine. Cooks et al (42) performed direct analysis of urine for picogram amounts of testosterone and homovanillac acid.

Hunt et al (36) analyzed industrial sludge for priority pollutants by MS/MS. Total analysis time was 15 minutes with several compounds found in the 100 ppb range (Table 4).

Table 4 Organic compounds found in industrial sludge by MS/MS analysis under negative ion chemical ionization conditions (36)

Compound[a]	Number	Mol. wt.
3-decanone	1	156
4-decanone	2	156
3-penten-2-one	3	84
3-methyl-2-butanone	4	86
cyclohexanone	5	98
2-methyl-cyclohexanone	6	112
nonyl aldehyde	7	142
ethyl hexanoate	8	144
methyl crotonate	9	100
n-pentyl acetate	10	130
dimethyl suberate	11	202
glucose	12	180
2,4-dinitrophenol	13	184
4-nitrophenol	14	139

[a] Ion source temperature, 100°C; collision gas, Ar for 3- and 4-decanone; Ne for compounds 3–12, N_2 for compounds 13 and 14.

McLafferty (43) has shown that MS/MS can be used to analyze complex hydrocarbon mixtures from petroleum refineries. Zakett et al (45) used negative ion MS/MS to identify and quantitate polycyclic aromatic hydrocarbons in solvent-refined coal. Schuetzle et al (47) compared the ability of triple stage quadrupole MS/MS, MIKES (MS/MS), and GC-MS to analyze diesel particle extract for nitrated polycyclics.

Meuzelaar et al (48) used a curie point MS/MS system in the analysis of body tissues, bacteria, and coal. Applications have included (*a*) determination of drugs and metabolites in a single drop of urine; (*b*) characterization of n-alkyl phenols in coal fractions, and (*c*) detection of white blood cell nucleic acid components. Glish et al (34) tested the ability of MS/MS to determine nanogram levels of pyridine, dimethyl ether, and urea in blood serum.

More recent applications include the identification and quantitation of TCDD with a detection limit of 50 pg (44, 51, 52), amino acid sequencing (1, 33, 39), analyses of underivatized peptides by negative ion MS/MS, and classification of natural products including chemotaxonomy of cacti (1, 33, 39).

The study of large molecules with soft ionization MS/MS has been recognized. However, although soft ionization methods provide molecular weight information, they give little structural information. Various soft ionization MS/MS techniques are beginning to emerge (1, 39, 49). Field desorption/MS/MS has been reported for organotin compounds (1), di- and tripeptides (34), and permethylated disaccharides (1). Covalent adducts of activated benzo-a-pyrene with DNA have also been identified by field desorption MS/MS (46). Cooks et al (50) are investigating laser desorption MS/MS, including the mechanism of desorption ionization and potential application of the technique.

In summary, the versatility of MS/MS should make it applicable to a wide range of problems where it could screen many more samples for contaminants than GC-MS. However, the technique requires that the analyst know something about the sample and what compounds to look for. Total characterization of a complex sample by MS/MS would be as time consuming and more expensive than GC-MS.

Tandem mass spectrometry coupled with other ionization techniques (field desorption, fast atom bombardment, laser desorption) has potential for the characterization of macromolecules (biological samples). There are numerous problems with the introduction and analysis of nonvolatile compounds by MS/MS (1, 39). Extensive research and instrumental development are needed in this direction before MS/MS becomes a widely accepted method for analysis of macromolecules.

Another major deterrent to MS/MS growth is price. Most laboratories are unable or unwilling to spend $400,000 or more for a MS/MS system.

IONIZATION TECHNIQUES FOR NONVOLATILES

An extremely active area of research in mass spectrometry is the development of methods for the analysis of nonvolatile and/or thermally labile compounds. There are two approaches to this problem: (*a*) conversion of the nonvolatile (thermally labile) compounds to a volatile (thermally stable) derivative, and (*b*) development of ionization techniques that allow for ionization of the underivatized sample.

Desorptive Chemical Ionization

This technique, recently reviewed by Cotter (53), has been referred to as direct exposure ionization, in-beam, surface ionization, and direct chemical ionization. This is a conceptually simple technique in which the sample is put on the surface of an extended probe (or emitter) and then inserted into the ion source. Figure 4 is a schematic of the direct exposure probe and conventional solid probe. Quartz, glass, teflon and vespel probe tips have been used (1, 53, 54). Various metal filaments with or without coatings have also been used as emitters in desorption chemical ionization (1, 53, 54). Usually the probe tip or emitters have programmable heaters and/or current control. This technique is simple and relatively inexpensive, and most mass spectrometers with a direct solids probe can be fitted with a DCI probe. DCI not only usually produces the molecular ion but also produces fragmentation information. DCI has natural products chemistry, biochemical, and biomedical applications.

The major problem in the use of desorption chemical ionization techniques is that underivatized nonvolatile samples often undergo thermal decomposition/adsorption or dehydration (53). Adsorption/decomposition may be eliminated by appropriate modification of experimental conditions. However, it is almost impossible to prevent dehydration for certain groups of compounds. Choice of tip (emitter) surface is very important, since some compounds show adsorption effects on glass or metal. Quantitation with this technique has been very limited.

Otashi et al (53, 55) analyzed numerous compounds including long chain aliphatic alcohols, sugars, and nucleosides by DCI. The structure of phorbal ester tumor promoters and anthracycline antibiotics (active agents against gram-positive bacteria and potential anti-tumor agents) have been determined by DCI (56, 57). Alderweireldt et al (58) used DCI to characterize and analyze biological fluids for 21 biologically significant guanidino compounds. DCI has been used for the structural determination of cholesterol, saturated and unsaturated steroids, guanosine, cyclic AMP, choline chloride, and many other biologically significant compounds (59–61). The structure of the red tide toxin, Brevetoxin B (Figure 5), was partially determined by DCI techniques (62).

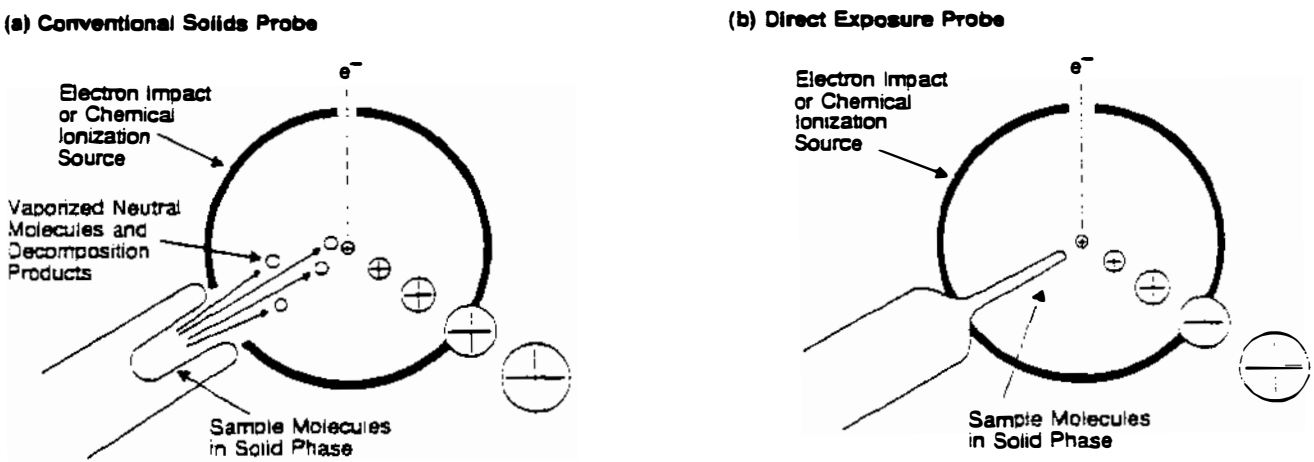


Figure 4 Comparison of conventional solids probe (a) and direct exposure probe (b). The conventional solids probe requires volatilization of the sample prior to entering the ion source, while the direct exposure methods introduce the solid directly into the ion source, close to the electron beam. From (53) wth permission.

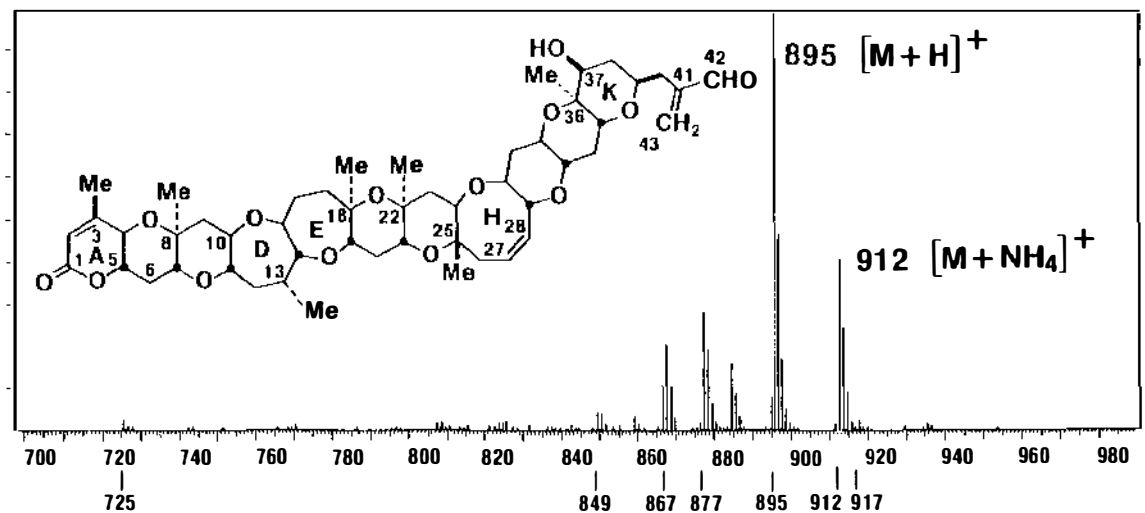


Figure 5 Desorption chemical ionization (D/CI) of Brevetoxin B (BTX-B). (62)

Horning et al (63) have investigated adduct ion formation in DCI of nonvolatile organic compounds. He concluded that adduct ion formation could be a useful tool in both qualitative and quantitative applications.

Fast Atom Bombardment

Ion-induced mass spectrometry for nonvolatile organics can use either low energy primary ion (atom) beams or high energy particles (^{252}Cf plasma desorption mass spectrometry). These techniques were the subject of a recent symposium at Johns Hopkins School of Medicine (64). Although only fast atom bombardment is discussed here, the reader is referred to MacFarlane's review (65) of ^{252}Cf plasma desorptive mass spectrometry and Brumley's review of mass spectrometry (1).

Fast atom bombardment (FAB), recently developed and reviewed by Barber (64–67), has made it possible to analyze many nonvolatile and/or thermally labile compounds. As the name implies, fast moving atoms collide with the sample causing it to desorb (65–69). FAB has several advantages over secondary ionization mass spectrometry (SIMS), which uses a charged particle beam to desorb the sample. The neutral beam in FAB reduces surface charge and simplifies the source. Since desorption is a surface phenomena, sample preparation is extremely important.

At the 30th Annual Conference on Mass Spectrometry and Allied Topics (June 1982), there was an oral session and workshop devoted to FAB. In addition, numerous studies of FAB were presented in other sessions.

Cotter et al (70) have used FAB for the characterization of a wide variety of compounds including antibiotics, drug metabolites, porphyrines, and organometallics. Other applications include characterization and identification of steroids (71), protein sequencing and analysis (72–75), measurement of brain neuropeptides (76), and analysis of transition metal complexes (77).

Fast atom bombardment has been combined with tandem mass spectrometry for structural characterization and mixture analysis (78–79) for many types of compounds including drugs, polyamides, polypeptides, and surfactants.

Barber et al (66) have characterized chlorophyll A by positive and negative ion FAB/MS. Grishy et al (80) evaluated FAB for the identification of nitrogen containing compounds in fossil fuels. His results indicated that FAB/MS had no advantage over electron impact mass spectrometry for the identification of compound types up to 600 amu molecular weight. However, FAB/MS has considerable potential at least as a qualitative analytical technique at higher mass ranges.

In summary, FAB makes it possible to perform mass spectrometric analysis of many nonvolatile and/or thermally labile compounds. Reportedly this is a relatively easy technique to master. Also, commercial FAB

guns are now available and many are adaptable to older instruments. It must be stressed that this is a new technique. As such, much is yet to be learned about its limitations and capabilities.

Other equally important developments in mass spectrometry cannot be discussed here because of space limitations. Therefore the reader is referred to recent reviews of mass spectrometry (1), laser ionization mass spectrometry (81), and Fourier transformer mass spectrometry (82).

SUMMARY

Analytical chemists faced with complex problems such as food or drug analysis, chemical dump site analysis, or incorporation of xenobiotics and natural toxins into the food chain, require increasingly sophisticated analytical tools. Recent developments in mass spectrometry may be applied to some of these analytical problems.

Negative chemical ionization mass spectrometry and to a lesser extent tandem mass spectrometry have passed the stage of expensive curiosities and are now vital screening tools.

Negative chemical ionization is a powerful new method for the analysis of complex environmental samples for trace levels of both oxidizing and alkylating agents. Since these compounds comprise a large number of substances known to cause cancer or other environmental health problems, it seems likely that use of NCIMS will continue to grow.

Tandem mass spectrometry has several advantages for the analysis of specific organic compounds in complex mixtures. Target compounds can be isolated and identified almost instantaneously at detection limits comparable to GC-MS with minimum sample preparation. A major deterrent to MS/MS is price ($400,000 or more). Also, the operator must know something about the sample and what to look for. Complete characterization of a sample by MS/MS is impractical.

In the past, application of mass spectrometry to the determination of molecular weight and structure of polar (or thermally labile) compounds was severely limited. The limitations are due to inability to vaporize samples or to prevent thermal decomposition. The development of desorption chemical ionization, fast atom bombardment, secondary ionization mass spectrometry, and ^{252}Cf plasma desorption mass spectrometry was in an attempt to rectify this situation. Each of the ionization techniques has advantages and limitations. With continued research into actual ionization/desorption process and continued instrumentation development (perhaps with a lower price tag), many of these techniques will become commonplace.

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