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Review

Ion mobility spectrometry detection for gas chromatography

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Abstract

The hyphenated analytical method in which ion mobility spectrometry (IMS) is coupled to gas chromatography (GC) provides a versatile alternative for the sensitive and selective detection of compounds after chromatographic separation. Providing compound selectivity by measuring unique gas phase mobilities of characteristic analyte ions, the separation and detection process of gas chromatography–ion mobility spectrometry (GC–IMS) can be divided into five individual steps: sample introduction, compound separation, ion generation, ion separation and ion detection. The significant advantage of a GC–IMS detection is that the resulting interface can be tuned to monitor drift times/ion mobilities (as a mass spectrometer (MS) can be tuned to monitor ion masses) of interest, thereby tailoring response characteristics to fit the need of a given separation problem. Because IMS separates ions based on mobilities rather than mass, selective detection among compounds of the same mass but different structures are possible. The most successful application of GC–IMS to date has been in the international space station. With the introduction of two-dimensional gas chromatography (2D-GC), and a second type of mobility detector, namely differential mobility spectrometry (DMS), GC prior to mobility measurements can now produce four-dimensional analytical information. Complex mixtures in difficult matrices can now be analyzed. This review article is intended to provide an overview of the GC–IMS/DMS technique, recent developments, significant applications, and future directions of the technique.
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Keywords: Ion mobility spectrometry; Differential mobility spectrometry; Gas chromatography; Detectors; Separation and detection techniques; Sampling techniques

Contents

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1. Introduction

1.1. Fundamental principles of GC–IMS

There are basically two types of ion mobility spectrometers which have been interfaced to gas chromatography for detecting analytes. The first type of mobility detector is IMS, and several excellent reviews have discussed the fundamental principles behind ion mobility measurements [1–6]. After separation by gas chromatography, individual components are introduced into the ionization region of an ion mobility spectrometer where they are converted to gas phase ions. These ions are then exposed to a weak homogenous electric field, and travel down a drift tube according to their mobility through a counter flowing drift gas. If mixtures of compounds are introduced into the IMS, then a mixture of gas phase ions is created. These ions can be separated according to their differences in mobilities through the counter flowing drift gas. This separation forms the basis of the analytical method known as ion mobility spectrometry. IMS is a highly efficient separation technique in that the ion separation is carried out within a milliseconds time scale with separation efficiencies as high as 100,000 theoretical plates.

In ion mobility measurements, the time required for an ion to transverse a region filled with inert drift gas and under the influence of a weak homogenous electric field is related to the mobility (K) of the ion [7]. In the presence of low-field conditions, the mobility of an ion through the drift gas is given by the following equation:

$$K = \upsilon_d E^{-1} \tag{1}$$

where υ_d is the velocity of the drifting ion and E is the electric field.

In order to permit comparison of measurements obtained from different environments, ion mobilities are reported as reduced mobility (K_0) values and can be calculated from the following equation:

$$K_0 = \left(\frac{L^2}{Vt_d}\right)\left(\frac{273.15}{T}\right)\left(\frac{P}{760}\right) \tag{2}$$

where L is the length of the drift region, V is the voltage applied across the drift region, t_d is the drift time of the ion, T is the absolute temperature in K and P is the pressure in Torr. Ion mobility measurements are highly reproducible and any two measurements from different environments should typically agree to within 2%.

Ion mobility theory reviewed by Revercomb and Mason [2] gave the fundamental relationship between ion mobility and collision cross section at the molecular level as the equation:

$$\Omega = \left(\frac{3q}{16N}\right)\left(\frac{2\pi}{\mu KT}\right)^{0.5}\left(\frac{1}{K_0}\right) \tag{3}$$

where q is the charge on the ion, N is the number density of the drift gas, k is the Boltzmann's constant, T is the absolute temperature, μ = reduced mass = $mM/(m+M)$, m is the mass of the ion, M is the mass of the drift gas, and Ω is the collision cross-section of the ion in the drift gas, and K_0 is the reduced mobility.

Fig. 1 illustrates the principal components and operation of an IMS detector interfaced to a one-dimensional capillary gas chromatograph. The principal steps of operation in Fig. 1 are as follows. A complex mixture is vaporized by a GC injector and separated into individual components by a capillary column. Individual neutral components of the mixture are then transported into the reaction region of the IMS where they are ionized. The ionization process can lead to protonated monomer and sometimes dimer ions. Ions formed in the reaction region are injected into the drift region. Individual ions then move at a constant velocity towards the IMS detector. The significant advantage of the interface between a GC and an IMS is that when adequate chromatography is obtained only single compounds

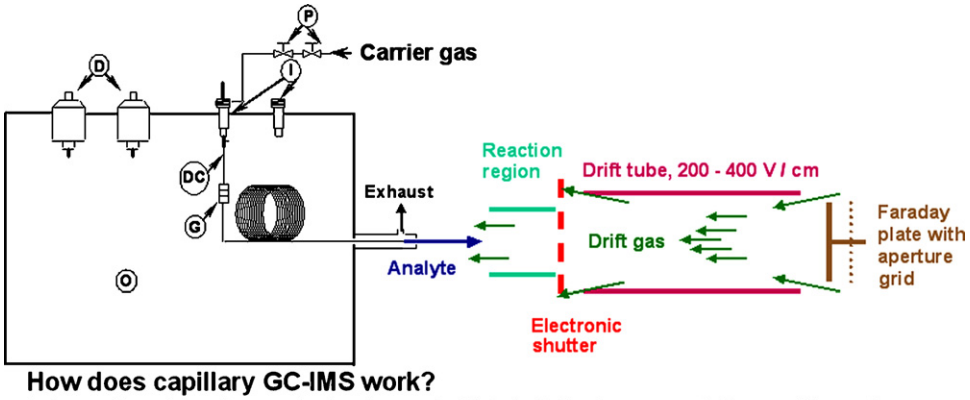

Fig. 1. Schematic cross-section of a capillary GC–IMS. P: pressure regulators; I: injectors; D: detectors; O: oven; G: glass column connector between deactivated capillary column and GC capillary column; DC: deactivated capillary column.