

ION MOBILITY STORAGE TRAP AND METHOD

FIELD OF THE INVENTION

The invention relates to ion mobility spectrometry to separate and store ions in gases using an asymmetric AC potential.

BACKGROUND OF THE INVENTION

Several devices are known that ionize a gaseous sample and analyze the product ions for the molecular makeup of the sample. The devices fall into two categories: those that operate under vacuum and those that operate under pressure conditions. The devices that operate under vacuum are known as mass spectrometers and separate ions according to charge-to-mass ratios using a combination of electromagnetic fields. The devices that operate under pressure are known as ion mobility spectrometers and separate ions according to mobilities through a drift gas in a constant electric field. Generally, mass spectrometers require a vacuum better than 10^{-3} mm Hg to eliminate the adverse effects of collisions between ions and neutral gas molecules. This is unlike ion mobility spectrometry where pressures greater than 10^{-3} mm Hg are needed to assure that collisions between the ions and neutral gas molecules firmly establish mobility values. Due to the absence of collisions in mass spectrometry, the ions can gain considerable energy as they respond to the imposed electromagnetic fields. In ion mobility spectrometry, the energy gained by the ions is rapidly dissipated by collisions between the ions and neutral gas molecules. One consequence of this difference in ion energy between mass spectrometry and ion mobility spectrometry is that the energetic ions of mass spectrometry do not follow electric field lines, while the thermal ions of ion mobility spectrometry do. Because of this difference, attempts to separate ions using one technique in the pressure regime of the other is generally unsuccessful. On the other hand, there are enough similarities between mass spectrometry and ion mobility spectrometry to encourage exploitation of common features.

The technique of ion mobility spectrometry (IMS) was first disclosed in U.S. Pat. No. 3,699,333 which issued on Oct. 17, 1972 to M. J. Cohen, D. I. Carroll, R. F. Wemlund and W. D. Kilpatrick. It was originally conceived as a method to analyze and detect organic vapors in a gas mixture. FIG. 1 shows a simplified IMS detector cell. It contains two regions: a reaction (or reactor) region where the ions are ionized, and a drift (or drift tube) region where the ions are separated. The ionization and separation processes occur under a wide range of pressure to, conditions, but the preferred operating pressure in U.S. Pat. No. 3,699,333 was atmospheric pressure. In the reaction region, the sample is either ionized directly by using ultraviolet radiation from a photoionization source, electro-spraying the ions as a mist into the ionizer, etc.; or indirectly by reacting with an intermediate set of reactant ions (designated by R^+ in FIG. 1). The indirect method of ionization is known as chemical ionization and the reactant ions are created by using a radioactive source (e.g., Ni^{63} , Am^{241} , tritium, etc.), a corona discharge source, a thermionic emitter of alkali ions, or another primary source of ions.

The nature of the reactant ions generated by the ionization source depends on the composition of the carrier gas used to transport sample into the reactor of the ion mobility spectrometer. This dependency can be used to selectively ionize a specific component in a sample matrix by adjusting the

composition of the carrier gas. This is accomplished by doping the carrier gas with a low level of a chemical reagent, such as acetone, a chlorinated solvent, methyl salicylate, etc. The reactant ions then become a protonated diacetone a chloride anion or a protonated monomer of methyl salicylate, etc. that react differently the ample.

While the reactant ions and product ions (designated by P^+ in FIG. 1) can be positively or negatively charged, the polarity of the ions that are extracted from the reactor and analyzed by the drift tube depends upon the directionality of the electric field applied to the drift tube. If the ionization source is biased positive relative to the ion collector, positive ions are extracted from the reactor and analyzed by the drift tube for mobility. If the ionization source is biased negative relative to the ion collector, negative ions are extracted from the reactor and analyzed by the drift tube for mobility. If no electric field is applied, the positive and negative ions recombine, and are otherwise lost for analysis by the drift tube.

A shutter grid positioned between the reactor and the drift tube provides a means whereby a localized concentration of ions is extracted from the reactor and introduced into the drift tube. Typically this shutter grid consists of a planar array of parallel wires with neighboring wires electrically independent. When the two sets of electrically independent wires are at the same potential, the ions pass freely through the grid and enter the drift tube. When the two sets of neighboring wires are at different potentials, the ions are captured by the grid and are denied entry into the drift tube. Ion injection into the drift tube is accomplished by momentarily removing the blocking potential from the shutter grid. Once inside the drift tube and exposed to the drift field applied to the drift tube, the ions migrate toward an ion collector (or Faraday plate) located at the other end of the drift tube. When the ions arrive at the collector, their drift time is recorded and correlated with the composition of the original sample delivered to the reactor.

The IMS technique, as described above, has several limitations. These include:

1. The basic limits of detection are restricted to about ten picograms or ten parts per trillion due to build up of space charge in the reactor. There is no capability of concentrating and storing ions.
2. Ion mobilities are sensitive to the composition of the drift gas, and decrease as the ion clusters with water vapor or other polar compounds. Ions attached to contaminant gases have different mobilities, making it difficult to identify the ions.
3. Miniature IMS sensors are plagued by low total ion currents (the ion current collected by the ion collector when the shutter grid is biased open continuously) that limit the dynamic range of the device.

U.S. Pat. No. 5,200,614 which issued on Apr. 6, 1993 to A. Jenkins and W. J. McGann describes an "ion trap mobility spectrometer" that attempts to remove one of the above limitations and improves the limits of detection of IMS for electrophilic compounds (e.g., nitro-compounds used as explosives). A schematic representation of their device is shown in FIG. 2. The two halves of the shutter grid are separated to create a field-free ion storage region within the device. When the two grids (E1 and E2 in FIG. 2) are at the same potential, the ions entering the ion storage region from the reactor become "trapped" (i.e., lie motionless). By momentarily applying a high potential between grids E1 and E2 (V_3 in FIG. 2), the "trapped" ions are injected into the drift tube. The ion storage region, therefore, behaves like a