

Full length article

A new instrument with high mass and high ion mobility resolution

Thomas Wyttenbach^a, Paul R. Kemper^a, Gökhan Baykut^b, Melvin A. Park^c,
Michael T. Bowers^{a,*}

^a Department of Chemistry and Biochemistry, University of California Santa Barbara, Santa Barbara, CA 93106, United States

^b Bruker Daltonik GmbH, Fahrenheitstrasse 4, 28359 Bremen, Germany

^c Bruker Daltonics Inc., Billerica, MA 01821, United States



ARTICLE INFO

Article history:

Received 23 May 2018

Received in revised form 10 August 2018

Accepted 12 September 2018

Available online 20 September 2018

Keywords:

Ion mobility spectrometry

Time-of-flight mass spectrometry

Drift tube

Proteins

Peptides

Oligomers

ABSTRACT

A new instrument combining a two meter long ion mobility drift tube fabricated of resistive glass with a high-resolution time-of-flight (TOF) mass spectrometer is presented and new features are discussed in detail. Ions are formed by electrospray ionization. An ion gate positioned at the exit of the drift tube allows analysis of mobility-selected ions. A quadrupole mass filter and a collision cell are located between the drift tube and the TOF analyzer, an arrangement which allows collision-induced dissociation experiments of mass-selected and/or mobility-selected ions. The ability of the TOF spectrometer to resolve isotopologues differing by 1 Da in mass even for multiply charged ions opens up exceptional possibilities for ion selection and mobility analysis. The unique combination of instrument attributes including gentle ion production and analysis, the first principles measurement of cross sections, and high mobility ($R \sim 100$) and mass ($R > 20k$) resolving powers allows for the analysis of a broad range of analytes including amino acid oligomer clusters (e.g. Phe₉₇), peptides, and proteins.

© 2018 Elsevier B.V. All rights reserved.

1. Introduction

For the analysis of complex mixtures, mass spectrometry (MS)—often in combination with a separation technique—is one of the fastest and most sensitive methods [1–3]. The separation methods coupled to MS are traditionally various chromatographic methods, but recently more and more approaches are based on ion mobility spectrometry (IMS) [4,5]. As commercial instrumentation has become more broadly available during the last two decades (see recent reviews [6,7]) the field of IMS-MS has grown sharply. In chromatography, the interaction of the analyte with the stationary and the mobile phase determines the retention time; and the separation of various analytes in a mixture depends on a distinctly different interaction for each analyte. Understanding and predicting the retention time theoretically is extremely difficult or impossible for most chromatographic systems. For IMS on the other hand, there is a reasonable chance to understand the drift time theoretically in terms of the interaction of the ion with the buffer gas and with the electric field [8]. In particular, if the electric field is weak and if the ion-buffer gas interaction is hard sphere-like, the ion mobility-derived cross section is a straightforward measure of the ion size and shape [9,10]. Because of this simple relationship

between ion mobility and ion size, IMS-MS instrumentation has increasingly been used to interpret IMS data in terms of ion size and ion shape.

However, in most commercially available instruments the experimental conditions are not ideal for structural analysis of ions. Ideal conditions would include a state-of-the-art IMS-MS instrument with high resolving power both for mass and ion mobility. Furthermore, very soft ion handling conditions require weak electric fields in the source, transfer, and IMS regions to avoid collisional heating. Near thermal ion-buffer gas collisions are essential for keeping the effective temperature of the ions within a few degrees of the buffer gas temperature, a necessary condition in IMS for staying within the low-field limit [8,11] and for preventing structural changes due to collisional heating. Further, the choice of the IMS buffer gas is also extremely important for data interpretation. Nitrogen is the most frequently used IMS gas in commercially available instruments because it is less susceptible to discharges. This provides much more robust operating conditions at the high voltages required for a high resolving power [8,11] and for improved separation of analytes. However, for the purpose of structural analysis and collision cross section determinations, using monoatomic helium gas as the drift gas is more advantageous because of its low polarizability which yields collisions resembling more closely the ideal of hard spheres [12,13].

Top-of-the-line IMS-MS instrumentation at today's standards includes a high-resolution ion mobility separation system com-

* Corresponding author.

E-mail address: bowers@chem.ucsb.edu (M.T. Bowers).

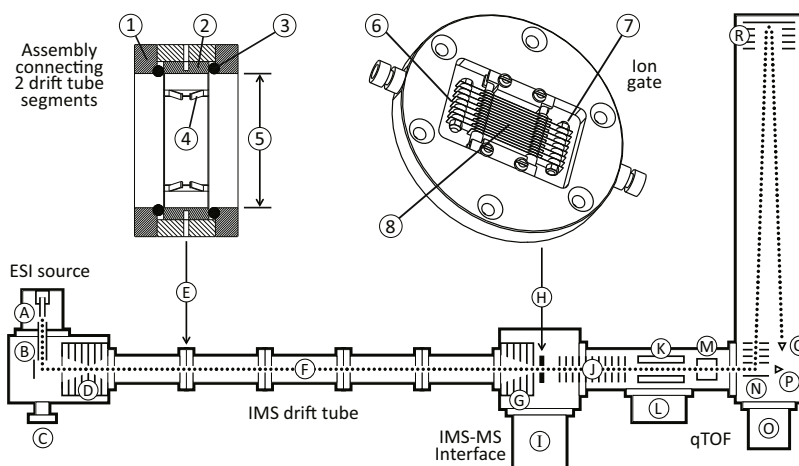


Fig. 1. Schematic representation of the instrument. Components A, B and K–R are part of a commercial Bruker maXis qTOF, I is an additional pump, the remaining items are custom built. Details of the assembly connecting two drift tube sections (top left) and of the ion gate (top center) are given in the inserts. A Electro spray tip. B Capillary. C Pump port to mechanical pump. D Hourglass ion funnel. E Assembly connecting two drift tube segments. F Resistive glass drift tube segment. G Exit ion funnel. H Ion gate. I Turbo pump. J Ion lens stack. K Quadrupole mass filter. L Turbo pump. M Collision cell. N TOF source. O Turbo pump. P First detector. Q Second detector. R Reflectron. 1 Plate squeezing the O-ring. 2 Stainless steel sleeve. 3 O-ring. 4 Metal blade for electrical connection. 5 Bore to accommodate glass tube. 6 Stack of metal blades of the ion gate carrying a positive voltage when gate is closed. 7 Metal blades carrying a negative voltage when gate is closed. 8 In the center of the ion gate where ions pass through, metal blades of stack 6 alternate with blades of 7.

bined with a high resolution time-of-flight (TOF) mass analyzer. The IMS-TOF combination has proven to be particularly powerful since the timing of the sequential analysis works out remarkably well: In IMS, different ions are separated from each other on the millisecond timescale whereas a TOF mass analysis can readily be done at a frequency of several kilohertz [14]. Hence, as ions exit the IMS drift tube and enter the TOF source, a narrow slice of ions (e.g. a slice 200 μs in width at a typical TOF frequency of 5 kHz) is constantly pulsed into the TOF analyzer and characterized by ion mass. In this work, we present a new state-of-the-art instrument designed at UCSB in collaboration with the Bruker mass spectrometry groups in Bremen and Billerica. This IMS-MS instrument is specifically designed to be used for the structural characterization of mass-selected ions which requires: a soft ion source previously designed and characterized [15–17] where ions are gently transferred to the IMS analyzer; an IMS drift tube which allows to measure absolute cross sections and features an IMS resolving power of roughly 100; and a TOF mass analyzer with high mass resolving power. Hence, the instrument comprises a 2 m horizontal IMS drift tube which feeds into the source region of a Bruker maXis qTOF featuring a 2 m vertical TOF chamber with reflectron.

2. Instrument

The various components of the IMS-MS instrument are schematically shown in Fig. 1. The basic components are a commercial qTOF spectrometer (Bruker maXis) and a custom-built IMS device. The Bruker electrospray ionization (ESI) source is removed from the mass spectrometer and coupled to the front end of the IMS drift tube. At the interface between source and drift tube is a home-built hourglass ion funnel which is used to focus and store ions before they are pulsed into the drift tube for IMS analysis.

The IMS drift cell is composed of ten tube sections fabricated of resistive glass (Photonis), each 20 cm long and 7 cm in diameter. This commercially available tubing is specifically designed for IMS applications [18,19]. The drift voltage applied across the entire drift length is typically 0.5–5 kV. The drift gas is helium held at a pressure of ~ 10 torr. An ion funnel is used to guide the ions leaving the drift region towards the exit hole 0.5 mm diameter. A large (2000 L/s) turbo pump (Pfeiffer HiPace 2300, I in Fig. 1) keeps the pressure on the outside of the exit hole, in the IMS-MS interface region, below

10^{-4} torr to avoid collisions and fragmentation of accelerated ions. However, before ions are accelerated into the mass spectrometer they pass through an ion gate which can be used to transmit only those ions that exit the ion funnel within a defined time window (see below for more detail). A custom-made electrostatic lens stack bridges the large vacuum chamber required for efficient pumping in the interface region and focusses the accelerated ions into the maXis quadrupole mass filter. The Bruker funnel cartridge which would be inserted in front of the quadrupole in a standard maXis setup is not needed here and is removed.

Once the ions enter the quadrupole they travel through the rest of the instrument as they would in a standard Bruker qTOF: They pass through a collision cell operated with nitrogen and enter the TOF source where they are pulsed into the TOF flight tube. In contrast to the IMS tube which is arranged in a horizontal position, the TOF tube is positioned vertically. At the end of the two-meter flight tube ions turn around in the reflectron and travel back another two meters before hitting the TOF detector.

If TOF analysis is not required, pulsing of the TOF source can be omitted and ion detection can be accomplished by a detector in the TOF source region (part P in Fig. 1). In this case mass selection can be accomplished with the quadrupole filter to obtain IMS data of mass-selected ions. A computer-controlled multichannel scaler (Ortec MCS Plus, 100 ns resolution) is used to record the data.

Mass spectra are recorded using the Bruker hardware and software available with the maXis. Mobility spectra of TOF mass-selected ions are obtained through an external computer-controlled digitizer (National Instruments, PXI 5154).

The general layout of the instrument and several of the custom-built parts such as the hourglass ion funnel and the exit funnel are based on established designs and have previously been introduced in the literature [14,15,20–22]. The dimensions of the funnels, the electronics to run them, the electrostatic lens stack following the drift tube and its electronic control are essentially identical to designs used in a similar setup which has been discussed in detail [15]. Two components that warrant a more thorough description here are the drift tube (assembly E and glass tube F in Fig. 1) and the ion gate (part H).

The drift tube comprises ten segments of resistive glass tubing. Applying a voltage across one segment from one end to the other provides a uniform electric field on the inside of the tube. For each

Download English Version:

<https://daneshyari.com/en/article/11029678>

Download Persian Version:

<https://daneshyari.com/article/11029678>

[Daneshyari.com](https://daneshyari.com)