Achieving High Resolution in a Benchtop Resistive Glass Drift Tube Ion Mobility Spectrometer

Introduction:

Ion mobility spectrometry (IMS) has become widely accepted for the detection of chemical warfare agents, explosives and narcotics as well as for pharmaceutical quality control and pesticide screening of food. Currently available commercial IMS instruments have resolving power between 10-60. In order to minimize the frequency of false positive and false negative results, it is necessary to design and construct an ion mobility spectrometer with high separation power without compromising instrument simplicity, serviceability, and cost.

Resistive Glass drift tubes provide key benefits such as uniform electric fields with minimal radial inhomogeneities and ease of construction. In addition, the single-piece construction allows uniform counter flow of drift gas without the need for additional containment. The photo below in Figure 1 shows the benchtop prototype ion mobility instrument constructed with Resistive Glass reaction and drift tubes. All associated electronics are contained in the enclosure beneath the IMS.

Figure 2 is a horizontal cross-section of the prototype instrument showing the reaction and drift tubes along with the Bradbury-Nielsen style ion gate and Faraday plate anode.





Background:

PHOTONIS Resistive Glass tubes are designed to guide ions by generating a uniform electric field. Resistive Glass tubes are composed of a proprietary lead silicate glass that has been hydrogen fired to create an integral semi-conductive layer, not simply a coating. This robust resistive layer is typically several hundred angstroms thick. The resistivity can be varied over several orders of magnitude from 10⁶ to 10¹¹ ohms/square to suit the specific application such as drift tubes, capillary inlet tubes and reflectron lenses shown in Figure 3.

Resistive Glass products are highly uniform in resistivity. 4-point probe data indicates an overall variation in resistance of +/- 1.5% across a 75 mm plate. Kelvin probe data indicates that the uniform resistance results in a uniform electric field. The Resistive Glass provides a uniform gradient with no significant anomalies. The smooth gradient indicates extremely uniform resistivity in the surface of the glass.





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Methods:

Reaction and drift regions of the ion mobility spectrometer were fabricated using Resistive Glass technology. The dimensions of the tubes were 40 mm OD and 30 mm ID. The length of the reaction and drift tubes were 90 mm and 250 mm, respectively. Ionization was achieved by a corona discharge, a Direct Analysis in Real Time, DART SVP source or an electrospray source. The DART SVP was manufactured by IonSense, Inc. The voltage applied to the entrance of the Resistive Glass reaction tube was 11-12 kV while the corona and electrospray voltages were set to 14.8 kV and 14 kV, respectively. For the DART SVP trials, the source operated at ground. Dry nitrogen drift gas flowed at a rate of 1 l/min. Dry nitrogen was also used as the DART gas with a flow rate of 2 I/min. The IMS was operated at room temperature for all experiments, although the instrument incorporates integral heaters and can be operated at 150°C.

Ion gating was accomplished with a Bradbury-Nielsen type electronic gate. The pulse width was set to 200 µs using a Stanford Research Systems Model DG535 pulse generator. The 25 mm diameter Faraday plate detector was located 0.7 mm from the back end of the drift tube. A Tektronix Model TDS 2002B digital storage oscilloscope captured 128 sweeps for each mobility spectrum with a 100 ms total scan time. All spectra are presented in raw form without background subtraction. Custom gate driver and amplifier circuits were designed and built to enhance the spectrometer's operation.

Resolving power was measured to demonstrate the capability of the Resistive Glass tube IMS using the ratio of the measured drift time to peak width (FWHM), $R_p = t_d/w_{0.5}$. Analytical performance was evaluated for a variety of small molecules. Reduced mobility Ko values were calculated in order to confirm the identification of the observed signals using the formula, $K_0 = K * P/P_0 * T_0/T$. Experimentally determined values were then compared to those published in the literature.

Results:

Ion mobility spectra were acquired for a well-known calibration compound, di-tert-butylpyridine (2,6 DtBP), Sarin simulant, dimethyl methylphosphonate (DMMP), caffeine, and the anti-malaria drug quinine.

Corona Discharge:

The mobility spectrum shown in Figure 6 was generated from four micrograms of the calibrant di-tert-butylpyridine (2,6 DtBP) in methanol. The peak at 39.7 ms is attributed to the DtBP while the peaks at shorter drift times are attributed to background ions. A resolving power of 82 was calculated for the background ion at a drift time of 29.4 ms.

Twenty-four micrograms of di-methyl-methylphosphonate (DMMP) in methanol was also analyzed. Figure 7 shows the mobility spectrum for the DMMP sample. The peak at 45 ms is attributed to the DMMP proton bound dimer while the remaining peaks are unidentified DMMP response peaks, likely due to clustering. The resolving power for the dimer was found to be 64.



DART SVP:

Figure 8 (right) shows the IMS prototype with the DART SVP ionization source along with a sample holder and screen mounted to the front of the Resistive Glass reaction tube.^{1,2} The DART capillary tube was positioned about 1 mm from the screen after sample spotting.

Four micrograms of DtBP in methanol was spotted onto the screen mounted to the IMS sample holder. The DART source was kept at room temperature. The mobility spectrum in Figure 9 shows the expected DtBP peak at a drift time of about 40 ms. A small background ion peak was also observed. The measured resolving power for the DtBP peak is 83.

Twenty four micrograms of DMMP in methanol was also spotted on the sample screen. Again, the temperature of the DART source was kept at ambient. The mobility spectrum in Figure 10 shows the expected DMMP peaks along with the background ion peaks.

The DMMP monomer appears at a drift time of 34.8 ms with a resolving power of 87.5 and the DMMP proton bound dimer appears at 44.8 ms with a resolving power of 112.

The temperature of the DART source was then increased to 300°C which is the typical operating temperature for most samples. The DMMP analyte was spotted and a mobility spectrum was acquired. The sharpness of the peaks remained high and a resolving power of 150 was measured for the DMMP proton bound dimer (Figure 11), which approaches the theoretical limit. The results of increasing the DART temperature support the assumption that the gas is aiding de-clustering and drying of the ions, thus increasing the resolving power.

The measured drift time for the DtBP and DMMP along with the precise room temperature and pressure were used to calculate the reduced mobility, K_0 in cm²/V-s. The K_0 values determined from these experiments are generally in good agreement with those published in the literature (Table 1).

Table 1: Reduced mobility values for DtBP and DMMP with corona discharge and DART sources			
Experimental K _o (cm ² /V-s)			
	Corona Discharge	DART SVP	Published K _o (cm²/V-s)
DtBP	1.42	1.41	1.42-1.46*
DMMP Monomer	1.37, 1.52, 1.66, 1.77 (cluster)	1.62	1.58**
DMMP Proton Bound Dimer	1.25	1.26	1.25**

G. A. Eiceman, E. G. Nazarov, J. A. Stone, Analytica Chimica Acta 2003, 493, 185-194. Ion Mobility and Mass Spectrometric Investigations of Organophosphates Related to Chemical Warfare Agents and Pesticides (p.55). Price, Sarah Ellen (2010) Ph.D. thesis, University of Birmingham.



IonSense DART SVP source.







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Results (continued):

The K_o value for the DMMP monomer from the corona trial is noticeably less than the reported value and the value obtained from the DART experiment. This is consistent with the longer drift time observed for the DMMP monomer when the corona source was used and supports the idea that the DART gas may be aiding declustering and drying of the ions in the reaction region.

Electrospray:

Analyte solutions flowed through an 11 µm diameter fused silica electrospray capillary at a rate of 1.5 microliters per minute. The mobility spectrum in Figure 12 was generated from a 0.1 micromolar solution of DtBP in methanol. The drift time of 43 ms was comparable to the drift time for the corona discharge for equivalent IMS voltage levels. The resolving power for the DtBP peak was 119.

A 100 micromolar solution of caffeine in methanol was also analyzed. Caffeine is a small molecule like DtBP with m/z of 195 for the protonated ion. A resolving power of 90 was measured for the caffeine peak observed at a drift time of 43.2 ms. The mobility spectrum is shown in Figure 13.

A 6 millimolar solution of quinine in 92% methanol/8% water was also analyzed. Quinine has a neutral mass of 324 Da. The mobility spectrum in Figure 14 shows an intense peak at a drift time of 49.7 ms attributed to quinine. The resolving power for this quinine peak was found to be 96.







Conclusions:

- A benchtop ion mobility spectrometer with ultra high resolving power was designed and constructed with Resistive Glass tubes and a photo-etched Bradbury-Nielsen type ion gate.
- Resolving power of 64-150 was achieved for a variety of small molecules. • The prototype ion mobility spectrometer was successfully coupled to an electrospray
- ionization source, a DART SVP source and a corona discharge.

Future Work:

Future work will include the generation of probability of detection curves for all analytes tested as well as the analysis of phthalate compounds by DART/IMS.

References:

- . Analytical Chemistry, 2011, 83, p.1908-1915.
- 2. US Patent Application 20120068063: Direct Atmospheric Pressure Sample Analyzing System, Filed 28 May, 2012; Published 22 March, 2012.