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Ambient ionization source based on a dielectric barrier discharge for direct testing of pharmaceuticals using ion mobility spectrometry

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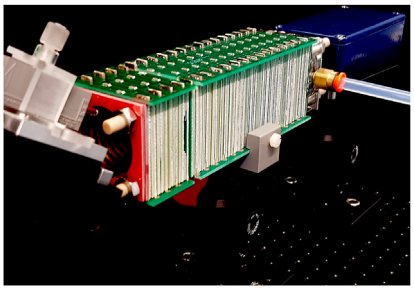
HIGHLIGHTS

- A low temperature helium plasma serves as ionization source.
- Argon as drift gas maintains the stability of the plasma source.
- The ion mobility spectrometer is of an open hardware design.
- The direct qualitative analysis of pharmaceutical tablets is possible.

GRAPHICAL ABSTRACT



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ABSTRACT

The instrument is based on a miniature plasma source mounted at an oblique angle close to the injection gate of the ion mobility spectrometer. The plasma torch consists of two 5 mm wide external cylindrical electrodes, 10 mm apart, which are placed coaxially around a fused silica tube (1.5 mm i.d. and 3.0 mm o.d.). A small helium plasma is created by applying a alternating voltage of 8 kV at 28 kHz and employed for the direct desorption and ionization of solid or liquid samples, which are placed on an electrically isolated support. The separation section of the ion mobility spectrometer has a drift tube of 10 cm length and an applied high voltage of 4 kV. The instrument was built in-house at low cost and can easily be duplicated. Its usefulness was demonstrated by the rapid identification of five different pharmaceutical drugs, namely acetaminophen, loratadine, norfloxacin, tadalafil, thiamine as well as caffeine in ground coffee beans.

1. Introduction

Ambient ionization refers to a range of techniques developed since about the year 2002, mostly for mass-spectrometry, in which samples are ionized at atmospheric pressure without or with only little sample preparation [1]. Thus solid samples may be analyzed directly without dissolution. The most common variants are DESI (Desorption Electrospray Ionization) and DART (Direct Analysis in Real Time), which are both commercially available. As described by Cooks and coworkers in 2004, the former method employs an electrospray created from an auxiliary liquid which then impinges onto the sample substrate and carries the analytes to the inlet of the mass-spectrometer [2]. DART, first reported by Cody et al., in 2005, is based on a DC (direct current) glow discharge formed in a helium stream between a needle electrode placed in the centre of an electrically insulating tube and a porous second electrode at the exit face of the tube [3]. Desorption and ionization of the analytes occur by interaction with the mild plasma. It was demonstrated

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later in 2008 by Cooks and coworkers that it is possible to use a modified arrangement in which the second electrode is placed concentrically on the outside of the tube [4]. By application of an AC voltage (typically 3 kV at 2.5 kHz) a so-called dielectric barrier discharge (DBD) is created, and this arrangement as used for ambient ionization was termed LTP (Low Temperature Plasma) probe [4]. Guchardi and Hauser had shown in 2003 [5–8] that such a plasma (used then for optical emission spectrometry) may also be created by application of an AC voltage when two tubular electrodes are arranged side-by-side on the outside of a tube. This is easier in construction than the needle based plasma cells, and more robust, because neither of the electrodes comes in direct contact with the plasma. This arrangement was adopted in 2007 by Franzke and coworkers [9], who demonstrated that this kind of microplasma source may be employed for ionization of gaseous heptanone for detection by ion-mobility spectrometry (IMS).

IMS is a versatile analytical method in which ions are separated through their differences in the gas phase mobility by employing an electric field as the driving force. While the resolution is generally not as good as that of mass-spectrometry, the IMS instruments are much simpler because a vacuum is not required, and the creation of the electric field for separation is straightforward. Therefore, field portable IMS instruments are feasible, and it is also possible to build well performing instruments in-house with limited effort [10,11]. While the orginal DART was initially intended for use with IMS [1], we are aware of only two reports on the use of plasmas as direct ambient ionization sources for IMS. Harris et al. employed a commercial DART source to sample small volumes of liquids (2 μL) which were deposited at the end of a capillary tube and then inserted into the system [12]. Jafari demonstrated the use of a He-LTP plasma source for the detection of a range of several species as cations and anions placed as liquid or solid samples onto a sample holder inserted into a specially modified IMS instrument [13].

The set-up reported herein is based on a He-DBD with two isolated electrodes, which had been demonstrated successfully for ambient ionization for mass spectrometry [14], and an IMS drift tube based on an open source design [10,11].

2. Experimental

2.1. Chemicals and reagents

Methanol (HiPerSolv Chromanorm) was purchased from VWR Chemicals (Dietikon, Switzerland). Trihexylamine (THA), acetaminophen, caffeine, loratadine, norfloxacin, tadalafil, and thiamine were purchased from Sigma-Aldrich (Buchs, Switzerland). Panadol tablets containing acetaminophen (500 mg), Klaryne tablets containing loratadine (10 mg), Norfloxacin tablets containing norfloxacin (400 mg), Cialis tablets containing tadalafil (5 mg), and vitamin B1 (Inpac Pharma Co., Ltd., Thailand) tablets containing thiamine (100 mg) were acquired from a pharmacy in Thailand. Ground coffee was purchased from a local supermarket. Samples in solid form (pharmaceutical tablets) were directly analyzed without dissolution. Samples in powder form were impregnated with a methanol/water mixture in order to prevent the loose powder to be blown into the IMS tube.

2.2. DBD ionization source

The construction of the DBD plasma probe followed the design reported by Furter and Hauser [14] with some modifications of the dimensions. The probe was based on a 8.0 cm long fused silica tube with 3.0 mm o.d. and 1.5 mm i.d. (Wisag, Fällanden, Switzerland). The tube was placed in a polymeric potting box for electronic components (S38 from Teko Enclosures, San Lazzaro Di Savena, Italy) with dimensions of 15 × 19 × 40 mm (width × height × length), with access holes drilled in the centres of the two narrow sides. The electrodes were created by wrapping adhesive copper tape with a thickness of 0.04 mm around the tube (3 M 1181, Distrelec, Nänikon, Switzerland). The circular electrodes bands were 5.0 mm wide and 10.0 mm apart. The electrode closest to the outlet (25 mm from the end of the tube) was connected to a high voltage AC generator (Plasma Generator G2000, Redline Technologies Elektronik, Baeswiler, Germany) via a cable rated for 40 kV (HSW-4022-2, Hivolt, Hamburg, Germany). The tube extends 15 mm outside the box. The second electrode was connected to the electrical ground. The box was filled with a thermally conductive but electrically insulating epoxy glue (EPO-TEK T7110, Epoxy Technology, Cham, Switzerland). The probe was held in place with a custom-designed holder attached to an XYZ mechanical arm (Thorlabs, Bergkirchen, Germany). Helium (99.996% purity, PanGas, Pratteln, Switzerland) was used as the plasma gas and the flow was regulated with a mass flow controller (F−201CV-500-ADD-22-V, Bronkhorst, Aesch, Switzerland). For analysis, the samples were placed on a small platform attached to a polymeric rod, which was then inserted 6−8 mm inside the reaction region of the IMS tube. The positioning of the sample holder was carried out using a mechanical arm (Thorlabs).

2.3. Ion mobility spectrometer

The IMS instrument is a reproduction of the open source design published by Reinecke and Clowers and more detail can be found in their publication [10]. The IMS instrument consists of two regions, *viz*. the reaction and drift zones. The reaction tube is 27 mm in length and the drift (or separation) tube is 106 mm long. Ring electrodes (1.6 mm) and spacers (1.0 mm, two were combined to create a gap between each electrode of 2.0 mm) produced from printed circuit boards (PCB) were ordered from PCBway (www.pcbway.com), as well as the two alignment boards fitted with 1 MΩ surface mount resistors (±1%, HVCB1206FKC1M00, Stackpole Electronics, Raleigh, NC, USA) to create the electric field. The high voltage was provided by a unit from Spellman (CZE1000R, Hauppauge, NY, USA). For injection of short ion swarms into the drift region, a 3-grid ion shutter as proposed by Langejuergen and coworkers [15] was used. The 3-grid ion shutter consisted of 3 metal grids according to the design of Reineke and Clowers (obtained from Newcut, Newark, NY, USA) with 300 μm thick PTFE spacers. The electrically floating pulse circuitry was trigged via a fibre optic cable, and was purchased from GAA Custom Electronics (http://www.mstar2k.com/gaace-home). Details can be found in a publication by Garcia et al. [16]. The timing was controlled with a Analog Discovery 2 multifunction instrument (Digilent, Pullman, WA, USA). A Faraday plate placed at the end of the drift tube was employed for detection and was fitted with an aperture grid of identical design as the injector grids. The detector was connected to a low noise current-to-voltage converter with two-stage amplification. The first stage was based on a LMC6001 operational amplifier (Texas Instruments, Dallas, TX, USA) in the transimpedance configuration with a 470 MΩ feedback resistor. This was followed by a non-inverting voltage amplifier (OPA227P, Texas Instruments) as second stage with an amplification factor of 10. The output signal was recorded with a 16 bit-resolution PC oscilloscope (Picoscope 4262, from Picotech, St. Neots, UK). Argon (99.996% purity, PanGas) was generally used as drift gas, and its flow was regulated with a mass-flow controller (F−201CV-500-ADD-22-V, Bronkhorst). The different parts were arranged on an optical breadboard using optomechanical components from Thorlabs.

2.4. Mass spectrometry

The instrument employed was a LCQ Deca 3D ion trap mass spectrometer (Finnigan MAT, San Jose, CA, USA). For ionization of trihexylamine (THA), the He-DBD plasma probe was set up in front of the mass spectrometer as detailed previously [14]. A full-scan with a range of 200–700 m/z in the positive ion mode was used to obtain the mass spectrum. Data was collected using the Tune Plus software vs. 2.0 (Thermo Fisher Scientific, Waltham, MA, USA).

2.5. Calculations

The experimentally obtained reduced mobilities, K_0 ($cm^2 \cdot V^{-1} \cdot s^{-1}$), were calculated from the measured drift times according to the following equation:

$$K_0 = (L/t_d \cdot E) \cdot (p/p_0) \cdot (T_0/T) \quad (1)$$

Where L is length (cm) of the drift tube, E the field strength (V/cm), t_d the drift time (s), p and p_0 the drift tube pressure and standard pressure (760 torr) respectively, and T and T_0 are the drift tube temperature and standard temperature (273.15 K) respectively. The temperature was determined with a standard laboratory thermometer and the ambient pressure was obtained from a local weather service (www.meteocentrale.ch).

The resolving power, R_p, was obtained as follows:

$$R_p = (t_d/W_{1/2}) \quad (2)$$

Where t_d is the drift time (s) and $W_{1/2}$ the full width at half maximum height (FWHM).

The formula used to convert the reduced mobilities (K_0) between N_2 and Ar as drift gas was derived from the Mason-Schamp equation [17]:

$$K = \frac{3}{16}\frac{q}{N}\left(\frac{1}{m}+\frac{1}{M}\right)^{1/2}\left(\frac{2\pi}{kT}\right)^{1/2}\frac{1}{\Omega} \quad (3)$$

where q is the charge on the ion, N the number density of the drift gas, m the mass of the ion, M the mass of the drift gas molecule, k the Boltzmann constant and Ω the collision cross section of the analyte. The conversion factor (K_{0N2}/K_{0Ar}) was obtained by ratioing the equations for the two gases, giving the following formula:

$$\frac{K_{0N2}}{K_{0Ar}} = \left(\frac{\frac{1}{m}+\frac{1}{M_{N2}}}{\frac{1}{m}+\frac{1}{M_{Ar}}}\right)^{1/2} \quad (4)$$

3. Results and discussion

3.1. The combination of DBD and IMS

The details of the dielectric barrier discharge plasma probe, following a design previously reported by our group [14], are shown in Fig. 1A. In contrast to most reported DBD and the LTP plasma torches, in our arrangement both electrodes are placed concentrically on the outside of a fused silica tube, which simplifies its construction. The arrangement is embedded in a high resistivity epoxy as used in electronics manufacturing for encapsulation, which prevents any arcing between the electrodes on the outside of the tube. Note, that in contrast to the earlier arrangement, it was found that the plasma in the new set-up was self-igniting, *i.e.* it was not necessary to momentarily place a grounded wire at the outlet of the tube. The tip of the plasma is pointed to the solid sample which is placed onto a sample holder. The spectrometer was built according to the open source design published by Reinecke and Clowers, who demonstrated it for electrospray and corona discharge ionization [10]. Besides a 10 cm drift tube for separation,

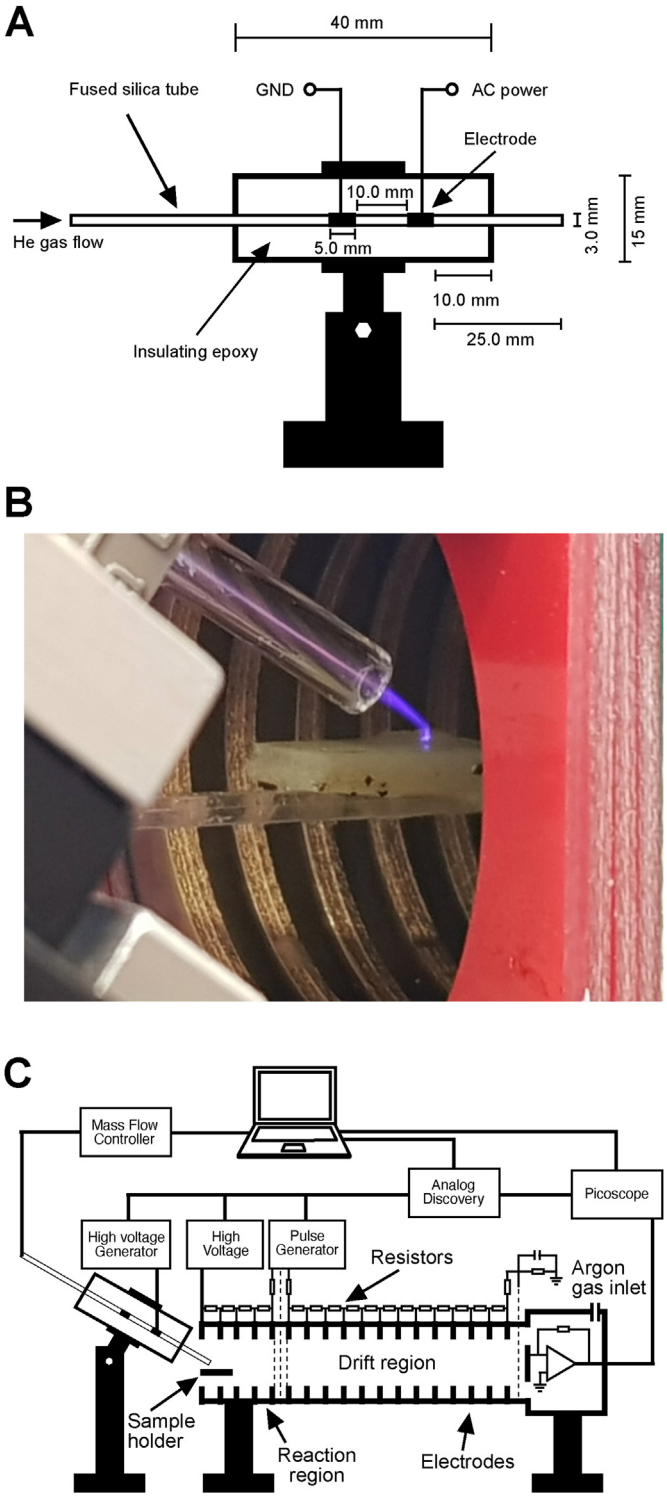

Fig. 1. A) Schematic diagram of the dielectric barrier discharge probe. B) Photograph of the DBD plasma inside the reaction region of the ion mobility spectrometer. C) Schematic diagram of the complete instrument.

it features a 10 cm long reaction region in front of the injection shutter. In order to achieve transport of the ions created by the plasma ionization towards the injection gate it is necessary to place both, the sample holder and the plasma torch, inside the reaction region of the drift tube. As it was found that with the plasma ionization significantly higher signals could be obtained by shortening the reaction region its length was reduced to 27 mm. The sample is placed about 6–8 mm from the entrance of the tube. A photograph of the plasma source inside the end of the IMS tube is shown in Fig. 1B and the complete set-up is illustrated in Fig. 1C. Note, that the plasma is placed close to the centre of the drift tube, which assures that no electrical discharge between the plasma and the drift tube electrodes occurs. The breakdown voltage is about 10 kV cm^{-1}. The flow of the drift gas out of the tube will suppress potential interferents which might be present in the ambient air. The IMS instrument and the DBD ion source were mounted on an optical breadboard in order to obtain a stable arrangement. Commercially available electronic units were employed for the generation of the plasma voltage, the drift tube voltage, the injection pulse, as well as for sequencing and data acquisition. The only dedicated circuitry which was built in-house was the detector amplifier. The injection pulses were controlled by the Analog Discovery multifunction instrument and its software running on the PC. This also provided a trigger signal for the measurement of the detector signal with the Picoscope PC oscilloscope using its own software.

3.2. The use of argon as drift gas

Jafari [18], who reported the use of an LTP source for ambient ionization in IMS, designed a special funnel arrangement to vent most of the N_2 drift gas from the tube ahead of the plasma source in order to prevent disruption of the He-plasma by the flow of the drift gas against the plasma plume. In addition, an auxiliary Ar gas flow was employed to facilitate the transport of the analyte ions toward the injector gate. It was found for our setup that it was not necessary to vent the drift gas from the reaction tube as a purely mechanical disruption of the plasma did not occur. Furthermore, an auxiliary gas flow towards the injector was also not required as the drift voltage before the injector causes the ions to move to the injector. On the other hand, Jafari also noted that the nature of the gas surrounding the plasma ion source was also having an effect as nitrogen was found to lead to a quenching of the He plasma. Therefore, we tested the use of Ar as an alternative to nitrogen as drift gas, which is not common, but promised a more straightforward design of the instrument.

In Fig. 2A, first of all, a mobility spectrum obtained while the plasma soure was not in operation is given and shows a blank, except for an electronic artefact immediately on injection. The basic operating conditions are given in Table 1. On igniting the plasma a background ion peak was observed at 13.3 ms under nitrogen as drift gas. According to Reininger et al. [19] the ionization mechanism for the analytes with a He DBD consists of a chain of reactions. This starts with the Penning ionization of impurity N_2, and subsequent formation of hydrated proton clusters, which in turn leads to the protonation of the analytes. As the reduced mobility (K_0) of the main background peak (1.95 $cm^2\ V^{-1}\ s^{-1}$) is consistent with that of a proton/water cluster [20] this is the likely identification and the peak may be considered to be the reactant ion peak (RIP). When trihexylamine (THA) was placed on the sample platform ion peaks were obtained at 25.7, 28.0, 29.6 and 35.5 ms when using N_2 as the drift gas. The reduced mobility of the first peak (1.01 $cm^2\ V^{-1}\ s^{-1}$) is close to the value reported by Keller et al. for protonated THA separated in air (1.06 $cm^2\ V^{-1}\ s^{-1}$) [21]. The RIP has disappeared indicating that perhaps all of the species have been consumed in the reaction with the analyte. In order to confirm the identity of the peaks, the He-DBD probe was also coupled to a mass spectrometer (MS). As shown in Fig. 2B a molecular ion peak $[M + H]^+$ was observed at 270.3 m/z units with three more peaks at 302.3, 387.9, and 602.2 m/z units, which are presumably due to clusters with plasma species. The peak pattern of the ion mobility spectrum matches well that of the mass spectrum. As evidenced by the last trace of Fig. 2, when using Ar as the drift gas, the intensity of the analyte peaks has increased, confirming the observation of Jafari regarding quenching in N_2. Therefore the use of Ar was adopted for the subsequent measurements. A consequence of the change of the

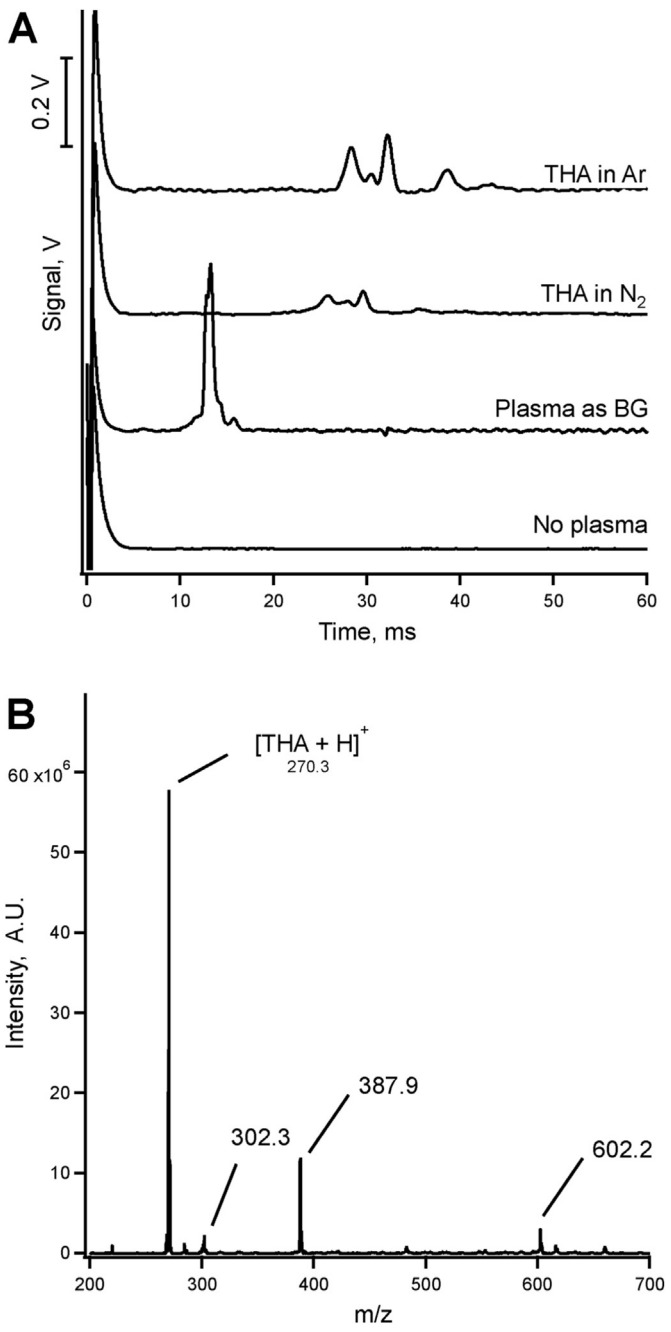

Fig. 2. A) Mobility spectra for blank run without the plasma in operation, the plasma without sample, trihexylamine (THA) separated in N_2, and trihexylamine (THA) separated in Ar. The operating parameters are given in Table 1. B) Mass spectrum for THA ionized with the plasma source. Details on the mass spectrometer are given in the experimental section.

Table 1
Operating parameters.

Dielectric barrier discharge plasma source	
Plasma voltage (kVp-p)	8.0
Frequency (kHz)	28
Inner diameter of tube (mm)	1.5
Outer diameter of tube (mm)	3.0
Length of tube (mm)	8.0
Gas supply (mL min^{-1})	400
Electrode width (mm)	5.0
Electrode gap (mm)	10.0
Injection gate	
Injection time (μs)	200
Gate closing voltage (V)	60
Drift tube	
Length of reaction tube (cm)	2.7
Length of separation tube (cm)	10.6
Reaction tube voltage (kV)	5.0
Separation tube voltage (kV)	4.0
Electrode width (mm)	1.5
Spacer width (mm)	2.0
Ar counter gas flow (mL min^{-1})	100
Drift tube temperature (°C)	23 ± 2
Drift tube pressure (Torr)	760
Ion detection	
Number of injections averaged	500
Total gain (VA^{-1})	4.7×10^9
Analysis time (s)	50

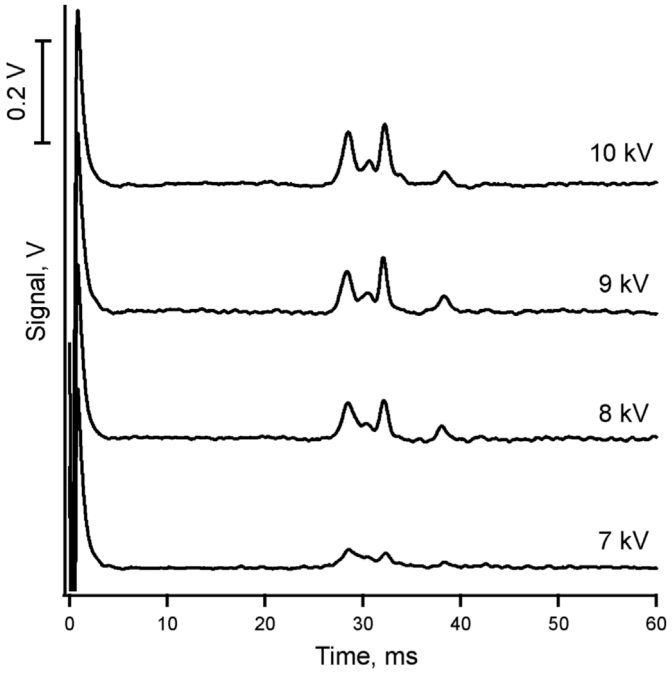

Fig. 3. Effect of plasma voltage on the signal for trihexylamine. For the other operating parameters see Table 1.

drift gas is also a change in mobility to lower values, which is also apparent in Fig. 2. The reduced mobility in Ar for the main peak is 0.91 $cm^2 V^{-1} s^{-1}$. The value expected when converting the reduced mobility in nitrogen to the argon value, as described in the experimental section, is 0.85 $cm^2 V^{-1} s^{-1}$.

3.3. Effects of the gas flow rates and the plasma voltage

Helium was employed as the plasma gas. In order to investigate the effect of its flow rate this was varied between 100 and 1000 mL min^{-1} (with the plasma generator set to 8 kV at 28 kHz). Above about 200 mL min^{-1} a signal could be observed for THA. A further increase in the flow rate led to higher intensities, but above 700 mL min^{-1} the signal was found to decrease. A flow rate of 400 mL min^{-1} was adopted as a compromise as it gave good intensities at a relatively low gas consumption. Also investigated was the effect of the flow rate of the argon drift gas between flow rates of 100 and 500 mL min^{-1}. It was found that the intensity of the peaks increased with the flow rate (about twofold). However, the resolving power was found to deteriorate with the increase in flow rate, possibly due to turbulances introduced. Therefore the Ar flow rate of 100 mL min^{-1} was retained for the subsequent measurements.

The electrical power applied to the plasma torch can also be expected to affect the plasma and therefore the ionization

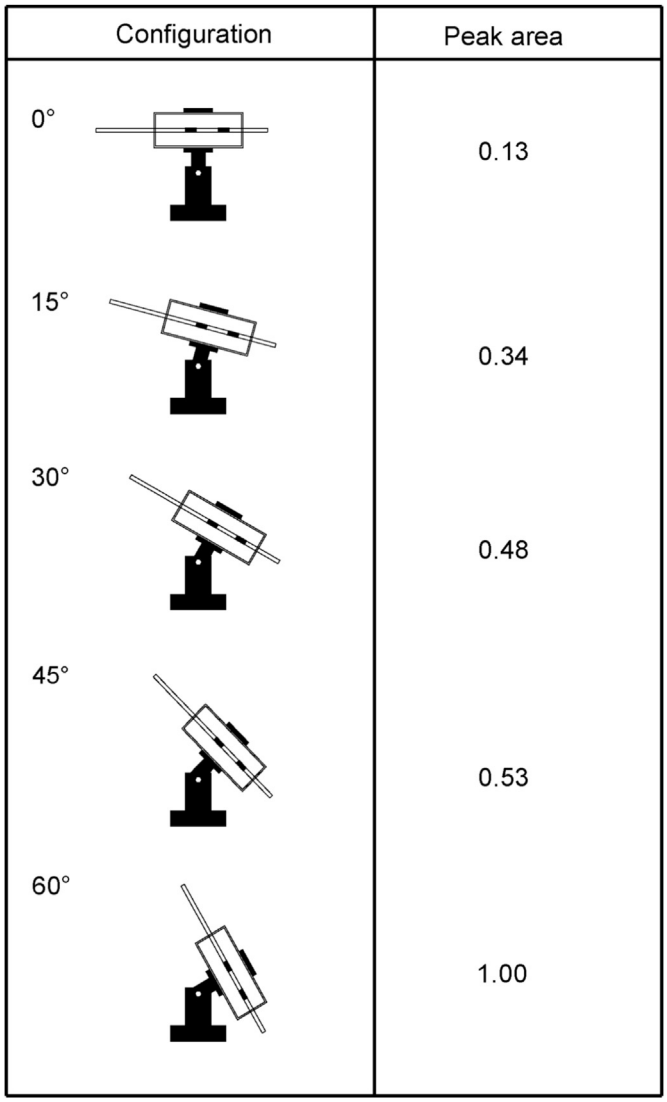

Fig. 4. Effect of the orientation of the plasma torch on the signal for trihexylamine. The operating parameters are given in Table 1.

efficiency. This can be regulated by adjustment of the amplitude of the alternating high voltage of the generator. For voltages below 5 kV (peak-to-peak) the plasma did not ignite. At 6 kV the formation of an unstable plasma was observed. For voltages of 7 kV up to the maximum of 10 kV a stable plasma was obtained and the power was sufficient to ionize THA. Voltages higher than 10 kV were found to lead to arcing from the plasma tip to the surrounding electrodes of the drift tube and could therefore not be employed. The effect of the plasma voltage between 7 kV and 10 kV on the intensities of the peaks for THA is shown in Fig. 3. Generally, the intensity increases with the plasma voltage, but there are also some small changes in the intensities relative to each other. The peak height for the first of the peaks for THA increased from 0.028 to 0.091 V when the plasma voltage was increased from 7.0 kV to 10.0 kV. As the signal was found to be more stable at 8.0 kV than at the maximum voltage, this setting was adopted for subsequent measurements.

3.4. Effect of the positioning of the plasma torch

The plasma was positioned so that the tip of the tube was about 2–3 mm from the sample. Another important aspect is the angle at which the plasma torch is oriented. The purpose-made holder of the plasma probe shown in Fig. 1A, allows it to move freely, so that the effect of different angles (0°, 15°, 30°, 45°, 60°) of the plasma probe with reference to the axis of the drift tube was investigated. The relative peak areas obtained for THA at different angles are

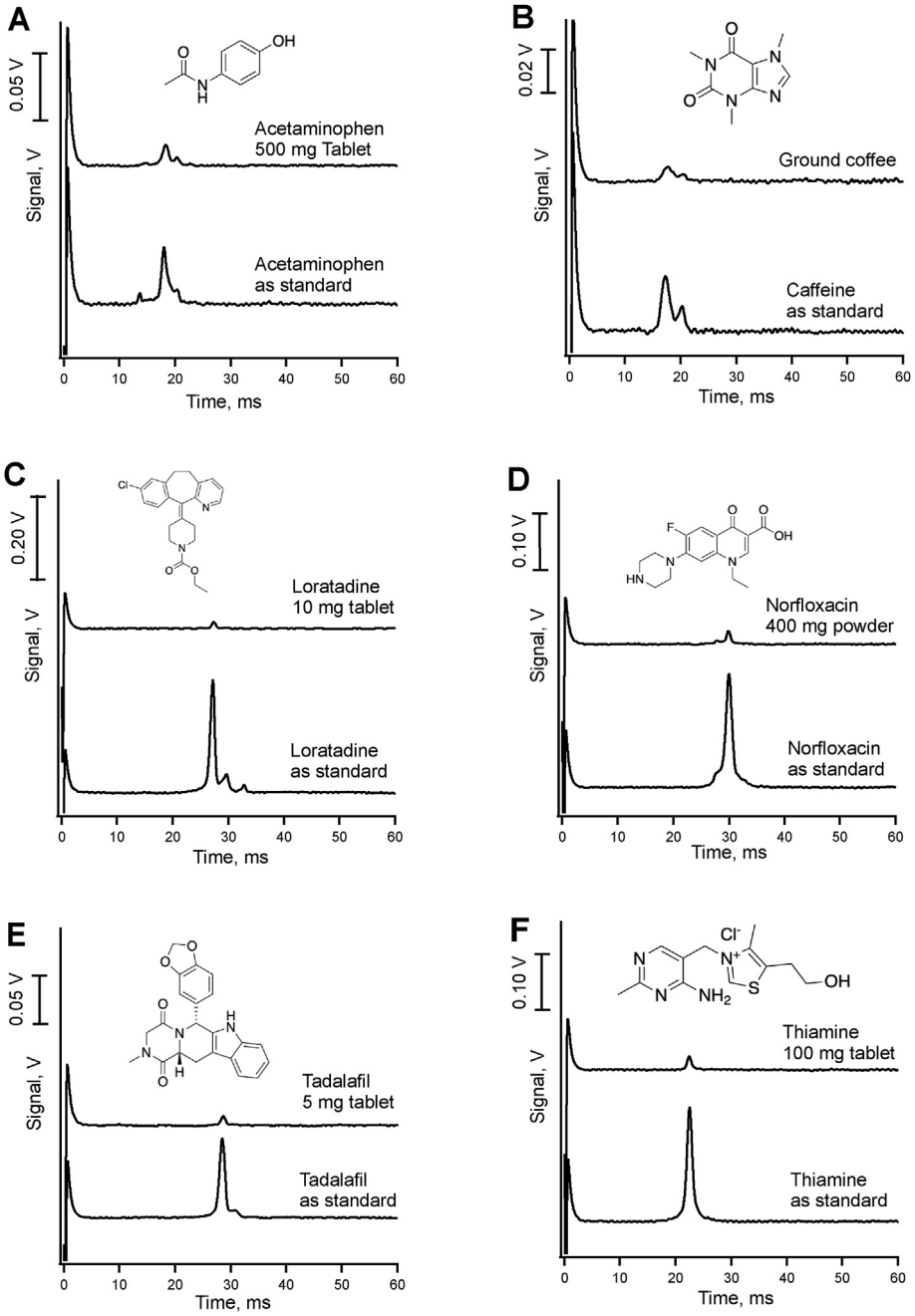

Fig. 5. DBD-IMS spectra for: A) acetaminophen, B) caffeine, C) loratadine, D) norfloxacin, E) tadalafil, and F) thiamine. For the standards ca. 5 mg of the powders were placed on the sample holder. The operating parameters are given in Table 1.

Table 2
Resolving powers (R_P) and reduced mobilities (K_0) of the molecular ion peaks for the pharmaceuticals (as determined for the standards).

Sample	Measured Resolving Power, R_P	Measured K_0 in Ar ($cm^2 \cdot V^{-1} \cdot s^{-1}$)	Estimated K_0 in N_2 ($cm^2 \cdot V^{-1} \cdot s^{-1}$)	Literature K_0 in N_2 ($cm^2 \cdot V^{-1} \cdot s^{-1}$)
Acetaminophen	29	1.40	1.62	1.65 [13]
Caffeine in ground coffee	18	1.30	1.51	1.54 [18]
Loratadine	57	0.94	1.11	1.04 [24]
Norfloxacin	42	0.87	1.02	–
Tadalafil	49	0.92	1.08	1.01 [25]
Thiamine	36	1.15	1.35	1.26 [24]

illustrated in Fig. 4. At 0° a strong RIP was observed while the signal for the THA was relatively small. As expected, the signal increased as the impact angle was changed through 15°, 30°, 45° and 60°, with the largest signal obtained for the 60° angle. However, as the stability was better for 45° this setting was adopted. This also agrees with the findings of Furter and Hauser for the use of the DBD plasma as an ambient ionization source for mass spectrometry [14].

3.5. Quantification

Although ambient ionization is better suited for qualitative analysis than for quantification we examined the possibility of the latter by using again THA as model substance. A 4 point calibration curve was acquired by dropping 50 μL of different dilutions of the stock solution in 50% (v/v) methanol/water onto the sample holder to yield amounts between 0.5 and 15 μg. Over this range a linear response was found with a correlation coefficient of 0.983. The limit of detection was determined as 0.45 μg (the amount giving a signal 3 x its standard deviation). This is comparable with the limit of detection of 0.15 μg for acetaminophen reported by Jafari for the LTP-IMS [13].

3.6. Application to pharmaceuticals

In Fig. 5, the ion mobility spectra of pharmaceutical preparations for acetaminophen (an analgesic), loratadine (an antihistamine), norfloxacin (an antibiotic), tadalafil (an erectile dysfunction treatment), thiamine (vitamin B_1) and ground coffee beans are shown together with the spectra of their pure active pharmaceutical ingredients (API). The surfaces of the tablets containing acetaminophen, loratadine, tadalafil, and thiamine were roughened with a small file in order to remove any surface coating before placing them on the sample plate. Norfloxacin was contained as a powder in a capsule which was opened. All powders, including the ground coffee, were moistened with 50% (v/v) of methanol/water in order to prevent them from being blown from the sample holder and contaminating the instrument.

All spectra show a dominant peak with some additional smaller peaks in some cases. The main peaks are generally the ones with the highest mobility and are assumed to be the protonated molecular ion, while the other peaks must due to heavier ion clusters. The resolving powers (R_P) for the main peaks of the standard substances are given in Table 2. The values at the higher end of the range ($R_P = 36–57$) are also comparable to those reported by Jafari for the ITP-IMS instrument [13]. The relatively low resolving powers for the two substances with the highest mobilities (acetaminophen and caffeine) presumably could be improved by different optimization of the operating parameters (length of the drift tube, field strength). The spectra obtained from pharmaceutical tablets are found to match very well the spectra for the pure standards. The reduced mobilities (K_0) values calculated from the drift times are given in Table 2. As these were determined in Ar as drift gas they cannot be compared directly with literature values, which mostly have been obtained in nitrogen. As evidenced by the measurement of THA above, the mobility of the ions is slower in Ar than in N_2. Therefore the experimental K_0 values in Ar were converted to expected K_0 values in N_2 by using the formula derived from the Mason equation given in the experimental section. As can be seen from the table, some of the converted values closely match the reported N_2 values, but in other cases the agreement is not perfect. The reason for the deviations is thought to lie in the application of the Mason equation which does not always predict the experimental results well, in particular for larger molecules [22,23].

4. Conclusions

The use of a DBD plasma for the ambient ionization of solid samples in IMS has been successfully demonstrated. The plasma torch as well as the spectrometer could be constructed inexpensively in-house. Both parts are simpler than for the LTP-IMS instrument previously reported [13] due to the use of two external electrodes for the DBD plasma torch and as the use of Ar as drift gas eliminates the need for a skimmer and an auxiliary gas flow. While ambient ionization from solid samples is not well suited for quantitative measurements the results for the drug substances shows that the method should in most cases allow the identification of pharmaceuticals from the mobilities of the main peaks and/or the peak patterns. Its performance should also be adequate for such applications as the detection of faked drugs, as these are expected not to show a peak for the active ingredient or have extraneous peaks not present in the genuine formulations.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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