Storage of protonated water clusters in a biplanar multipole rf trap

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Abstract. We present the storage properties of protonated water clusters \( \text{H}^+ (\text{H}_2\text{O})_n \) \( (n = 1–4) \) in an improved biplanar ion trap. The design is based on our recently reported realization of a biplanar multipole radiofrequency (rf) ion trap (Debatin et al 2008 Phys. Rev. A 77 033422). The new experimental setup is composed of the ion trap in tandem time-of-flight configuration for mass-selective ion loading and mass-selective detection of stored ions. Special attention is paid to the supersonic discharge cluster source and our improved realization of a biplanar multipole ion trap with a simplified electrode layout. The source performance is presented and mass-selective loading into our trap is demonstrated with \( \text{H}^+ (\text{H}_2\text{O})_n \) clusters. We achieve stable trapping of \( \text{H}^+ (\text{H}_2\text{O})_n \) clusters \( (n = 1–4) \) with storage lifetimes of 3–12 s, which is comparable to former achievements with stable atomic Ar⁺ ions in the first trap generation. Collision-induced cluster dissociation during the loading process is observed.

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1. Introduction

The trapping of ions and their manipulation during the storage phase are the basis for many developments in atomic and quantum physics. In particular, radiofrequency (rf) Paul traps are used for high-precision mass spectrometry [1], for the development of optical clocks [2], for investigations of laser-cooled ion crystals [3] and for quantum computation with ions [4].

In recent years, a great deal of research has been directed towards miniaturized realizations of rf ion traps using microelectromechanical system fabrication methods as well as printed circuit boards [5]. In the field of mass spectrometry, traps with dimensions in the micrometer scale in combination with arrays of thousands of traps are developed for realizing a portable mass spectrometer with low power consumption [6, 7]. Multiple trap arrays are necessary to maintain a high sensitivity with only a few stored ions per trap. Realizations for quantum computing employ micro-structured multi-level traps [8] as well as surface traps that confine ions above a single chip plane [9–12].

Rf multipole ion traps show the same basic design as the linear Paul trap with the difference of more rf electrodes. This leads to a larger effectively field-free trapping region. Due to geometrical reasons the 22-pole trap has gained special importance [13, 14]. In these traps, buffer gas cooling can be used more effectively than in low-order multipole ion traps for the thermalization of complex molecular and cluster ions to cryogenic temperatures where not only translational but also internal degrees of freedom are effectively cooled within a few milliseconds [15, 16]. This allows investigations of collision processes and chemical reactions at variable temperatures [13, 17], as well as analysis of questions of astrophysical relevance, such as measurements of photodetachment cross-sections of negative ions [18].

Microfabrication techniques are also advantageous for the production of multipole rf traps. They allow one to reach sub-micrometer positioning accuracy at almost arbitrary shape for many individual electrodes, which is more difficult for conventional ion traps and may lead to subtle distortions in the effective potential there [19]. On a chip, trapping fields can be realized with a much higher multipole order than is suitable for conventional mechanical designs. Furthermore, microfabrication offers the opportunity to implement a variety of electrode geometries, in particular the integration of additional ion optics or several ion traps onto the same chip. In this way, chemical micro-reactors may be realized. Transparent electrodes made from indium tin oxide may be used instead of metallic electrodes, which allows for optical access to the trapped
ions from almost all directions in space. Chip-based multipole ion traps are therefore considered much more suitable for optical, infrared and even rf spectroscopy of complex biomolecular and cluster ions than conventional multipole ion traps with their limited optical access. Due to the good optical access, the ion trap can also be combined with a trap for ultracold and quantum degenerate neutral atoms to study ultracold ion–atom collisions and the perturbations of Bose–Einstein condensates by single charges [20]. We have recently started to develop biplanar chip-based multipole rf ion traps. In a first-generation trap, the storage of Ar\(^+\) ions with a maximum storage time of about 16 s was demonstrated [21].

In this article, we describe our second-generation biplanar multipole ion trap and its integration into a tandem time-of-flight mass spectrometer, which enables mass-selective ion loading and mass-resolved detection. We demonstrate the performance of this setup with protonated water cluster ions. H\(^+\)(H\(_2\)O)\(_n\) ions are extensively studied model systems of cluster ions with a complex internal structure. They are of fundamental importance in acid–base theory [22] in aqueous solutions as well as enzyme catalysis [23]. Moreover, they play a crucial role in the chemistry of the ionosphere where solvated protons constitute the dominant ion species [24] and they are predicted to be created in interstellar clouds by collision with high energetic (keV) particles on ice [25]. Most measurements of water clusters are to date performed using mass spectrometry on ion beams. Recently, rf traps have been introduced for highly sensitive vibrational spectroscopy [26]–[28] and for precise calorimetry [28] of charged water clusters.

In the following section the experimental setup is described, with emphasis on the cluster ion source and the new realization of a biplanar multipole rf chip trap. Then the results on the loading and storage properties of protonated ion clusters in our biplanar multipole ion trap are presented.

2. Experimental setup

Our experimental setup (see figure 1) comprises a biplanar multipole ion trap in a tandem time-of-flight configuration [29] with a pulsed discharge ion source. This allows us to mass selectively load the produced cluster ions into the trap. After variable storage times, the complete mass spectra of stored ion species are detected on a channeltron electron multiplier. A detailed description of all components of the setup is given in the following sections.

2.1. Cluster production and time-of-flight selection

The cluster ion source is based on a pulsed piezo-controlled valve followed by a glow discharge with supersonic expansion. The discharge unit we use stems from a design by Osborn et al [30]. For the creation of protonated water clusters, we use admixtures of H\(_2\) with a few per cent of water as obtained by running the carrier gas at a stagnation pressure of typically 2 bar through a water-filled bubbler at room temperature.

A 100 \(\mu\)s gas pulse is emitted through the conical nozzle (170 \(\mu\)m in diameter) of the piezo valve into a narrow channel that is composed of a cylindrical anode and cathode, as well as insulating teflon and ceramic tubes. During a short time of typically 2 \(\mu\)s, the applied anode voltage is switched from ground to 600–1000 V, while the cathode electrode remains on ground. In the presence of this strong electric field of 300–500 V mm\(^{-1}\), electrons and ions are accelerated, creating secondary electrons and ions by impact ionization onto the aqueous gas in
Figure 1. Experimental setup with the ion trap in tandem time-of-flight configuration and the discharge source. The created clusters are accelerated by Wiley–McLaren field plates, collimated and mass-selectively loaded into the trap according to their time-of-flight separation. After variable storage times, the complete time-of-flight (TOF) trace of the trapped ions is recorded using a channeltron detector. Distances are not true to scale. The total length of the setup is 1.35 m.

an avalanche breakdown, which triggers a self-sustained discharge in the channel from anode to cathode. Electron impact on neutral water molecules creates mainly $\text{H}_2\text{O}^+$ ions [31], which further react with water molecules to hydronium: $\text{H}_2\text{O}^+ + \text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+ + \text{OH}$. At the end of the channel, the free jet expansion leads to the onset of supersaturation. The hydronium ions form centers for the condensation of $\text{H}_2\text{O}$ molecules. Stepwise attachment then leads to the formation of protonated water clusters: $\text{H}^+ (\text{H}_2\text{O})_{n-1} + \text{H}_2\text{O} \rightarrow \text{H}^+ (\text{H}_2\text{O})_n$. As this reaction is exothermic by about 1.4 eV for $n = 2$–0.4 eV at $n = 8$ [26, 32], a third collision partner $\text{M}$ (typically the carrier gas) is necessary for deactivation of the forming cluster.

In order to reach a great enhancement in stability and intensity of the discharge and thus more stability in the created ion signal, a short 1 keV electron pulse emitted by a self-made electron gun opposing the ion source provides seeding with electrons and positive ions in the discharge channel. The point of ignition can hereby be pinned down to a fraction of a microsecond and the source may be operated at a lower anode voltage without the risk of discharge misfires.

The created cluster ions fly in between the two temporarily grounded rear field plates of a Wiley–McLaren mass spectrometer [33] that is mounted perpendicular to the ion drift direction.
Figure 2. Top view showing the front side of the first- (left) and second- (right) generation chip design. Rf electrodes are differentiated by red and blue color for better visualization. Dc electrodes that are switched for trap loading are marked yellow. The backside electrodes shown in the middle are switched for extraction, creating a linear ramp, which allows the pushing of ions out of the trap. During storage, dc and rf electrodes create an effective trapping potential of almost box-like shape with a typical trap depth of 0.5 eV.

out of the source. A sudden increase in the field plate voltages from ground to typically 240 and 200 V, respectively, by two high-speed voltage switches accelerates the ions. Their final kinetic energy, determined by their initial position between the Wiley–McLaren electrodes, is estimated to be $215 \pm 5$ eV, taking into account field inhomogeneities due to grounded surfaces around the acceleration electrodes. Deflection plates placed shortly after the acceleration stage compensate for the ions’ transverse velocity components. In the field-free drift region between the ion source and the trap, ions of different masses separate in space due to their velocity difference, and different ion species reach the trap after different flight times.

2.2. Trap loading, storage and mass-selective detection

The heart of the experiment is the biplanar multipole rf ion trap (see figure 1). In contrast to multipole traps in cylindrical configuration that are composed of several rods arranged on a circle with neighboring rods alternately connected to the outputs of an rf power supply, we have realized a biplanar trap geometry [21]. In this trap, two opposing chips with physical dimensions of $3 \times 3$ cm$^2$ are mounted with a spacing of 5 mm. Figure 2 shows the chip design of the first-generation trap [21] and the improved second-generation trap, which is presented here. The electrode structure on each chip is made of 100 nm thin gold, which is deposited on a glass substrate and structured by methods of microelectromechanical system technologies in a double-side lift-off process. The cylindrically shaped electrodes of cylindrical designs are projected onto two opposing planes, which leads to a stripe structure for the rf electrodes on
each chip. The second-generation rf electrodes are designed as equidistant stripes with a center-to-center distance of 1120 µm and a constant width of 620 µm. Stripes with the same phase are combined to a comb structure to facilitate electrical contact. The two inter-meshing combs on each chip are connected to the outputs of a self-build high-power rf oscillator in push–pull configuration [34], which creates ion confinement perpendicular to the chip surface.

The shape of the effective potential that is created in the planar chip trap by the rf voltage has been described previously [21]. Near the chip surface it increases exponentially and thereby forms an overall box-like shape with a flat field-free central region and steep walls. The effective depth of the trapping potential is given by the effective potential when the ions either reach the chip surface or experience such a large rf amplitude that their motion is no longer adiabatic [29, 35]. For the experiments discussed here, the latter case holds for small clusters, leading to a trap depth of about 0.4 eV, proportional to ion mass. For larger clusters, the trap dynamics are adiabatic in close proximity to the chip, so that surface effects are expected to reduce the effective trap depth from the linear scaling (which would yield about 1.5 eV for \( n = 4 \)) to a value that may well lie below 1 eV.

Additional electrostatic electrodes allow confinement in the plane parallel to the chip surface. Apart from fine tuning of the generated trapping field, these dc electrodes may be switched to enable the loading of ions into the trap. On the back side of each chip, there are additional electrodes that are used to create a linear electric field ramp that is superimposed onto the trapping field to extract the ions after storage (shown at the bottom of figure 2). To improve the electrode geometry on the chip, we have developed the second-generation biplanar ion trap. The main improvement of the new design (see the right panel of figure 2) is the simplification of the dc electrode layout. This substantially facilitates and speeds up optimizations of loading and extraction efficiency as well as storage lifetimes.

In the experiment the trap is held on a dc offset potential of 200 V, which is added to the rf potential. This offset is lower than the kinetic energy of the ions as defined by the acceleration voltages of the Wiley–McLaren mass spectrometer (see the previous section). Therefore, ions approaching the trap are decelerated and eventually enter the trapping region between the two chips with a remaining kinetic energy of between 10 and 20 eV. For further retardation and translational cooling, an intense He buffer gas pulse of typically 90 µs is injected into the trapping region by a close-by piezo-electric valve. The decelerated ions traverse the ion trap and are deflected by the repulsive dc potential applied to the electrode at the exit side of the trap. This barrier is indicated in the schematic potential in figure 3. Before they can escape the trap on the entrance side, the dc electrodes located at the loading side of the chip (see figure 2) are switched to repulsive voltages with respect to the trap offset, which leaves the ions captured in the trap. Shifting the time period during which the trap is open for loading is used to choose a specific ion mass to be loaded and stored in the trap (see section 3.1).

For extraction of the ions after the desired storage time, the backside electrodes on each chip (shown in the bottom of figure 2) are used to create a linear potential ramp that is superimposed over the trapping field (see figure 3). Even before extraction there is a small gradient applied with the backside electrodes, which helps to extract the ions and obtain good mass resolution. The penetration of this field into the middle of the trapping region is reduced due to shielding by the gold electrodes placed on the front side of each chip. When also taking the increase due to the glass dielectric into account, a potential fraction of about 3% is estimated in numerical simulations. Despite this reduction, ions can still be effectively pushed out of the trap. The extraction field in combination with properly adjusted dc electrode voltages at the exit side
of the trap is used to create a Wiley–McLaren-type acceleration field suitable for time-of-flight mass spectrometry. Collimated by ion optics, the ions then drift through an 80 cm long field-free region towards a channel electron multiplier where the time-of-flight mass spectrum of the stored ions is recorded with a digital oscilloscope. The entire sequence of loading, storage and detection is run multiple times while the time-of-flight spectra are averaged on the oscilloscope and eventually read out by a personal computer. Accurate timings, which are required to properly operate the experiment, are provided by a Berkeley Nucleonics pulse and delay generator.

3. Results

The measurements presented in the following were performed with the second generation of our biplanar ion trap, described in the previous section. First we demonstrate the operation of the ion source, followed by measurements of the loading and storage characteristics.

3.1. Source performance and mass-selective loading

When no storage but only a characterization of the source mass spectra is desired, all trap electrodes are fixed to ground. The ion beam is then directly steered through the trap onto the detector and the unbiased source mass distribution is obtained. To form water cluster ions, we use aqueous H$_2$O ([H$_2$]/[H$_2$O] = 150/1) at a total stagnation pressure of 2 bar with a discharge current of 6 mA. With these settings, the discharge cluster source produces H$^+$(H$_2$O)$_n$ clusters.
Table 1. Typical operating voltages applied to the chip electrodes during ion loading, trapping and extraction. If no value is given, then the voltage is left unchanged. The rf frequency applied to the trap is \( \omega_{rf} = 2\pi \times 7 \text{ MHz} \).

| Electrode | Loading | Trapping | Extraction |
|-----------|---------|----------|------------|
|           | \( U_A = -U_B (V) \) | \( U_{dc} + 150 \sin(\omega_{rf}t) \) |          |
|           | \( U_{dc} (V) \) | 200      |            |
|           | \( U_I (V) \) | 22       |            |
|           | \( U_J (V) \) | 58       |            |
|           | \( U_K (V) \) | 162      | 253        |
|           | \( U_L (V) \) | 222      |            |
|           | \( U_M (V) \) | 111      |            |
|           | \( U_N (V) \) | 65       |            |
|           | \( U_O (V) \) | 253      |            |
|           | \( U_R (V) \) | 231      | 231        |
|           | \( U_S (V) \) | 194      | 462        |

Figure 4. Time-of-flight mass spectra of created cations using the discharge source with moist H\(_2\) at 2 bar. Apart from intense H\(^+\)(H\(_2\)O)\(_n\) with \( n = 1–4 \), slight cluster peaks stemming from hydrated CO\(_2^+\) ions are visible. The H\(_3\)O\(^+\) and H\(^+\)(H\(_2\)O)\(_3\) peaks are used for TOF-to-mass calibration.

In order to allow cluster ions to enter the trap, the deceleration and trapping fields of the trap are turned on. Typical electrode voltages (see figure 2) for the rf voltages \( U_A, U_B \) and for the dc voltages on the front, \( U_I \) to \( U_O \), and back side of the chip, \( U_R, U_S \), are given in table 1.

with \( n = 1–4 \). This is shown in figure 4. The estimated number of clusters changes from about \( 10^3 \) at \( n = 1 \) to about \( 10^2 \) at \( n = 4 \) per ion pulse. Apart from the protonated water cluster peaks, we identify tiny additional peaks composed of hydrated CO\(_2^+\) cations. They are due to traces of impurities in the gas system. The mass resolution in this time-of-flight measurement amounts to about \( m/\delta m = t/(2\Delta t) = 30–35 \).

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New Journal of Physics 12 (2010) 065035 (http://www.njp.org/)
Confinement on the loading side of the trap is disabled during a short time window of typically 3 μs by switching the electrode voltage $U_L$ from repulsive to attractive (see table 1). This allows approaching ions to enter the trap. Ions that do not reach the trap during this loading window are repelled by the dc electrodes at the loading side of the trap. For the repulsive electrode $U_L$ on the exit side of the trap, a substantial voltage (typically 20–50 V higher than $U_{dc}$) has to be applied to yield a potential barrier of a few electronvolts in the center plane between the two chips.

We demonstrate mass-selective trap loading with the series of $\text{H}^+ (\text{H}_2\text{O})_n$ ($n = 1–3$) clusters. We shift the loading time window and simultaneously observe the extracted ion mass spectra of the trap after a fixed storage time of 100 ms in the trap. The measured time-of-flight traces for the three clusters are shown superimposed in figure 5. Here, a typical mass resolution of 20–25 is obtained. The spectra show that at optimized timings indeed basically only a single ion species $\text{H}^+ (\text{H}_2\text{O})_n$ with $n = 1, 2$ or 3 is loaded into the trap. When loading $\text{H}^+ (\text{H}_2\text{O})_3$, a fraction of typically 10% of the ions is found to be $\text{H}^+ (\text{H}_2\text{O})_2$. As discussed in more detail in the next section, this is caused by collision-induced dissociation (CID) of a small fraction of the clusters during loading.

The observed high value of the trapping efficiency shows that the pulsed buffer gas decelerates most of the ions to a kinetic energy below the effective depth of the ion trap before...
they can reach a trap boundary. Based on the geometry of the pulsed gas valve and the trap, we estimate the buffer gas density between the chip surfaces to be about 3 to 6 × 10^{15} \text{cm}^{-1} for the 90 \mu s opening time of the valve. Assuming a Langevin collision rate of the ions with the helium atoms, this results in a time between collisions of about 0.4 \mu s. Under these conditions, water cluster ions with 20 eV initial kinetic energy are decelerated to 3 eV (0.5 eV) kinetic energy within 8 \mu s (15 \mu s) flight time or 25 mm (35 mm) path length, for \( n = 4 \). Ions are therefore trapped before or right after the first reflection at the potential barrier near the trap exit. The lighter clusters are stopped within even shorter times and path lengths. The transverse velocity that the ions acquire during the stopping process is too small to allow them to overcome the effective trapping potential provided by the rf field.

After the ions have been slowed down in the buffer gas to a kinetic energy below the effective trap depth, they undergo many further collisions with helium that thermalize their translational and rovibrational degrees of freedom at about the temperature of the buffer gas. The time scale for thermalization is of the order of a few milliseconds, because the helium density decreases by about a factor of 10^{3} when the gas pulse expands in the vacuum chamber. The gas is then pumped out of the vacuum chamber by a turbo-molecular pump with a decay time constant of roughly 50 ms.

3.2. Storage properties of protonated water clusters

We have performed storage measurements with protonated water clusters \( \text{H}^+(\text{H}_2\text{O})_n \) \((n = 1–4)\). Figure 6 shows the measured ion intensities after trap extraction as a function of storage time. The corresponding 1/e storage lifetimes are obtained from a fit to the ion intensity from 2 s storage time onwards. The extracted lifetimes lie in the range of 3–12 s, as indicated in figure 6. They are found to increase by a factor of 4 with increasing cluster size \( n \). Even when considering systematic variations that arise from the influence of the degree of optimization of the dc electrode, this increase is assumed to remain significant. It may be attributed to a slightly enhanced stability of heavier ions in the rf field against evaporation of ions from the trap [35]. This is supported by the fact that the lifetime of 16 s that was found for monoatomic \( \text{Ar}^+ \) ions in the first trap design compared well with an evaporation-limited lifetime [21].

For the cluster \( \text{H}^+(\text{H}_2\text{O})_4 \), a faster decay is observed during the first two seconds of storage in the trap. The mechanism for this decay is currently not understood. The electric field and buffer gas conditions are constant throughout the trapping period. Also, no fragmentation or reaction products are observed in the mass spectrum of the stored ions that could account for an additional decay channel. Further investigations are needed to find the cause for this fast decay.

As mentioned above, for loaded clusters with \( n = 3 \), we observe not only the parent clusters but also, with 10% probability, the corresponding cluster with \( n - 1 \) (see figure 5). The same effect is found for \( n = 4 \), now with a fraction of 25% for the \( n = 3 \) clusters. Insufficient mass resolution in the loading process does not explain this observation. When the loading window is scanned over the complete range, only the smaller \( n - 1 \) peak but never an additional \( n + 1 \) peak is observed in the trap extraction spectra. Moreover, when scanning the loading window to higher cluster sizes, lighter clusters turn up at the same time with the parent clusters, although the lighter daughter ions cannot be present in that later part of the beam. Cluster dissociation during storage, taking place at time scales longer than a few milliseconds after loading, can be excluded as the additional daughter peaks are visible even at low storage times of only a few milliseconds. CID [36], which takes place at the time when ions are decelerated in the intense

New Journal of Physics 12 (2010) 065035 (http://www.njp.org/)
pulse of He buffer gas, may explain the emergence of the daughter clusters. CID is an inelastic collision process of ions with neutrals that results in the transfer of a portion of the ions’ kinetic energy into internal ion energy. This collisional activation is followed by dissociation of the internally excited ion, according to

\[
\text{H}^+ (\text{H}_2\text{O})_n + \text{M} \rightarrow \text{H}^+ (\text{H}_2\text{O})^{*}_n + \text{M} \rightarrow \text{H}^+ (\text{H}_2\text{O})_{n-1} + \text{H}_2\text{O} + \text{M}.
\]

Assuming only single collision processes, the increase in the internal cluster energy due to the collision has to exceed the cluster dissociation energies for H\(_2\)O ejection, which amounts to 7.2, 1.4, 0.8 and 0.7 eV, respectively, for clusters with \(n = 1, 2, 3, 4\) \cite{32}. For estimating the maximum transferable energy into the cluster, we need to regard the center-of-mass system composed of the cluster ion and a helium atom. The relative energy amounts to \(E_{\text{rel}} = \frac{1}{2} \mu v_{\text{rel}}^2\) with the reduced mass \(\mu = m_{\text{He}}m_{\text{Cluster}}/(m_{\text{He}} + m_{\text{Cluster}})\) and the relative velocity \(v_{\text{rel}} = v_{\text{Cluster}} - v_{\text{He}} \approx v_{\text{Cluster}}\). This gives the relative kinetic energy

\[
E_{\text{kin,rel}} = \frac{\mu}{m_{\text{Cluster}}} E_{\text{kin,Cluster}} = \frac{m_{\text{He}}}{m_{\text{He}} + m_{\text{Cluster}}} E_{\text{kin,Cluster}}.
\]

As discussed above, the typical kinetic energy \(E_{\text{kin,Cluster}}\) of the cluster upon entering the trapping region amounts to 10–20 eV. For the H\(^+\)(H\(_2\)O)\(_n\) clusters with \(n > 1\), this leads to relative kinetic

**Figure 6.** Lifetime measurements of H\(^+\)(H\(_2\)O)\(_n\) clusters starting from \(n = 1\) on the very top to \(n = 4\) on the very bottom. The rf amplitude is set to 150 V and the rf is set to 7 MHz. The data are fitted with an exponential decay curve added to a constant offset.
energies that may exceed the cluster dissociation energy. This therefore explains the observation of cluster dissociation for the larger water cluster ions.

Note that CID occurs in the first microseconds of the interaction of cluster ions with the buffer gas, before they have undergone enough elastic collisions for deceleration. In the first milliseconds of storage, both the parent and the daughter cluster thermalize in the helium buffer gas, as discussed in the previous section. Once the ions are trapped, CID requires thermal activation to proceed. The rate coefficient for this process is too slow to be relevant on the time scale of the experiment [26].

4. Conclusion

We have presented the second generation of our biplanar multipole rf ion trap. Several electrodes for loading and extraction have been integrated on the chip. The setup has been successfully integrated into a tandem time-of-flight mass spectrometer that acts as a versatile and robust setup to prepare, store and detect complex ions. We have demonstrated the mass selection and storage capabilities using protonated water cluster ions H+(H2O)n with n = 1–4. A high trapping efficiency was achieved due to the compact arrangement of the ion trap and the pulsed buffer gas valve. A sufficient mass resolution has been observed, which will be further improved using more elaborate electric field configurations.

In the future, even larger clusters will be studied with this ion trap, making use of the well-controlled thermal conditions for the translational and internal degrees of freedom that are achieved with buffer gas cooling. For ion–molecule reaction studies, the biplanar ion trap will be used as a micro-reactor that may contain preparation, reaction and analysis sections on the same chip. The excellent optical access to trapped ions offers new opportunities for spectroscopy and light-induced reaction dynamics experiments from the visible to the far-infrared region of the electromagnetic spectrum. Furthermore, overlapping trapped ions with ultracold atoms in a magneto-optical or all-optical trap offers opportunities for elastic and inelastic collision studies, which may lead to ensembles of complex and cluster ions at sub-kelvin temperatures.

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