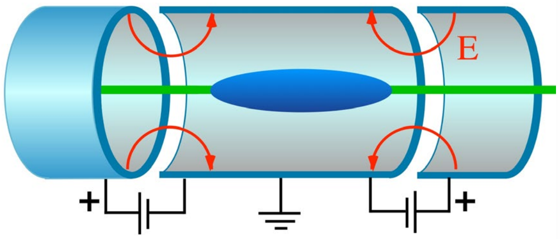
Classic paper

Cryogenic ion trap

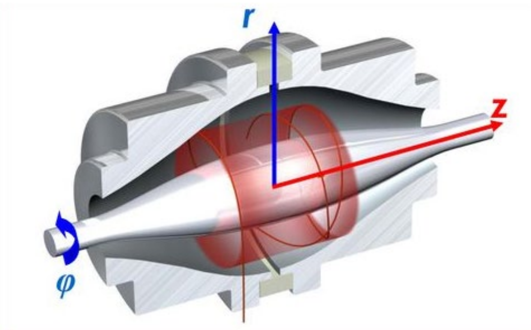
Soham Chowdhury
02 March 2024

Ion trap

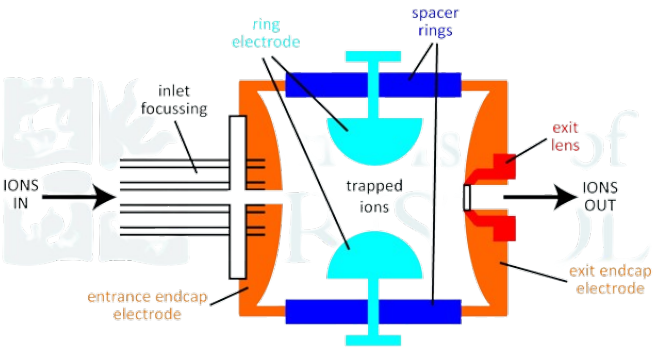
> “A single trapped particle floating forever at rest in free space would be the ideal object for precision measurements”
>
> – H. Dehmelt



Penning trap



Kingdon’s trap



Paul trap

Linear ion trap

Physica Scripta. Vol. T59, 256–263, 1995

Ion-Neutral Collisions in a 22-Pole Trap at Very Low Energies

Dieter Gerlich

Institut für Physik, TU Chemnitz-Zwickau, D-09107 Chemnitz, Germany

Received December 29, 1994; accepted January 26, 1995

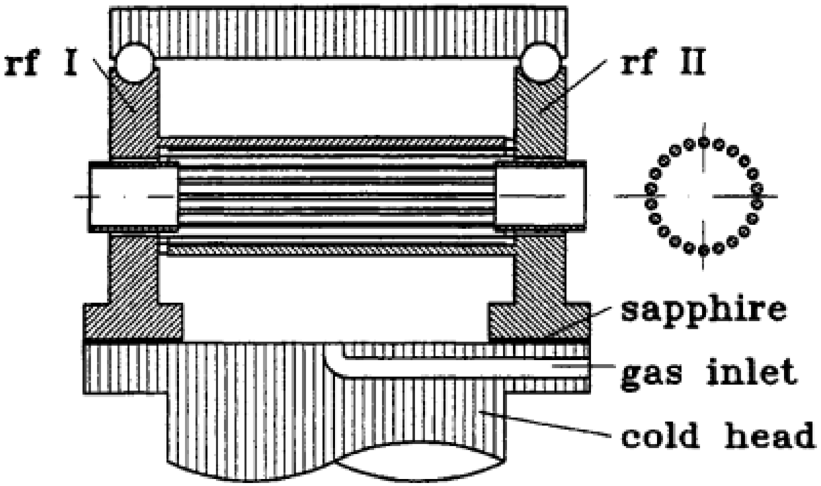


Fig. 4. Variable temperature 22-pole ion trap (rod diameter 1 mm, rod length 36 mm, inscribed radius $r_0 = 5$ mm). The rf electrodes I and II are mounted onto the cold head using sapphire for electrical insulation and good heat conductance. In the axial direction the ions are confined by electrostatic voltages applied to the two cylindrical tubes. These electrodes are operated in a pulsed mode for injecting selected ions on one side and for extracting all initial and product ions on the other side for analysis.

The ion trap depicted in Fig. 4 is the central part of an apparatus which was described elsewhere [2, 3]. Ions are prepared in a separate ion source, mass selected and then injected via the pulsed entrance electrode. They can be stored for many minutes or even hours. In the absence of target gas the mean decay time is only determined by reactions with the background gas the pressure of which is estimated to be below 10^{-11} mbar at $T_n = 10$ K. For the study of reaction processes, target gas is added at a number density varying from below $10^9\,\mathrm{cm}^{-3}$ to above $10^{15}\,\mathrm{cm}^{-3}$. By choosing a suitable combination of number density and interaction time, the rates of rather fast as well as very slow bimolecular reactions can be measured. The accessible number density range allows us also to determine reliable ternary association rate coefficients and to operate under conditions where the rate for three-body collisions becomes negligible and where radiative association prevails.

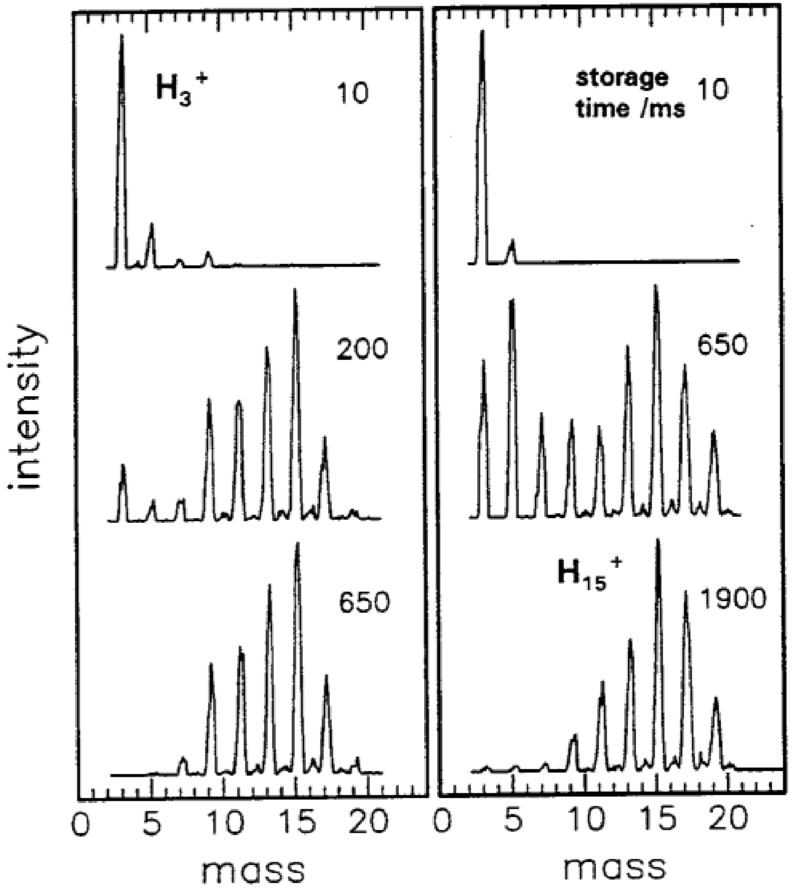


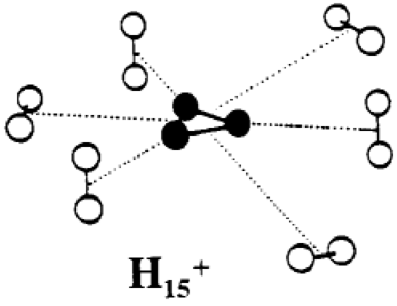
Fig. 10. Time dependence of the mass composition of the ion trap content after initial injection of H_3^+ ($T_n = 10\,K$, $[H_2] = 3.5 \times 10^{14}\,cm^{-3}$). Left panel: p-$H_2$, right panel n-$H_2$. The spectra are in relative units, normalized to the maximum. Note the difference in the storage times which are given in ms. The two lowest mass spectra are in both cases already very close to thermodynamic equilibrium. Their similarity is completely unexpected due to the rotational energy which can be provided by the n-H_2.

In the present experiment, H_3^+ ions have been injected into the 22-pole trap where neutral hydrogen was present at a number density of several $10^{14}\,cm^{-3}$. By ternary collisions according to the reaction

$$H_3^+ \cdot (H_2)_x + 2H_2 \rightarrow H_3^+ \cdot (H_2)_{x+1} + H_2 \qquad (9)$$

Figure 10 shows a few selected mass spectra, recorded at torage times up to 1.9 s. the left panel is for p-H_2, the right one for n-H_2. In both measurements the temperatures and densities were identical ($T_n = 10\,K$, $[H_2] = 3.5 \times 10^{14}\,cm^{-3}$). Note, however, the differences in the delay times. A comparison of the two middle spectra again shows that cluster formation is much faster with p-H_2 target. After 200 ms, most of the H_3^+ already have reacted whereas, for n-H_2 target and after 650 ms, still a significant fraction of the ions are H_3^+ and H_5^+.

Inspection of the near-equilibrium distributions shows that at 10 K and at the given density of $3.5 \times 10^{14}\,cm^{-3}$, the H_{15}^+ ion dominates. For symmetry reasons one would expect that this cluster consists of an H_3^+ core and of 6 more or less equivalent H_2 molecules as illustrated schematically by Fig. 11. However, the molecules are not necessarily confined to



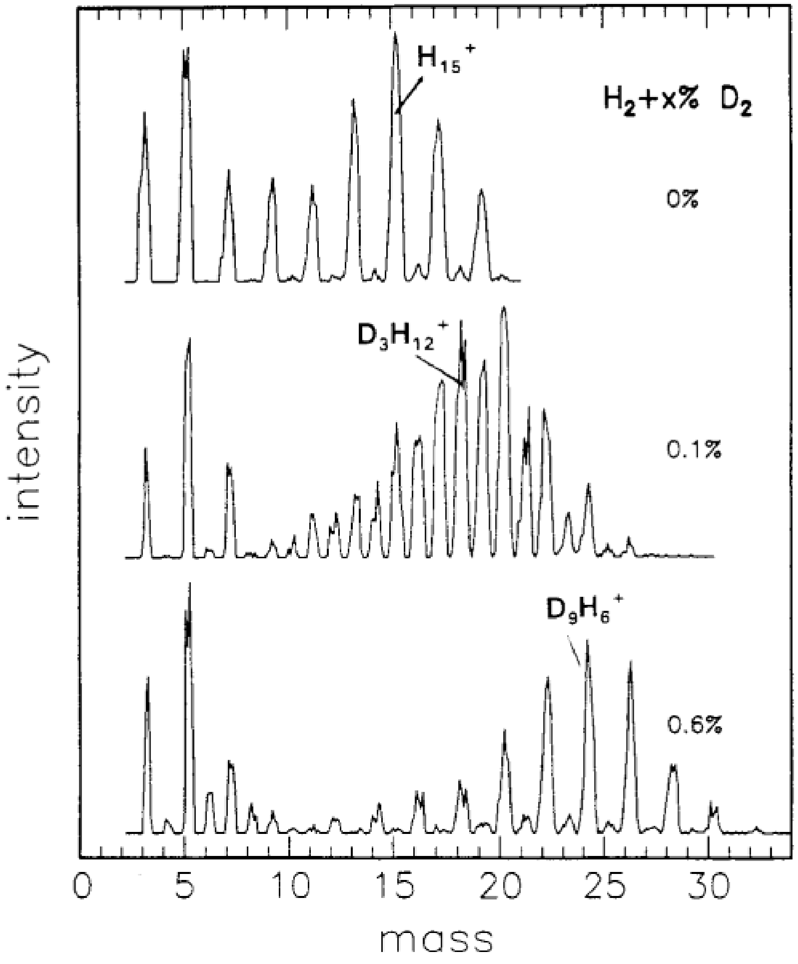


Fig. 12. D–H isotope exchange in hydrogen clusters. Small amounts of D impurities (0.1%, 0.6%) lead to significant deuteration of the clusters.

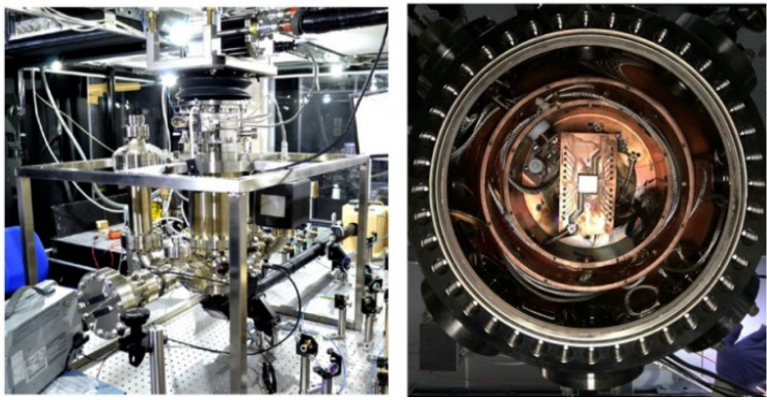
A last point deals with the partial deuteration of the hydrogen clusters. The dominant peaks in Fig. 11 are all at odd masses and belong to clusters with a structure $H_3^+ \cdot (H_2)_x$. In addition there are some small peaks at even masses. Although it is known, that clusters with an even number of hydrogen atoms do exist, it is more likely that these small mass peaks are predominantly due to D–H exchange occurring in collisions with HD. This effect occurring at low temperatures and called isotopic fractionation is due to differences in zero point energies and well-known in interstellar chemistry, where certain molecules have been observed to be enriched in heavy isotopes. For a qualitative test we have stored H_3^+ in the 22-pole and added D_2 to the hydrogen target. As can be seen from Fig. 12, already minor traces of D_2 lead to a significant shift of the mass distribution towards higher masses. It is interesting to note, that H_3^+ and H_5^+ are only weekly affected, whereas the higher clusters are significantly deuterated. The fact that even mass numbers prevail can be taken as an indication that the H_3^+ core gets replaced by D_3^+. A quantitative interpretation of these observations is handicapped by the fact, that in experiments such as shown in Fig. 12, cluster growth, deuteration and fragmentation take place in parallel. Experiments with externally produced clusters are in progress in order to separate these processes.

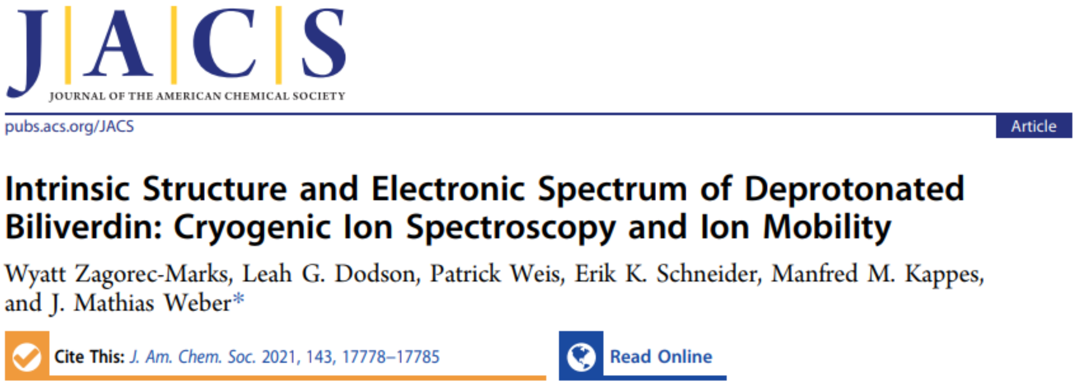
Article | Open access | Published: 08 February 2023

A high-fidelity quantum matter-link between ion-trap microchip modules

M. Akhtar, F. Bonus, F. R. Lebrun-Gallagher, N. I. Johnson, M. Siegele-Brown, S. Hong, S. J. Hile, S. A. Kulmiya, S. Weidt & W. K. Hensinger ✉

Nature Communications **14**, Article number: 531 (2023) | Cite this article





J|A|C|S

JOURNAL OF THE AMERICAN CHEMICAL SOCIETY

pubs.acs.org/JACS

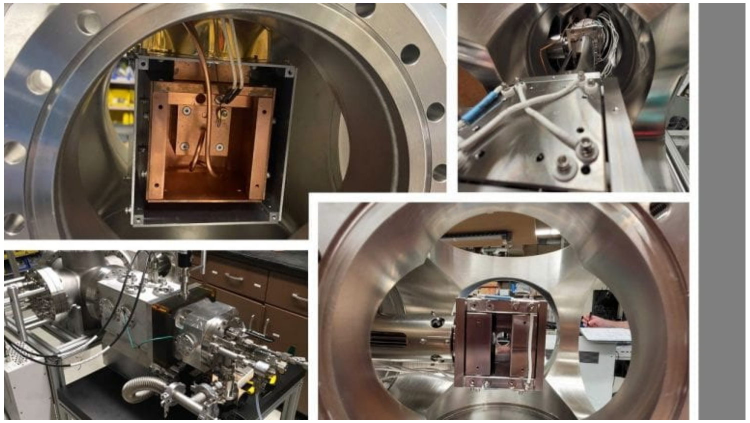
Article

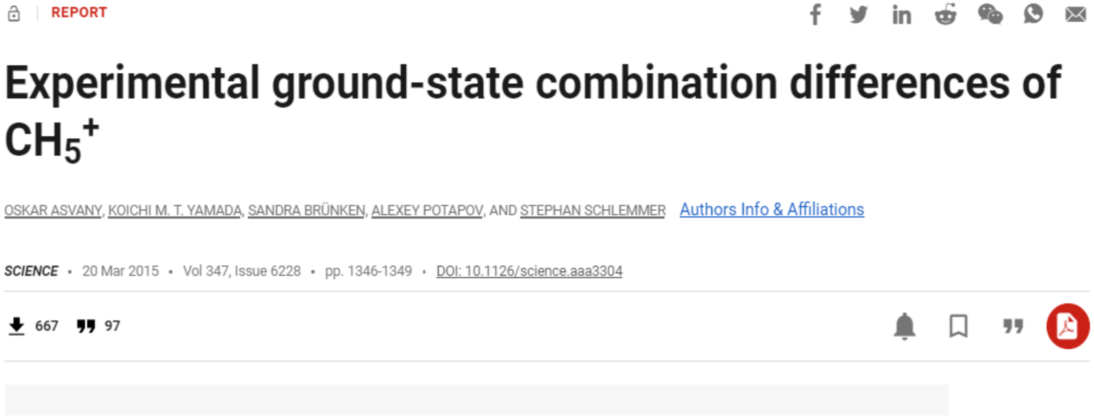
Intrinsic Structure and Electronic Spectrum of Deprotonated Biliverdin: Cryogenic Ion Spectroscopy and Ion Mobility

Wyatt Zagorec-Marks, Leah G. Dodson, Patrick Weis, Erik K. Schneider, Manfred M. Kappes, and J. Mathias Weber*

Cite This: *J. Am. Chem. Soc.* 2021, 143, 17778–17785

Read Online





REPORT

Experimental ground-state combination differences of CH_5^+

OSKAR ASVANY, KOICHI M. T. YAMADA, SANDRA BRÜNKEN, ALEXEY POTAPOV, AND STEPHAN SCHLEMMER Authors Info & Affiliations

SCIENCE • 20 Mar 2015 • Vol 347, Issue 6228 • pp. 1346-1349 • DOI: 10.1126/science.aaa3304

667 97