



Multidimensional analysis of complex ion structures in the gas phase

Dr. Mathias Schäfer

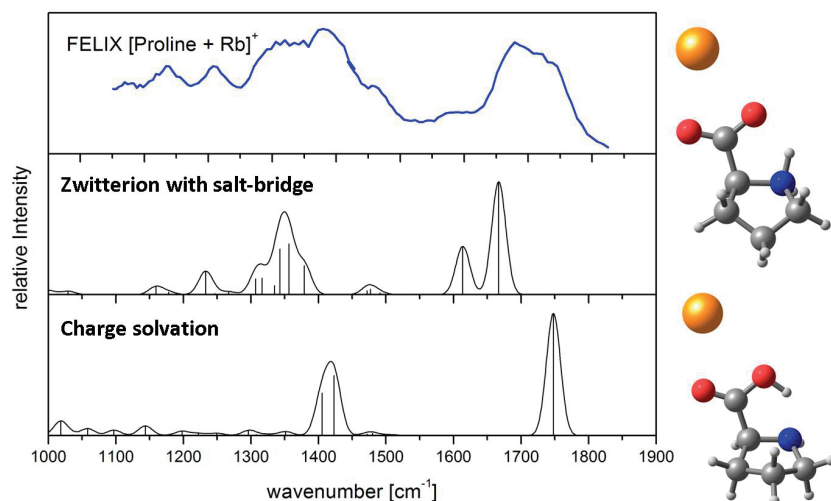


Fig. 1: Infrared multiple photon dissociation spectrum of rubidiated proline [Proline + Rb]⁺ acquired with a free electron laser (FELIX). The calculated absorption spectra of the depicted zwitterion and the charge-solvation structure of [Proline + Rb]⁺ identified by theory both match the recorded spectrum convincingly pointing towards the concomitant presence of both in the gas phase. *JMS*, **2010**, 297, 18-27.

Multidimensional analysis of complex ion structures in the gas phase

The precise knowledge on intrinsic features of ionic species in the gas phase is of vital interest for a wide variety of research aspects. In particular, the question on the comparability of solution- and gas-phase properties of complex ions is an issue of constant scientific debate. Still unclear is the extent of structural changes as a result of solvent removal and the interactions that govern stability of the desolvated species in the gas phase, especially relevant for the phase transfer processes in electrospray ionization mass spectrometry. Correct predictions or a quantification of the magnitude of the changes are currently still difficult or impossible. Consequently, the nature and strength of non-covalent interactions in gas-phase ions can differ substantially from those in the solution phase.

In this context the important question arises whether compounds (e.g. peptides or α -amino acids) that are predominantly zwitterions in aqueous solution (at least at their isoelectric points) can conserve salt-bridge structures in the gas phase. The solution-phase preference of amino acids for zwitterionic structures is mainly the result of significant solvation effects of polar or protic media that are able to stabilize charges. The lack of this stabilization by solvent in the vacuum supports the common assumption that zwitterions, or salt-bridge structures are substantially less stable in the gas phase where the corresponding nonionic, neutral structures should be predominantly present.

In principle the stability of a zwitterion without a solvate shell is exclusively determined by the basicity and acidity of the functional groups involved: the more basic the base, and the more acidic the acid, the more stable the zwitterion. However, gas-phase zwitterions can be substantially stabilized by the presence of the additional charge (e.g. an ion) compulsive in mass spectrometry and by additional non-covalently bound neutral molecules present in cluster ions. An impressive example for that is the protonated serine octamer [(serine)₈ + H]⁺ gas-phase cluster, discussed in the context of homochirality, which is very likely held together by electrostatic interactions of eight serine zwitterions. Also, intramolecular charge solvation in proteins and peptides has been shown to provide enough stabilization for the formation of salt-bridge structures in the gas phase. Systematic studies indicate that the size of the additional ion as well as the character of the analyte strongly influence the gas-

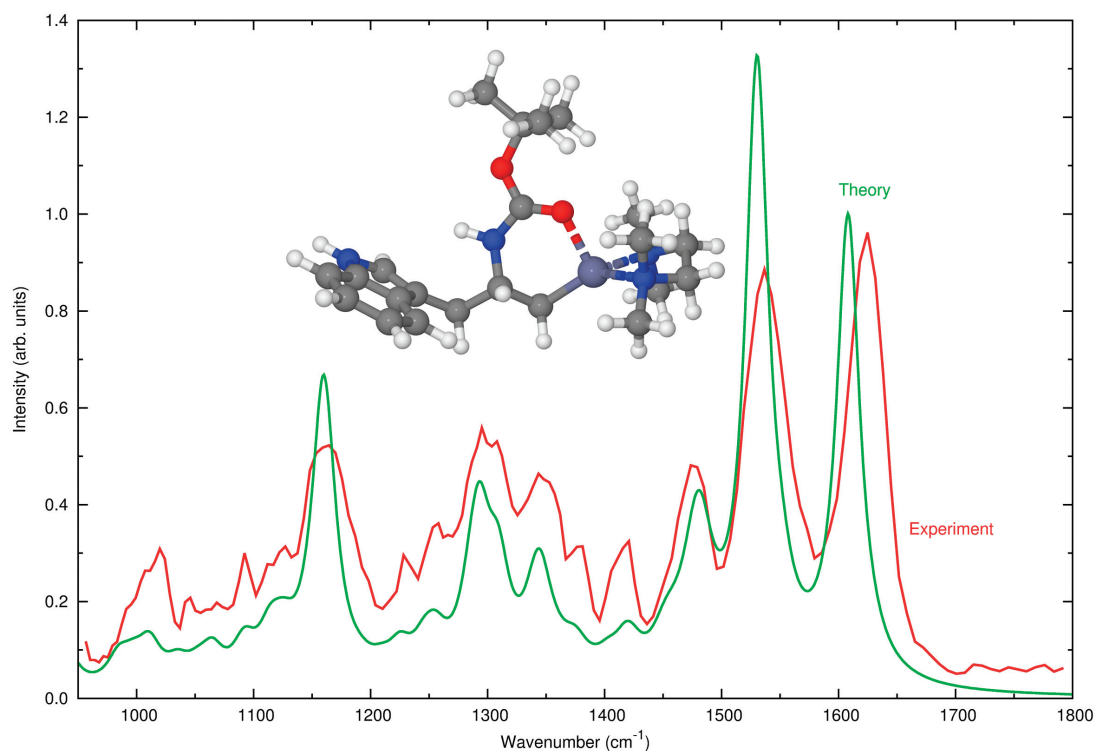


Fig. 2: Infrared multiple photon dissociation spectrum of a Tryptophane-derived Tetramethylethylenediamine (TMEDA)-organozinc-complex ion relevant for *Negishi*-type cross-coupling reactions compared to the calculated IR-spectrum of the global minimum structure depicted in the inset. *PCCP*, **2011**, *13*, 13255-13267

phase structure of the molecule in the respective cationized adduct ion. It was shown that charge solvation structures of a given amino acid (arginine, lysine) are very likely found with small alkali metal ions (proton, sodium), whereas zwitterionic structures can be found in the gas phase with larger metal ions (potassium, rubidium, cesium). It is reasonable to assume that the substantial increase of polarizability within the group of alkali metals is responsible for that effect.

To determine actual gas-phase structures we apply different experimental strategies, such as tandem mass spectrometry with collision induced dissociation including the kinetic method, studies of reaction kinetics by infrared multiphoton dissociation experiments with monochromatic laser light (CO_2 -laser). Additionally, photo action spectroscopy with a free electron laser, ion mobility spectroscopy and computational modelling with density functional theory and *ab initio* calcula-

tions is employed as well. We study not only gas-phase structures of natural compounds like amino acids (e.g. proline, *N*-methylated amino acids etc.) but this methodology is also applied to examine the structure and reactivity of transition metal complex ions relevant for synthetic organic chemistry e.g. organo-zinc-complex ions.

References

- [1] *Int. J. Mass Spectrom.*, **2011** DOI:10.1016/j.ijms.2011.07.013.
- [2] *Phys. Chem. Chem. Phys.*, **2011**, *13*, 13255-13267.
- [3] *Ana. Chem.*, **2010**, *82*, 6958-6968.
- [4] *Int. J. Mass Spectrom.*, **2010**, *297*, 18-27.
- [5] *J. Mass Spectrom.*, **2010**, *45*, 880-891.
- [6] *J. Mass Spectrom.*, **2010**, *75*, 1203-1213.
- [7] *J. Mass Spectrom.*, **2010**, *45*, 178-189.
- [8] *J. Phys. Chem.*, **2009**, *A 113*, 7779-7783.
- [9] *Int. J. Mass Spectrom.*, **2009**, *281*, 97-100.
- [10] *J. Mass Spectrom.*, **2009**, *44*, 278-284.
- [11] *J. Phys. Chem.*, **2008**, *A 112*, 11972-11974.
- [12] *Eur. J. Org. Chem.*, **2007**, *31*, 5162-5174.

THE AUTHOR



Dr. Mathias Schäfer

Mathias Schäfer (MS) studied Chemistry in Cologne, where he received his Ph.D. and the Kurt Alder Award in 1998. After a post-doc stay in the group of M. Linscheid at the Humboldt University, Berlin, he returned to Cologne in 1999. In 2011 he finalized his *Habilitation* in Organic Chemistry (Privat Dozent) at the University Cologne. MS is heading the Mass Spectrometry laboratories of the Department of Chemistry. His research is focused on structural analysis of natural compounds, the elucidation of ionization and fragmentation mechanisms and the examination of gas-phase ions by means of ion chemistry and spectroscopy. He co-authored a text book on Mass Spectrometry and contributed to more than 70 research articles in peer reviewed journals.