

A Journal of the Gesellschaft Deutscher Chemiker

Angewandte Chemie

GDCh

International Edition

www.angewandte.org

Accepted Article

Title: Capture of Hydroxyl Radicals by Hydronium Cations in Water Microdroplets

Authors: Dong Xing, Yifan Meng, Xu Yuan, Shuihui Jin, Xiaowei Song, Richard Neil Zare, and Xinxing Zhang

This manuscript has been accepted after peer review and appears as an Accepted Article online prior to editing, proofing, and formal publication of the final Version of Record (VoR). The VoR will be published online in Early View as soon as possible and may be different to this Accepted Article as a result of editing. Readers should obtain the VoR from the journal website shown below when it is published to ensure accuracy of information. The authors are responsible for the content of this Accepted Article.

To be cited as: *Angew. Chem. Int. Ed.* **2022**, e202207587

Link to VoR: <https://doi.org/10.1002/anie.202207587>

COMMUNICATION

Capture of Hydroxyl Radicals by Hydronium Cations in Water Microdroplets

Dong Xing,^a Yifan Meng,^{+b} Xu Yuan,^a Shuihui Jin,^a Xiaowei Song,^b Richard N. Zare,^{b*} and Xinxing Zhang^{a*}

[a] D. Xing, X. Yuan, S. Jin, X. Zhang

College of Chemistry, Key Laboratory of Advanced Energy Materials Chemistry (Ministry of Education), Renewable Energy Conversion and Storage Center (RECAST), Frontiers Science Center for New Organic Matter, Nankai University, Tianjin, 300071, China. Haihe Laboratory of Sustainable Chemical Transformations, Tianjin 300192, China. Beijing National Laboratory for Molecular Sciences, Beijing 100190, China
E-mail: zhangxx@nankai.edu.cn

[b] Y. Meng, X. Song, R. N. Zare

Department of Chemistry, Stanford University, Stanford, CA 94305, USA.

E-mail: rnz@stanford.edu

+These authors contributed equally to this work.

Supporting information for this article is given via a link at the end of the document.

Abstract: Despite the high stability of bulk water, water microdroplets possess strikingly different properties, such as the presence of hydroxyl radicals ($\text{OH}\cdot$) at the air-water interface. Previous studies exhibited the recombination of $\text{OH}\cdot$ into H_2O_2 molecules and the capture of $\text{OH}\cdot$ by oxidizing other molecules. By spraying pure water microdroplets into a mass spectrometer, we detected $\text{OH}\cdot$ in the form of $(\text{H}_4\text{O}_2)^+$ that is essentially $\text{OH}\cdot\text{---}\text{H}_3\text{O}^+$, a hydroxyl radical combined with a hydronium cation through hydrogen bonding. We also successfully captured it with two $\text{OH}\cdot$ scavengers, caffeine and melatonin, and key oxidation radical intermediates that bear important mechanistic information were seen. It is suggested that some previous reactions involving $(\text{H}_4\text{O}_2)^+$ should be attributed to reactions with $\text{OH}\cdot\text{---}\text{H}_3\text{O}^+$ rather than with the water dimer cation $(\text{H}_2\text{O}\text{---}\text{OH}_2)^+$.

In recent years, water microdroplet chemistry has emerged as an exciting new field because of its abilities to accelerate chemical reactions by many orders of magnitude compared to the same reactions in bulk water and/or trigger spontaneous reactions that cannot occur in bulk solution.^[1-4] Among the unique properties of water microdroplets, is the observation that water microdroplets form the highly reactive hydroxy radical $\text{OH}\cdot$, which has been observed indirectly by using salicylic acid as a scavenger.^[5] Another indirect observation is the detection of the recombination of hydroxyl radicals to form hydrogen peroxide (H_2O_2) in water microdroplets.^[6-10] The power of water microdroplets to promote redox chemistry unlike that found in bulk water has also been demonstrated in the reduction of dissolved chloroauric acid (HAuCl_4) in water microdroplets to yield gold nanoparticles and nanowires,^[11] the reduction of doubly charged ethyl viologen (EV^{+2}) dissolved in water microdroplets to singly charged ethyl viologen (EV^{+1}),^[12] and the formation of pyridyl anion and m-hydroxypyridine in spraying an aqueous solution containing dissolved pyridine to form microdroplets.^[13] It is possible to generate $\text{OH}\cdot$ radicals by other means, such as by cavitation,^[14] and by reactions of O_3 or O_2 at the microdroplet periphery.^[9,15] The $\text{OH}\cdot$ inside microdroplets has never been directly detected, because it has no charge and is extremely reactive, hampering its observation. In this study, we present observation of $\text{OH}\cdot$ in the form of the $(\text{H}_4\text{O}_2)^+$ cation by spraying pure water microdroplets into a mass spectrometer. We also

successfully captured it using caffeine (CAF) and melatonin (MLT), two well-known $\text{OH}\cdot$ scavengers.

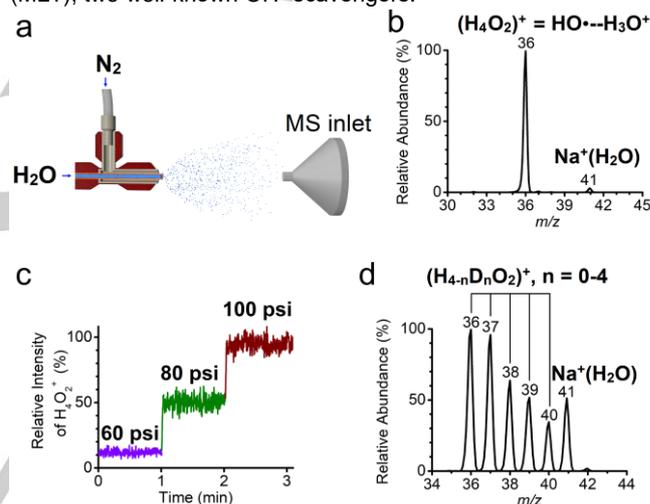


Figure 1. Observation of $\text{OH}\cdot$ with mass spectrometry. (a) A schematic drawing of the experimental setup. (b) A typical mass spectrum showing the H_4O_2^+ peak. (c) Relative intensities of H_4O_2^+ when the sheath gas pressure is increased stepwise from 60, to 80, and then to 100 psi. (d) A typical mass spectrum showing the proton scrambling when spraying D_2O .

Figure 1a presents the experimental setup. Detailed experimental conditions are described in the Supporting Information. Pure water is forced by a syringe pump through a capillary that sits inside a larger capillary through which N_2 gas flows at high pressure. The resulting spray of microdroplets is aimed toward the inlet of a mass spectrometer (LTQ-XL, Thermo-Fisher, Waltham, MA) operated in positive mode of detection (Fig. S1 shows a photograph of the setup). Figure 1b presents a typical mass spectrum showing the spontaneous generation of $(\text{H}_4\text{O}_2)^+$ at m/z 36 when pure water is sprayed to form microdroplets. The signal can be as high as 5×10^4 a.u. and is the strongest peak. It is estimated to have a concentration in excess of 1 mg/L. In addition, a minor signal of the $\text{Na}^+(\text{H}_2\text{O})$ impurity was observed. The same $(\text{H}_4\text{O}_2)^+$ species was also produced by spraying water microdroplets with an ultrasonic humidifier (Fig. S2). The spray

COMMUNICATION

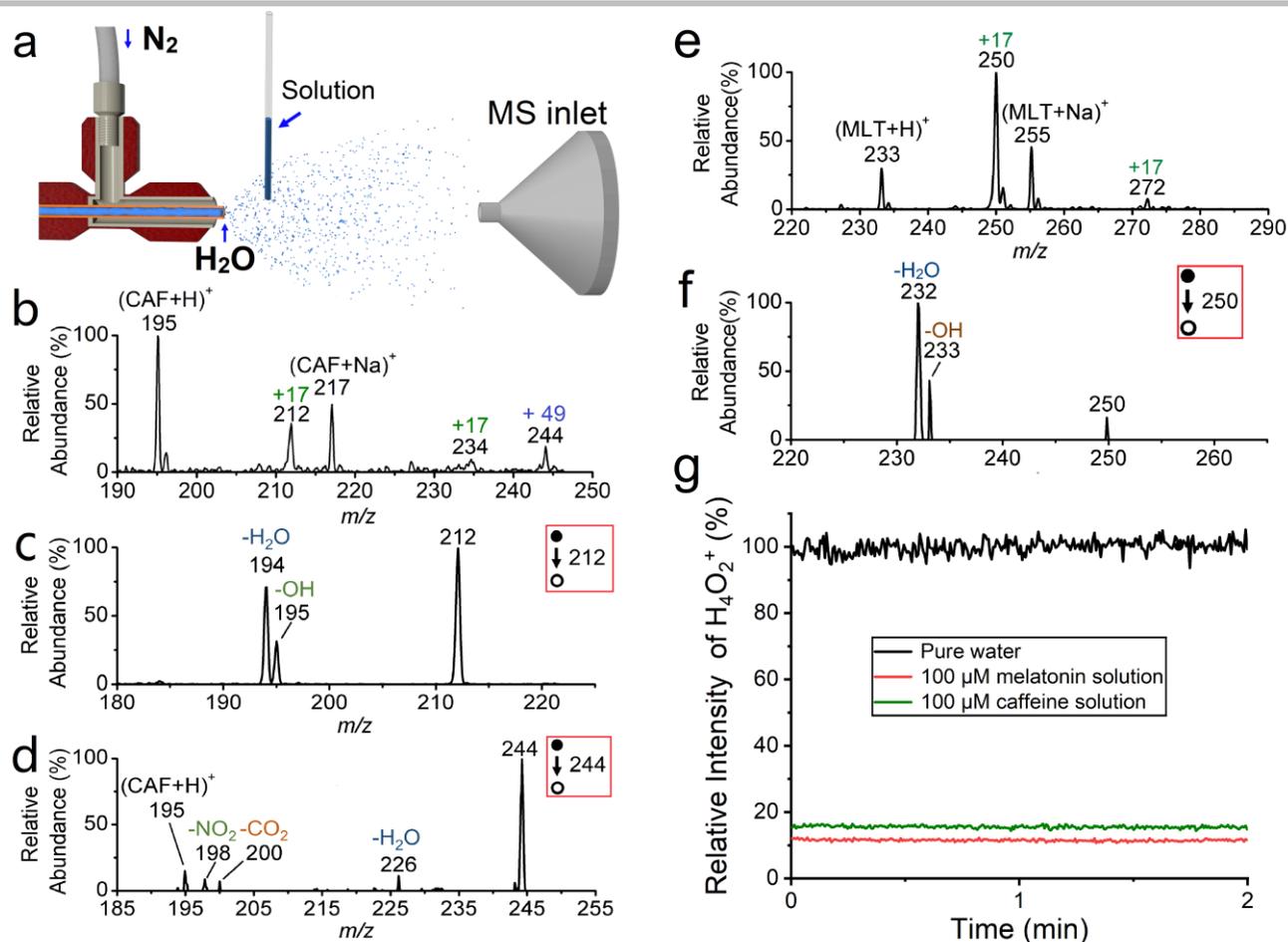


Figure 2. Capture of OH^\bullet with caffeine (CAF) and melatonin (MLT). (a) A schematic drawing of the experimental setup. (b) A typical mass spectrum showing the oxidation products of CAF. (c) MS^2 of the m/z 212 product. (d) MS^2 of the m/z 244 product. (e) A typical mass spectrum showing the oxidation products of MLT. (f) MS^2 of the m/z 250 product. (g) Decrease of the H_4O_2^+ signal when CAF or MLT is added to water.

experiments were repeated separately at both Nankai University and Stanford University. To investigate the significance of the air-water interface of the microdroplets in forming $(\text{H}_4\text{O}_2)^+$, we also monitored the $(\text{H}_4\text{O}_2)^+$ intensity when the sheath gas pressure is changed (Fig. 1c). A clear increase in the intensity of $(\text{H}_4\text{O}_2)^+$ is observed upon consecutively increasing the pressure from 60 psi to 80 psi, and then to 100 psi. Increasing the pressure decreases the sizes and increases the ratios of surface area to volume of the microdroplets,^[16] manifesting the importance of the microdroplet water-air and water-support interface in generating OH^\bullet . Figure 1d presents the mass spectrum by spraying D_2O , which confirms the presence of H_4O_2^+ when H_2O is sprayed. The microdroplets pick up ambient H_2O , resulting in the proton scrambling products, $(\text{H}_4\text{-nD}_n\text{O}_2)^+$ ($n = 0 - 4$). The ultrafast D/H exchange observed here might also be a result of the microdroplet effect.^[17] The mass spectrometer inlet temperature is maintained at 45 °C for all experiments shown in Fig. 1. Increasing the temperature significantly decreases the signal of $(\text{H}_4\text{O}_2)^+$, indicating its weakly bound character. Efforts were made to fragment the H_4O_2^+ by collision induced dissociation (CID) but we were unable to find the fragments. This failure, although disappointing, is common for small molecular ions in CID.

Two OH^\bullet scavengers, caffeine (CAF) and melatonin (MLT),^[18-20] are used to capture the OH^\bullet generated by

microdroplets. A glass capillary soaked with 100 μM CAF or MLT solutions is positioned between the sprayer and the mass spectrometer inlet (Fig. 2a). Directly spraying CAF or MLT solutions can obtain qualitatively similar results. For CAF, two major radical products are observed (Fig. 2b), corresponding to the addition of a OH^\bullet radical to the parent ion at m/z 212 and 234 (+ 17 Da), followed by the uptake of an ambient O_2 molecule (+ 49 Da) to form a peroxy radical at m/z 244 (*vide infra*). Collision-induced dissociation (MS^2) of these products led to loss of OH, H_2O , CO_2 , and NO_2 (Figs. 2c and d), further confirming that what is being observed are the oxidation products of CAF. Especially the loss of CO_2 and NO_2 of the m/z 244 product supports the observation of the peroxy radicals (*vide infra*). For MLT, only the +17 Da products are observed (Fig. 2e), and again MS^2 of the product confirms that they are the oxidation products of MLT (Fig. 2f). The decreasing of the H_4O_2^+ peak with the rise of the CAF or MLT oxidation products (Fig. 2g) confirms that H_4O_2^+ is the carrier of the hydroxyl radical that is causing these reactions to happen.

We next consider how the products observed in these mass spectra are formed. It has been reported that OH^\bullet prefers to attack the C5, C8, and C4 positions of CAF (ranked by the reaction probability),^[21,22] resulting in three distinct radicals, which are 17 Da more than the parent molecule. A striking observation is the subsequent uptake of an ambient O_2 molecule by C4, N9, or C5

COMMUNICATION

(Fig. 3a). Even though this step has been predicted by theory,^[22] here we show the first experimental confirmation. The loss of CO₂ and NO₂ in MS² (Fig. 2d) provides evidence for the coexistence of these three potential isomers at *m/z* 244 with the –COO• and –NOO• moieties (Fig. 3a). The consecutive uptake of a OH• radical and an ambient O₂ molecule is a widely accepted mechanism in the atmospheric oxidation of olefins initiated by •OH (red box in Fig. 3a),^[23] but seldom do we observe the two radicals simultaneously, which clearly supports these mechanistic steps, indicating the in-situ advantage of using microdroplets to study reaction mechanisms.

The observation of the peroxy radical product at *m/z* at 244 clearly demonstrates that reaction of CAF with OH•--H₃O⁺ is occurring. If the double bond at the position between the C4 and C5 in CAF is oxidized by (H₂O-OH₂)⁺, the oxidation product cannot be the one at *m/z* 244. However, the oxidation product at *m/z* 212 could result from reaction of CAF with either OH•--H₃O⁺ or (H₂O-OH₂)⁺. Consequently, these observations support the existence of OH•--H₃O⁺ in solution, but cannot rule the presence of any (H₂O-OH₂)⁺, although as will be argued, we regard that as unlikely.

For MLT, OH• preferentially attacks the C2, C3, or the benzene ring,^[20,24] resulting in the +17 Da radical products (Fig. 3b). Further uptake of O₂ was not observed, which might be a result of the fragile nature of the resulting peroxy product that cannot survive the long detection cycle of the mass spectrometer. As a side observation, the resolutions (*m/Δm*) of the product peaks at *m/z* 212, 234, and 244 for CAF and *m/z* 250 and 272 for MLT are obviously poorer than the reactant peaks (Table S1), suggesting that these unstable radical products are decomposing during the resonance ejection in mass analysis, resulting in broadened kinetic energy distribution and consequently broadened mass spectral peaks. This phenomenon has been previously documented and explained.^[25]

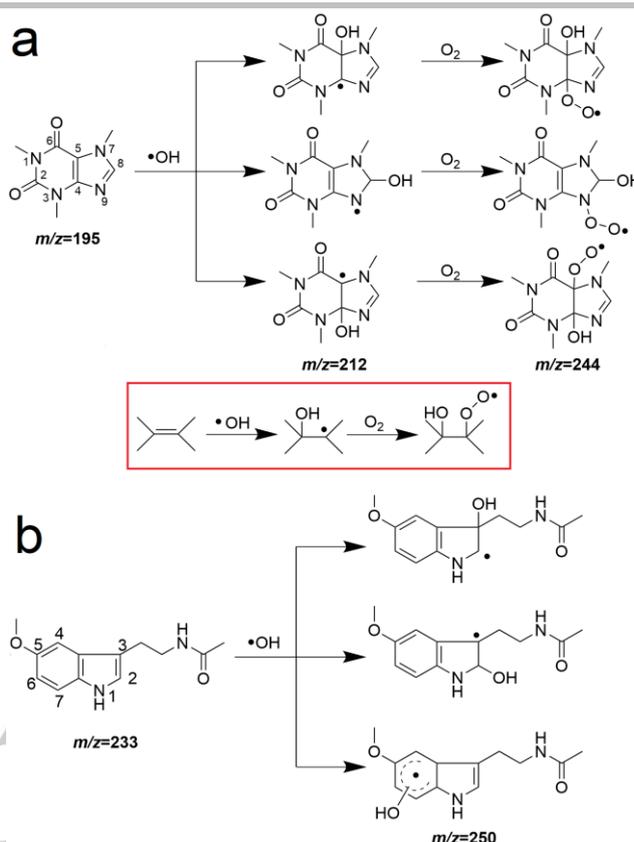


Figure 3. Proposed mechanisms for the oxidation of caffeine and melatonin. The red box highlights a general mechanism for the oxidation of olefins initiated by OH•.

The H₄O₂⁺ cation has been observed before in many different contexts, such as exposing water vapor to UV photoionization, electron-impact ionization, dinitrogen chemical ionization, femtosecond multiphoton ionization, photoionization in a supersonic jet expansion, or soft X-ray irradiation. References to these previous studies can be found in Wang et al.,²⁶ who made H₄O₂⁺ in an energy-tunable discharge in atmospheric-pressure water vapor as well as in electrosprayed water microdroplets. It seems that the H₄O₂⁺ cation has not previously been observed in uncharged water microdroplets as reported here. The strong oxidizing power of H₄O₂⁺ has been beautifully illustrated by the spontaneous oxidation in water microdroplets of benzene,^[26] aromatic sulfones to sulfonic acids,^[27] and the oxidation of molecules containing double bonds.^[28]

The H₂O₄⁺ cation has commonly been referred to as the water dimer cation, but as we will argue this often might be a misnomer. The H₂O₄⁺ cation can exist in two forms. The first involves a two-center three-electron O-O half bond, (H₂O-OH₂)⁺, reminiscent of hydrazine (H₂N-NH₂), and is called the water dimer cation. The second is a hydroxyl radical combined with a hydronium cation through hydrogen bonding, OH•--H₃O⁺. Theoretical calculations by Barnett and Landman^[29] place (H₂O-OH₂)⁺ lower in energy than OH•--H₃O⁺, whereas calculations by Schaefer and coworkers^[30] reach the opposite conclusion. Infrared studies^[31,32] clearly demonstrate that the lowest energy structure is OH•--H₃O⁺ in the gas phase, which is also supported by mass spectrometry experiments on the photodissociation of rare gas water clusters cations,³³ but what is needed is evidence of what happens in the liquid phase.

COMMUNICATION

In 2021, Lin et al.^[34] succeeded in using an ultrafast electron diffraction technique to measure the intermolecular oxygen-oxygen and oxygen-hydrogen bonds of H_2O_4^+ formed by ionizing liquid water with a focused 800 nm laser beam with $\sim 65 \pm 5$ fs pulse width. They reported that their femtosecond electron diffraction measurements of the intermolecular revealed the presence and structure of the solvated $\text{OH}^{\bullet}-\text{H}_3\text{O}^+$ radical-cation pair that was formed at ~ 140 fs following water ionization, directly confirming previous theoretical results,^[35,36] suggesting that hydronium cations and hydroxyl radicals dominate the initial structural dynamic response in the laser ionization of water. It would seem that the H_2O_4^+ cation we are observing under very gentle conditions is correctly assigned to the capture of the hydroxyl radical by the hydronium ion in water microdroplets. It should also be expected that hydroxyl radicals will also be captured by H_2O itself, again by hydrogen bonding.

It is useful to clarify that the $\text{HO}^{\bullet}-\text{H}_3\text{O}^+$ observed here is not a result of the ultrafast proton transfer from $(\text{H}_2\text{O}-\text{OH}_2)^+$. Instead, it is just the spontaneously formed $\bullet\text{OH}$ that recombines with hydronium at the surface of water microdroplets, because $(\text{H}_2\text{O}-\text{OH}_2)^+$ needs to ionize a water molecule, but the ionization energy of H_2O (12.6 eV)^[37] is much higher than the electron detachment energy of OH^{\bullet} (1.8 eV, determined by the electron affinity of $\bullet\text{OH}$).^[38] Second, the cationic $\text{HO}^{\bullet}-\text{H}_3\text{O}^+$ is not the only form that $\bullet\text{OH}$ can exist in microdroplets, but only a charged form that can be observed by a mass spectrometer; $\bullet\text{OH}$ can also form hydrogen bonding with neutral water molecules.

It may be wondered how hydroxy radicals are formed in the first place in the absence of contact of the water microdroplet with any reactive gas. It has been speculated that the presence of a strong electric field at the gas-water or solid-water interface may assist OH^{\bullet} to lose its electron.¹³ Another exciting possibility has recently been suggested by Ben-Amotz³⁹ who has proposed at the interface a water dimer spends part of its time as $\text{H}_2\text{O}^{\bullet}-\text{H}_2\text{O}^+$, which if it loses an electron rapidly converts into $\bullet\text{OH} + \text{H}_3\text{O}^+$. We have argued that this species becomes in less than 200 fs $\text{HO}^{\bullet}-\text{H}_3\text{O}^+$.

In conclusion, we have provided observation of $\bullet\text{OH}$ in sprayed water microdroplets in the form of H_2O_4^+ using a mass spectrometer operated in positive ion mode. Arguments are presented that H_2O_4^+ results predominantly, if not exclusively, from the hydrogen bonding of $\bullet\text{OH}$ to H_3O^+ under our gentle conditions of formation. Two hydroxyl radical scavengers were shown to capture $\bullet\text{OH}$ in water microdroplets, and key radical intermediates were observed, supporting previously proposed oxidation mechanisms. We wish that this study deepens our understanding of the intriguing properties of water microdroplets and helps to inform us what distinguishes their chemistry from that of bulk water.

Acknowledgements

X.Z. acknowledges the National Key R&D Program of China (2018YFE0115000), the National Natural Science Foundation of China (22174073 & 22003027), the NSF of Tianjin City (21JJCJQC00010), Haihe Laboratory of Sustainable Chemical Transformations, Beijing National Laboratory for Molecular Sciences (BNLMS202106), and the Frontiers Science Center for

New Organic Matter at Nankai University (63181206). R.N.Z. acknowledges support from the Air Force Office of Scientific Research through the Multidisciplinary University Research Initiative (MURI) program (AFOSR FA9550-21-1-0170).

Keywords: microdroplet, air-water interface, hydroxyl radical, mass spectrometry, olefin oxidation

- [1] X. Yan, R. M. Bain, R. G. Cooks, *Angew. Chem. Int. Ed.* **2016**, *55*, 12960–12972.
- [2] Z. Wei, Y. Li, R. G. Cooks, X. Yan, *Annu. Rev. Phys. Chem.* **2020**, *71*, 31–51.
- [3] J. K. Lee, S. Banerjee, H. G. Nam, R. N. Zare, *Q. Rev. Biophys.* **2015**, *48*, 37–444.
- [4] S. Banerjee, E. Gnanamani, X. Yan, R. N. Zare, *Analyst.* **2017**, *142*, 1399–1402.
- [5] J. K. Lee, D. Samanta, H. G. Nam, R. N. Zare, *J. Am. Chem. Soc.* **2019** *141*, 10585–10589.
- [6] J. K. Lee, K. L. Walker, H. S. Han, J. Kang, F. B. Prinz, R. M. Waymouth, H. G. Nam, R. N. Zare, *Proc. Natl. Acad. Sci. USA.* **2019**, *116*, 19294–19298.
- [7] D. Gao, F. Jin, J. K. Lee, R. N. Zare, *Chem. Sci.* **2019**, *10*, 10974–10978.
- [8] J. K. Lee, H. S. Han, S. Chaikasetin, D. P. Marron, R. M. Waymouth, F. B. Prinz, R. N. Zare, *P. Natl. Acad. Sci. USA.* **2020**, *117*, 30934–30941.
- [9] T. Kakeshpour, B. Metaferia, R. N. Zare, A. Bax, *Proc. Natl. Acad. Sci. USA* **2022** *119*, e2121542119.
- [10] M. A. Mehrgardi, M. Mofidfar, and R. N. Zare, *J. Am. Chem. Soc.* **2022**, *144*, 7606–7609.
- [11] J. K. Lee, D. Samanta, H. G. Nam, R. N. Zare, *Nat. Comm.* **2018**, *9*, 1–9.
- [12] C. Gong, D. Li, X. Li, D. Zhang, D. Xing, L. Zhao, X. Yuan, X. Zhang, *J. Am. Chem. Soc.* **2022** *144*, 3510–3516.
- [13] L. L. Zhao, X. W. Song, C. Gong, D. M. Zhang, R. J. Wang, R. N. Zare, X. X. Zhang, *Proc. Natl. Acad. Sci. USA.* **2022**, *199*, e2200991119.
- [14] D. Nguyen, S. C. Nguyen, *J. Phys. Chem. B.* **2022**, *126*, 3180–3185.
- [15] A. Gallo Jr, N. H. Musskopf, X. Liu, Z. Yang, J. Petry, P. Zhang, S. T. Thoroddsen, H. G. Im, H. Mishra, *Chem. Sci.* **2022** *13*, 2574.
- [16] Y. H. Lai, S. Sathyamoorthi, R. M. Bain, R. N. Zare, *J. Am. Soc. Mass. Spectr.* **2018**, *29*, 1036–1043.
- [17] E. T. Jansson, Y. H. Lai, J. G. Santiago, R. N. Zare, *J. Am. Chem. Soc.* **2017**, *139*, 6851–6854.
- [18] D. X. Tan, R. J. Reiter, L. C. Manchester, M. T. Yan, M. El-Sawi, R. M. Sainz, J. C. Mayo, R. Kohen, M. C. Allegra, R. Hardeland, *Curr. Top. Med. Chem.* **2002**, *2*, 181–197.
- [19] D. M. Zhang, C. Gong, J. Wang, D. Xing, L. L. Zhao, D. Y. Li, X. X. Zhang, *J. Phys. Chem. Lett.* **2021**, *12*, 7387–7393.
- [20] X. Shi, N. S. Dalal, A. C. Jain, *Food. Chem. Toxicol.* **1991**, *29*, 1–6.
- [21] J. R. Leon-Carmona, A. Galano, *J. Phys. Chem. B.* **2011**, *115*, 4538–4546.
- [22] M. X. Li, Q. Mei, D. D. Han, B. Wei, Z. X. An, H. J. Cao, J. Xie, M. X. He, *Sci. Total. Environ.* **2021**, *768*, 144733.
- [23] R. Atkinson, J. G. Calvert, J. A. Kerr, S. Madronich, G. K. Moortgat, T. J. Wallington, *Yarwood. G.: The mechanism of Atmospheric Oxidation of the Alkenes Oxford University Press, 2000, pp. 172-335.*
- [24] D. X. Tan, L. C. Manchester, M. P. Terron, L. J. Flores, R. J. Reiter, *J. Pineal. Res.* **2007**, *42*, 28–42.
- [25] J. E. McClellan, J. P. Murphy, III, J. J. Mulholland, R. A. Yost, *Anal. Chem.* **2002**, *74*, 402–412.
- [26] M. Wang, X. F. Gao, R. Su, P. He, Y. Y. Cheng, K. Li, D. B. Mi, X. P. Zhang, X. L. Zhang, H. W. Chen, R. G. Cooks, *CCS Chem.* **2022**, *4*, 1224–1231.
- [27] L. Qiu, M. D. Psimos, R. G. Cooks, *J. Am. Soc. Mass Spec.* **2022**, March 21.
- [28] L. Qiu, N. M. Morato, K.-H. Huang R. G. Cooks, *Front. Chem.* **2022**, *10*, 903774.
- [29] R. N. Barnett, U. Landman, *J. Phys. Chem. A* **1997**, *101*, 164–169.
- [30] Q. Y. Cheng, F. A. Evangelista, A. C. Simmonett, Y. Yamaguchi, H. F. Schaefer, *J. Phys. Chem. A.* **2009**, *113*, 13779–13789.
- [31] G. H. Gardener, M. A. Johnson, A. B. McCoy, *J. Phys. Chem. A.* **2009**, *113*, 4772–4779.

COMMUNICATION

- [32] K. Mizuse, A. Fujii, *J. Phys. Chem. A* **2013**, *117*, 929–938.
- [33] R. T. Jongma, Y. Huang, S. Shi, A. M. Wodtke, *J. Phys. Chem. A* **1998**, *102*, 8847–8854.
- [34] M.-F. Lin, N. Singh, S. Liang, M. Mo, J. P. F. Nunes, K. Ledbetter, J. Yang, M. Kozina, S. Wethersby, X. Shen, A. A. Cordones, T. J. A. Wolf, C. D. Pemmaraju, M. Ihme, X. J. Wang, *Science* **2021**, *374*, 92–95.
- [35] O. Marsalek, C. G. Elles, P. A. Pieniazek, E. Pluhařová, J. VandeVondele, S. E. Bradforth, P. Jungwirth, *J. Chem. Phys.* **2011**, *135*, 224510.
- [36] E. Kamarchik, O. Kostko, J. M. Bowman, M. Ahmed, A. I. Krylov, *J. Chem. Phys.* **2010**, *132*, 194311.
- [37] K. B. Snow, T. F. Thomas, *Int. J. Mass. Spectrom. Ion. Processes*, **1990**, *96*, 49–68.
- [38] J. R. Smith, J. B. Kim, W. C. Lineberger, *Phys. Rev. A* **1997**, *55*, 2036–2043.
- [39] D. Ben-Amotz, *Science* **2022**, *376*, 800–801.

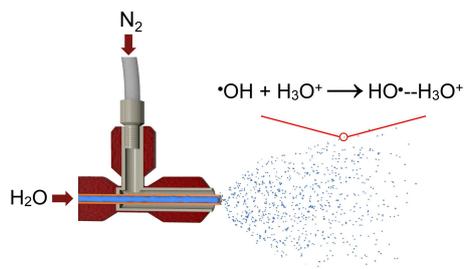
COMMUNICATION

Entry for the Table of Contents (Please choose one layout)

Layout 1:

COMMUNICATION

This work reports the observation and capture of hydroxyl radicals spontaneously generated at the air-water interface of water microdroplets in the form of HO•--H₃O⁺.



D. Xing, Y. Meng, X. Yuan, S. Jin, X. Song, R. N. Zare, and X. Zhang**

Capture of hydroxyl radicals by hydronium cations in water microdroplets

Page No. – Page No.