Transactions IAU, Volume XXVIIIA
Reports on Astronomy 2009–2012
Ian Corbett, ed.

doi:10.1017/S1743921312003110

DIVISION XII / COMMISSION 14 / WORKING GROUP SOLIDS AND THEIR SURFACES

CHAIR **Gianfranco Vidali**

TRIENNIAL REPORT 2009–2011

1. Introduction

The *ISO* and *Spitzer* space observatories yielded a treasure trove of data on dust and ices covering dust grains. Now *Herschel*, and soon *SOFIA* and *ALMA*, will provide unprecedented views of the molecular world of the interstellar medium (ISM). It is on dust grains that key ISM molecules, such as hydrogen, formaldehyde, methanol, and water are formed. As a result of these new observations, there is a great need to know more about the interaction processes of atoms and molecules with dust grains. (The Proceedings of the 2010 NASA Laboratory Astrophysics Workshop (www-cfadc.phy.ornl.gov/nasa_law/) give a good view of recent accomplishments in the study of atom/molecule - solid interactions as well as other aspects of laboratory astrophysics.)

In the last decade and a half there has been a tremendous increase of interest in laboratory studies of ISM processes occurring on interstellar dust grains. This has prompted the entrance into this field of a number of laboratories with a tradition in surface science. Besides the standard probes that have been used in the past, techniques are now available that can give precise information at the atomic/molecular level about the formation of molecules on dust, including: Thermal Programmed Desorption (TPD), Reflection Absorption Infrared Spectrometry (RAIRS), Resonant Enhanced Multiphoton Ionization (REMPI), and Atom Force Microscopy (AFM). These techniques yield information about the kinetics and energetics of atomic/molecular diffusion on and desorption from surfaces, the products of reactions, the ro-vibrational state of ejected products, and the morphology of the solid surfaces, respectively. The success of research in atom/molecule/charged particle/photon-dust interaction has produced a surge of publications. Studies of interest to astrochemistry are now regularly published in chemical physics/surface science journals. A representative sample of such literature is listed below. It can be of use to astronomers and astrochemists in understanding the crucial steps of reactions on dust analogues.

In theoretical research, there are two developments of note: the use of new stochastic tools to predict the molecule formation process on grains of different sizes, and the study of reaction mechanisms (Langmuir-Hinshelwood, Ealy-Rideal, and hot-atom) on surfaces of materials of astrophysical interest. Most of these studies pertain to hydrogen interaction with graphite/graphene/PAHs and appear in the chemical-physics literature.

Several research groups that are currently working in this area are listed here, each with its group leader and main research focus:

- Catania Observatory, E. Palumbo (ions in ices)
- Heriot-Watt University Edinburgh, M. R. S. McCoustra (desorption of mixed ices)

• Hokkaido University, N. Watanabe / A. Kouchi (ice formation, photon-ice interaction)
• Jet Propulsion Laboratory, A. Chutjian (ions on ices)
• Leiden University, H. Linnartz / E. van Dishoeck (photodesorption from ices, water formation on ices)
• Max Planck Institute for Astronomy, T. Henning (solids)
• NASA Ames Research Center, L. Allamandola (UV on ices, PAHs)
• NASA Ames Research Center, F. Salama (dust exposure, dust formation, PAHs)
• NASA - Goddard Space Flight Center, M. Moore (ions in ices)
• Syracuse University USA, G. Vidali (formation of H_2 and water on dust grain analogues)
• University College London, W. A. Brown (desorption of mixed ices)
• University College London, S. Price (H_2 formation on graphite)
• University of Cergy-Pontoise, J.-L. Lemaire (D_2 on ices, silicates)
• University of Hawai'i, R. Kaiser (keV electron in ices)
• University of Missouri, A. Speck (dust)
• University of Virginia, R. Baragiola (ions in ices)

2. Meetings

During the reporting period, a number of meetings containing sessions about atomic and molecular interaction with surfaces have been held. They are often featured at regularly scheduled COSPAR, American Astronomical Society and Lunar and Planetary Institute meetings. Unfortunately, meeting Web sites may no longer be accessible.

Important meetings (listed in inverse chronological order):
• European Conference on Laboratory Astrophysics, Paris, France, 2011
• The Molecular Universe, IAU Symposium 280, Toledo, Spain 2011
• Fifth Workshop on Titan Chemistry, Kauai, Hawai'i, 2011
(http://www.chem.hawaii.edu/Bil301/Titan2011.html)
• Herschel and the Characteristics of Dust in Galaxies, Lorentz Center, Leiden, Netherlands, 2011
• Pacifichem, Honolulu, Hawai'i, USA, 2010
• NASA Laboratory Astrophysics Workshop, Gatlinburg, TN, USA, 2010
• Stormy Cosmos: the Evolving ISM from Spitzer to Herschel and Beyond, Pasadena, CA, USA, 2010
• WittFest: Origin and Evolution of Dust, Toledo, OH, USA, 2010
• Molecules in Galaxies, Oxford Physics Conference Series, Oxford, United Kingdom, 2010
• Dust and Ice: Their Roles in Astrophysical Environments, Univ. of Georgia, Athens, GA, USA, 2010
• Recent Advances in Experimental and Observational Astrochemistry, Amer.Chem.Soc. Symposium, San Francisco, CA, USA, 2010
• Infrared Emission, ISM and Star Formation, MPI, Heidelberg, Germany, 2010
• International Conference on Laboratory Astrophysics, Dunhuang, Gansu, China, 2009
• Bridging Laboratory and Astrophysics: Molecules, Dust and Ices in Regions of Stellar and Planetary Formation, AAS 214^{th}, Pasadena, CA, 2009
• The Chemical Enrichment of the Intergalactic Medium, Lorentz Center, Leiden, the Netherlands, 2009

https://doi.org/10.1017/S1743921312003110 Published online by Cambridge University Press

• Interstellar Surfaces: from Laboratory to Models, Lorentz Center, Leiden, the Netherlands, 2009

3. Notable publications

Most of the works cited below regard the laboratory experiments and theories of photon and particle interaction with solid surfaces that are relevant to understanding similar processes occurring in space. Included in this selection are papers about PAHs (Polycyclic Aromatic Hydrocarbons) that are relevant to atom/surface interactions. Additional information on PAHs can be obtained in the report of the Commission 14 Working Group on Molecular Data. Key observations that are related to dust are included.

Gianfranco Vidali
Chair of Working Group
Solids and Their Surfaces

References

3.1. *2011*

Accolla, M., Congiu, E., Dulieu, F., Manico', G., Chaabouni, H., Matar, E., Mokrane, H., Lemaire, J.-L., & Pirronello, V. 2011 Changes in the morphology of interstellar ice analogues after hydrogen atom exposure *PhysChemChemPhys* 13, 8037.

Acharyya, K., Hassel, G. E., & Herbst, E. 2011 The Effects of Grain Size and Grain Growth on the Chemical Evolution of Cold Dense Clouds *ApJ* 732, 73.

Andersson, S., Arasa, C., Yabushita, A., Yokoyama, M., Hama, T., Kawasaki, M., Western, C. M.,, & Ashfold, M. N. R.A theoretical and experimental study on translational and internal energies of H_2O and OH from the 157 nm irradiation of amorphous solid water at 90 K *PhysChemChemPhys*13, 15810.

Bennett, C. J., Hama, T., Kim, Y. S., Kawasaki, M., & Kaiser, R. I. 2011 Laboratory Studies on the Formation of Formic Acid (HCOOH) in Interstellar and Cometary Ices *ApJ* 727, 27.

Das, A. & Chakrabarti, S. K. 2011 Composition and evolution of interstellar grain mantle under the effects of photodissociation *MNRAS* in press.

Dukes, C. A., Chang, W-Y. Fam, M., & Baragiola, R. A. 2011 Laboratory studies on the sputtering contribution to the sodium atmospheres of Mercury and the Moon *Icarus* 212, 436.

Ennis, C., Bennett, C. J.; Jones, B. M., & Kaiser, R. I. 2011 Formation of D_2-water and D_2-carbonic Acid in Oxygen-rich Solar System Ices via D_2^+ Irradiation *ApJ* 733, 79.

Fayolle, E. C., Bertin, M., Romanzin, C., Michaut, X., Oberg, K. I., Linnartz, H., & Fillion, J.-H. 2011 CO Ice Photodesorption: A Wavelength-dependent Study *ApJ* 739, 36.

Fayolle, E. C., Oberg, K. I., Cuppen, H. M., Visser, R., & Linnartz, H. 2011 Laboratory H_2O:CO_2 ice desorption data: entrapment dependencies and its parameterization with an extended three-phase model *A& A* 529, 74.

Garozzo, M., La Rosa, L., Kanuchova, Z., Ioppolo, S., Baratta, G. A., Palumbo, M. E, & ; Strazzulla, G. 2011 The influence of temperature on the synthesis of molecules on icy grain mantles in dense molecular clouds *A&A* 528, 118.

Godard, M., Fraud, G., Chabot, M., Carpentier, Y., Pino, T., Brunetto, R., Duprat, J., Engrand, C., Brchignac, P., D'Hendecourt, L., & Dartois, E. 2011 Ion irradiation of carbonaceous interstellar analogues. Effects of cosmic rays on the 3.4 μm interstellar absorption band *A&A* 529. 146.

Goumans, T. P. M. 2011 Isotope effects for formaldehyde plus hydrogen addition and abstraction reactions: rate calculations including tunnelling *MNRAS* 413, 261.

Hama, T., Watanabe, N., Kouchi, A., & Yokoyama, M. 2011 Spin Temperature of Water Molecules Desorbed from the Surfaces of Amorphous Solid Water, Vapor-deposited and Produced from Photolysis of a CH_4/O_2 Solid Mixture *ApJ* 738, 15.

https://doi.org/10.1017/S1743921312003110 Published online by Cambridge University Press

Hama, T., Yokoyama, M., Yabushita, A., Kawasaki, M., & Watanabe, N. 2011 Translational and rotational energy measurements of desorbed water molecules in their vibrational ground state following 157 nm irradiation of amorphous solid water *NuclInstrMethB* 269, 1011.

He, J., Frank, P., & Vidali, G. 2011 Interaction of hydrogen with surfaces of silicates: single crystal vs. amorphous *PhysChemChemPhys* 13, 15803.

Ioppolo, S., van Boheemen, Y., Cuppen, H. M., van Dishoeck, E. F., & Linnartz, H. 2011 Surface formation of CO_2 ice at low temperatures. *MNRAS* 413, 2281.

Ioppolo, S., Cuppen, H M., van Dishoeck, E. F., & Linnartz, H. 2011 Surface formation of HCOOH at low temperature *MNRAS* 410, 1089.

Jing, D., He, J., Brucato, J., De Sio, A., Tozzetti, L., & Vidali, G. 2011 On water formation in the interstellar medium: laboratory study of the O+D reaction on surfaces *ApJ* 741, L9.

Kinugawa, T., Yabushita, A., Kawasaki, M., Hama, T., & Watanabe, N. 2011 Surface abundance change in vacuum ultraviolet photodissociation of CO2 and H_2O mixture ices *PhysChemChemPhys* 13, 15785.

Kristensen, L. E., Amiaud, L., Fillion, J.-H., Dulieu, F., & Lemaire, J.-L. 2011 H_2, HD, and D_2 abundances on ice-covered dust grains in dark clouds *A&A* 527, 44.

Laas, J. C., Garrod, R. T., Herbst, E., & Widicus Weaver, S. L. 2011 Contributions from Grain Surface and Gas Phase Chemistry to the Formation of Methyl Formate and Its Structural Isomers *ApJ* 728, 71.

Lattelais, M., Bertin, M., Mokrane, H., Romanzin, C., Michaut, X., Jeseck, P., Fillion, J.-H., Chaabouni, H., Congiu, E.& Dulieu, F. 2011 Differential adsorption of complex organic molecules isomers at interstellar ice surfaces *A&A* 532, 12L.

Lepetit, B., Lemoine, D., Medina, Z., & Jackson, B. 2011 Sticking and desorption of hydrogen on graphite: A comparative study of different models *JChemPhys* 134, 114705

Oba, Y., Watanabe, N., Kouchi, A., Hama, T., & Pirronello, V. 2011 Experimental studies of surface reactions among OH radicals that yield H_2O and CO_2 at 40-60 K *PhysChemChemPhys* 13, 15792.

Oberg, K., Boogert, A., Pontoppidan, K. M. *et al.* 2011 Ices in starless and star forming cores *The Molecular Universe Proceedings IAU Symposium No. 280* J. Cernicharo, & R. Bachiller, Eds.

Ormel, C. W., Min, M.,Tielens, A. G. G. M., Dominik, C., & Paszun, D. 2011 Dust coagulation and fragmentation in molecular clouds. II. The opacity of the dust aggregate size distribution *A&A* 532, 43.

Roman-Duval, J., Israel, F. P., Bolatto, A., Hughes, A., Leroy, A., Meixner, M., Gordon, K., Madden, S. C., Paradis, & D. Kawamura, A. 2010 Dust/gas correlations from Herschel observations *A&A* 518, 74L.

Romanzin, C.; Ioppolo, S.; Cuppen, H. M.; van Dishoeck, E. F.; Linnartz, H. 2011 Water formation by surface O_3 hydrogenation *JChemPhys* 134, 084504.

Shi, J., Raut, U., Kim, J.-H., Loeffler, M., & Baragiola, R. A. 2011 Ultraviolet Photon-induced Synthesis and Trapping of H_2O_2 and O_3 in Porous Water Ice Films in the Presence of Ambient O_2: Implications for Extraterrestrial Ice *ApJ* 738, L3.

Tachibana, S., Nagahara, H., Ozawa, K., Ikeda, Y., Nomura, R., Tatsumi, K., & Joh, Y. 2011 Kinetic Condensation and Evaporation of Metallic Iron and Implications for Metallic Iron Dust Formation *ApJ* 736, 16.

Talbi, D., Wakelam, V., the Kida team 2011 KIDA : The new kinetic database for astrochemistry *JPhysConfSeries* 300, 012019.

Vidali, G. 2011 Molecule formation on interstellar grains *Proc.2010NASA LabAstWorkshop*I-19.

3.2. *2010*

Anderson, L. D., Zavagno, A., Rodn, and 36 coauthors 2010 The physical properties of the dust in the RCW 120 H II region as seen by Herschel *A&A* 518, 99.

Bennett, C. J., Jamieson, C. S., & Kaiser, R. I. 2010 Mechanistical studies on the formation and destruction of carbon monoxide (CO), carbon dioxide (CO2), and carbon trioxide (CO_3) in interstellar ice analog samples *PhysChemChemPhys* 12, 4032.

Burke, D. J., & Brown, W. A. 2010 Ice in space: surface science investigations of the thermal desorption of model interstellar ices on dust grain analogue surfaces *PhysChemChemPhys* 12, 5947.

https://doi.org/10.1017/S1743921312003110 Published online by Cambridge University Press

Cazaux, S., Cobut, V., Marseille, M., Spaans, M., & Caselli, P. 2010 Water formation on bare grains: When the chemistry on dust impacts interstellar gas *A&A* 522, 74.

Cooper, P. D., Moore, M. H., & Hudson, R. L. 2010 O atom production in water ice: Implications for O_2 formation on icy satellites *JGRE* 11510013

Cuppen, H. M., Ioppolo, S., Romanzin, C., & Linnartz, H. 2011 Water formation at low temperatures by surface O_2 hydrogenation II: the reaction network *PhysChemChemPhys* 12, 12077

Seperuelo D. E., Domaracka, A., Boduch, P., Rothard, H., Dartois, E., & da Silveira, E. F. 2010 Laboratory simulation of heavy-ion cosmic-ray interaction with condensed CO *A&A* 512, 71.

Dulieu, F., Amiaud, L., Congiu, E., Fillion, J.-H., Matar, E., Momeni, A., Pirronello, V., & Lemaire, J. L. 2010 Experimental evidence for water formation on interstellar dust grains by hydrogen and oxygen atoms *A&A* 512, 30.

Fam, M., Loeffler, M. J., Raut, U., & Baragiola, R. A. 2010 Radiation-induced amorphization of crystalline ice *Icarus* 207, 314.

Ferullo, R. M., Domancich, N. F., & Castellani, N. J. 2010 On the performance of van der Waals corrected-density functional theory in describing the atomic hydrogen physisorption on graphite *ChemPhysLett* 500, 283.

Fleming, B., France, K., Lupu, R. E., & McCandliss, S. R. 2010 Spitzer Mapping of Polycyclic Aromatic Hydrocarbon and H_2 Features in Photodissociation Regions *ApJ* 725, 195.

Godard, M.;& Dartois, E. 2010 Photoluminescence of hydrogenated amorphous carbons. Wavelength-dependent yield and implications for the extended red emission *A&A* 529, 39.

Hama, T., Yokoyama, M., Yabushita, A., & Kawasaki, M. 2010 Role of OH radicals in the formation of oxygen molecules following vacuum ultraviolet photodissociation of amorphous solid water *JChemPhys* 133, 104504.

Hama, T., Yokoyama, M., Yabushita, A., Kawasaki, M., Andersson, S., Western, C. M., Ashfold, M. N. R., Dixon, R. N., & Watanabe, N. 2010 A desorption mechanism of water following vacuum-ultraviolet irradiation on amorphous solid water at 90 K *JChemPhys* 132, 164508.

Hama, T.,Yokoyama, M.,Yabushita, A., Kawasaki, M., Wickramasinghe, P., Guo, W., Loock, H.-P., Ashfold, M. N. R., & Western, C. M. 2009 Translational and internal energy distributions of methyl and hydroxyl radicals produced by 157 nm photodissociation of amorphous solid methanol *JChemPhys* 131, 224512

He, J., Gao, K., Vidali, G., Bennett, C. J., & Kaiser, R. I. 2010 Formation of Molecular Hydrogen from Methane Ice *ApJ* 721, 1656

Henning, T. 2010 Laboratory Astrophysics of Cosmic Dust Analogues *LectNotesPhys* 815, 313.

Henning, T. 2010 Cosmic Silicates *ARA&A* 48, 21.

Henning, T. & Mutschke, H. 2010 Optical properties of cosmic dust analogs: a review *JNanophotonics* 4, 041580.

Ioppolo, S., Cuppen, H. M., Romanzin, C., van Dishoeck, E. F. & Linnartz, H. 2010 Water formation at low temperatures by surface O_2 hydrogenation I: characterization of ice penetration *PhysChemChemPhys* 12, 12065.

Islam, F., Cecchi-Pestellini, C., Viti, S., & Casu, S. 2010 Formation Pumping of Molecular Hydrogen in Dark Clouds *ApJ* 725, 1111.

Juhsz, A., Bouwman, J., Henning, Th., Acke, B., van den Ancker, M. E., Meeus, G., Dominik, C., Min, M., Tielens, A. G. G. M. & Waters, L. B. F. M. 2010 Dust Evolution in Protoplanetary Disks Around Herbig Ae/Be Stars the Spitzer View *ApJ* 721, 431.

Kalvans, J. & Shmeld, I. 2010 Subsurface chemistry of mantles of interstellar dust grains in dark molecular cores *A&A* 521, 37.

Lemaire, J.-L., Vidali, G., Baouche, S., Chehrouri, M., Chaabouni, H., & Mokrane, H. 2010 Competing Mechanisms of Molecular Hydrogen Formation in Conditions Relevant to the Interstellar Medium *ApJ* 725, 156L.

Matar, E., Bergeron, H., Dulieu, F., Chaabouni, H., Accolla, M., & Lemaire, J. L. 2010 Gas temperature dependent sticking of hydrogen on cold amorphous water ice surfaces of interstellar interest *JChemPhys* 133, 104507.

Oba, Y., Watanabe, N., Kouchi, A., Hama, T.,, & Pirronello, V. 2010 Experimental Study of CO_2 Formation by Surface Reactions of Non-energetic OH Radicals with CO Molecules *ApJ* 712, L174.

Oba, Y., Watanabe, N., Kouchi, A., Hama, T., & Pirronello, V. 2011 Formation of Carbonic Acid (H_2CO_3) by Surface Reactions of Non-energetic OH Radicals with CO Molecules at Low Temperatures *ApJ* 722, 1598.

Oberg, K. I., van Dishoeck, E. F., Linnartz, H., & Andersson, S. 2010 The Effect of H_2O on Ice Photochemistry *ApJ* 718, 832.

Pagani, L., Steinacker, J., Bacmann, A., Stutz, A., & Henning, T. 2010 The Ubiquity of Micrometer-Sized Dust Grains in the Dense Interstellar Medium *Science* 329, 1622.

Palumbo, M. E., Baratta, G. A., Leto, G., & Strazzulla, G. 2010 H bonds in astrophysical ices *JMolecStruct* 972, 64.

Quan, D., Herbst, E., Osamura, Y., & Roueff, E. 2010 Gas-grain Modeling of Isocyanic Acid (HNCO), Cyanic Acid (HOCN), Fulminic Acid (HCNO), and Isofulminic Acid (HONC) in Assorted Interstellar Environments *ApJ* 725, 2101.

Sandstrom, K. M., Bolatto, A. D., Draine, B. T., Bot, C., & Stanimirovi, S. 2010 The Spitzer Survey of the Small Magellanic Cloud (S3MC): Insights into the Life Cycle of Polycyclic Aromatic Hydrocarbons *ApJ* 715, 701.

Semenov, D., Hersant, F., Wakelam, V., Dutrey, A., Chapillon, E., Guilloteau, St.. Henning, Th., Launhardt, R., Pitu, V., & Schreyer, K. 2010 Chemistry in disks. IV. Benchmarking gas-grain chemical models with surface reactions *A&A* 522, 42.

Siebenmorgen, R., & Krugel, E. 2010 The destruction and survival of polycyclic aromatic hydrocarbons in the disks of T Tauri stars *A&A* 511, 6.

Sturm, B., Bouwman, J., Henning, Th., Evans, N. J., Acke, B., Mulders, G. D., Waters, L. B. F. M., van Dishoeck, E. F., Meeus, G., Green, J. D *et al.* 2010 First results of the Herschel key program "Dust, Ice and Gas In Time" (DIGIT): Dust and gas spectroscopy of HD 100546 *A&A* 518, 129.

Tsvetkov, A. G. & Shematovich, V. I. 2010 Kinetic Monte Carlo method for simulating astrochemical kinetics: Hydrogen chemistry in diffuse clouds *SolarSystemRes* 44, 177.

Yang, Z., Eichelberger, B., Carpenter, M. Y., Martinez, O., Jr., Snow, T. P., &Bierbaum, V. M. 2010 Experimental and Theoretical Studies of Reactions Between H Atoms and Carbanions of Interstellar Relevance *ApJ* 723, 1325.

van Hoof, P. A. M., van de Steene, G. C., Barlow, M. J., Exter, K. M., Sibthorpe, B., Ueta, T., Peris, V., Groenewegen, M. A. T., Blommaert, J. A. D. L., Cohen, M., *et al.* 2010 Herschel images of NGC 6720: H_2 formation on dust grains *A&A* 518, L137.

Vasyunin, A. I., Wiebe, D. S., Birnstiel, T., Zhukovska, S., Henning, T., & Dullemond, C. P. 2011 Impact of Grain Evolution on the Chemical Structure of Protoplanetary Disks *ApJ* 727, 76.

Vidali, G.; Li, L. 2010 Molecular hydrogen desorption from amorphous surfaces at low temperature *JPhysCondMat* 22, 304012.

Voshchinnikov, N. V. & Henning, Th. 2010 From interstellar abundances to grain composition: the major dust constituents Mg, Si, and Fe *A&A* 517, 45.

Wakelam, V. , Smith, I. W. M., Herbst, E., Troe, J., Geppert, W., Linnartz, H., Oberg, K., Roueff, E., Agndez, M., P. Pernot, P. *et al.* 2010 Reaction Networks for Interstellar Chemical Modelling: Improvements and Challenges *SSRv* 156, 13.

Watanabe, N., Kimura, Y., Kouchi, A., Chigai, T., Hama, T., & Pirronello, V. 2010 Direct Measurements of Hydrogen Atom Diffusion and the Spin Temperature of Nascent H_2 Molecule on Amorphous Solid Water *ApJ* 714, 233.

3.3. *2009*

Arakawa, M., Kagi, H., & Fukazawa, H. 2009 Laboratory Measurements of Infrared Absorption Spectra of Hydrogen-ordered Ice: A Step to the Exploration of Ice XI in Space *ApJS* 184, 361

Bachellerie, D., Sizun, M., Aguillon, F., Teillet-Billy, D., Rougeau, N., & Sidis, V. 2009 Unrestricted study of the Eley-Rideal formation of H_2 on graphene using a new multidimensional graphene-H-H potential: role of the substrate *PhysChemChemPhys* 11, 2715

https://doi.org/10.1017/S1743921312003110 Published online by Cambridge University Press

Bennett, C. J., Jamieson, C. S., & Kaiser, R. I. 2009 An Experimental Investigation of the Decomposition of Carbon Monoxide and Formation Routes to Carbon Dioxide in Interstellar Ices *ApJS* 182,1.

Bennett, C. J., Jamieson, C. S., & Kaiser, R. I. 2009 Mechanistical studies on the formation of carbon dioxide in extraterrestrial carbon monoxide ice analog samples *PhysChemChemPhys* 11, 4210.

Brickhouse, N., Cowan, J., Drake, P., Federman, S., Ferland, G., Frank, A., Haxton, W., Herbst, E., Olive, K., Salama, F., and 2 coauthors 2009 Laboratory Astrophysics and the State of Astronomy and Astrophysics *Astro2010: The Astronomy and Astrophysics Decadal Survey, Position Papers, no. 68*

Brunetto, R., Pino, T., Dartois, E., Cao, A.-T., D'Hendecourt, L., Strazzulla, G., & Brchignac, Ph. 2009 Comparison of the Raman spectra of ion irradiated soot and collected extraterrestrial carbon *Icarus* 200, 323.

Casolo, S., Martinazzo, R., Bonfanti, M., &Tantardini, G. F. 2009 Quantum Dynamics of the Eley-Rideal Hydrogen Formation Reaction on Graphite at Typical Interstellar Cloud Conditions *JPhysChemA* 113, 14545

Congiu, E., Matar, E., Kristensen, L. E., Dulieu, F., & Lemaire, J. L. 2009 Laboratory evidence for the non-detection of excited nascent H_2 in dark clouds *MNRAS* 397, 96.

Cuppen, H. M., van Dishoeck, E. F., Herbst, E., & Tielens, A. G. G. M. 2009 Microscopic simulation of methanol and formaldehyde ice formation in cold dense cores *A&A* 508, 275.

Seperuelo, D. E., Boduch, P., Rothard, H., Been, T., Dartois, E., Farenzena, L. S., & da Silveira, E. F. 2009 Heavy ion irradiation of condensed CO_2: sputtering and molecule formation *A&A* 502, 599.

Fuchs, G. W., Cuppen, H. M., Ioppolo, S., Romanzin, C., Bisschop, S. E., Andersson, S., van Dishoeck, E. F., & Linnartz, H. 2011 Hydrogenation reactions in interstellar CO ice analogues. A combined experimental/theoretical approach *A&A* 505, 629.

Garrod, R. T., Vasyunin, A. I., Semenov, D. A., Wiebe, D. S., & Henning, Th. 2009 A New Modified-Rate Approach For Gas-Grain Chemistry: Comparison with a Unified Large-Scale Monte Carlo Simulation *ApJ* 700 L43

Glauser, A. M., Gdel, M., Watson, D. M., Henning, T., Schegerer, A. A., Wolf, S., Audard, M., & Baldovin-Saavedra, C. 2009 Dust amorphization in protoplanetary disks *A&A* 508, 247.

Gontareva, N. B., Kuzicheva, E. A., & Shelegedin, Vladimir N. 2009 Synthesis and characterization of peptides after high-energy impact on the icy matrix: Preliminary step for further UV-induced formation *P&SS* 57, 441.

Goumans, T. P. M., Richard, C., Catlow, A., & Brown, W. A. 2009 Formation of H_2 on an olivine surface: a computational study *MNRAS* 393, 1403.

Goumans, T. P. M., Catlow, C. R. A., Brown, W. A., Kstner, J., & Sherwood, P. 2009 An embedded cluster study of the formation of water on interstellar dust grains *PhysChemChemPhys* 11, 5431.

Green, S.,D., Bolina, A. S., Chen, R., Collings, M. P., Brown, W. A., & McCoustra, M. R. S. 2009 Applying laboratory thermal desorption data in an interstellar context: sublimation of methanol thin films *MNRAS* 398, 357.

Hama, T., Yabushita, A., Yokoyama, M., Kawasaki, M., & Watanabe, Naoki 2009 Formation mechanisms of oxygen atoms in the O(3PJ) state from the 157 nm photoirradiation of amorphous water ice at 90 K *JChemPhys* 131, 054511.

Hama, T., Yabushita, A.,Yokoyama, M., Kawasaki, M., & Watanabe, Naoki 2009 Formation mechanisms of oxygen atoms in the O(1D2) state from the 157 nm photoirradiation of amorphous water ice at 90 K *JChemPhys* 131, 054510.

Hama, T., Yabushita, A., Yokoyama, M., Kawasaki, M., & Andersson, S. 2009 Desorption of hydroxyl radicals in the vacuum ultraviolet photolysis of amorphous solid water at 90 K *JChemPhys* 131, 054508.

Herbst, E. & van Dishoeck, E. F. 2009 Complex Organic Interstellar Molecules*ARA&A* 47, 427.

Hersant, F., Wakelam, V., Dutrey, A., Guilloteau, S., & Herbst, E. 2009 Cold CO in circumstellar disks. On the effects of photodesorption and vertical mixing *A&A* 493, 49.

Hollenbach, D., Kaufman, M. J., Bergin, E. A., & Melnick, G. J. 2009 Water, O_2, and Ice in Molecular Clouds *ApJ* 690, 1497.

Jger, C., Huisken, F., Mutschke, H., Jansa, I. L., & Henning, Th. 2009 Formation of Polycyclic Aromatic Hydrocarbons and Carbonaceous Solids in Gas-Phase Condensation Experiments *ApJ* 696, 706

Juhsz, A., Henning, Th., Bouwman, J., Dullemond, C. P., Pascucci, I., & Apai, D. 2009 Do We Really Know the Dust? Systematics and Uncertainties of the Mid-Infrared Spectral Analysis Methods *ApJ* 695, 1024

Kozasa, T., Nozawa, T., Tominaga, N., Umeda, H., Maeda, K., & Nomoto, K. 2009 Dust in Supernovae: Formation and Evolution *Cosmic Dust - Near and Far, ASP Conf. Series, Th. Henning, E. Grun, J. Steinacker, eds.* 414, 43.

Le Page, V., Snow, T. P., & Bierbaum, V. M. 2009 Molecular Hydrogen Formation Catalyzed by Polycyclic Aromatic Hydrocarbons in the Interstellar Medium *ApJ* 704, 274

Le Petit, F., Barzel, B., Biham, O., Roueff, E., & Le Bourlot, J. 2009 Incorporation of stochastic chemistry on dust grains in the Meudon PDR code using moment equations. I. Application to the formation of H_2 and HD *A&A* 505, 1153.

Loeffler, M. J. & Baragiola, R. A. 2009 Physical and chemical effects on crystalline H_2O_2 induced by 20 keV protons *JChemPhys* 130, 114504

Lohmar, I., Krug, J.& Biham, O. 2009 Accurate rate coefficients for models of interstellar gas-grain chemistry *A&A* 504, 5L.

Mastrapa, R. M., Sandford, S. A., Roush, T. L., Cruikshank, D. P.,& Dalle Ore, C. M. 2009 Optical Constants of Amorphous and Crystalline H2O-ice: 2.5-22 μm (4000-455 cm^{-1}) Optical Constants of H_2O-ice *ApJ* 701, 1347

Madzunkov, S. M., MacAskill, J. A., Chutjian, A., Ehrenfreund, P., Darrach, M. R., Vidali, G., & Shortt, B. J. 2009 Formation of Formaldehyde and Carbon Dioxide on an Icy Grain Analog Using Fast Hydrogen Atoms *ApJ* 697, 801.

Mokrane, H., Chaabouni, H., Accolla, M., Congiu, E., Dulieu, F., Chehrouri, M., & Lemaire, J. L. 2009 Experimental Evidence for Water Formation Via Ozone Hydrogenation on Dust Grains at 10 K *ApJ* 705, 195.

Muoz Caro, G. M., & Dartois, E. 2009 A tracer of organic matter of prebiotic interest in space, made from UV and thermal processing of ice mantles *A&A* 494, 109.

Nuevo, M., Milam, S. N., Sandford, S. A., Elsila, J. E., & Dworkin, J. P. 2009 Formation of Uracil from the Ultraviolet Photo-Irradiation of Pyrimidine in Pure H_2O Ices *AsBio* 9, 683.

Oba, Y., Miyauchi, N., Hidaka, H., Chigai, T., Watanabe, N., & Kouchi, A. 2009 Formation of Compact Amorphous H_2O Ice by Codeposition of Hydrogen Atoms with Oxygen Molecules on Grain Surfaces *ApJ* 701, 464.

Oberg, K. I., Garrod, R. T., van Dishoeck, E. F., & Linnartz, H. 2009 Formation rates of complex organics in UV irradiated CH_3OH-rich ices. I. Experiments *A&A* 504, 891.

Oberg, K. I., Linnartz, H., Visser, R., & van Dishoeck, E. F. 2009 Photodesorption of Ices. II. H_2O and D_2O *ApJ* 693, 1209.

Oberg, K. I., van Dishoeck, E. F., & Linnartz, H. 2009 Photodesorption of ices I: CO, N_2, and CO_2 *A&A* 496, 281.

Oberg, K. I., Fayolle, E. C., Cuppen, H. M., van Dishoeck, E. F.& Linnartz, H. 2009 Quantification of segregation dynamics in ice mixtures *A&A* 505, 183.

Ormel, C. W., Paszun, D., Dominik, C.; &Tielens, A. G. G. M. 2009 Dust coagulation and fragmentation in molecular clouds. I. How collisions between dust aggregates alter the dust size distribution *A&A* 502, 845.

Ratajczak, A., Quirico, E., Faure, A., Schmitt, B., & Ceccarelli, C. 2009 Hydrogen/deuterium exchange in interstellar ice analogs *A&A* 496, L21.

Shi, J., Teolis, B. D., & Baragiola, R. A. 2009 Irradiation-enhanced adsorption and trapping of O_2 on nanoporous water ice *PhysRevB* 79, 235422.

Shiraiwa, M., Garland, R M., & Poschl, U. 2009 Kinetic double-layer model of aerosol surface chemistry and gas-particle interactions (K2-SURF): degradation of polycyclic aromatic hydrocarbons exposed to O_3, NO_2, H_2O, OH and NO_3 *AtmosChemPhys* 9, 9571

Schou, J. & Hilleret, N. 2009 Sputtering of cryogenic films of hydrogen by keV ions: Thickness dependence and surface morphology *NuclInstrMethodsB* 267, 2748.

Teolis, B. D., Shi, J., & Baragiola, R. A. 2009 Formation, trapping, and ejection of radiolytic O_2 from ion-irradiated water ice studied by sputter depth profiling *JChemPhys* 130, 134704.

Tsvetkov, A. G. & Shematovich, V. I. 2010 Kinetic Monte Carlo method for simulating astrochemical kinetics: Test calculations of molecular hydrogen formation on interstellar dust particles *SolarSystemRes* 43, 301.

Thrower, J. D., Collings, M. P., Rutten, F. J. M., & McCoustra, M. R. S. 2009 Laboratory investigations of the interaction between benzene and bare silicate grain surfaces *MNRAS* 394, 1510.

Vasyunin, A. I., Semenov, D. A., Wiebe, D. S., & Henning, Th. 2009 A Unified Monte Carlo Treatment of Gas-Grain Chemistry for Large Reaction Networks. I. Testing Validity of Rate Equations in Molecular Clouds *ApJ* 691, 1459

Verhoelst, T., van der Zypen, N., Hony, S., Decin, L., Cami, J., & Eriksson, K. 2009 The dust condensation sequence in red supergiant stars *A&A* 498, 127.

Vidali, G., Li, L., Roser, J., E., & Badman, R. 2009 Catalytic activity of interstellar grains: Formation of molecular hydrogen on amorphous silicates *AdvSpaceRes* 43, 1291.

Vidali, G. 2009 Division XII / Commission 14 / Working Group: Solids and their Surfaces *TransIAU*v.4, p.400.

Visser, R., van Dishoeck, E. F., Doty, S. D., & Dullemond, C. P. 2009 The chemical history of molecules in circumstellar disks. I. Ices *A&A* 495, 881.

Yabushita, A., Hama, T., Yokoyama, M., Kawasaki, M., Andersson, S., Dixon, R. N., Ashfold, Michael N. R., & Watanabe, N. 2009 Translational and Rotational Energy Measurements of Photodesorbed Water Molecules in their Vibrational Ground State from Amorphous Solid Water *ApJ* 699, 80.

https://doi.org/10.1017/S1743921312003110 Published online by Cambridge University Press