

47th Symposium on Theoretical Chemistry 2011 (STC 2011)

Designing Molecular Functionality: Challenges for Theoretical Approaches

August 21st – 25th, 2011,
Campus Sursee, Switzerland

Moritz P. Haag and Arndt R. Finkelmann

Laboratorium für Physikalische Chemie, ETH Zurich, Wolfgang-Pauli-Strasse 10
8093 Zürich, Switzerland

October 21, 2011

Introduction

The 47th Symposium for Theoretical Chemistry (STC 2011) took place in Switzerland in August 2011. The conference site was Campus Sursee near Lake Sempach in the beautiful Swiss countryside. The modern conference center (Fig. 1) offered comfortable accommodation for the 211 participants.



Figure 1: The conference center: Campus Sursee, Switzerland.

The conference was devoted to theoretical and computational methods for the design of molecules and materials with specific properties and functionality at a molecular level. It brought together experts with a background in quantum chemistry and molecular dynamics. Relevant areas of method development and applications were discussed in 39 lectures in 13 sessions. There were also two poster sessions with a total of 141 posters (Fig. 4), where the participants presented their research. Toru Shiozaki, Axel Schild and Udo Benedikt were awarded prizes for their posters (Fig. 5). Topics covered molecular properties, catalysis, molecular electronics and materials design, among others. The Hellmann Award 2011, whose winner is traditionally announced at the STC, was given to Daniel Sebastiani. He was honored for his contributions to the theoretical characterization of structure and dynamics in disordered supramolecular systems (Fig. 6). In addition to the scientific program there was an excursion to mount Pilatus on the third conference day from where one could take in the marvelous view over the Alps and Lucerne (Fig. 2).



Figure 2: Impressions from the excursion: View from Mount Pilatus across Lake Lucerne.

Also the conference dinner, on the boat ‘Wilhelm Tell’ in Lucerne Harbor, was a good occasion for stimulating discussions. The conference was sponsored by IBM, the Swiss National Science Foundation, the Swiss Chemical Society, Novartis, Syngenta, Merck Serono, Roche, BASF and the Swiss Academy of Sciences. Support came also from Campus Sursee, Wiley-VCH and Eichhof. In the following sections a detailed overview on all sessions and talks will be given.

Session 1

Starting with a welcome and a short introduction by Markus Reiher, the organizer of the conference and chairman of the first session, the meeting opened with the experimental keynote lecture by **François Diederich**, ETH Zürich. His talk ‘Opto-Electronic Organic Materials by Novel Acetylene Chemistry’ reported novel compounds with opto-electronic properties which were recently synthesized in his laboratory. In the first part of his talk, he illustrated that macro-cyclization of di-*tert*-butyl-diethynylallene building blocks yielded conformationally stable, all-carbon macro-cycles which show strong absorption intensities in circular dichroism (CD) spectra and a pronounced Cotton effect. Spectra of these compounds could be reproduced by semi-empirical ZINDO calculations. In the second part allenacetylenic oligomers were introduced which show strong chiroptical effects. He obtained an unprecedented ‘amplification of chirality’ in electronic CD spectra which Diederich rationalized with a helical superstructure that can be adopted with these acyclic compounds. In the last part, electronic ‘super acceptors’ were introduced which had been obtained by a formal [2 + 2] cycloaddition and successive retro-cyclization of donor-substituted alkynes and electron-accepting olefins. These D- π -A chromophores exhibit efficient intramolecular charge transfer (CT) with absorption bands expanding far into the near infrared and show high third-order optical nonlinearities. Reproduction of properties and spectra of such novel compounds is a challenge for theory, and the lecture was followed by a lively discussion on properties of the compounds presented like conformational flexibility and on molecular features which determine the extraordinary non-linear optical properties.

The second talk was given by **David N. Beratan**, Duke University (Durham, NC), on ‘Theoretical Guidance for Chemical Synthesis’. The question Beratan addressed in his talk was how to design new molecules by theory. Most of the vast chemical space is as yet unexplored and new strategies to discover molecular structure with optimal properties are needed. The methods Beratan outlined were the variation of the molecular Hamiltonian and the variation of the external potential to generate molecules with distinct properties. He lectured on diversity-oriented molecular libraries as a representation of molecular space. A broad sampling and a map of structure to chemical functionality is necessary here. Evolutionary algorithms can be a solution to create molecular diversity and to sample molecular space.



Figure 3: Coffee break between the lectures.

Session 2

The second session which covered new methodological developments in density functional theory (DFT), started on Monday morning with the talk by **Alàn Aspuru-Guzik**, Harvard University (Cambridge), on ‘Approaches for the Simulation of Open Quantum Systems and Quantum Computation with Time-Dependent Density Functional Theory’. As an introduction to the topic, Aspuru-Guzik stated that every quantum system interacts with its environment. Therefore, simulation of molecular systems as energy-conserving, closed quantum mechanical objects is an idealization. Hence, most of the conventional approaches cannot exhibit relaxation or dissipation dynamics. Aspuru-Guzik recently developed a framework for simulating the time-evolution of an open quantum system utilizing an auxiliary closed Kohn-Sham system evolving under a unitary propagation. He presented a linear-response time-dependent DFT (TDDFT) approach which incorporates both effects via a Görling-Levy type perturbative formalism developed in his group. Aspuru-Guzik’s final remarks were on a description of the connection between TDDFT and quantum-computing.

Lucas Visscher, VU University Amsterdam, reported on ‘A Subsystem Approach for the Quantum Mechanical Description of Large Biomolecules’. One approach to describe large (bio)molecules quantum mechanically is to use chemical knowledge and treat a macromolecule and molecules with which it interacts as a set of well-defined subsystems which are calculated individually. The speaker reported on the coupling between the subsystems that is based on the frozen-density embedding method. Here the total density in a DFT calculation is constructed by adding the subsystem densities. Visscher reviewed that this approach works well for organic molecules and biomolecules but transition-metal complexes prove to be difficult. The exact reproduction of the density and thus the accuracy of the description is dependent on the kinetic energy functional, which he demonstrated at the example of the ArAuF molecule. Moreover, he discussed a partitioning scheme for biomolecules.

‘Unambiguous Optimization of Effective Potentials in Finite Basis Sets’ was the title of **Christoph R. Jacob**’s (Karlsruhe Institute of Technology) presentation. As an introduction to the topic Jacob explained that, given an electronic target density $\rho_0(\vec{r})$, numerical procedures for reconstructing the local potential $v_s(\rho_0)(\vec{r})$ that yield $\rho_0(\vec{r})$ as its ground state density are important for fundamental developments in DFT and subsystem DFT (e.g. within the frozen-density embedding schemes). The introduction of a finite basis set turns this into an ill-posed problem because multiple v_s can yield the same ρ_0 . In his talk he presented a new approach to the optimized effective potential problem. He showed that it unambiguously selects the potential, also within an infinite basis set, and thus systematically approaches the exact numerical solution. It is also numerically stable and allows for independent variation of orbital and potential basis set. Unphysical oscillations of the potential could be overcome by regularization of the density in the Lagrangian with a parameterized penalty function.

Session 3

Session 3 chaired by *Johannes Neugebauer*, Technical University of Braunschweig, was devoted to bio-molecular simulations. **Wilfred van Gunsteren**, ETH Zurich, lectured on ‘Methodological Advances in the Computation of Relative Free Energies’. Van Gunsteren started by pointing out that free energy is the central quantity in the computer simulation of the dynamics of bio-molecular systems. Relative free energies are computable but there are limits for time and spatial scale due to finite computing capabilities. After a short review of available methods for free energy difference calculations with thermodynamic integration (TI) as a benchmark, van Gunsteren reported on the so-called enveloping distribution sampling (EDS) method developed recently in his group. EDS can rapidly compute many free energies from a single simulation or find paths between different states of a system. The influence of the two parameters (energy offset and smoothness parameter) which are important for the performance was demonstrated and many examples on performance and applications were shown. Van Gunsteren stated that EDS is faster than TI and the accuracy is comparable to TI so it can become a standard method for the computation of free energies.

Brian Kuhlman, University of North Carolina at Chapel Hill, reported on the ‘Computational Design of Protein Structures and Interfaces’. The challenging topic of protein design requires the identification of low energy conformations and sequences. The approach Kuhlman followed is based on iterating sequence design and structure refinement using the Rosetta program. He presented three different design studies. Starting with the redesign of a protein core to have zero sequence identity with the starting protein he continued with the design of a novel binding conformation for a protein binding peptide. The *de novo* design of symmetric homodimers was achieved by metal mediated protein-protein interactions. In most cases close agreement between design and experimental structures was found. Kuhlman concluded that a comparison between failed and successful designs shows that, while the design and refinement of hydrophobic interactions are often successful, the design of novel hydrogen bond networks is still challenging and often fails. The lecture ended with an impressive example of a redesigned photo-activable protein which worked as a photo-switch in living cells.

The following talk was given by **Milan Ončák**, Institute of Chemical Technology (Prague), with the title ‘Modeling the UV Absorption Spectra in Solution Using the Path Integral Molecular Dynamics’. The speaker started with an introduction on molecular spectroscopy and the problems with simulating spectra for highly anharmonic flexible systems. His approach for calculations of spectra is to use path integral molecular dynamics (PIMD) techniques. UV absorption and photoionization spectra are modeled with the reflection principle approximation and PIMD sampling of the ground state combined with various quantum chemical methods. After this introduction the speaker presented two case studies to demonstrate the capabilities of this approach. The experimental absorption and photoelectron spectra of liquid water can be reproduced. Theoretical analysis of the experimental photoionization spectra of hydrogen peroxide in water helped to determine the structure of the solvated species.



Figure 4: The scene at a busy Wednesday poster session.

Session 4

Christian Ochsenfeld, University of Munich, chaired the fourth session which started with a lecture on ‘The Well-Tempered Ensemble’ by **Michele Parrinello**, ETH Zurich and Università della Svizzera Italiana. As already mentioned by van Gunsteren, sampling of complex systems is one of the most important issues in molecular dynamics simulations. To improve the sampling Parrinello introduced well-tempered metadynamics. Parrinello demonstrated that at intermediate scaling factors the average energy is close to its canonical value but fluctuations are strongly enhanced which can be used to enhance sampling, especially in combination with parallel tempering. Collective variables are chosen to represent the desired movement. With a recently developed re-weighting scheme canonical ensemble averages can be recovered. In the last part of the talk he showed how the dimension of the collective variables could be reduced by projection on a lower dimensional space for better visualization.

Philippe H. Hünenberger’s (ETH Zurich) talk on ‘The Representation of Ions, a Challenge for Classical Simulations’ started with an emphasis on the importance of ions as ubiquitous species in nature and common targets or participants in classical simulation studies concerning (bio)molecular systems. Unfortunately, due to the long-range nature and large magnitude of the Coulomb interaction, accurately representing the electrostatic interactions between charged species and their solvation properties is a true challenge. For force-field parameterization, as was pointed out by the speaker, there is a lack of unambiguous experimental thermodynamical data. An intrinsic solvation free energy (ΔG_{solv}^0) would be needed for chemical purposes. Single-ion solvation free energies are determined in reference to $\Delta G_{\text{solv}}^0(H^+)$ which is only known within the range of 1050–1100 kJ/mol. Predicting $\Delta G_{\text{solv}}^0(H^+)$ from theory is difficult, too. The Born model is inaccurate and molecular dynamic (MD) simulations fail because the system sizes are too small. Finally, P-sum and M-sum methods were discussed where he made clear that the M-sum method is the method of choice and which yields an estimate of $\Delta G_{\text{solv}}^0(H^+) = 1100$ kcal/mol, based on MD simulations with different ion radii.

O. Anatole von Lilienfeld, Argonne National Laboratory (Illinois), closed the first afternoon session with his lecture entitled ‘From Electronic Structure Theory to Rational Compound Design’. Referring to the lecture given by D. Beratan in the very first session, he introduced the topic of computational design of compounds and the screening of chemical compound space. He stressed that there exists no analytical map between compound space and property space. In the next part of his lecture he discussed DFT-based property derivatives in chemical compound space, which are necessary to describe properties that can only be calculated from first principles. In this context, he mentioned the alchemical potentials which is used to calculate the response of the system to changes in atom type. In the final part he showed how machine learning can be used to rapidly predict molecular potential energies.

Session 5

The last session of the day, chaired by *Michael Hanrath*, University of Cologne, covered methodological developments for DFT and TDDFT for excited states. It started with a talk by **Paul W. Ayers**, McMaster University (Canada) on ‘Two-Point Weighted Density Approximations for the Kinetic Energy and Exchange-Correlation Energy’. The concept that Ayers explained is that many problems in DFT can be mitigated by carefully designing an exchange-correlation hole with the proper mathematical properties. The solution he presented is a generalized and extended version of the weighted density approximation (WDA). Here the exchange hole is constructed from the uniform electron gas and also correlation is introduced. Ayers showed that the new WDA functional works well for the kinetic energy, exchange energy, and exchange-correlation energy. It is also able to deal with fractionally occupied sites and is variationally stable compared to, e.g., kinetic energy functionals (H_2 dissociation is correctly described with WDA). The method is costly but the speaker presented algorithms using a limited-memory quasi-Newton method which render the method comparable to other modern methods.

In the following talk **Andreas Dreuw**, Ruprecht-Karls University Heidelberg, presented ‘Quantum Chemical Methods for Electronic Excited States of Large Molecules: From TDDFT to ADC’. The speaker started by discussing linear response TDDFT as one of the current standard methods to study excited states. However, TDDFT has problems in particular with charge transfer (CT) states where excitations are predicted too low in energy and unphysical asymptotic behavior with respect to the distance coordinate can also be observed. TDDFT results are also sensitive to the proportion of exact exchange. To overcome these problems, Dreuw introduced a long-range exact-exchange-corrected potential and an orbital-overlap-dependent empirical energy shift. In the second part of his talk he reported on the algebraic diagrammatic construction scheme of second order (ADC(2)) which is a wavefunction-based method that correctly handles double excitations and CT. He presented a recently implemented unrestricted ADC scheme, which allows for calculation of medium sized radicals with an error of ~ 0.3 eV, and a local ADC(2) scheme.

The next talk was delivered by **Mathias Nest**, Technical University of Munich, on ‘TDDFT as a Tool for Coherent Control of Valence Electrons’. Nest began by noting that TDDFT as he applies it is not considered in the linear response frame but to describe the real-time dynamics of many electron systems. A recent challenge, he explained, is the combination of TDDFT with quantum control theory. He then compared TDDFT and time-dependent CI approaches to achieve various control tasks like switching the dipole moment of a molecule by state-to-state transitions or creating an electronic wave packet. Whereas the frequencies and amplitudes are reproduced well for wave packets, state-to-state transitions (single electron excitation) are a challenge. Interestingly, the TDDFT results turned out to be independent of the functional chosen.

The last presentation on Monday was given by **Tobias Schwabe**, Aarhus University, on ‘Environmental Effects on Electronic Excitations: Recent Advances for the Polarizable Embedding Method’. To understand environmental effects on electronic excitation properties in large systems, Schwabe presented a hybrid QM/MM approach as an efficient way to apply sophisticated electronic structure methods. He introduced polarizable embedding as an accurate method to describe the interface between the two regions. The performance was demonstrated at the example of acrolein in water. The method also works well for solvents other than water.



Figure 5: The award winners of the poster prizes together with the organizer of the conference.

Session 6

The study of chemical problems and bonding situations was the topic of the morning session on Tuesday which was opened by chairman *Martin Kaupp* from the Technical University of Berlin. The first lecture by **Paul Geerlings**, Free University of Brussels, entitled ‘Conceptual Density Functional Theory’ gave a short introduction to general density functional theory and then proceeded to his main topic. He discussed the role of the energy functional derivatives of the type $\partial^n E / \partial v^m \partial N^{m'}$, which can be identified as properties like chemical hardness. After that Geerlings pointed out the chemical relevance of the mixed third order derivatives and gave examples such as

the dual descriptor as a guide for a density-only interpretation of the Woodward-Hoffmann rules. In the last part of his talk the emphasis was on the linear response function and its relevance in quantifying inductive and mesomeric effects and also aromaticity.

After this lecture, **Gernot Frenking** from the Philipps-University Marburg continued with a talk on ‘Donor-Acceptor Complexes of Main-Group Elements with Unusual Bonds’. In the first part of his talk a new class of molecules was discussed that features enhanced donor-acceptor interactions due to their separation by spacers. As an example, he described a compound where Xe and BF₃ are separated by a C₆F₄ group. In this compound, the Xe-C bond is unusually short and the bond order is almost one. In the second part he focused on divalent E(0) compounds EL₂ of group-14 elements (E = C - Pb), where L is a σ -donor ligand. In particular, he discussed carbones (E = C) and the case of carbon suboxide, which is bent at the central C atom with an angle of 156°. The heavier homologues in the same group were also discussed. He then continued in the third part with the group-13 (E = B - Tl) and group-15 (E = N - Bi) homologues.

The sixth session ended with a talk by **Stefan Knecht**, University of Southern Denmark (Odense), on ‘The Nature of Chemical Bonding in *f*-Elements: U₂ Revisited with Full Treatment of Spin-Orbit Coupling’. He started with an introduction to the 2005 bonding picture of the U₂ molecule, in which the calculated effective bond order is five. After a short presentation of the DIRAC program and its components he outlined the computational approach leading to the 2005 bonding picture. This approach included scalar relativistic effects with a second-order Douglas-Kroll-Hess Hamiltonian and treated spin-orbit coupling *a posteriori* through a spin-orbit state-interaction approach. Applying the recently developed MCSCF code, which allows the use of both 4-component relativistic Hamiltonians as well as the 2-component one-step X2C Hamiltonian, he found a different result for the bond order. He closed his talk stating that not only is the variational treatment of spin-orbit coupling important in the case of U₂, but a large active space is also necessary to obtain the correct picture.

Session 7

Chairman *Max Holthausen*, Frankfurt University, led the audience through the second morning session on Tuesday. It started with a lecture by **Sason Shaik** from the Hebrew University of Jerusalem entitled ‘Reactivity Patterns of Bond Activation by Metal Oxo Complexes’. In his talk about bio-inorganic reactivity Shaik first described the application of valence bond (VB) theory to bio-inorganic chemistry, using as an example the reactivity of the iron-oxo species of Cytochrome P450 in H-abstraction, sulfoxidation, aromatic hydroxylation and double-bond epoxidation. He also described the way by which VB theory creates order and makes predictions in this complex field. The second part of his lecture concerned the oxy complexes of Myoglobin and Hemoglobin and their bonding features, which were first outlined in 1936 and have remained disputed for 75 years. He illustrated then how VB theory resolves the dispute by transforming the CASSCF wave function to a VB wave function, which shows clearly the bonding mechanism of O₂ to the ferrous heme complex including a negative charge on the O₂ molecule as it was predicted by Weiss. Finally, he argued that VB theory and the VB reading of complex multi-reference wave functions is a fruitful future paradigm in the field.

Franziska Schoenebeck, ETH Zurich, lectured on ‘Catalysis from a Computational Perspective’. She emphasized the importance of a detailed understanding of catalytic transformations for the design of better catalysts. For the example of Pd catalyzed transmetalations she illustrated how computational chemistry was applied to gain insights into reaction mechanisms, active catalytic species, ligand and additive effects of selected metal-catalyzed transformations. She showed that the different selectivity of a Suzuki coupling reaction in various solvents can be explained by different active species of the catalyst. As a second example she mentioned a Stille-type reaction and the role of the binuclear Pd(I)-Pd(I) precatalyst. Her studies revealed that the precatalyst disproportionates into a Pd(0) and Pd(II), where the former is the catalytically active species. Schoenebeck concluded explaining how computational results and experimental studies can be

combined to develop improved applications in catalysis.

The talk held by **Hélène Bolvin** from the University Paul Sabatier Toulouse was on ‘Magnetic Properties of Sandwich Complexes of Lanthanides and Actinides’. After an introduction on single-molecule magnets, she presented her work on the magnetic properties of sandwich complexes with lanthanide and actinide atoms. Examples were $[\text{Np}(\text{COT})_2]$ and $[\text{Tb}(\text{pc})_2]^-$, which both show hysteresis. The calculations on these complexes were performed by changing both the nature of the central ion and of the ligand in order to understand the physical mechanisms that determine the crystal field parameters and consequently the ground state. It was found that the nature of the ground state depends strongly on the nature of the sandwich complex ligands.

Session 8

The eighth session started with the announcement of the Hellmann Award winner of 2011 **Daniel Sebastiani**, Free University of Berlin, by chairman *Jürgen Gauss*, Johannes Gutenberg University Mainz. After receiving the award Daniel Sebastiani presented his lecture on ‘Theoretische Chemie ungeordneter Systeme: Die Herausforderungen der strukturellen Komplexität’, which was delivered in German. In his talk he discussed the theory and applications of computational approaches to disordered systems, touching a wide range of topics, from theoretical spectroscopy and general density functional theory to nuclear quantum effects (proton momentum distribution), supramolecular systems, liquids, solutions and finally protonation in proteins.



Figure 6: The Hellmann Award winner of 2011, Daniel Sebastiani (right), and chairman Jürgen Gauss (left).

Afterwards, **Trond Saue** from the University Paul Sabatier Toulouse talked about ‘4-Component Relativistic Calculations of the Magnetically Induced Current Density in Aromatic Systems’. After a short definition of the current density and how it is calculated in theoretical chemistry, he focused on the magnetically induced ring current density, which is a property closely related to the aromaticity of molecular systems. Saue reported on the first implementation of the calculation of magnetically induced ring current density in a 4-component relativistic framework, including the recent extension to gauge including atomic orbitals and the calculation of individual orbital contributions.

Closely related to the talk of Trond Saue was the talk given by **Dage Sundholm** from the University of Helsinki. He lectured on the ‘Calculation of Magnetically Induced Current Densities for Designing Molecular Functionality’. In his introduction Sundholm stated that the magnetically induced current strengths are not only used as aromaticity indicators, but also for providing information about molecular electron and spin transport properties. Diatropic strong ring currents are an indicator of aromaticity, such as for benzene, and paratropic strong ring currents indicate anti-aromaticity like in cyclobutadiene. The applications he discussed were Hückel and also

Möbius aromatic compounds like 16-annulene, coronene and circumcoronene as graphene models, polycyclic anti-aromatic hydrocarbons and hydrocarbon nanorings. He closed his lecture with a perspective on molecular conductivity and spintronics as applications.

Session 9

The ninth session of the STC 2011 was led by chairman *Robert Berger*, Technical University of Darmstadt. The opening lecture was held by **Jochen Autschbach** from the State University of New York at Buffalo with the title ‘Calculating and Analyzing Response Properties’. He gave a brief overview of methods for calculating electric and magnetic response properties of molecules in the framework of DFT and discussed various applications at the example of androstadienone and a Co complex. Among the response properties he discussed were magnetic resonance parameters, optical activity, magnetizability, dynamic polarizability and some higher order properties. The analysis of such properties in terms of local or orbital contributions can be useful for the design of new materials.

The lecture was followed by another one on molecular properties delivered by **Kenneth Ruud** from the University of Tromsø. He entitled his lecture ‘Relativistic Calculations of Molecular Properties’. In the talk, a quasi-energy derivative formalism for self-consistent field approaches (including Kohn-Sham density-functional theory) for calculating molecular properties using two- and four-component relativistic wave functions was discussed. Various aspects related to recent improvements such as the evaluation of corrections due to the dependence of the basis sets on the applied perturbations or the evaluation of two-electron integrals using restricted kinetic or magnetic balance was given. In the applications part, he focused on the higher-order molecular properties and on properties that involve structural or magnetic perturbations, such as NMR and EPR parameters, nonlinear birefringence as well as relativistic calculations of Raman Optical Activity Spectra.

The session was closed by **Christoph van Wüllen** from the TU Kaiserslautern with a talk about ‘Density Functional Calculation of Zero Field Splittings—Towards a Consistent Theory’. After an introduction to the topic of zero field splittings the speaker explained how these splittings and the **D** tensor (one of the Spin-Hamiltonian parameters) can be calculated in DFT, which resolved discrepancies existing in the recent literature. Christoph van Wüllen lucidly explained to the audience the problem and how it can be solved.

Session 10

The first afternoon session on Wednesday was chaired by *Peter Botschwina* from the University of Göttingen and had an emphasis on the calculation of molecular properties. The session started with a lecture on coupled cluster theory given by **Hans-Joachim Werner** from the University of Stuttgart entitled ‘Explicitly Correlated Local Coupled-Cluster Methods for Large Molecules’. In the first part he reviewed explicitly correlated local coupled-cluster methods for closed- and open-shell systems as implemented in MOLPRO. He presented two ways to span the virtual orbital space: By orbital specific virtuals or by projected atomic orbitals. The impact of these local approximations was discussed in detail. Werner identified the simplified treatment of weak and distant electron pairs in the local approximations. To reach the intrinsic accuracy of the method, the classes of strong and close pairs (explicitly treated in LCCSD) must be larger than it was previously assumed. In the end he illustrated his statements with benchmark applications which demonstrated that results of near CCSD(T)/CBS quality can be obtained for molecules with up to 90 atoms and over 2600 basis functions.

Antonio Rizzo from the CNR in Pisa continued with a lecture on ‘Nonlinear Spectroscopies and Chirality’. He started with an introduction to nonlinear properties and external fields mentioning many effects which can be measured spectroscopically. He then introduced the audience to the

two photon circular dichroism spectroscopy which is the nonlinear analogue to electronic CD spectroscopy. Rizzo then explained how the corresponding spectra can be calculated based on a modern analytical response theory, within a TDDFT approach. After illustrating the techniques with some examples he also discussed other nonlinear optical properties exhibited by chiral assemblies like the excited state electronic CD and pump-probe chiral spectroscopies.

The session ended with a lecture given by **T. Daniel Crawford** from Virginia Tech with the title ‘Through the Looking Glass and What the Quantum Chemist Found There’ also on chiral spectroscopy. In his talk Crawford introduced the audience to property tensors and optical activity. He then demonstrated how these tensors can be calculated employing coupled cluster theory. Using the examples of carvone and norbornenone, he illustrated the methods by analyzing different influences like vibrations, solvent and liquid phase effects. Then he discussed Gauge invariance on coupled cluster response theory. At the end of his lecture he talked about the calculation of optical rotation, electronic CD and vibrational Raman optical activity.

Session 11

The last session on Wednesday, chaired by *Irmgard Frank* from the University of Hannover started with a lecture held by **Haibin Su** from the Nanyang Technological University in Singapore entitled ‘Versatile Character of Carbon’. After an introduction to carbon nanotubes and fullerenes and two fascinating hybrid structures of them—peapod and NanoBuds—Su described the reaction dynamics of C_{60} dimerization and the more challenging complex tubular fullerene formation process in the peapod structures. Both DFT and the recently developed Reactive Force Field (ReaxFF) were applied. In the second part Su presented a study of electron transport employing non-equilibrium Green’s function theory. The last part of the lecture was on optics in nanotubes. He discussed excitation effects calculated employing first-principles Green’s function theory and the GW approximation.

Following Haibin Su, **Gemma C. Solomon**, University of Copenhagen, gave a talk on ‘Describing Local Currents in Molecular Electronic Transport’. To introduce the topic she pointed out that local descriptions are a cornerstone in understanding the properties of a system. She then presented her research on electron transport through single molecules bound between two metallic electrodes. A Green’s function description for local currents is utilized to map out these parts of the molecule that participate in coherent electron transport. With this methodology she discussed σ - and π -transport. The latter usually does not result in substantial electron transport because destructive interference induced by cyclic π -systems hinder π -transport. This results in the unexpected behavior of π -stacking systems, where reduced orbital overlap leads to an increasing transmission. She accompanied this with the theoretical design of mechanically activated molecular switches where the orbital overlap controls the transmission.

The last talk of the session was given by **Carmen Herrmann**, University of Hamburg. In her talk with the title ‘Designing Molecular Spintronic Devices in the Coherent Tunneling Regime’ Herrmann presented her research on spin transport through single molecules to understand and design spintronic devices. This emerging topic is important for biological processes and nanotechnology, for example, for heatless information transport. DFT and the Green’s function techniques are used to describe transport. With this methodology she showed examples of *ortho*- or *para*-substituted benzenes as organic spin filters and demonstrated that one can determine whether the electron tunnels through the iron center or through the porphyrin in a heme junction. In both cases the transport properties can be influenced by the choice of ligands or heme substituents.

Session 12

The first session of the last conference day was chaired by *Christel Marian*, Heinrich Heine University of Düsseldorf, and covered methodological developments in DFT and wavefunction methods.

She introduced **Stefan Grimme**, University of Münster, as the first speaker who gave his talk on the ‘Importance of London Dispersion Interactions for Chemical Functions’. In his introduction, Grimme stated that London dispersion interaction is a many-particle electron correlation effect which is not covered by standard approximate density functionals over long- and medium-range. Although representing only a small effect per individual atom, they can be substantial for larger systems as Grimme illustrated with several examples. As a solution to this problem he presented his dispersion correction to standard DFT (with DFT-D3 as the most recent variant) which corrects the medium- to long-range behavior of most modern density functionals. The improvement on thermochemical data was demonstrated with his GMTKN30 testset and 45+ different density functionals. Then the speaker introduced dispersion energy donors as a concept for the stabilization of large molecules, presented a binuclear Rhodium complex with huge dispersion effects, and discussed the hexaphenylethane riddle. Finally he showed the activation of small molecules by so-called frustrated Lewis pairs concluding that dispersion interactions are omnipresent and cannot be omitted for larger systems.

In the next presentation **Roland Lindh**, University of Uppsala, addressed ‘Analytic CD Gradients for HF, DFT, MP2 and CASSCF’. He presented the implementation of Cholesky Decomposition (CD) analytic gradients for the above mentioned methods. Lindh started by introducing the CD approach. He showed that the separate treatment of the effective two-particle density matrices in connection with the Coulomb, exchange and active space terms of the 2-center and 3-center two-electron integral derivatives is the key to an efficient implementation. The performance was illustrated with examples that showed that the Coulomb part performs very well, whereas the exchange part is not significantly faster. Lindh concluded that the method is fast, robust and automatically applicable for any method.

The session ended with the talk of **Martin Korth**, MPI for Coal Research (Mülheim an der Ruhr), who reported on ‘Third-Generation Hydrogen-Bonding Corrections for Semiempirical QM Methods and Force Fields’. For large biomolecules, extensive sampling is required which calls for fast methods like semiempirical QM (SQM) methods. The speaker presented a hydrogen-bond correction scheme for the poor performance of non-covalent interactions in SQM methods. This third generation correction scheme relies on an energy correction which is dependent on the hydrogen bond donor, the acceptor strength and a geometry factor. The geometry factor is symmetric with respect to donor and acceptor in the third generation. The speaker demonstrated the improved performance for AM1, PM6, OM3 and SCC-DFTB and force field methods for standard benchmarks. He emphasized that SQM methods will be improved for many applications like docking or scoring and can reach the accuracy of DFT-D in certain cases.

Session 13

The thirteenth and last session, which covered theoretical bio-inorganic chemistry, was chaired by *Hans Martin Senn*, University of Glasgow. **Walter Thiel**, MPI for Coal Research (Mülheim an der Ruhr) opened the session with his talk on ‘Theoretical Studies of Enzymatic Reactions’. The speaker started with a theoretical and methodological review on the QM/MM method which is the method of choice to study large molecules like enzymes or other biomolecules. He then introduced a three layer approach (QM/MM/continuum solvent) which is currently being developed in his group as possible improvement to the standard QM/MM approach. Generalized solvent boundary potential and solvated macromolecule boundary potential methods were introduced as three layer approaches and are implemented in ChemShell. He showed that the energetics of reactions with charge transfer can be influenced by the third layer. In the second part of the talk Thiel described recent work on biocatalysis by enzymes, namely on the Lewis acid/base mechanism of aldehyde oxidoreductase and on the role and structure of the cofactor in xanthine oxidase. Both demonstrated that QM/MM calculations can give detailed and accurate insights into biocatalysis. Finally he discussed the case of *P. aeruginosa* lipase modified by directed evolution to increase enantioselectivity. With the help of MD and QM/MM calculations the important mutations could be identified and a less strongly mutated form was suggested which turned out to

be as enantioselective as the variant obtained with directed evolution.

In the second talk of the session **Claudio Greco**, Humboldt University of Berlin, lectured about ‘New Perspectives for the Computation of Electronic and Vibrational Properties in Metalloproteins: The Case of [FeFe] Hydrogenase’. [FeFe] hydrogenases, are the most efficient hydrogen evolving enzymes and thus understanding their mechanism is of great interest. The speaker first presented a study where IR spectra of different active site models and oxidation states were calculated with DFT and compared to experimental spectroscopic results. 32 experimentally known model clusters were investigated to calibrate the methods, and reproduce the experimental results. Furthermore he reported on QM/MM calculations where, in addition to the active site’s H-cluster, two Fe₄S₄ cubanes were included into the QM part. Insight into oxidation states of the active site and the interplay between the cubanes could be captured in these calculations. In the last part of the talk the connection to the experimental design of biomimetic complexes was established.

The last presentation of the conference was the talk of **Matthias Stein**, MPI for Dynamics of Complex Technical Systems, Magdeburg, which was related to Claudio Greco’s talk. ‘Structural and Functional Mimics of Hydrogenase’ was the title. The speaker presented a theoretical study on cluster models of the [NiFe] hydrogenase’s active site. From calculation of EPR spectra and comparison to experiments, hints on the identity of the ligands were obtained. Then, he reported DFT studies of two biomimetic models of [FeFe] hydrogenase. For a structural active site model, calculations assisted in the spectral assignments to elucidate the conformation of the complex. From the obtained structure the speaker concluded that an azadithiolate ligand is also the ligand present in the natural enzyme. The second model complex was a functional model for which Stein studied a reaction mechanism which can aid the design of further mononuclear functional models of the [FeFe] hydrogenase’s active site.