Cluster of Excellence Precision Physics, Fundamental Interactions and Structure of Matter
PRISMA

Mainz Institute for Theoretical Physics

Searching for New Physics with Cold and Controlled Molecules

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Recently a remarkable progress has been achieved in control over both internal (electronic, vibrational, spin and rotational) and external (translational) degrees of freedom for a wide range of molecules. In particular, direct laser and opto-electric cooling of polyatomic molecules has been successfully demonstrated. This opens a way for much higher precision in measuring tiny effects in molecular spectra connected with possible new physical forces, that include exotic spin-dependent interactions, parity (P) and time-reversal invariance (T) violating interactions among others. In this connection, considerable interest should be devoted to, for example, the identification of closed-shell and also chiral laser-coolable molecules/ions. On the other hand, consideration of P- and P,T-odd effects for classes of molecules that were already successfully cooled and trapped is of great interest.

Nearly 30 scientists took part in the topical workshop including several "local" researchers from MITP and Helmholtz Institute Mainz (HIM). About half of the participants were students and young scientists.

The idea of this topical workshop was to bring together people who actively work in the application of AMO (atomic, molecular, and optical) methods to study fundamental physics. It was planned to focus on the remarkable progress that has been recently achieved regrading internal (electronic, vibrational, spin and rotational) and external (translational) degrees of freedom for a wide range of molecules. In particular, the direct laser and opto-electric cooling of polyatomic molecules has been successfully demonstrated. This opens a way for much higher precision of molecular spectroscopic experiments previously only achievable in atomic spectroscopy.

In many cases the molecules appear to be much more sensitive to new physics than atoms. In particular, molecules have higher sensitivity to (i) parity non-conserving interactions (P-odd); (ii) parity and time-reversal invariance non-conserving interactions (P,T-odd); (iii) possible variation of the fundamental constants; and (iv) exotic spin-dependent inter-actions. All this make it possible to search for new physics in a previously unreachable domain. An inspiring example is the recent result of the ACME collaboration on the ThO molecule which placed a new limit on electric dipole moment of the electron d_e (eEDM) at the level of $|d| < 1.1 \times 10^{-29}$ e cm. This limit is more than a hundred times more stringent than the limit following from the best atomic experiment on thallium atoms.

At the topical workshop, there were several talks describing new calculations of the P, T-odd effects in di-atomic molecules, molecular ions, and solids. The size of the eEDM signal depends on the effective electric field E_{eff} on the unpaired electrons. Theoretical predictions for the E_{eff} were reported for many molecules including all the molecules that are currently used for the eEDM search.

Anatoly Titov presented some approaches used by him and his colleagues for calculations of various molecular properties, inluding P- and P, T-odd ones. Alexander Petrov reported on a comprehensive theoretical study of the possible systematic effects in the EDM experimentswith ThO and $HfF^{+\cdot}$ Steven Hoekstra reported recent results of the NL-eEDM collaboration from the ongoing eEDM experiment with a slow BaF beam. Timo Fleig discussed the prospects of breaching the gap between the present limit on the eEDM and the value predicted by the Standard model, $|d_e| \approx 10^{-32}$ e cm.

During the workshop, several talks were devoted to the problem of identification of laser-coolable polyatomic molecules, in particular chiral ones. The latter provide a unique opportunity to measure P-odd interaction in purely spectroscopic experiments. Robert Berger gave an extensive overview of the possible studies of new physics with chiral molecules. Martin Zeppenfeld and Hendrick Bethlem reported progress on cooling polyatomic molecules. An impressive talk by Ronald Fernando Garcia Ruiz from CERN showed a fascinating picture of experiments with exotic species, including heavy ions and molecules, which include short-lived isotopes with very interesting properties. All in all, there were 25 talks (including one Skype presentation by Bhanu Das) which were followed by sometimes rather extensive discussions. As part of the week's program, a joint seminar with JGU QUANTUM was held featuring an inspiring talk presented by Hendrick Bethlem.

An important part of the workshop were presentations from young researchers - MS and PhD students. Konstantin Gaul from the Marburg University presented his research on parity and time-reversal violation in laser-coolable triatomic molecules, Sergey Prosnyak and Daniel Maison from Saint-Petersburg University reported on quantum-electrodynamic effects in heavy-atom systems.

The schedule of the topical workshop was not too dense and allowed for discussions between and after the talks and most of the participants used this opportunity to exchange ideas, establish new collaborations and reinforce existing ones.

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