

In the last decades, halogen bonding has acquired particular relevance for the building up of supramolecular patterns [1]. Heavier halides, especially iodines, are particularly sensitive to residual interactions, which allow formation of compounds of large nuclearities. In fact, anionic I_n^m species with n up to 29 and $m = -1, -2, -3$ have been reported [2], the simplest one being obviously I_3^- . Grouping of already electron rich atoms with similars, possibly with negative charge, is usually attributed to the high polarizability of the element. Calculations of the electron density are available, which highlight the points of its accumulation/depletion hence the capabilities of subsequent aggregations [3]. From the MO point of view, it is important to understand the electronic parameters which affect the stereochemistry of the higher nuclearity assemblies and, in particular, the variable strengths of the I-I interactions. The variability of the effects are already observed in the simplest linear systems I_3^- and I_4^{2-} , of which there are numerous crystal structures available. The I-I distances significantly vary depending on the nature of the counterion(s) and the overall packing arrangement. Thus I_3^- has not always the expected $D_{\infty h}$ symmetry but the two distances can become as different as 0.2 Å. Also for I_4^{2-} , which in principle consists of a central I_2 molecule residually interacting with two external I^- anions, it is evident that the three I-I separations depend on the crystal environment with possible loss of the highest symmetry. Here, we present a simple model based on experimental and theoretical data, which highlights how the mixing of the key σ orbitals is affected by a different distribution of the positive charges in various crystals [4]. To determine the latter, the Hirshfeld surface approach has been applied to some selected experimental structures where the differences are most remarkable [5]. Systematic DFT calculations (in vacuum and solvent) confirm that variously localized positive charges around the polyiodide can significantly affect the geometries of even the smallest I_3^- and I_4^{2-} units. The satisfactory results are interpreted in terms of a simple qualitative MO model, which monitors the σ orbital mixing for different positive charge distributions, hence the variable strength of the I-I bonding. The reciprocal validation between experiment and calculations and the predictability of the trends are the interpretational key to predict the variability of the halogen bonding in the smallest polyiodides and possibly in those of higher nuclearity.

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Computational and CSD analysis of $I_3^- \cdots I_3^-$ halogen bonds

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Iodide ions have a strong affinity to iodine molecules, forming polyiodide species such as triiodide (I_3^-), where the $I^- \cdots I_2$ interaction is extremely strong ($\sim 180 \text{ kJ mol}^{-1}$) [1]. These triiodide species can then form further interactions to neighbouring I_3^- ions, often forming infinite chains of ions [2]. These $I_3^- \cdots I_3^-$ interactions are surprisingly common, as seen from the number of crystal structures that contain this motif in the Cambridge Structural Database (CSD) [3]. Although the most

commonly observed chains are linear, or contain the triiodide ions oriented at 90° with respect to each other, as would be expected from the sigma-hole model of halogen bonding [4], a wide deviation from these angles has been observed. In this work we describe a detailed analysis of the relative orientations of I_3^- ions involved in interactions with neighbouring I_3^- ions, which we show with the aid of MP2 and density functional theory calculations is the result of the bending potential in $I_3^- \cdots I_3^-$ interactions being very low. Furthermore, we have found that the chemical environment of the ions plays a major role in stabilising the interactions. Although I_3^- is calculated as being stable in the “gas-phase”, the presence of a surrounding electric field, as found in ionic crystals, is necessary for the stabilisation of $I_3^- \cdots I_3^-$ interactions.

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Perovskite oxynitride materials: anion order, Valence States and physical properties

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Oxynitrides represent a vast group of compounds to explore new materials with properties analogous to oxides [1]. The similarities in electronegativity, polarizability, ionic radii and coordination numbers of nitrogen and oxygen allow the formation of the same structural types when combined with cations, as well as the mutual substitution of both anions at the same crystallographic sites. This may result in the formation of solid solutions where the formal oxidation state of one or more cations changes according to the O/N ratio.

Oxynitride perovskites have been recently reported as non-toxic inorganic pigments, dielectric materials, visible light photocatalysts and colossal magnetoresistance materials among other applications. Perovskites of alkaline earth and early transition metals with formula AMO_2N ($A = \text{Sr, Ba}$) have been reported as dielectric materials ($M = \text{Ta}$) and visible active photocatalysts for water splitting ($M = \text{Nb, Ta}$). Perovskites of europium and Nb, Ta or W show a variety of electrical and magnetic properties that are tuned by the valence states of the cations, adjusted by the N/O ratio. They are prepared by treating precursor oxides in $\text{NH}_3(\text{g})$ and the nitrogen stoichiometry is controlled by changing the temperature, flow rate and treatment time in the ammonolysis reaction. Depending on the electronic configurations of europium and the transition metal these compounds may show electronic conductivity and ferromagnetism that if coupled result in giant to colossal magnetoresistance [2,3]. Moreover microstructural inhomogeneities lead to non-intrinsic magnetocapacitance and non-ohmic conductivity [4].

The differences in electrical charge and electronegativity between nitrogen and oxygen direct the ordering of both anions in many oxynitrides [5]. In the above perovskites the ordering is driven by covalency and this lead to a preferred *cis* configuration of nitride anions in the octahedra MO_4N_2 and the formation of disordered zig-zag M-N chains [6]. The anion order remains at high temperature in the pseudocubic phase and directs the rotations of the octahedra in the room-temperature superstructure.

This lecture will present recent results on perovskite oxynitrides of europium, strontium and early transition metals focussing on the

relationships between the synthesis conditions, the oxidation states of the cations, the crystal symmetries and tilt transitions, the anion ordering and the physical properties.

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Keywords: oxynitride perovskites, anion ordering, colossal magnetoresistance

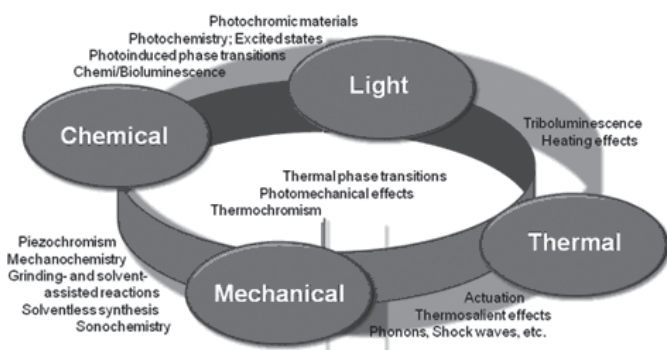
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Molecular mechanisms of photoinduced and thermally induced effects in crystals

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The recent revival of the interest in solid-state reactivity was partially triggered by the view that it can bridge the ‘classic’ solid-state photochemistry, which has been largely focused on elucidation of mechanisms of photochemical processes in solids, with contemporary chemical fields—notably, materials science and green chemistry—in the course of target-oriented design of photoresponsive/reactive materials. The efforts have been generally aimed at better understanding of structural changes induced by external stimuli (light, temperature and pressure), which can provide a platform for optimization of the performance of new materials for efficient conversion, at a macroscopic scale, among light, chemical, thermal and mechanical energy.



Most attention in the past has been devoted to conversion of *light* into *chemical energy*, and we have contributed to those efforts with a number of case studies that include photodimerizations [1], [2], solid-state rearrangements [3–6], photomagnetization effects and photoinduced phase transitions of persistent organic radicals [7], unstable radical transients [4], [6] exotic radical states [6], as well as photochromic [8–10] and thermochromic systems [11–14]. Recently, however, there has been an increased awareness that the realm of the solid-state research should be expanded to explore processes underlying conversion of light, chemical or thermal energy into *mechanical energy* (work), which has been elegantly exemplified, among the others, by the pioneering works of Boldyreva, Desiraju,

Etter and Toda. The prospects and the practical importance of these processes as solventless routes to synthetically challenging molecular topologies, as energy-storage or actuator materials, or simply as convenient methods for polymorph differentiation, are reflected as increasing number of reports on mechanochemical, piezochromic, sonochemical, triboluminescent and chemiluminescent reactions. By elucidating the molecular mechanism of thermosolient (jumping) effects [2], [15], photomechanical effects [2] and chemi/bioluminescence [2], [16], [17], we have recently added up a few interesting cases to these, still rare but rapidly expanding studies.

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Insights into reactions of functional materials using pair distribution function analysis

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Understanding how materials react, at an atomic scale, is key to controlling their functional behaviors. These functionalities can be directly derived from the material’s reactivity, for example, reversible electrochemical reactions for lithium-ion batteries or reactions for sequestering radiological waste. Further, functional properties can be strongly dependent on the structure and morphology produced during synthesis, for example, the catalytic activity of metal nanoparticles.

The structural characterization of these reactions can be challenging, due to the diverse phenomena possible; with multiple components of evolving particle size, morphology, and microstructure from multi-atom clusters to multi-million atom crystals. The pair distribution function (PDF) method shows great promise for providing quantitative insight into the kinetics and structure mechanism of such reactions. Recent advances in experimental methods, have improved the efficiency of X-ray PDF measurements, to allow time-resolved experiments with sufficient resolution to study reactions in solid materials (up to 30 Hz). The PDF analysis probes the complete reaction from clusters to bulk, amorphous or crystalline, liquid or solid. This is in contrast to Bragg crystallographic analysis which is “blind” to the clusters which nucleate before growing into long-range ordered, crystalline materials. The structural insights from the PDF data are obtained in parallel with phase fractions and concentration to allow different components to be distinguished and a robust quantitative analysis.

Keywords: PDF, in-situ, reaction