Theoretical Study of Hydrated Gold Nanoparticles for Radiotherapy Applications

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The use of gold nanoparticles (AuNPs) for enhancing radiotherapy performance is very promising. This success has been demonstrated by highly active in vivo and in vitro experimental studies. High Z AuNPs contribute to radiosensitization effect, thus making tumor cells more responsive to ionizing radiation. Upon water radiolysis, AuNPs generate electrons and reactive species such as oxygenated compounds (ROS). Those species favor radiotherapy by amplifying the damages caused by radiations and by concomitantly improving the radiation dose. In principle, AuNPs are synthesized in a PEGylated (encapsulated in a complex assembly of polyethylene glycol ligands) and aqueous environment. To date, little is known regarding the morphology, the structure, and energetics of those nanoparticle systems, especially at the atomic scale.

In this work, we use theoretical approaches to study the mechanism of generation of ROS by AuNPs and to model the water/AuNPs interface explicitly at the atomic level. In particular, we aim to rationalize the interaction between water molecules and AuNPs as a function of the nanoparticle morphology and size. Density Functional Theory (DFT) calculations have been performed to explore the adsorption structures and energetics of water molecules on AuNPs, from single adsorption to a monolayer. Several morphologies of gold clusters have been modeled in the range 0.9-3.3nm. Around 1nm and for a singly adsorbed water molecule, the adsorption strength is the largest one for the icosahedral shape. The most competitive adsorption positions are top sites for water, essentially at the corners of the nanoclusters. The adsorption strength of one water molecule progressively decreases inversely with respect to the nanoparticle size. The stability loss is significant since the adsorption energy is roughly reduced by a factor of two. This suggests weaker solvation effects at larger nanoparticle sizes. For a water monolayer on gold nanoclusters, the adsorption strength is twice stronger, due to the presence of a stabilizing hydrogen bond network (see Figure 1). The interaction energy of water on AuNPs has been decomposed into covalent and dispersive (Van der Waals forces) contributions. These interaction energies are key parameters for future theoretical developments related to multiscale simulations and radiotherapy.

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![Figure 1: Optimal adsorption structure of an explicit water monolayer in interaction with a Au38 nanocluster](image)

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