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Energy deposition at nanometer scale on biological targets irradiated with ion beams

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The understanding of the physical mechanisms producing energy deposition on biological matter, under ion beam irradiation, is a subject of principal interest in radiotherapy and, in particular in hadrontherapy. Modeling the radiobiological damages induced by the ionizing particles crossing the living matter requires a precise knowledge of the full radiation history. It is of prime importance to quantify the full kinematics of the main ionization reactions. Different electronic processes like electron emission and charge exchange appear as the main candidates to get an appropriate description. By using quantum-mechanical models, different molecular targets irradiated with single and multiple charged ions impacting at intermediate and high collision velocities are investigated. Among them, we must mention the four nucleobases (adenine, cytosine, thymine and guanine) as well as the sugar phosphate backbone of DNA and the RNA uracil. Electron emission multiple differential, single differential (as a function of the subtended emission angle and/or the final energy of the ejected electrons) and total cross sections are compared with very good success to represent recent experimental data. For electron capture, measurements are much scarcer and only a few values of total cross sections can be contrasted with theoretical predictions. First calculations show that the energy deposited on the target is governed by charge exchange from core orbitals. On the contrary, outer electrons dominate target ionization total cross sections and also electron capture ones. However, it is proved that energy deposition is dominated by the electron capture reaction, at high enough impact velocities. We focus also our interest in the case of water molecular targets, considering that it is the main compound of the biological tissue. In all ionization and electron capture reactions the role played by Auger emission is evaluated.

To compare the energy deposition patterns at nanometer scale in liquid water and DNA material a Monte Carlo code is applied for the transport of impacting particles. Results are obtained using a simplified cellular nucleus model made of spherical voxels, each one containing randomly oriented nanometer-size cylindrical targets filled with either water or DNA nucleobases. These cylindrical volumes have dimensions comparable to chromatin fiber segments, nucleosomes and DNA segments. The dose absorbed in DNA cylinders is larger than the dose absorbed by cylinders filled with liquid water.

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