

Theoretical Study on Electronic Properties of the Active Site of Multicopper Protein

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[Introduction] The number of metalloproteins is almost half of known protein crystal structure in protein data bank (PDB) file. The metalloprotein takes the important role in many reactions on the biomolecular system, such as redox reaction. The transition metals are the most common ion that exists on the active site of metalloprotein, which copper is the prominent one. There are several popular metalloproteins that contain a varied number of copper ions, such as azurin, plastocyanin, and multicopper oxidase (MCO). The knowledge of electronic properties of these copper protein is important to get the insight into the catalytic mechanism. In this study, we focus on investigating the electronic properties of type I copper site in MCO protein for both reduced (4E9T) and oxidized state (4NER). This protein carries out the oxidation of oxygen into water by involving electron transfer process.

[Computational Method] The type I copper site was extracted from the structure of protein. The hydrogen atom was added into the site and the coordinate was optimized using B3LYP/6-31G(d,p) method. Some electronic properties, such as charge distribution, frontier molecular orbital (FMO) and spin density, was analyzed by recalculating single point energy of optimized structure using B3LYP and M06 method. The electrostatic potential (ESP) charge was derived using Merz-Singh-Kollman scheme. All calculations was conducted using Gaussian 09 package.

[Results and Discussion] The type I copper site in MCO protein consists of copper ion, two histidines, cysteine, and methionine residue. The analysis of FMO in Figure 1 shows that $d_{x^2-y^2}$ orbital of copper ion was found on both HOMO and SOMO. This orbital was involved in the electron transition in ligand to metal charge transfer (LMCT) process. The shape of HOMO and SOMO orbital calculated using both B3LYP and M06 is quite similar. The charge distribution analysis in Figure 2 reveals that partial charge of copper ion calculated using B3LYP is more positive than those calculated using M06. Meanwhile, the partial charge of ligand atom bonded to copper ion is less negative when it was calculated using M06. This reveals that M06 method can account the effect of electron of ligand atom into copper ion better than B3LYP. The existence of one unpaired electron initiates the spin activity on 4NER protein. Figure 3 shows that surface of spin density of 4NER protein calculated using B3LYP and M06 have similar shape with SOMO orbital. The analysis of spin distribution confirms that the activity of unpaired electron was dominant on d orbital of copper ion. The spin distribution of copper ion calculated using M06 is less positive than those calculated using B3LYP. It reveals that the M06 method is better in accounting the activity of unpaired electron on ligand atoms.

[Conclusion] The electronic properties of both reduced and oxidized MCO has been investigated using B3LYP and M06 method. The results show the difference characteristic of electronic properties between both protein. The comparison of calculation method reveals that M06 is better than B3LYP method in representing the electronic properties of type I copper site due to the ability to consider the dispersion effect. It confirms by the difference in charge distribution and spin distribution of copper ion calculated using both methods.

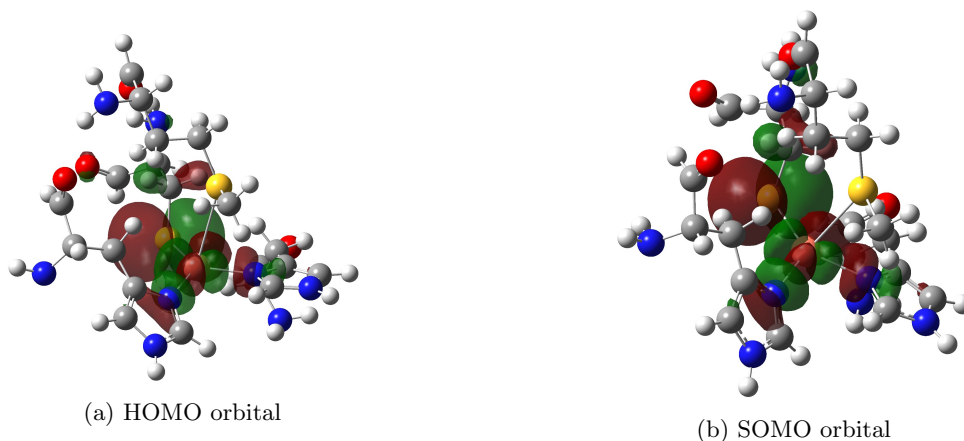


Figure 1: The frontier molecular orbital of (a) 4E9T and (b) 4NER protein.

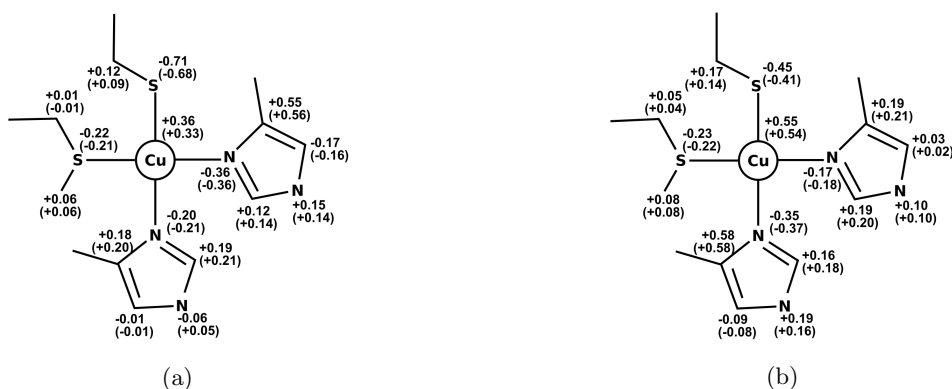


Figure 2: The charge distribution of (a) 4E9T and (b) 4NER protein. The value without parentheses are calculated using B3LYP and these with parentheses are calculated using M06.

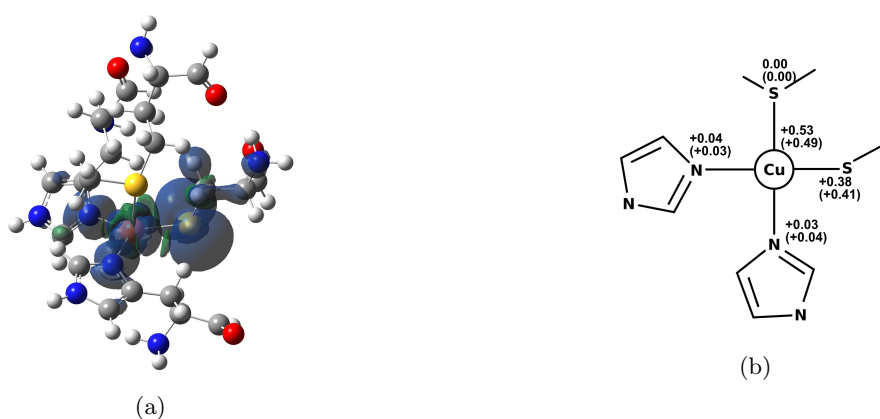


Figure 3: (a) The spin density and (b) spin distribution of 4NER protein. The value without parentheses are calculated using B3LYP and these with parentheses are calculated using M06.

Reference

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