

Research Article

Application of glucose modified bicyclopophite derivative of tri-ruthenium carbonyl cluster as advanced photo acoustic contrast agent

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Abstract: Metal clusters at zero oxidation state are found to have very good applications in medical and bio-medical field of research including drug designing. Very recently organometallic carbonyl clusters of group 8 elements are tested as very good contrast agent for photoacoustic spectroscopy based live cell imaging. Quantum computation based investigation is initiated by Bag and Ghorai to improve contrast behavior of this class of compounds. In this article I have presented the efficiency of glucose modified bicyclopophite derivative of tri-ruthenium carbonyl clusters as photoacoustic contrast agent. I have studied the effect of number of substitutions. In my calculation solvent effect is also included.

Keywords: Photoacoustic contrast agent; Organometallic clusters; Solvent effects; Quantum computation

INTRODUCTION

Quantum computation based investigation of photoacoustic contrast (PAC) behavior of organometallic carbonyl clusters of group 8 elements are initiated by Bag and Ghorai [1] following experimental study on these compounds in this direction by Kong *et al.* in 2014 [2]. Kong *et al.* [2] used an organic derivative of trimetallic carbonyl clusters of iron, ruthenium and osmium and found that osmium derivative has better contrast (410 nm). They used organic derivatives to make the compounds water soluble. But, only a molecular level investigation by Bag and Ghorai [1] explain why osmium derivative shows better contrast. They have shown that the lowest energy absorption of iron cluster has the longest wave length but on derivatization of this clusters with organic ligands change the geometry of osmium cluster which is the reason behind the reverse shift of absorption peak for osmium. They have also shown that substitution of carbonyl ligand (CO) by a soft ligand improves the PAC behavior of the clusters. For this study they replace CO ligand by NO ligand one by one and found that absorption peaks shift to the longer wave length region but not in a regular way rather in a up and down way. Also at the same time the absorption coefficients decrease with increase of number of substitutions. The change of organic chain length is also studied and found that for thiopropanoate derivatives have the optimum activity. Thus, we can't improve the PAC behavior by increasing the organic chain length.

In this article, I have reported the PAC behavior of glucose modified bicyclopophite derivatives of tri-

ruthenium carbonyl cluster. It is observed that this organic ligand improves the PAC capacity of ruthenium clusters. In previous study only one organic ligand is substituted. Here, up to four organic ligands is substituted. Here both gas phase and solvent phase studies are done.

COMPUTATIONAL DETAILS

Geometries of the clusters are optimized using Gaussian 09 package [3]. Geometry optimizations are done without any symmetry constraints. All the minimum energy structures are confirmed by checking that only positive mode of harmonic vibrational frequency are present. The convergence thresholds are set to 0.000015 Hartree/Bohr for the forces, 0.00006 Å⁰ for the displacement and 10⁶ Hartree for the energy change. All calculations are performed with the density functional theory (DFT). For all DFT calculations, unrestricted Becke's three parameter hybrid exchange functional [4] combined with exchange component of Perdew and Wang's 1991 functional [5-8], abbreviated as B3PW91, are used. Basis set used for all calculations are Lanl2dz basis which is available in Gaussian 09 package. This basis is used because for ruthenium (Ru), only this series of basis functions are available.

To study the absorption spectra of the compounds used here time-dependent DFT (TDDFT) calculations are performed with optimized geometries. Here *nstates* (number of excited states specification for TDDFT calculation) is set to 50. Thus, only few lower energy absorptions are considered.

RESULTS AND DISCUSSIONS

Glucose modified bicyclic phosphite derivative of tri-ruthenium carbonyl clusters have been chosen for this study because it is synthesized and tested for the treatment of cancer disease [9]. These compounds are found as stable and less toxic. Mono-, di-, tri- and tetra-substituted cluster derivatives are used for this study. Both gas phase and solution phase (water is taken as solvent) calculations are done. For solution phase calculation IEFPCM model is used which is available in Gaussian 09 package. Calculated results are presented in Table-1.

Table-1: Absorption peaks of different cluster derivatives

Number of substitutions	Absorption peak – Gas phase (nm)	Absorption peak – Solution phase (nm)
1	498 (0.07)	513 (0.07)
2	506 (0.06)	540 (0.06)
3	498 (0.06)	524 (0.05)
4	495 (0.05)	507 (0.06)

All four derivatives are having absorption near 500 nm. Thiopropanoate derivative of ruthenium carbonyl cluster has absorption at 296 nm with oscillator strength 0.045. But mono substituted derivative of

ruthenium carbonyl cluster with glucose modified bicyclic phosphite ligand shows a huge improvement in absorption. Absorption shifts to words low energy region by more than 200 nm. At the same time oscillator strength increases significantly. Absorption peaks do not vary too much with change of number of substitutions. This implies that low lying excitations are involved only metal atoms and charge cloud over metal atoms do not change significantly on di-, tri- or tetra- substitutions. Very small increase (8 nm) of lambda for di-substitutions may be due to increase of dipole moment which indicates charge separation to some extent. But significant improvement is observed when solvent effect is included in DFT calculations. Thus, we expect that calculated results would not deviate too much in practical case.

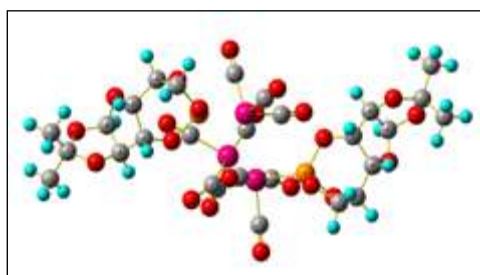


Fig-1: Optimized geometry of di-substituted tri-ruthenium carbonyl cluster

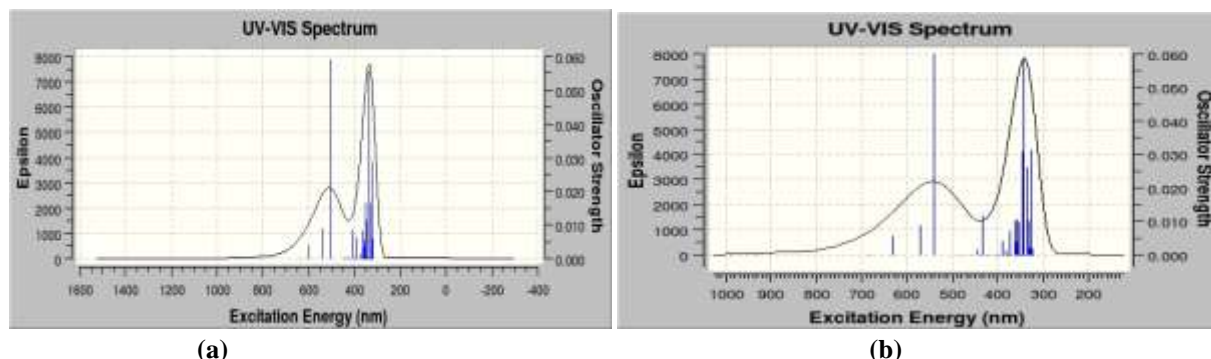


Fig-2: Absorption spectrum of di-substituted tri-ruthenium carbonyl cluster derivatives (a) in gas phase (b) in solution

CONCLUSIONS

In the present study, effect of number of substitutions to the organometallic clusters is studied with respect to their photoacoustic contrast behavior. It is found that di-substituted glucose modified bicyclic phosphite derivative of tri-ruthenium carbonyl cluster has very good PAC capacity with intense absorption near 540 nm with high oscillator strength (0.06). From this study we may conclude that by increasing the number of substitutions of the same kind we cannot improve PAC activity of these types of clusters. Organic substitutions with different ligand may be number dependent. Clusters with different metal atoms may have improved PAC behavior. Increase of

metal cluster size may be another way to improve PAC behavior. These studies would be the next target to words improved PAC agent using organometallic clusters.

ACKNOWLEDGMENTS

I acknowledge IISER Kolkata, India, for funding and research facilities and Dr. Pradip Kr. Ghorai, Associate Professor, IISER Kolkata to allow me to publish this work independently.

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