

Prediction of the Molecular Structure, Internal Rotational Barriers and Vibrational Frequencies of Formamide by Non-local Density Functional Theory

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A state-of-the-art non-local density functional study of formamide is reported and compared with experimental molecular structure, internal rotational barriers and vibrational frequencies.

Formamide is the simplest molecule containing a peptide moiety and hence has been the focus of numerous experimental²⁰ and theoretical studies.³⁹ Many of these studies were carried out on formamide with a view to understand the molecular structure and energetics of the peptide moiety, which is of fundamental importance to protein structure.

The calculation of the energy surface for even the simplest peptide is a challenging task. Therefore continuing refinement of the force fields for proteins depends on first-principle quantum chemical methods. Density functional theory (DFT), originally developed for problems in solid state physics, is a first-principle quantum chemical method⁶ which includes a treatment of electron correlation and has also been demonstrated to be of comparable accuracy and computational efficiency⁷ to post-Hartree–Fock methods. The precise extent of the importance of electron correlation in the calculation of conformational energies of peptides remains unknown at the present time, although its importance has been demonstrated by previous studies.¹⁰

DFT is better suited for application to large molecules of biological interest.¹¹ Previously, DFT calculations were performed with local density functionals (LDF) for exchange and correlation.⁶ However, more recently DFT calculations are being performed using non-local density functionals (NLDF) which are considered to be more accurate than LDF theory especially for the description of molecular structure and energetics.^{6,7}

Despite the large number of experimental²⁰ and theoretical studies³⁹ of formamide, its structure has been controversial. The peptide moiety was assumed from the early work of Pauling and Corey to be planar, and more recently, however, the planarity of the peptide moiety has been questioned. Two early microwave studies of formamide have reached different conclusions^{12,13} on the planarity of the peptide moiety. From a theoretical point of view, only recently have very high-level first-principle quantum chemical methods, Hartree–Fock,⁴³ n^{th} order Moller–Plesset perturbation,⁴³ configuration interaction,⁴¹ coupled-cluster³⁶ and DFT^{38–40} been applied to formamide. To date, no systematic study of the geometries, internal rotational barriers, and vibrational frequencies of formamide using different NLDF has been reported in the literature.

The DFT-calculated geometries of formamide are generally better than those predicted by HF theory, while those calculated using the adiabatic connection method (ACM)²⁵ in particular are comparable with MP2, with the remaining NLDFs falling inbetween the HF and MP2 methods. Two transition states (Fig. 1) were found at the DFT level for the internal rotation about the peptide bond of formamide. The DFT-calculated rotational barrier heights for the two transition states range from 18 to 20 kcal mol⁻¹, which are within the experimentally observed rotational barrier heights.¹⁷ The

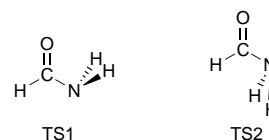


Fig. 1 Schematic representations of the two transition states found in this study (TS1 and TS2)

vibrational frequencies for formamide are significantly in better agreement with experiment than both the HF and MP2 calculated frequencies.

Techniques used: Non-local density functional theory

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Table 1: Comparison of experimental and calculated geometries of formamide

Table 2: Calculated geometries for the transition states of formamide

Table 3: Comparison of experimental and calculated rotational barriers for formamide

Tables 4 and 5: Comparison of experimental and calculated vibrational frequency for formamide

Table 6: Comparison of calculated vibrational frequencies for the transition states of formamide

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