

^{13}C – ^{13}C Spin–Spin Coupling Constants in Structural Studies: XLIV. Carbonyl-Containing Oximes

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Abstract— ^{13}C – ^{13}C spin–spin coupling constants in carbonyl-containing oximes were calculated in terms of the second-order polarization propagator approximation (SOPPA) with account taken of the results of theoretical conformational analysis. Stable conformations of all carbonyl-containing oximes were found to have *s-trans* orientation of the carbonyl group in the *E* and *Z* isomers. The corresponding ^{13}C – ^{13}C coupling constants showed a characteristic dependence upon internal rotation of the carbonyl-containing substituent, which may be used to determine predominant rotational conformations of these compounds. A relation between orientation of the C=O bond and ^{13}C – ^{13}C coupling constants for the adjacent bonds in oximes was revealed; it may be attributed to hyperconjugation between the corresponding carbon–carbon bond and antibonding orbital of the C=O bond.

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The present work continues the series of our previous studies [1] aimed at establishing the configuration of the double C=N bond in oximes using ^{13}C – ^{13}C coupling constants. As shown in [2], these constants are clearly related to orientation of the lone electron pair (LEP) on the imino nitrogen atom [2]. Oximes play versatile role in organic synthesis and practical applications [3]. Strong interest in oximes originates from their use in the synthesis of various heterocyclic systems, in particular pyrroles and *N*-vinylpyrroles [4] as structural fragments of conducting polypyrroles, materials for optoelectronics, and sensors based thereon [5]. Therefore, elucidation of structural specificity and intramolecular interactions in oximes is undoubtedly an important problem.

Of exceptional interest are carbonyl-containing oximes that have unusual structure and open a direct route to the corresponding carbonyl-containing aziridines characterized by slow pyramidal inversion [6]. In the present article we report on four most interesting derivatives of this series, which contain acetyl and ester fragments at the oxime group: butane-2,3-dione 2-oxime (**I**), pentane-2,3,4-trione 3-oxime (**II**), methyl 2-hydroxyiminopropanoate (**III**), and dimethyl 2-hydroxyiminomalonate (**IV**). These carbonyl-containing

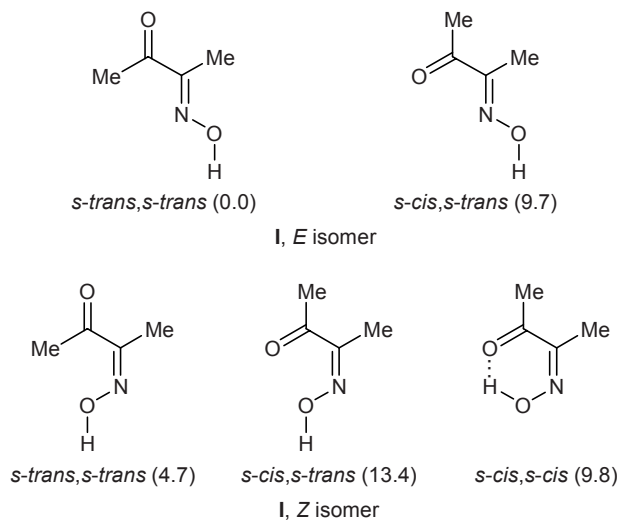
oximes are characterized by strong conformational effects related to internal rotation of the acetyl or methoxycarbonyl group with respect to the C=N bond plane.



I, R¹ = Ac, R² = Me; **II**, R¹ = R² = Ac; **III**, R¹ = MeOCO, R² = Me; **IV**, R¹ = R² = MeOCO.

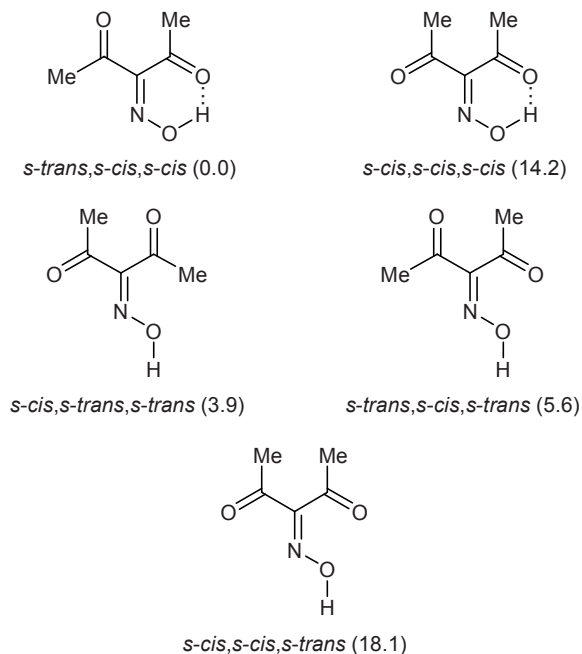
Stereochemical dependence of ^{13}C – ^{13}C coupling constants on the configuration of the C=N bond and rotation of the carbonyl-containing groups in oximes **I–IV** was studied by high-level nonempirical calculations. Apart from *E/Z* isomerism with respect to the C=N bond, compounds **I–IV** give rise to rotational isomerism with a relatively low barrier. Stable rotamers of both *E* and *Z* isomers of all the examined compounds are characterized by *s-trans* orientation of the carbonyl group with respect to the C=N bond, presumably due to more effective π – π interaction between the oxime and carbonyl groups.

Calculation of the relative total energies E_t of localized conformers of butane-2,3-dione 2-oxime (**I**), performed at the B3LYP/6-311G* level of theory, showed that the *E* isomer with *s-trans* orientation of the acetyl group is preferred (E_t values, kcal/mol, are given in parentheses). This result was confirmed by the IR spectral data [7]. The corresponding *s-trans,s-trans* conformer was also found to predominate for the less energetically favorable *Z* isomer of **I**. It should be noted that formation of intramolecular hydrogen bond in the *s-cis,s-cis* conformer of *Z*-**I** (cisoid orientation of the hydroxy group with respect to the N–O bond) gives rise to an energy gain of 3.6 kcal/mol relative to transoid orientation of the OH group (*s-cis,s-trans* conformer). The results of our calculations showed that all localized conformers of both isomers of compound **I** have planar structure which ensures optimal overlap of interacting π orbitals.



On the other hand, the presence of two acetyl groups and one hydroxy group in the molecule of oxime **II** creates considerable steric hindrances to coplanar arrangement of the double bonds in all localized conformers. For example, intramolecular interactions in the *s-cis,s-cis,s-trans* conformer between lone electron pairs on two carbonyl oxygen atoms and one hydroxy oxygen, as well as on the nitrogen atom, force both acetyl groups to decline from the C=N bond plane by an angle of up to 60°. In terms of the additivity scheme, the energy of such interaction may be estimated at 3.9 kcal/mol. Despite numerous attempts, we failed to localize a planar conformer of compound **II**. The nonplanar *s-cis,s-trans,s-trans* conformer is more favorable by 1.7 kcal/mol than *s-trans,s-cis,s-trans* with *s-trans* orientation of the acetyl group. The latter

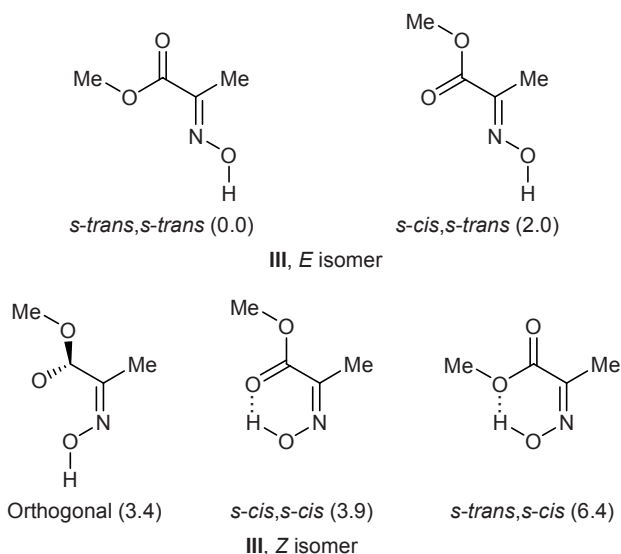
is characterized by strong repulsion between lone electron pairs on the carbonyl and hydroxy oxygen atoms.



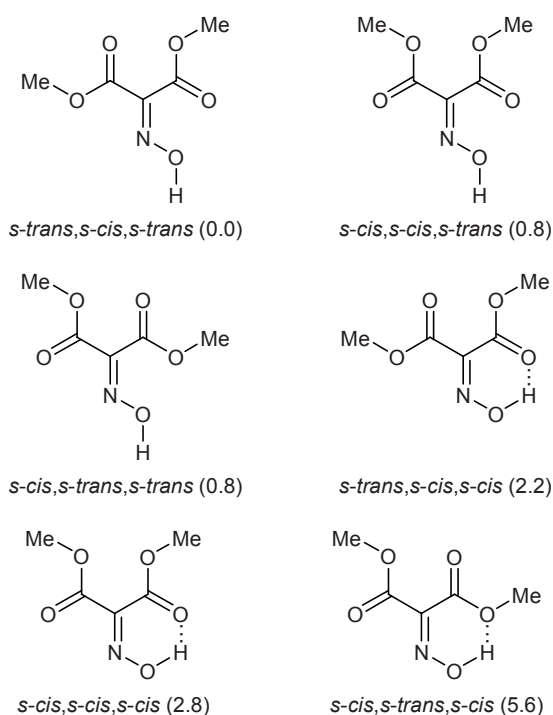
Intramolecular hydrogen bonding in the *s-trans,s-cis,s-cis*, *s-cis,s-cis,s-cis* and *s-cis,s-cis,s-trans* conformers produces an energy gain of 5.6 and 3.9 kcal/mol, respectively, as compared to *s-trans,s-cis,s-trans* and *s-cis,s-cis,s-trans*. The acetyl group in the most energetically favorable *s-trans,s-cis,s-cis* conformer has *s-trans* orientation; however, the stability of this conformer is determined by intramolecular hydrogen bond between the acetyl oxygen atom and hydroxy proton (the interatomic distance O...H is 1.767 Å). This factor, i.e., orientation about the N–O bond, is crucial in the stabilization of the above conformer. The relative total energies of conformers with cisoid orientation of both acetyl groups (*s-cis,s-cis,s-cis* and *s-cis,s-cis,s-trans*) are considerably higher due to strong steric repulsion between LEPs on the oxygen and nitrogen atoms.

The localized rotamers of the *E* and *Z* isomers of oxime **III** are shown below. The *E* isomer preferentially adopts *s-trans,s-trans* conformation, while the relative total energy of the *s-cis,s-trans* conformer is 2.0 kcal/mol. The *Z* isomer was found to give rise to three rotational conformers: two conformers with cisoid orientation of the hydroxy group (stabilized by intramolecular hydrogen bond) and one orthogonal conformer in which the ester group is turned through an angle of 105° with respect to the oxime fragment. The stability of the latter conformer is determined mainly by strong steric interactions rather than by π – π

conjugation between the C=N and C=O bonds, which may be effective only in the planar structure.



The calculations of diester **IV** revealed three non-planar low-energy conformers with transoid orientation of the hydroxy group and three high-energy conformers with cisoid orientation of the hydroxy group and intramolecular hydrogen bond. Strong steric repulsion between the oxime oxygen atom and carbonyl (*s-trans,s-cis,s-trans* and *s-cis,s-cis-s-trans*) or ester oxygen atom (*s-cis,s-trans,s-trans*) induce rotation of the methoxycarbonyl group by an angle of up to 94°



with respect to the oxime fragment. No such interaction occurs for the substituent oriented *trans* with respect to the hydroxy group, so that the second methoxycarbonyl group oriented both *s-cis* and *s-trans* can be arranged almost in the same plane as the oxime fragment, the corresponding dihedral angle being only 6° . The fact that *s-trans* orientation of the methoxycarbonyl group in the *s-trans,s-cis,s-trans* conformer of **IV** is more stable (by 0.8 kcal/mol) provides further support to the general relation found for carbonyl-containing oximes, according to which *s-trans* orientation of the carbonyl group is preferred.

Our results indicate that the stability of different conformers of carbonyl-containing oximes is determined by several factors. On the one hand, effective interaction between π orbitals of the C=N and C=O bonds is possible in planar structure with *s-trans* orientation of these multiple bonds, as in compounds **I**, **II**, and *E*-**III**. On the other hand, increase in the size of substituents destabilizes the system as a result of strong steric interactions between lone electron pairs on the oxygen atoms in the ester and oxime fragments, as in structures *Z*-**III** and **IV**. Finally, intramolecular hydrogen bond in structures with cisoid orientation of the oxime hydroxy group stabilizes the corresponding conformers, which is clearly observed for oximes **I** and **II** having acetyl groups and is weakly reflected for oximes with **III** and **IV** with bulkier methoxycarbonyl fragments.

The results of theoretical conformational analysis of compounds **I**–**IV** were used to calculate ^{13}C – ^{13}C coupling constants for the predominant conformers (see table). The ^{13}C – ^{13}C coupling constants were calculated in terms of the second-order polarization propagator approximation (SOPPA) [8] with account taken of Fermi-contact (J_{FC}), spin-dipole (J_{SD}), diamagnetic spin-orbital (J_{DSO}), and paramagnetic spin-orbital contributions (J_{PSO}) with the use of special correlation-consistent Dunning basis sets [9] extended by internal correlation functions [10] as described in [11]. This high-level nonempirical approach was shown to be appropriate for the calculation of ^{13}C – ^{13}C coupling constants in small and medium-size organic molecules [12], including oximes [1]. The data in table show a good agreement between the calculated ^{13}C – ^{13}C coupling constants and available experimental values [13], indicating suitability of the applied calculation method.

Interactions of lone electron pairs with bonding and antibonding molecular orbitals of the neighboring carbon-carbon bonds [2] in carbonyl-containing oximes **I**–**IV** lead to considerable variations of $J(\text{C}^1, \text{C}^2)$ and

Calculated^a (SOPPA) and experimental ^{13}C – ^{13}C coupling constants (Hz) for the predominant conformers of carbonyl-containing oximes **I–IV**

Comp. no.	Isomer	Conformer	J_{DSO}	J_{PSO}	J_{SD}	J_{FC}	J	J_{exp} [13]
I	<i>E</i>	<i>s-trans,s-trans</i>	0.35	–1.57	0.84	57.24	56.86	59.0
	<i>Z</i>	<i>s-trans,s-trans</i>	0.35	–1.18	0.98	42.67	42.82	
II		<i>s-trans,s-cis,s-cis</i>	0.37	–1.56	0.90	56.91	56.62	58.5
			0.38	–0.98	0.74	45.06	45.20	47.9
III	<i>E</i>	<i>s-trans,s-trans</i>	0.40	–1.48	0.72	80.76	80.40	
	<i>Z</i>	Orthogonal	0.41	–1.28	0.75	64.88	64.76	
IV		<i>s-trans,s-cis,s-trans</i>	0.44	–1.42	0.69	85.00	84.71	87.9
			0.45	–0.83	0.63	75.12	75.37	75.3

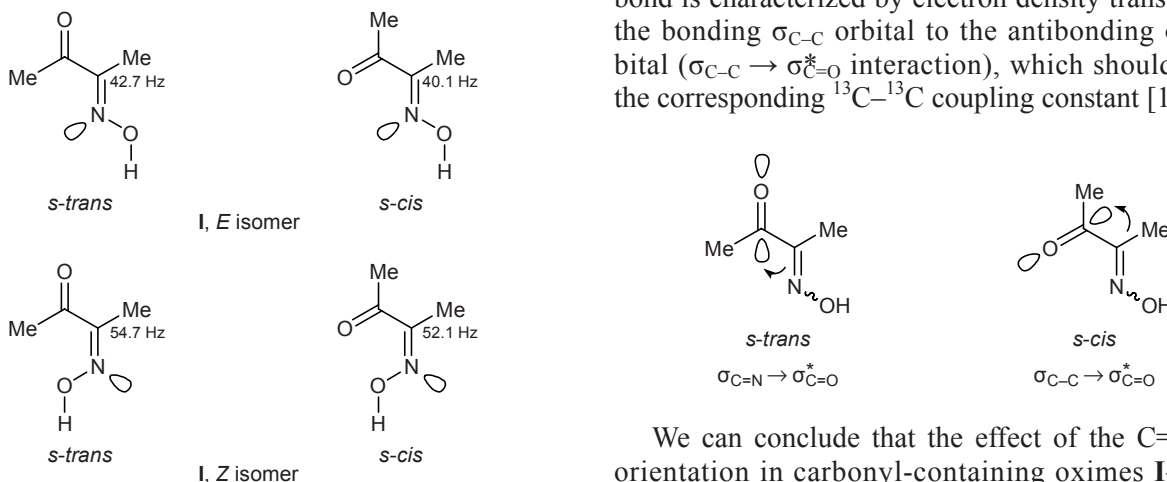
^a All calculations were performed assuming C_1 point symmetry group with the use of cc-pVTZ-Cs basis set for the interacting carbon atoms and cc-pVDZ basis set for the other atoms.

$J(\text{C}^2, \text{C}^3)$. As might be expected, the total ^{13}C – ^{13}C coupling constant for oximes **I–IV** is determined by the Fermi–contact contribution which ranges from 43 to 85 Hz. Noncontact interactions J_{PSO} , J_{DSO} , and J_{SD} are weakly sensitive to the substituent nature, and their contributions to the overall $^1J_{\text{CC}}$ values are insignificant (their sum generally does not exceed 1%). The total ^{13}C – ^{13}C coupling constants also depend to an appreciable extent on mutual orientation of the C=O and C=N bonds. For example, the difference in the coupling constants $J(\text{CO}, \text{CN})$ for the *s-trans* and *s-cis* conformers of **I–IV** exceeds 6 Hz; presumably, the reason is different orders of the corresponding formally single carbon–carbon bond in structures with *s-cis* and *s-trans* orientations of the C=O and C=N bonds.

Thus the LEP effect on the ^{13}C – ^{13}C coupling constants predominates over strong conformational effects related to internal rotation of the acetyl and methoxy-carbonyl groups. Therefore, $^1J_{\text{CC}}$ values can be used to determine configuration of carbonyl-containing oximes having a complex structure. Apart from the LEP effect,

the ^{13}C – ^{13}C coupling constants in oximes **I–IV** are influenced by hyperconjugation effects depending upon spatial orientation of the C=O bond. For example, hyperconjugation in the *E* and *Z* isomers of oxime **I** affects stereochemical behavior of $J(\text{C}^2, \text{C}^3)$ in going from *s-trans* to *s-cis* orientation of the carbonyl group with respect to the C=N bond.

The above relations were studied in [14] by theoretical methods. It was shown that the reason is different hyperconjugation interactions in the two conformers, which imply electron density transfer from the bonding C–C and C=N orbitals to the antibonding C=O orbitals. Two types of hyperconjugation effects in oximes **I–IV** may be distinguished. On the one hand, cisoid orientation of the double C=O bond with respect to the C=N bond gives rise to electron density transfer from the bonding σ orbital of the C=N bond to the antibonding σ^* orbital of the C=O bond ($\sigma_{\text{C=N}} \rightarrow \sigma_{\text{C=O}}^*$ interaction), which should increase the ^{13}C – ^{13}C coupling constant [14]. On the other hand, transoid orientation of the double C=O bond with respect to the C=N bond is characterized by electron density transfer from the bonding $\sigma_{\text{C-C}}$ orbital to the antibonding $\sigma_{\text{C=O}}^*$ orbital ($\sigma_{\text{C-C}} \rightarrow \sigma_{\text{C=O}}^*$ interaction), which should reduce the corresponding ^{13}C – ^{13}C coupling constant [14].



We can conclude that the effect of the C=O bond orientation in carbonyl-containing oximes **I–IV** ap-

pears as a result of combination of two types of hyperconjugation interactions, one of which considerably increases the ^{13}C – ^{13}C coupling constant (*s-trans* orientation of the C=O and C=N bonds) while the other reduces it (*s-cis* orientation). The sum of these effects determines the difference in the ^{13}C – ^{13}C coupling constants for the *s-cis* and *s-trans* conformers of carbonyl-containing oximes, which is estimated at about 3 Hz. Our results are supported by our previous data [15] on the ^{13}C – ^{13}C coupling constants in iminodihydrofurans, according to which the overall effect of the $\sigma_{\text{C}=\text{C}} \rightarrow \sigma_{\text{C}=\text{O}}^*$ and $\sigma_{\text{C}-\text{C}} \rightarrow \sigma_{\text{C}=\text{O}}^*$ hyperconjugation interactions on $^1J_{\text{CC}}$ values was also about 3 Hz.

The effect of C=O bond orientation in carbonyl-containing oximes I–IV does not exceed 4 Hz, i.e., it is much lower than the effect of LEP, which can reach 15–20 Hz. Therefore, $^1J_{\text{CC}}$ values can be used for unambiguous assignment of configuration of carbonyl-containing oximes with different structures. On the other hand, the effect of C=O bond orientation on ^{13}C – ^{13}C coupling constants is sufficiently large to be used in conformational analysis of carbonyl-containing oximes, specifically for studying internal rotation of acyl and alkoxy carbonyl groups with respect to the oxime bond plane.

EXPERIMENTAL

Quantum-chemical calculations were performed using GAMESS [16] and DALTON software [17]. The geometric parameters were optimized, and the total energies were calculated, in terms of the Moeller–Plesset second-order perturbation theory (MP2/6–311G**). The ^{13}C – ^{13}C coupling constants were calculated using the second-order polarization propagator approximation (SOPPA) with standard or modified basis sets (for detailed specification, see [11]).

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