

A computational investigation of the photochemical oxaziridine and amide conversion process of open-chain conjugated nitron with electron-withdrawing trifluoromethyl group on nitrogen

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Abstract. This computational study investigates the photo-excitation process and subsequent photoproduct formation steps through non-radiative deactivation channels in open-chain conjugated N-substituted nitron systems (model compounds of corresponding retinyl nitrones) having electron-withdrawing groups on nitrogen. Calculations mostly based on CASSCF/6-31G* and CASMP2/6-31G* level of theories on a representative system with N-trifluoromethyl substituent have predicted initial photo-excitation to a planar singlet state. This photochemical path is subsequently followed by a barrierless non-radiative channel towards the lowest-energy conical intersection (CI) geometry having a terminal CNO kink, and situated at 30 kcal/mol below the planar excited state. Following the direction of its gradient difference (GD) vectors, an oxaziridine-type species ($R_{C-O} = 1.38 \text{ \AA}$, $R_{N-O} = 1.53 \text{ \AA}$, $\angle CNO = 55.8^\circ$) appears at 3–6 kcal mol⁻¹ below the ground state nitron system through a transition state (along its reverse direction of minimum-energy path), situated on the reaction pathway. This species with an elongated N-O bond seems to be heading towards an amide geometry. On the other hand, in the opposite GD vector direction a proper oxaziridine geometry has been obtained with a much shorter N-O bond distance ($R_{N-O} = 1.42 \text{ \AA}$).

Keywords. CASSCF; N-substituted nitron; oxaziridine; conical intersection; singlet excited state.

1. Introduction

The nitron-oxaziridine photochemical conversion has been experimentally attempted by several groups in the last few decades. Photo-irradiation study on nitrones reported in the last century by Splitter *et al.*^{1,2} is considered to be one of the most significant contributions in this field. In contrast to the photochemical conversion to oxaziridine, the cis-trans isomerization reactions of nitrones were found to occur thermally or in presence of photosensitizers, such as uranine, eosine, iodine, etc. This cis-trans isomerisation^{3,4} process was reported to involve the triplet excited states, while the normal photo-excitation of the ground state nitron species was found to involve the singlet excited state in the formation of oxaziridine and several rearrangement products. The oxaziridines formed on photo-irradiation of nitrones were found to vary in stability. Photochemical studies on α -(2-naphthyl)-N-methylnitron and its N-t-butyl derivatives were found⁵ to give stable oxaziridines, while its N-(p-tolyl) derivative was found to be highly unstable. Several other examples are

also there, where N-alkyl- α -arylnitrones were reported to give more stable oxaziridines on photo-irradiation in comparison to the N, α -diarylnitrones.^{1,2} Photo-excitation studies on conjugated long-chain nitrones have also given similar indications. The chemopreventive N-methyl retinyl nitron⁶ was found to convert slowly to stable oxaziridine under the exposure to room light. Recently our group⁷⁻⁹ has also identified oxaziridine as the primary photoproduct of these types of nitrones from computational analysis. In fact, it is now well-known from experimental studies that N-alkyl group on nitrones stabilizes the oxaziridine while the N-aryl or electron-withdrawing groups (EWG) on nitrogen have an opposite effect. In the latter cases, an amide is usually found to form, which was suspected to happen through a biradical mode¹⁰ after the N-O bond cleavage.

Oxaziridines with electron-withdrawing groups (N-sulfonyl, N-acyl, perfluorinated oxaziridines) on nitrogen are known to be electron deficit and used as the source of electrophilic oxygen. However, conversion of nitrones to these oxaziridines by photo-irradiation is not well-known. It must be mentioned here that the photolysis of nitrones is not the only method for preparation of

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oxaziridines; oxidation of imines and electrophilic amination of ketones are also known to be popular methods for preparing oxaziridines. In fact, oxaziridines containing electron-withdrawing groups on nitrogen are usually prepared by these methods only. This work is aimed to investigate the possibility of oxaziridine formation on photo-irradiation of these types of acyclic nitrones. It is quite interesting that in spite of being a well-known starting material for oxaziridine preparation, nitron photo-irradiation is not preferred for its preparation except for *N*-alkyl (and *N*-benzyl) substituted systems. The appearance of a lone pair of electrons on the nitrogen atom is required to form oxaziridine from nitron which initially contains a positive charge; the change from sp^2 to sp^3 hybridization (planar to pyramidal) of nitrogen is essential for its formation. The presence of +I effect of alkyl groups on nitrogen can satisfy this requirement and probably facilitate the oxaziridine formation. On the contrary, electron-withdrawing groups will take the electron cloud away from the nitrogen and may not facilitate the formation of a proper oxaziridine structure due to the less-availability of lone pair. From the experimental point of view, lack of study on this photochemical reaction is probably due to the fact that detecting and isolating oxaziridines formed on photo-irradiation of such nitrones are difficult in practice. It is possible that electron-withdrawing groups on nitrogen make the nitron highly unstable, and therefore unavailability of a stable nitron of this kind makes them a poor choice for oxaziridine preparation under photo-irradiation.

Our choice of conjugated chain nitrones (figure 1) with EWG on nitrogen (which can be considered as a model compound of the corresponding *N*-substituted retinyl nitron system) is related to the fact that this sort of nitrones can bring some stability in the systems due to the conjugated bonds. In fact, the *N*-substituted retinyl nitron compounds⁶ were reported to be highly stable nitrones in dark. We have assumed that a conjugated nitron system with electron withdrawing *N*-substituent might be more stable than a smaller non-conjugated one, though it has not been reported experimentally, so far. In other words, we have tried to choose a possible stable nitron system as the starting material so that maximum chance of oxaziridine formation can be given to that species, as it is not known experimentally whether the unstable nature of the parent nitron has restricted the nitron-oxaziridine formation by photo-irradiation or is it truly not possible for some other reason.

In this present study we have avoided aryl nitrones as they are already known to be a poor choice for stable oxaziridine preparation. Another reason for

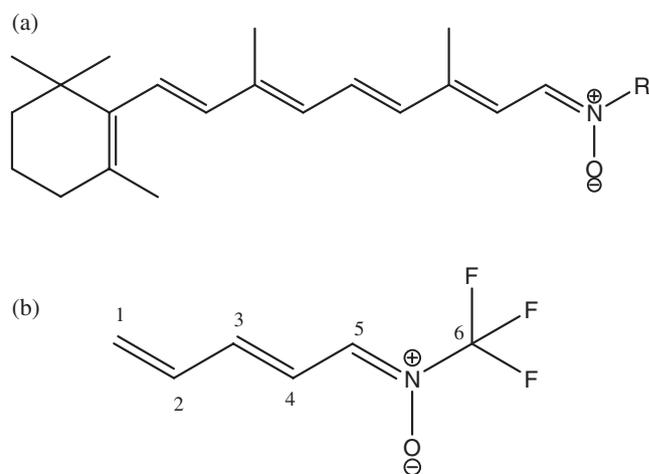


Figure 1. (a) Structure of *N*-alkyl retinyl nitron; and (b) studied *N*-trifluoromethyl-substituted model nitron system.

choosing the model 2,4-pentadiene-nitron system with *N*-electron withdrawing group is to compare this system with our earlier reported structurally similar nitron system with electron-donating *N*-alkyl substituents.⁸ Now let us focus on the reason for choosing trifluoromethyl group as an EWG on the nitrogen atom in this conjugated nitron system. It has already been stated that presence of *N*-substituted phenyl rings in nitrones always lead to non-isolable oxaziridines; on the other hand, *N*-sulfonyl,^{11–13} and perfluorinated¹⁴ oxaziridines are never reported to be prepared from the photo-irradiation of their corresponding nitrones. So, electron-withdrawing π -conjugating or hyperconjugating *N*-substituents in nitrones either forms an unstable oxaziridine or no oxaziridine during their photo-irradiation process. For some certain reasons in our present theoretical studies, the trifluoromethyl group is chosen as an EWG on the nitrogen atom in this conjugated nitron system. This small halomethyl group is taken as a representative one for an electron-withdrawing group capable of involving the accumulated electronic charge on the nitrogen atom in π -conjugation through its negative hyperconjugative effect^{15,16} (discussed later on), which is capable of taking away the lone pair cloud from nitrogen. Our primary objective was to include a strong electron-withdrawing group on nitrogen having the above-mentioned features with a relatively smaller size. The simplest of the perfluoroalkyl family, the trifluoromethyl group has been chosen for this purpose which has a van der Waals radius of 2.7 Å and a comparable electronegativity (3.5) as the oxygen atom.¹⁷ A bulky group on the nitrogen atom will hinder the planar to pyramidal conversion step of nitrogen in the oxaziridine formation process, and we have tried to avoid this steric factor by using a relatively smaller group. Overall,

our choice of the studied nitron system is basically related to provide a maximum possible chance of stable oxaziridine formation. Whether oxaziridine formation from nitrones with such electron-withdrawing group on nitrogen is possible or not, can be significant in nitron photochemistry, which is still yet to be explored.

The success of this entire investigation depends on the proper analysis of the possible non-radiative decay channels operating through the conical intersections. Our studies involve high-level quantum mechanical investigations on the important points on the excited state surfaces, such as the excited state minima, transition states and conical intersection points. The resulting mechanism of the studied nitron system is compared with our previously reported nitron-oxaziridine photochemical conversion process of the N-alkyl-substituted conjugated nitron system.⁸ The final results of this study has not only proposed a mechanism for the photoexcitation process of this kind of model nitron system but also indicated that one of the predicted photoproducts of the corresponding retinyl system may lie in the category of pharmacologically important class of compounds.

2. Computational Details

Quantum mechanical studies presented in this work are mostly done by the Gaussian 09 suite of program¹⁸ The equilibrium geometry and conical intersection optimization calculations have been carried out using the CASSCF^{19–24} method with the 6-31G* basis set. The optimized geometries are compared using different active space sizes, which include (4,4), (6,6) and (8,8). However, for studies related to the transition states and conical intersections, we have preferred to use a smaller (4,4) active space. The reason for choosing this active space has been explained in this section. It is always better to have some amount of prior knowledge of the system under photochemical investigation for the choice of appropriate molecular orbitals for setting up the CAS space. Use of a large active space is not always a good idea and may often lead to huge computational costs; moreover, it may take our desired reaction to a completely different direction as well, and lead to a different photo product. However, reducing the active space size without any prior knowledge of the studied photochemical path can also introduce huge errors in the results. Therefore, if we have some prior knowledge of the studied photochemical reaction path, certain intuitions may be extremely helpful to choose an accurate minimal active space by eliminating the less important orbitals for that particular reaction from the

calculations. In our present calculations, we have used an active space consisting of 4 active electrons in 4 active orbitals (4, 4) for studying the possibility of oxaziridine formation from the trifluoromethyl-substituted nitron. This choice of CAS space in our present work has been done based on the prior experience of successful tracking of the nitron-oxaziridine photoconversion path of our previously studied retinyl nitron, their model compounds and naphthyl nitron systems;^{7–9} the choice made in those cases were based on the chemical intuition looking at their reported experimental photochemical results.^{5,6} In all these cases, the CASSCF studies had confirmed that the oxaziridine ground state species is formed through the lowest-energy conical intersection geometry which involves a terminal CNO twist, and this process was found to be perfectly captured by use of a proper (4,4) active space. It is a well-known fact that there is no single correct active space in a molecule;²⁵ the choice of active space depends on the particular process being carried out. For the oxaziridine conversion process from the conjugated N-substituted nitrones, this smaller active space is found to be the successful one to correctly capture this photochemical route; however, for some other processes of these conjugated nitrones, this chosen active space may not be correct. A similar result is also expected to be true in our current calculations as this system is structurally similar to our previously studied N-alkyl conjugated model compounds of retinyl nitrones, and therefore, we have used the (4,4) active space. The orbitals involved in the active space are shown in figure 2. It should be added here that we have also carried out test calculations using the higher active spaces, such as (6,6) and (8,8) to check whether they are capable to produce any terminally twisted oxaziridine geometry or not. However, our attempts were unsuccessful, and this has been discussed in Supplementary Information of this paper. Their inability to produce such a reaction path has actually justified our initial intuition to be correct behind choosing the smaller (4,4) active space.

Dynamic correlation effect of Moller-Plesset perturbation (MP2) level has been included through single point calculations on top of the CASSCF/6-31G* optimized geometries. For locating the transition states, the normal TS technique based on the Berny-algorithm has been employed.²⁶ Intrinsic reaction coordinate (IRC) method has been used to follow the minimum energy path from the transition state.^{27–29} In addition to these studies, GUGA (Graphical Unitary Group Approach)-based configuration interaction singles and doubles (CISD) technique has also been used for some important calculations through the GAMESS^{30–34} suite of programs. In the CISD calculations, the RHF/6-311G* method

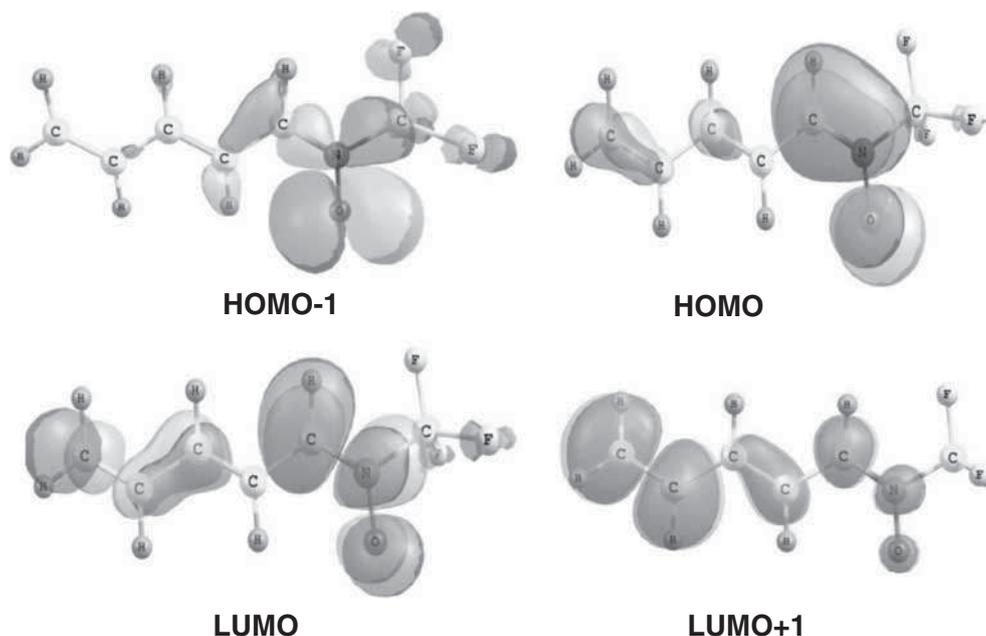


Figure 2. Molecular orbitals involved in the (4, 4) active space in the CASSCF/6-31G* calculations.

Table 1. Structural parameters (Å) of the optimized ground state and excited state geometries at various level of calculations.

STATE	METHOD	C1-C2	C2-C3	C3-C4	C4-C-5	C5-N	N-O	N-C6
Ground state	CASSCF(8,8)/6-31G*	1.322	1.465	1.350	1.449	1.317	1.273	1.455
	CASSCF(6,6)/6-31G*	1.341	1.463	1.329	1.452	1.314	1.276	1.455
	CASSCF(4,4)/6-31G*	1.343	1.464	1.330	1.451	1.312	1.254	1.456
	RHF /6-311G**	1.322	1.458	1.330	1.446	1.276	1.280	1.453
Excited State	CASSCF(8,8)/6-31G*	1.447	1.388	1.423	1.412	1.434	1.266	1.423
	CASSCF(6,6)/6-31G*	1.434	1.356	1.418	1.433	1.406	1.273	1.423
	CASSCF(4,4)/6-31G*	1.434	1.350	1.425	1.444	1.405	1.274	1.423

has been used in the first step for the self-consistent molecular orbital (SCFMO) calculations of the ground states, and these MOs are subsequently used for the configuration interaction steps. Radiative transition³⁵⁻³⁷ calculations have been carried out between the two configuration interaction wave functions at the ground state equilibrium geometry, based on this GUGA CISD code. Electrostatic potential-based atomic charges are calculated for the ground and excited state species using the Merz-Kollman^{38,39} scheme in Gaussian 09 program. For visualization of the output files, ChemCraft⁴⁰ and Gauss view software have been employed throughout this work.

3. Results and Discussion

3.1 Optimized ground state and excited state: Structure, Energy and atomic charges

Ground state geometry has been optimized at the CASSCF and RHF level of theories (table 1). This state

is found to be planar with alternate double and single bonds with a positive charge on nitrogen and a negative charge on oxygen which makes it zwitterionic. The first excited singlet state (table 1) is also found to be planar with an elongated C5-N bond. The vertical excitation energy (VEE) values of the lowest energy transition ($S_0 \rightarrow S_1$) (table 2) are reported at different level of calculations. The VEE value at the CASSCF (4,4) level is 4.94 eV (114 kcal/mol). Increase in the active space size is found to lower the VEE value while the CASMP2 values are slightly higher than the corresponding CASSCF values. The initial photo-excitation to the planar Franck-Condon excited state is followed by a relaxation to another planar geometry with net stabilization of 28 kcal mol⁻¹. The CASMP2 calculations have given slight deviations from the CASSCF results, and the above-mentioned stabilization is ~30 kcal mol⁻¹ after including the dynamical correlation effects.

Analysis of the atomic charges based on the electrostatic model of Merz-Kollman (table 3) clearly reveals

Table 2. Ground and excited state energies at CASSCF and CASMP2 levels.

Molecular State	CASSCF		CASMP2	
	E (hartree)	ΔE (kcal/mol)	E (hartree)	ΔE (kcal/mol)
Optimized ground state	-658.2627 ^a ,	0 ^a ,	-659.8365 ^a ,	0 ^a ,
	-658.2912 ^b	0 ^b ,	-659.8154 ^b ,	0 ^b ,
	-658.2916 ^c	0 ^c	-659.8203 ^c	0 ^c
Vertically excited state	-658.0809 ^a	114.08 ^a ,	-659.6425 ^a ,	121.75 ^a ,
	-658.0891 ^b	127.10 ^b ,	-659.6549 ^b ,	100.17 ^b ,
	-658.1480 ^c	90.16 ^c	-659.6237 ^c	123.37 ^c
Optimized excited state	-658.1254 ^a ,	86.11 ^a ,	-659.6907 ^a ,	91.48 ^a ,
	-658.1301 ^b ,	101.44 ^b ,	-659.6945 ^b ,	75.86 ^b ,
	-658.1901 ^c	63.75 ^c	-659.6580 ^c	101.84 ^c

Energy values reported at CASSCF/6-31G* and CASMP2/6-31G* level with ^a(4,4), ^b(6,6) and ^c(8,8) active spaces.

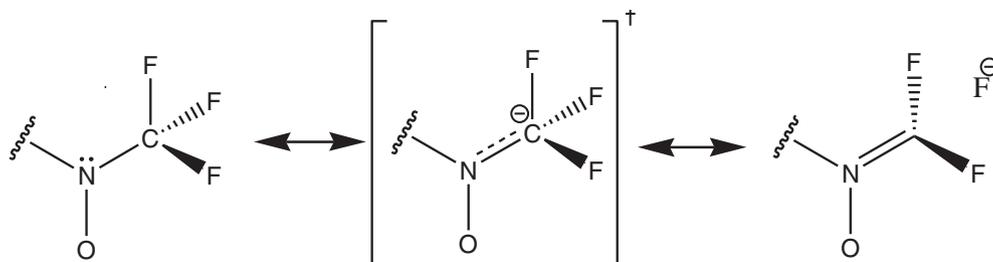
Table 3. Atomic charges determined from electrostatic potential (using Merz-Kollman scheme) at the CASSCF/6-31G* level of calculation of trifluoromethyl and methyl- substituted model systems of retinyl nitron.

Atom	CF ₃ -substituted						CH ₃ -substituted			
	Ground State	Excited state	CI	TS _G	Ox ₁	Ox ₂	Ground State ^a	Excited state ^a	CI ^a	Ox
C(1)	-0.378	-0.375	-0.435	-0.422	-0.425	-0.427	-0.368	-0.366	-0.452	-0.437
C(2)	-0.125	-0.071	-0.062	-0.085	-0.111	-0.089	-0.072	-0.060	0.035	-0.125
C(3)	-0.102	-0.234	-0.098	-0.114	-0.017	-0.065	-0.141	-0.289	-0.350	-0.024
C(4)	-0.166	-0.091	-0.241	-0.085	-0.289	-0.288	-0.179	-0.087	0.028	-0.235
C(5)	-0.077	-0.137	0.051	-0.050	0.376	0.527	-0.135	0.035	-0.034	0.341
N	0.160	0.122	-0.238	-0.154	-0.374	-0.436	0.506	0.188	-0.161	-0.317
C(6)	0.589	0.650	0.642	0.597	0.758	0.783	-0.448	0.077	-0.192	0.071
O	-0.417	-0.337	-0.102	-0.146	-0.229	-0.257	-0.610	-0.305	-0.149	-0.285

^aReference.⁸

that an electronic transfer from oxygen to the nitrogen (or to the conjugated chain) takes place as the relaxed excited state is approached. This reduces the positive charge on nitrogen. Similar results were also found in our previously studied N-methyl and N-isopropyl-substituted systems, as well; however, the extent of electron transfer from oxygen to nitrogen was much more pronounced in those systems than the N-trifluoromethyl substituted system. The excess negative charge accumulated on nitrogen (gained from the breaking of the C=N pi bond and electron transfer from oxygen) in

this system is probably taken away by the electron-withdrawing effect of the -CF₃ group, and hence the positive charge on nitrogen will be less affected in the excited state of this system. This is evidenced by the shortened N-CF₃ bond distance in the planar excited state (1.42 Å) in comparison to that of the ground state (1.45 Å). It seems that a negative hyperconjugative effect^{15,16} is occurring due to the donation of electron density from the filled p-orbital of nitrogen to the neighbouring σ^* -orbital of the carbon of CF₃ group (figure 3). This negative hyperconjugation is expected

**Figure 3.** A schematic representation of the possible negative hyper-conjugative effect operating in the excited state (S_1) of the N-trifluoromethyl nitron system.

to stabilize the planar excited state, and the accumulated electron cloud on nitrogen is not easily available. In recent times, rehybridization of nitrogen atom holding lone pair of electrons and thereby their possible participations in negative hyperconjugation have been extensively studied by Alabugin *et al.*^{41–43} A completely planar transition state (TS_{ex}) of this system on the excited state surface has been detected, which is situated at only 1 kcal mol^{-1} above the relaxed singlet excited state geometry. This low barrier on the surface can open up an easily accessible route for the excited state.

3.2 Conical intersections and transition states

Presence of non-radiative decay channels through conical intersections have been investigated in this portion of our work. In recent times, conical intersection studies have revealed the mechanisms of several important photochemical processes.^{44–59} In our earlier work on the conjugated N-methyl nitron system,⁸ we have proposed that the lowest energy conical intersection geometry with a terminal CNO twist is responsible for the formation of the oxaziridine ground state species. This photochemical path through the biradicaloid

lowest-energy conical intersection geometry was found to have some similarity with the benzene-prefulvene photoisomerization process, commonly known as the channel 3 decay.^{60–62}

In this present work, several interesting conical intersection geometries have also been noticed corresponding to different types of turns and twists in the N-trifluoromethyl-substituted nitron system. The conical intersection point of lowest energy (CI) in the (4,4) active space calculation is found to correspond to a geometry shown in figure 4, which arises due to a terminal twist in the C-N-O moiety. The resulting structure seems to form an out-of-plane CNO triangle and closely resembles an oxaziridine system. However, the geometrical parameters, such as C5-O distance ($\sim 2.19 \text{ \AA}$) and N-O (1.36 \AA) bond length are substantially different from the reported values of these parameters⁶³ of the well-known 3-membered heterocyclic species; further stretching of N-O bond and shortening of C5-O bond will be required to form an oxaziridine from this structure. The gradient difference (GD) and the derivative coupling (DC) vectors (figure 4) give the directions in which the degeneracy of the two states might be lifted and thereby indicate the possible relaxation channels leading to the photoproduct

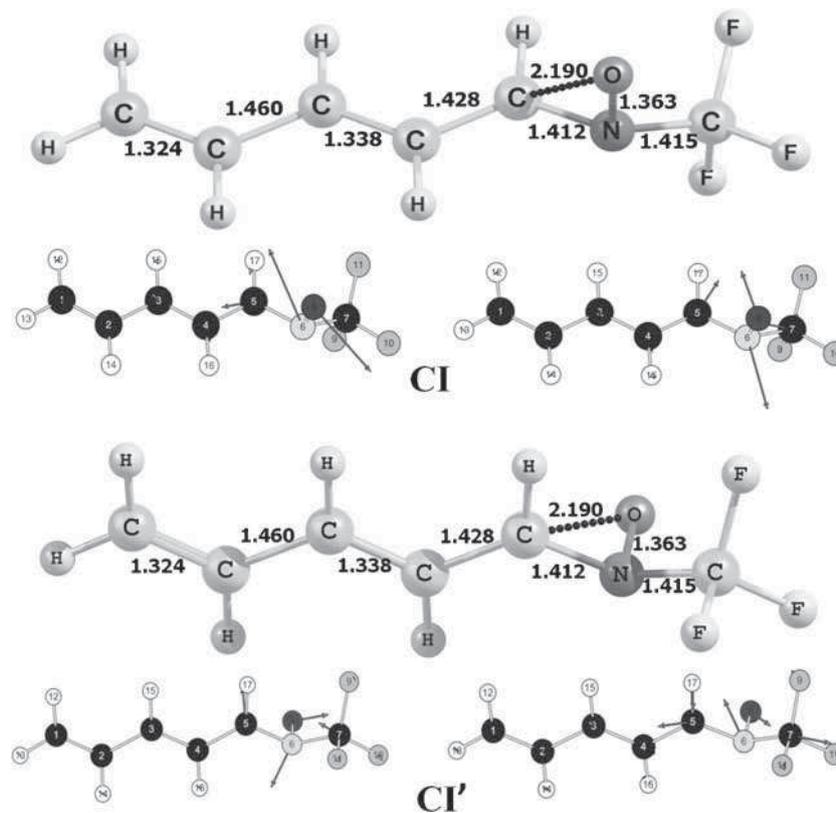


Figure 4. Optimized conical intersection geometries (CI and CI') at the CASSCF/6-31G* level. The gradient difference and derivative coupling vectors are also shown.

formation. The opposite direction of the gradient difference (-GD) vectors shows a possibility of the C5-O bond shortening and therefore may lead to an oxaziridine structure.

Table 4. Absolute and relative energy values (with respect to the relaxed planar excited state) at various important geometries on the potential energy surfaces.

Geometries on PES	CASSCF/6-31G*		CASMP2/6-31G*	
	Energy in hartree	Relative Energy in kcal mol ⁻¹	Energy in hartree	Relative Energy in kcal mol ⁻¹
E. S.	-658.1254	0	-659.6907	0
CI	-658.1685	-27.01	-659.7395	-30.66
CI'	-658.1683	-26.92	-659.7452	-34.24
TS _{ex}	-658.1237	1.07	-659.6900	0.43
TS _G	-658.2113	-53.88	-659.7527	-38.94
Ox ₁	-658.2386	-71.04	-659.8469	-98.01
Ox ₂	-658.2717	-91.81	-659.8410	-94.35

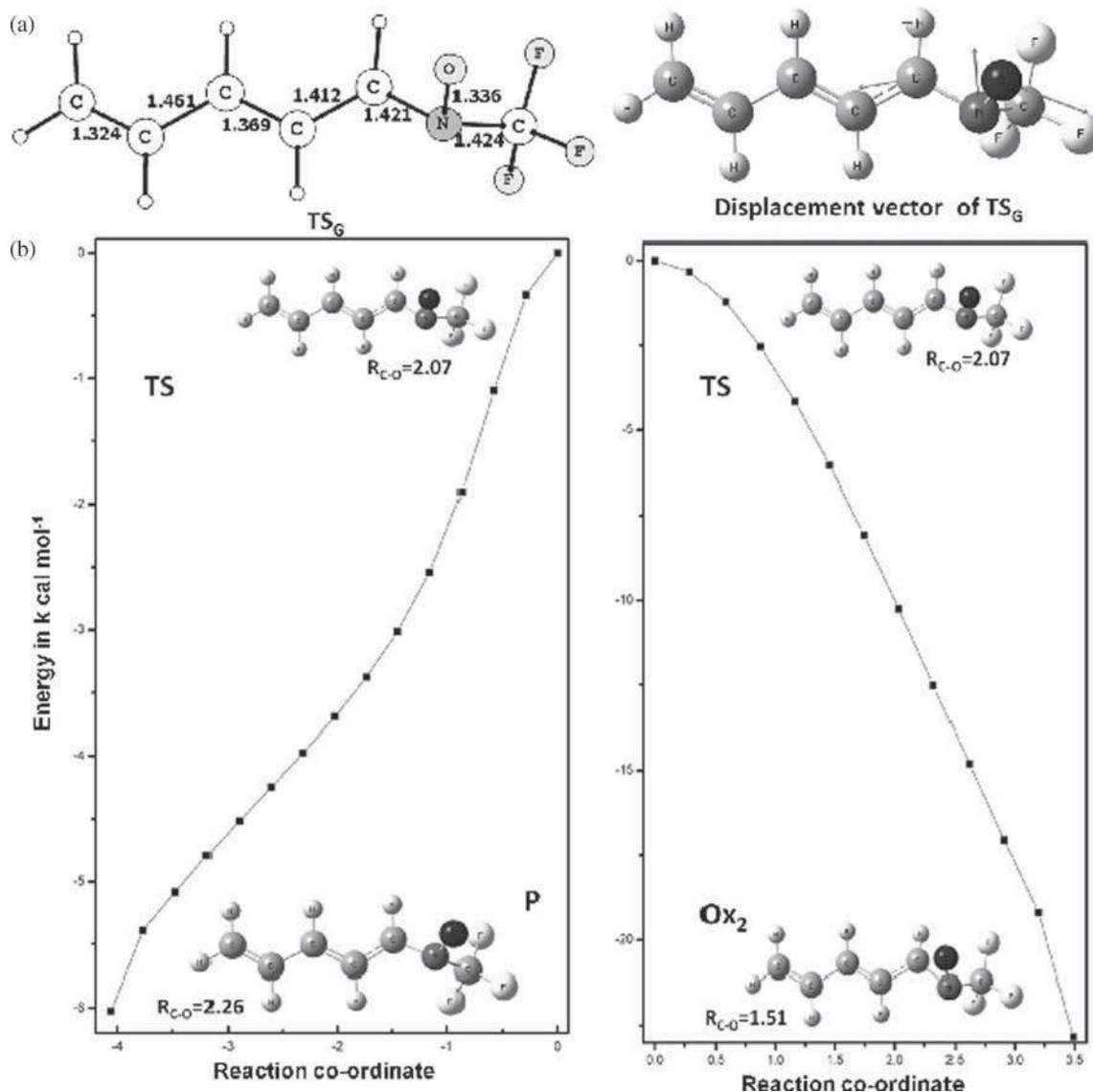


Figure 5. (a) Transition state (TS_G) with displacement vectors of the negative frequencies; (b) Intrinsic reaction coordinate path of TS_G along the forward and reverse directions.

The above-mentioned conical intersection geometry (**CI**) has been obtained by giving a CI optimization^{64–67} run on the optimized planar excited state geometry. No barrier has been found between this kinked CI geometry and the planar excited state. Interestingly, a mirror-image of this CI geometry has been found by giving an optimization run on the planar transition state geometry (**TS_{ex}**). This geometry (**CI'**) has identical geometrical parameters, atomic charges and energy as the other lowest energy CI species (**CI**). These enantiomeric geometries are situated around 27 kcal/mol (table 4) below the planar excited state at the CASSCF level. Inclusion of dynamic correlation effect has created a gap of 3.5 kcal mol⁻¹ between these two low-lying conical intersection geometries. The direction of GD vectors and DC vectors indicate that these mirror-image CI geometries are heading towards completely different types of photo products at the end. In contrast to **CI**, no indication of oxaziridine formation has been noticed from the vectors of the **CI'**.

3.3 Possible photoproducts

Oxaziridines with EWG or π -conjugating substituents on nitrogen are well-known, and mostly synthesized by oxidation of imines. To the best of our knowledge, the photochemical excitation of nitrones with EWGs

on nitrogen has never been attempted for the corresponding oxaziridine formation. Following the opposite direction of the GD vectors of the **CI**, an optimized oxaziridine geometry (**Ox₁**) has been obtained. The geometrical parameters of this species resemble the reported structure of oxaziridine.⁶³ In addition to this, a transition state (**TS_G**) has been located on the ground state surface, situated at 32 kcal mol⁻¹ above the starting ground-state nitron geometry at CASSCF level (and 52 kcal mol⁻¹ at CASMP2) of calculation. The transition vectors corresponding to its negative frequency have shown some interesting features; the **TS_G** vectors have indicated a stretching of the C5-O moiety (figure 5) in the forward direction, and found to be exactly parallel to the vectors of the gradient difference of the **CI** intersection point. This indicates that the **TS_G** is a continuation of the actual reaction path passing through the mentioned conical intersection point, **CI**; following the reverse direction of the arrows of the transition vectors in **TS_G**, an oxaziridine-type (**Ox₂**) geometry results. However, the N-O bond length of this geometry is elongated (1.52 Å) in comparison to the **Ox₁** geometry (figure 6). Comparing these two structures with the reported oxaziridine structure it seems that **Ox₂** is more towards an amide than an oxaziridine. Formation of amide from oxaziridine having electron-withdrawing group on nitrogen was earlier suspected by Khoei and Memarian¹⁰ through a biradical intermediate

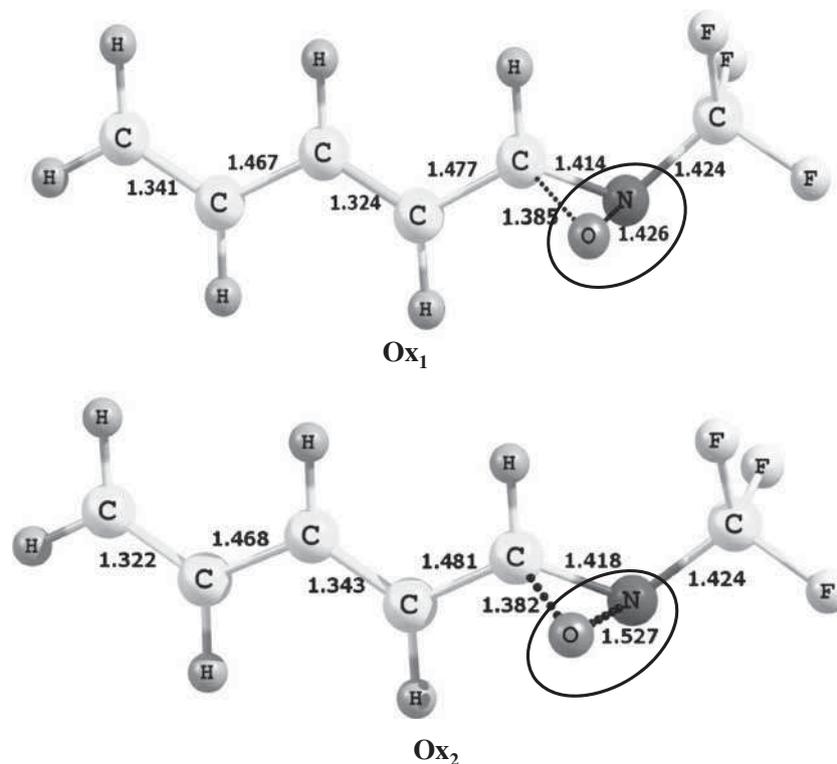


Figure 6. Optimized geometries of **Ox₁** and **Ox₂** at the CASSCF/6-31G* level.

involving N-O bond cleavage. The electronic charge scheme (total 3-electrons on nitrogen, and an odd electron on oxygen) described by this group (path B mentioned in their paper) for oxaziridines having electron-withdrawing group on nitrogen, is quite consistent with the ESP-derived atomic charges of the Ox_2 species (table 3). We have tested IRC run on the TS_G geometry (figure 5), which reveals that this transition state connects **P** and Ox_2 geometries on the ground state surface, where **P** is a product along the photochemical reaction path (figures 5 and 7). The actual photochemical route (figure 7) seems to be starting from the photoexcitation of the ground-state nitron to its singlet excited state followed by a non-radiative decay through **CI**. A photochemical route from here goes towards Ox_1 while another path passes through a transition state (TS_G) to form the photoproducts, **P** and Ox_2 , where the latter contains a possibly broken N-O bond which may form amide on further [1,2-H] shift. A possible summary of the whole process is shown in figure 8.

This result shows an interesting fact that an amide may appear directly as a photoproduct, provided TS_G is connected to the actual photoisomerization path through **CI**. The path **CI- TS_G - Ox_2** involves a gradual increase in the N-O bond length (1.363–1.527 Å) and a decrease in the C-O bond length (2.19–1.382 Å). An opposite trend can be seen in the **CI- TS_G -**P**** conversion process. Overall, the predicted photoproducts are Ox_1 and Ox_2 (along with **P**), where the latter has an elongated (or broken) N-O bond which may eventually form amide.

3.4 Radiative transition properties

Oscillator strength and radiative transition moment values of the lowest energy singlet-singlet transition have been predicted at the ground state equilibrium geometry using the GUGA-CISD code in GAMESS. These radiative transition parameters in our presently studied trifluoromethyl-substituted system are found to be

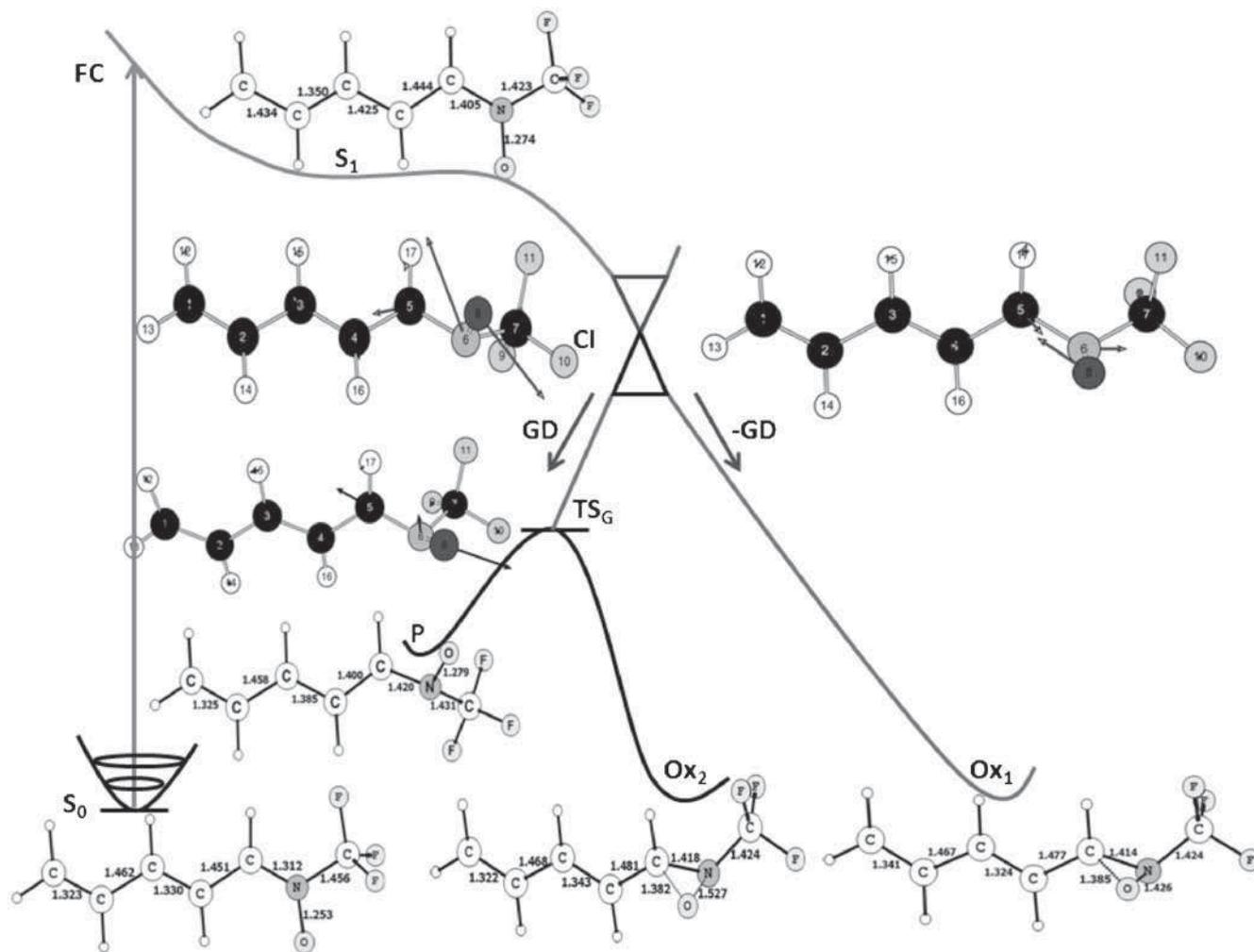


Figure 7. Schematic representation of the non-radiative decay processes involving the low-lying conical intersection (**CI**) leading to Ox_1 and Ox_2 in N-trifluoromethyl-substituted model nitron system.

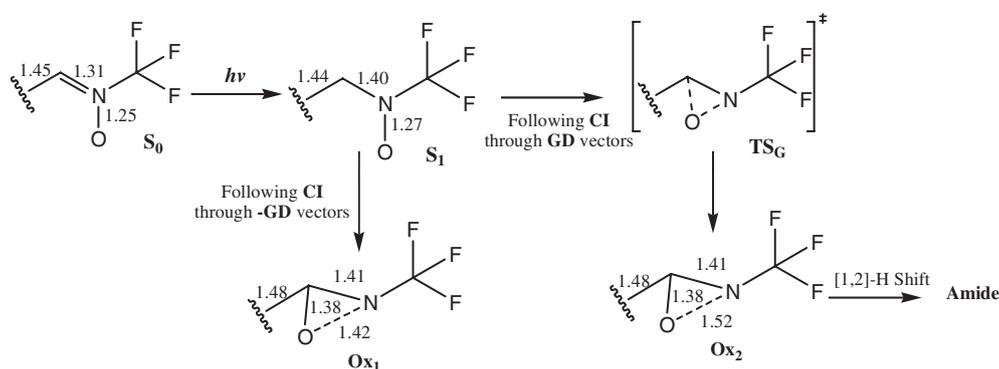


Figure 8. A summary of the whole photochemical process operating in N-trifluoromethyl-substituted model nitron system.

Table 5. Radiative transition properties corresponding to the lowest-energy vertical transition ($S_0 \rightarrow S_1$) at the ground state equilibrium geometry using GUGA CISD code.

Systems	Radiative transition Moment in Debye				Oscillator Strength	
	μ	μ_x	μ_y	μ_z	f_L	f_V
N-trifluoromethyl-substituted model retinyl nitron compound	4.98	-4.589	-1.933	-0.002	1.049	0.123
N-methyl-substituted model retinyl nitron compound ^a	4.86	-4.684	-1.296	0.002	0.706	0.195

^aReference. ⁸

higher than the values observed for the N-methyl-substituted nitron systems, studied in our earlier work. A comparison of these parameters for these two systems is shown in table 5.

3.5 Possible importance in practical field

The retinyl nitrones with electron-donating groups are found to give stable oxaziridines under roomlight⁶ and the parent nitron is obtained back as soon as the light is removed. Our theoretical studies on the model compound of these nitrones⁸ had also identified oxaziridine as the primary photoproduct. However, the presence of electron-withdrawing groups on nitrogen in this type of nitron seems to produce an oxaziridine-type species with a stretched N-O bond along with a proper oxaziridine, both originating from the lowest-energy conical intersection geometry. The latter species (**Ox₁**) resembles (geometrically and charge-wise) the oxaziridine obtained from the analogous N-methyl nitron system (table 3). On the other hand, the possibility of **Ox₂** and thereafter an amide compound through a barrierless path on photo-excitation of nitrones could be an important finding, especially when our study on the model compound is extended to the corresponding retinyl nitron system. Retinamides⁶⁸⁻⁷⁰ are well-known as chemo-preventive materials with low toxicity. Their

possible importance in the prevention of chemically-induced cancer of the skin, mammary gland and urinary bladder are already reported in the last century. Moreover, N-trifluoromethyl amide and their derivatives are known for their antifungal properties⁷¹ and have found importance in the HIV therapy.^{72,73} Overall, the possibility of formation of the so far unexplored N-trifluoromethyl retinamide system from the corresponding retinyl nitron compound under photo-excitation may lead to a significant route to form a pharmaceutically important compound. In fact, other electron-withdrawing groups may also lead to their corresponding retinamide systems, through a similar mechanism.

4. Conclusions

The reported theoretical results in this work can contribute significantly to the oxaziridine and amide chemistry. Two different types of oxaziridines are found to be formed in the photo-excitation process of the conjugated open-chain nitron systems having electron-withdrawing groups at the nitrogen atom. A comparison with the reported experimental observations on N-sulfonyl and N-aryl nitrones with our presently studied N-trifluoromethyl-substituted nitron reveals several similarities and indicates that the proposed mechanism is equally applicable to any acyclic nitron systems

having strong electron-pulling and pi-conjugation (hyperconjugative group) on the nitrogen atom. The corresponding oxaziridines are usually known to be prepared from imine-oxidation or ketone amination, rather than the nitron photo-excitation. Our present study concludes that in addition to a conventional oxaziridine system, an oxaziridine-type look-alike species is also predicted to appear in the photo-excitation process with a broken N-O bond, which may lead to an amide as the photoproduct. Both these barrierless processes pass through the lowest energy conical intersection (S_0/S_1) point having a terminal C-N-O twisted geometry. A continuous decrease of the C-O bond distance and increase in the N-O bond distance ultimately results in both these species from this low-lying CI with a possible amide compound from one of them. This study has justified the possibility reported almost a decade ago by other groups that the unstable oxaziridine-type species obtained from nitrones with electron withdrawing groups on nitrogen may result in N-O bond cleavage with three electrons on nitrogen and one electron on oxygen, which eventually leads to amide. There remains huge scope for the experimentalists to explore this important possibility of obtaining amide as one of the photoproduct through this expected barrierless photochemical route, starting from a suitably substituted nitron system.

Supporting Information

Conical intersection geometries using (6,6) and (8,8) active spaces and figure S1; Cartesian coordinates of optimized geometries are available at www.ias.ac.in/chemsci.

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