Probing Intramolecular Interactions in Arylselenides Using a Property Descriptor Based Approach

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Although a large volume of experimental evidence is available on the existence of intramolecular nonbonding interactions between chalcogen atoms in main group organometallic compounds, the primary focus has been on the contact distances involving the chalcogen atoms. The important class of intramolecular Se···X (where X is O, S, N) nonbonding interaction in a series of organoselenium compounds is quantified using a new scheme based on a molecular property descriptor. In the present study, we have employed the nucleus-independent chemical shift [NICS(0)] values, as a property descriptor to evaluate the strength of exocyclic nonbonding interactions in a series of aryl selenides. The ab initio MP2 as well as density functional theory methods have been used in conjunction with Dunning's cc-pVDZ basis set. The quantified values of Se···X nonbonding interactions are compared with other schemes based on thermochemical equations such as homodesmic and ortho−para methods. The changes in NICS(0) values at the aryl ring center are found to be sensitive to the strength of exocyclic Se···X interaction.

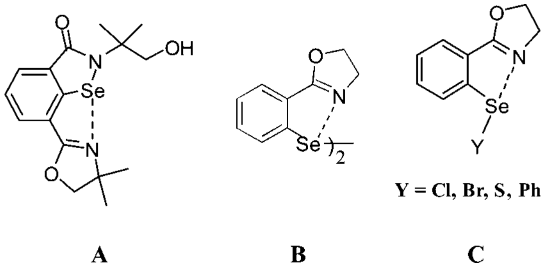
Introduction

The nonbonding interaction involving divalent selenium and sulfur atoms has received immense attention owing to their importance in various chemical transformations as well as in the design of enzyme mimics.[1] There have been several reports on the importance of intramolecular chalcogen−chalcogen interactions contributing toward the chemical as well as biological activity of organoselenium compounds.[2] For example, selenazoles such as compound **A** and other selenides like **B** and **C**, shown in Scheme 1, are known to exhibit antithyroid as well as glutathione peroxidase activities. It is the hallmark of supramolecular chemistry that weak interactions such as these play important roles.[3]

Weak nonbonding interaction in organoselenium compounds is proposed to arise due to the hypervalent nature of selenium. It is widely accepted that the hypervalency in divalent chalcogens increases in the order O < S < Se < Te, though the strength of such interactions as well as the essential forces leading to such nonbonding interaction are not completely understood.[4e−i] A considerable body of main group organometalloid chemistry literature refers to the existence of noncovalent interaction in organoselenium compounds.[4] With the help of post wave function analysis based on the natural bond orbital (NBO) method[5] and atoms in molecule (AIM)[6] the importance of $n_{\mathrm{donor}} \rightarrow \sigma^*_{\mathrm{Se-Y}}$ orbital interaction is by now well established.[4e−i] The $n_{\mathrm{donor}} \rightarrow \sigma^*_{\mathrm{Chalcogen-Y}}$ interaction corresponds to the expansion of the valence shell of the chalcogen (10-Se-3) and is even suggested as "premature hypervalent bonds".[7]

We have been addressing the role of orbital interactions in the above kinds of secondary bonding in organochalcogens. In an earlier report, we have delineated the need for further analyses than the commonly employed distance-based criteria for judging whether intramolecular interaction is present or not.[8] It has been widely accepted that the strength of nonbonding interactions vary quite dramatically depending on the "donor−acceptor" combination (i.e., nature of X and Y, vide infra) since the nonbonding electrons on the donor atom (X) delocalize into the suitably aligned acceptor antibonding σ* orbital (Se−Y).

SCHEME 1: Examples of Biologically Relevant Selenazoles and Selenium-Containing Oxazoline Derivatives Possessing Se···N Nonbonding Interaction



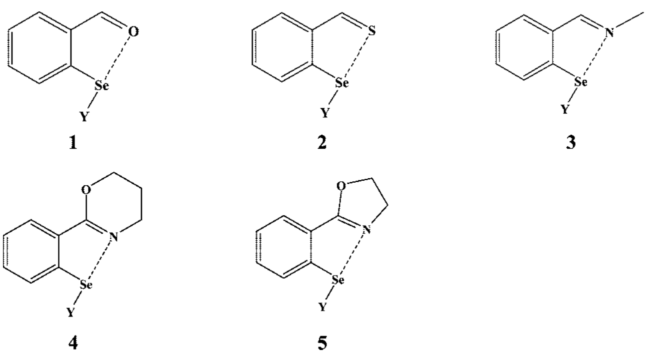


Figure 1. Organoselenium compounds exhibiting intramolecular nonbonding interaction, where the substituent on selenium Y = Me (**a**), Ph (**b**), CN (**c**), Br (**d**), Cl (**e**), and F (**f**). These labels (**a**−**f**) are assigned on the basis of the accepting ability of the Se−Y bond.

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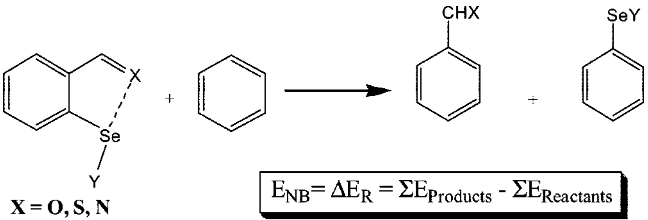
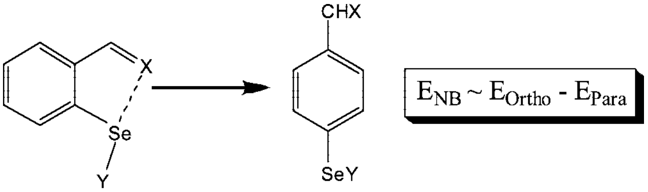
SCHEME 2: Homodesmic Reaction (HDR) Used for Quantification of Intramolecular Interaction



$E_{NB} = \Delta E_R = \Sigma E_{Products} - \Sigma E_{Reactants}$

X = O, S, N
Y = Me, Ph, CN, Br, Cl, F

SCHEME 3: Ortho−Para (OP) Method Used for Quantification of Intramolecular Interaction



$E_{NB} \sim E_{Ortho} - E_{Para}$

X = O, S, N
Y = Me, Ph, CN, Br, Cl, F

Interestingly, the ability of several glutathione peroxidase mimetics was found to exhibit varying degrees of activity depending on the extent of nonbonding interaction.[2b] Surprisingly, there have been no reports, except the work by Iwaoka et al., on systematic quantification of intramolecular chalcogen···chalcogen nonbonding interactions.[9] Thus, it is intuitively appealing to devise reliable methods to quantify such an important class of intramolecular nonbonding interaction.

Quantifying intermolecular interactions are less complicated as compared to the intramolecular case, as one can derive accurate intermolecular potentials by suitable choice of model chemistries in conjunction with available experimental data. On the other hand, it will be difficult to formulate a simpler mathematical relationship between potential energy and chalcogen···X distance in an intramolecular situation due to inherent geometrical constraints. Among several methods tried in quantifying weak intramolecular interactions those used in understanding hydrogen-bonding interaction require special mention. A suitably chosen thermochemical cycle, isodesmic reactions, as well as molecular tailoring based methods are introduced to achieve this goal.[10]

To achieve the goal of quantifying intramolecular interactions in organochalcogens, we have earlier reported four different schemes, which are based on thermochemical equations.[11] One of the important protocols toward quantifying intramolecular interactions is by constructing suitable homodesmic reactions where the number and kinds of bonds on both sides of the equation are conserved and each atom maintains an identical immediate environment. Alternatively, the ortho−para method is also developed that relies on the energy difference between isomers, when the nonbonding interaction is turned on (ortho) and turned off (para). The energy difference between ortho and para isomers is taken as a measure of intramolecular nonbonding interaction. These two quantification methods, viz., homodesmic reaction method and ortho−para method, are used for quantifying intramolecular nonbonding interactions (E_{NB}).

Thus far we have been able to establish the usefulness of thermochemical methods to estimate the strength of nonbonding interactions in organochalcogens. In this work we intend to examine whether any electronic property of the molecule would vary depending on the strength of the exocyclic interaction in aryl selenides. In particular, the magnetic shielding tensor at the ring center has been considered. This approach termed as a property descriptor method is summarized in the following sections.

The total electronic energy of a molecule would depend on electron delocalization and steric effects. Thus, in organoselenium systems (Figure 1) exhibiting intramolecular interactions, the change in electronic environment and total electronic energy should reflect the presence of such interaction. However, in the current context the intramolecular nonbonding interaction (E_{NB}) is present only in the ortho-substituted phenyl selenides. The difference in electronic energies between ortho ($\varepsilon^{el}{}_{o}$) and meta ($\varepsilon^{el}{}_{m}$) isomers, arising due to the differences in the total electron delocalizations, can be written as

$$\Delta E_{om} = E_{NB} + \varepsilon^{el}{}_{o} - \varepsilon^{el}{}_{m} = E_{NB} + \Delta\varepsilon^{el}{}_{om} \qquad (1)$$

Similarly between ortho and para isomers

$$\Delta E_{op} = E_{NB} + \varepsilon^{el}{}_{o} - \varepsilon^{el}{}_{p} = E_{NB} + \Delta\varepsilon^{el}{}_{op} \qquad (2)$$

where $\Delta\varepsilon$ is the difference in energies associated with the differences in the electronic environments between different isomers. Since $\Delta\varepsilon$, unlike ΔE, is not a directly measurable quantity, we have decided to examine the correlation of this term with other molecular property descriptors (χ). The property of interest χ is chosen such that it should respond to the differences in the electronic environments in ortho, para, and meta isomers. Nucleus-independent chemical shift [NICS(0)] value at the aryl ring center is chosen as the property descriptor toward this objective.

When this property is incorporated into eqs 1 and 2, we get

$$\Delta E_{om} = E_{NB} + \zeta[\Delta\chi_{om}] \qquad (3)$$

and

$$\Delta E_{op} = E_{NB} + \zeta[\Delta\chi_{op}] \qquad (4)$$

where, ζ is a proportionality constant. (See the Appendix)

Thus, solving eqs 3 and 4 one can compute E_{NB}. For instance, eq 4 can be rearranged to

$$\zeta = (\Delta E_{op} - E_{NB})/\Delta\chi_{op} \qquad (5)$$

Substituting for ζ in eq 3 by eq 5, one can solve for the intramolecular interaction energy as

$$\Delta E_{om} = E_{NB} + [\Delta\chi_{om}]\{(\Delta E_{op} - E_{NB})/\Delta\chi_{op}\}$$

Hence,

$$E_{NB} = [\{(\Delta\chi_{op})(\Delta E_{om})\} - \{(\Delta\chi_{om})(\Delta E_{op})\}]/(\Delta\chi_{op} - \Delta\chi_{om}) \qquad (6)$$

The key assumption that the proportionality constants are the same in these equations can be explained by considering the following facts. The NICS value by definition is a local property and not a global property of the molecule.[12] Moreover, NICS is a quantitative measure of the ring current in individual rings in a polycyclic system. Isotropic NICS(0) values are influenced by their immediate electronic environment (σ as well as π). Studies on a large number of aromatic systems have established that the NICS exhibits a linear relationship with aromatic stabilization energy (ASE),[13] harmonic oscillator model of aromaticity (HOMA), exaltation of magnetic susceptibility,[14] and chemical shift differences.[15] Thus, the differences in electronic energies between the two isomeric disubstituted benzenes can be taken to be linearly proportional to the differences in their NICS(0) values.

TABLE 1: Nonbonding Interaction Energies (in kcal/mol) Computed Using the Property Descriptor, Homodesmic Reaction, and Ortho−Para Methods at the MP2 and DFT Levels of Theory in Combination with the cc-pVDZ Basis Set

	$E_{\text{Nonbonding}}$								
	BHandHLYP			mPW1PW91			MP2		
system	$E_{(\text{OP})}$	$E_{(\text{HDR})}$	$E_{\text{NICS(0)}}$	$E_{(\text{OP})}$	$E_{(\text{HDR})}$	$E_{\text{NICS(0)}}$	$E_{(\text{OP})}$	$E_{(\text{HDR})}$	$E_{\text{NICS(0)}}$
1a	1.13	0.41	0.89	0.11	2.39	2.16	0.05	0.09	0.05
1b[a]	0.98	1.36	1.14	2.94	2.36	3.89			
1c	3.09	1.76	3.10	3.91	2.15	4.04	3.33	2.78	3.40
1d	4.02	2.64	3.37	7.73	5.21	7.40	4.87	4.24	5.51
1e	5.74	4.25	4.96	9.34	8.63	9.35	6.21	5.51	6.66
1f	10.31	10.26	10.99	13.68	10.97	14.95	10.25	10.88	10.66
2a	3.79	2.69	2.65	1.72	1.44	2.21	1.66	1.25	1.54
2b[a]	3.75	3.53	2.98	1.51	1.50	2.83			
2c	0.32	0.68	1.84	3.02	1.17	4.65	1.79	1.41	2.13
2d	6.20	4.83	6.18	13.57	11.19	13.87	8.17	7.89	9.11
2e	8.05	6.55	7.99	15.05	14.65	15.72	9.60	9.25	10.18
2f	15.02	13.39	15.08	22.33	19.53	22.87	14.90	15.86	16.13
3a	1.35	0.91	0.39	2.21	1.07	2.93	0.68	0.68	0.57
3b[a]	3.01	2.96	2.95	0.83	2.89	0.91			
3c	3.60	3.36	3.59	7.93	5.86	7.76	5.40	5.60	6.00
3d	7.16	7.05	8.08	12.54	13.01	14.46	11.72	11.95	10.23
3e	9.35	9.20	11.59	17.07	16.94	16.96	13.49	13.68	12.95
3f	15.87	15.66	15.81	23.28	21.36	23.87	19.09	19.83	28.31

[a] MP2 calculations could not be performed for these systems due to larger size.

TABLE 2: Nonbonding Interaction Energies (in kcal/mol) Computed Using the Property Descriptor, Homodesmic Reaction, and Ortho−Para Methods Using Two Density Functional Theories in Combination with the cc-pVDZ Basis Set

	$E_{\text{Nonbonding}}$					
	BHandHLYP			mPW1PW91		
system	$E_{(\text{OP})}$	$E_{(\text{HDR})}$	$E_{\text{NICS(0)}}$	$E_{(\text{OP})}$	$E_{(\text{HDR})}$	$E_{\text{NICS(0)}}$
4a	2.18	1.64	2.12	0.80	1.39	0.94
4b	2.47	2.32	3.73	0.40	2.01	1.27
4c	3.59	3.75	1.28	5.47	4.50	5.28
4d	7.61	7.74	7.35	9.27	8.33	11.56
4e	9.76	9.85	9.77	14.22	12.17	14.38
4f	16.12	16.14	16.20	20.15	19.07	20.19
5a	2.37	1.82	2.27	3.82	4.37	2.87
5b	2.67	2.66	0.94	1.12	1.05	0.47
5c	2.57	2.10	2.33	3.62	2.50	4.08
5d	4.20	3.80	4.43	8.14	3.95	7.61
5e	6.18	5.74	6.31	10.75	10.28	10.24
5f	12.62	12.10	12.57	17.65	14.68	16.16

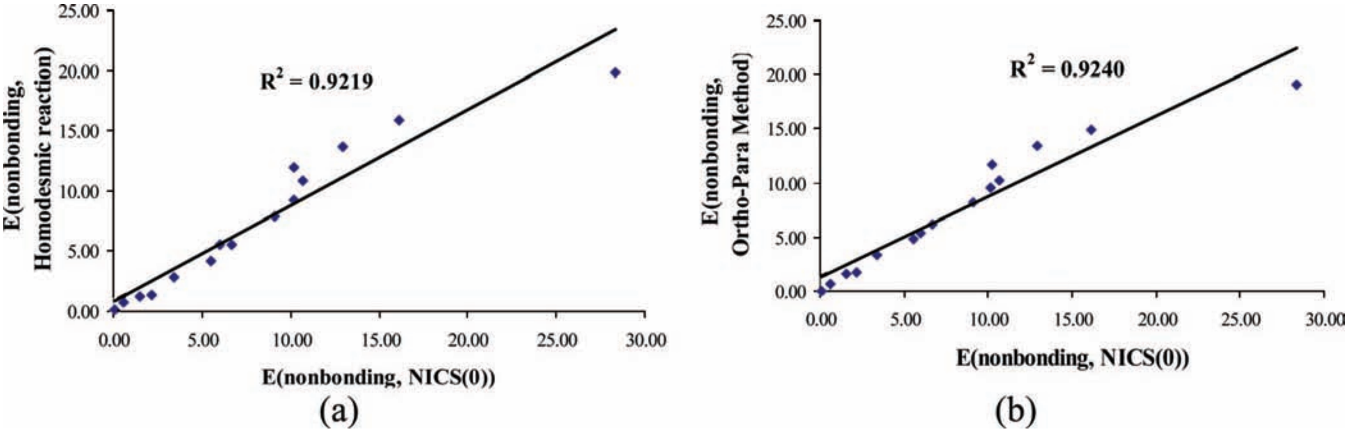
Computational Methods

All calculations were performed with the Gaussian03 and Gaussian98 quantum chemical programs.[16] Full geometry optimizations followed by frequency calculations on the stationary points were carried out to ascertain the stationary points as minima on potential energy surface. We have employed the hybrid density functional methods, namely, BHandHLYP and mPW1PW91, for this study.[17] The nonlocal BHandHLYP density functional (50% HF mixing) is well-known toward obtaining reliable interaction energies in charge-transfer complexes.[18] The choice of the other density functional, viz., mPW1PW91 (25% HF mixing), is based on its successful application in organochalcogen chemistry.[19] The second-order Møller−Plesset (MP2)[20] theory was also employed to verify the results obtained at the density functional theory (DFT) levels. Dunning's cc-pVDZ basis set was used for all calculations.[21] The NICS(0) values were calculated at the center of the aromatic ring using gauge invariant atomic orbital (GIAO) formalism at the above-mentioned levels.[22] The nucleus-independent chemical shift (NICS) criterion for aromaticity was evaluated at desired geometric points of a molecule on the basis of the chemical shielding experienced by a virtual nucleus used as a probe. It has been reported that the experimental NMR chemical shift of a ^{3}He nucleus inside the fullerene agrees very well the calculated NICS value for a virtual probe nucleus placed at the center of the cage.[23] The use of NICS has been quite successful toward assessing aromaticity of a variety of compounds such as carbo and metalacycles, boranes, as well as metal clusters.[24]

Results and Discussion

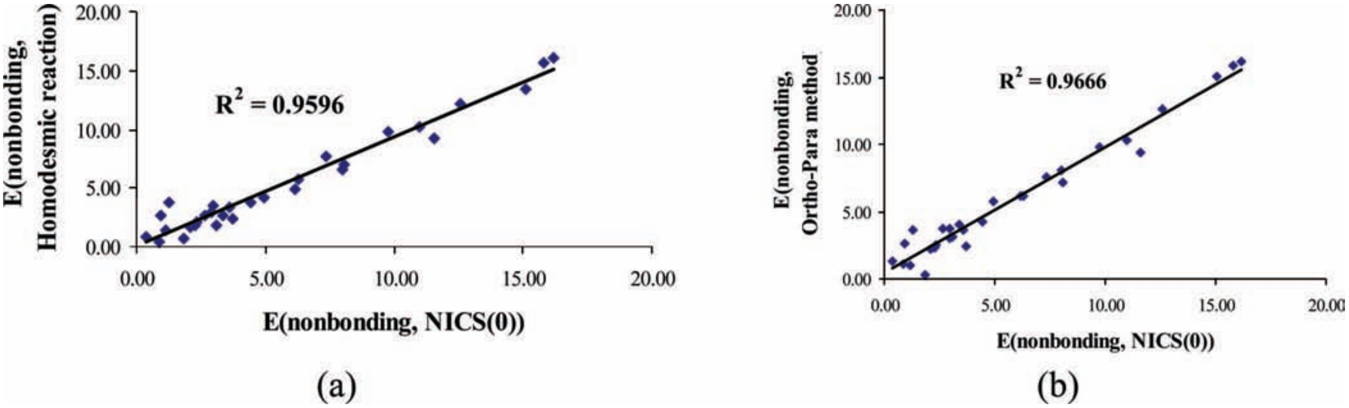
The hypothesis that an electronic property of the aryl ring could exhibit correlation with the strength of the exocylic interaction is tested on a series of ortho aryl selenides as shown in Figure 1. The first series includes formyl (**1**), thioformyl (**2**), as well as imine (**3**) as donors and a group of Se−Y acceptors (where Y = Me, Ph, CN, Cl, Br, and F). In the second family of compounds, the nitrogen of 2-oxazoline (**4**) and 2-oxazine (**5**) are involved in nonbonding interaction with the selenium atom.

Two approaches based on DFT are employed to examine whether the chosen electronic property of the molecule exhibits any sensitivity to the nonbonding interaction. We have chosen the BHandHLYP and mPW1PW91 functionals to estimate the electronic properties of **1**−**5** (Figure 1). Suitable homodesmic as well as ortho−para schemes are first formulated to estimate the strength of nonbonding interaction in these compounds. These thermochemical methods are based on the presence or absence of nonbonding interaction. The DFT-based approaches are earlier reported to be quite good as compared to the higher-order correlated calculations such as the MP2 and CCSD(T) level of theories.[11] The homodesmic reactions (HDR) are widely used in assessing molecular stability as well as intramolecular interactions in various situations where a direct measurement is not quite possible (Scheme 2).[10,11] The error associated with computing energies of reactants and products are expected to cancel in such approach and thus serve as a simple and efficient computational protocol in estimating the energetics.[25] The strength of intramolecular interactions quantified using the HDR



(a) (b)

Figure 2. Correlation of E_{NB} calculated using the property descriptor based method to those obtained using (a) homodesmic reaction (HDR) and (b) the ortho−para (OP) method at the MP2/cc-pVDZ level of theory.



(a) (b)

Figure 3. Correlation of E_{NB} calculated using the property descriptor based method to those obtained using (a) homodesmic reaction (HDR) and (b) the ortho−para (OP) method at the BHandHLYP/cc-pVDZ level of theory.

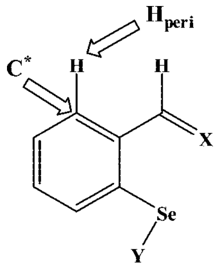


Figure 4. Atoms selected for the examination of changes in isotropic shielding tensors as a function of the strength of nonbonding interaction.

is subsequently employed as a standard in evaluating nonbonding interaction energies using the property descriptor based method. The calculated interaction energies are further compared with those obtained using the ortho−para (OP) quantification method (Scheme 3).[26]

We have chosen NICS(0) at the center of the aromatic ring as a property descriptor, which is expected to show subtle changes depending on (i) the variations in the substitution patterns, (ii) presence or absence of nonbonding interactions, and (iii) strength of nonbonding interactions. The nonbonding interaction energies calculated using the property descriptor approach ($E_{NICS(0)}$) along with those obtained using the HDR as well as the OP methods are summarized in Tables 1 and 2. A closer inspection of the data provided in Table 1 reveals a good agreement between the computed nonbonding interaction energies using different levels of theories. More specifically, the agreement between the MP2 as well as the mPW1PW91 values is very good. Interestingly, it is observed that E_{NB} computed using density functionals having a high percentage of Hartree−Fock mixing are much closer to those obtained with theories having higher-levels of electron correlation.[27] This feature holds well irrespective of the method of quantification.

TABLE 3: Intramolecular Interaction Energies (E_{NB} in kcal/mol) Calculated Using the Chemical Shift Values of H_{peri} and C* as the Property Descriptor at the MP2/cc-pVDZ Level of Theory

	E_{NB}	
system	δH_{peri}	δC^*
1a	0.16	0.16
1c	3.29	3.17
1d	5.38	5.09
1e	6.73	6.39
1f	10.13	10.34
2a	1.77	1.74
2d	9.73	8.46
2e	11.25	9.84
2f	14.33	15.19
3a	1.34	0.85
3c	5.48	5.71
3d	13.84	11.97
3e	14.17	13.45
3f	19.54	18.91

The methyl and phenyls are weak acceptors (**a** and **b**), evidently due to lower accepting ability of a less polarized bond. The highest nonbonding interaction is found to be with the Se−F bond as the acceptor (species **f**). In between, in general are the cyano, bromo, and chloro species (**b**, **d**, and **e**). This interaction

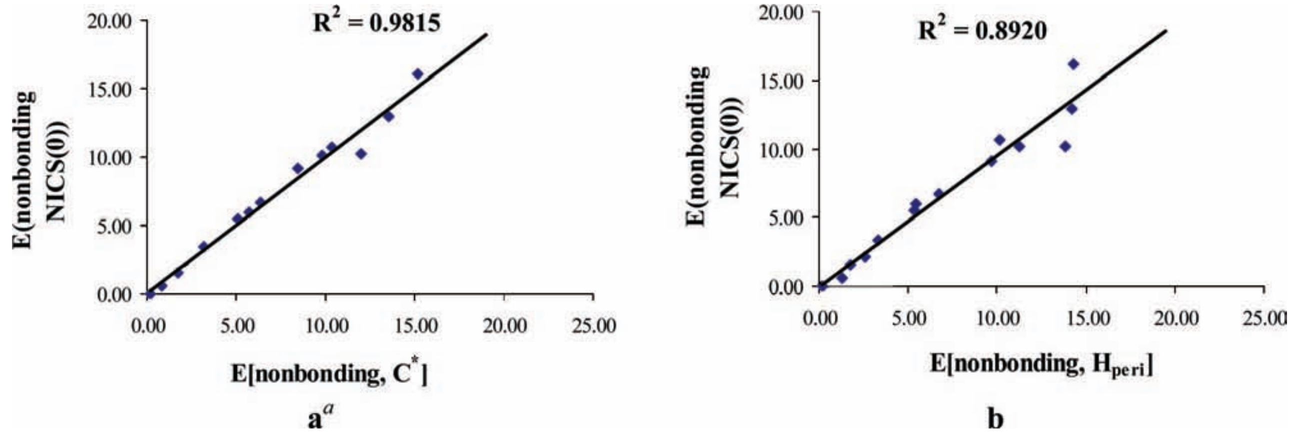


Figure 5. Correlation of E_{NB} calculated using NICS(0) and (a) C* isotropic tensor as property descriptors and (b) H_{peri} isotropic tensor as the property descriptor at the MP2/cc-pVDZ level of theory. (*a*: data point for system **2c** has been excluded due to larger deviation).

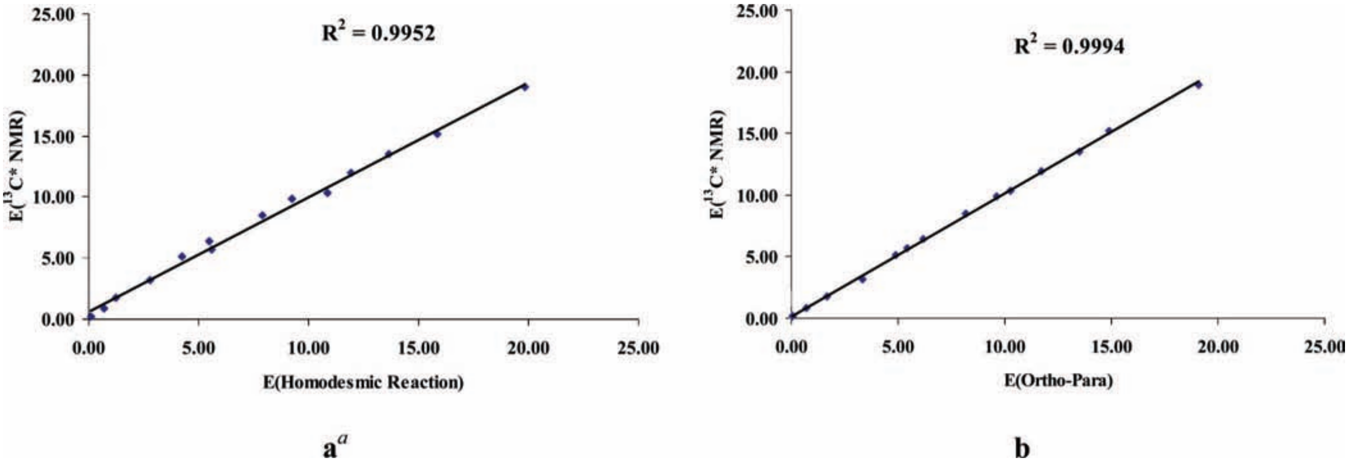


Figure 6. Correlation of nonbonding interaction energy evaluated using C* chemical shift as property descriptor with nonbonding interaction energy calculated using (a) homodesmic reaction (HDR) and (b) the ortho−para (OP) method at the MP2/cc-pVDZ level of theory. (*a*: data point for system 2c has been excluded due to larger deviation).

order roughly corresponds to the electronegativities of the affixed groups (Y) and to the generally understood (dare we say "folkloric") stability of hypervalent species.

The extent of nonbonding interaction evidently depends on the atom/group attached to the selenium (Y) as well as the nature of the donor atom (X). When Y is an alkyl group, the interaction is found to be the weakest among the present series of compounds. The E_{NB} shows a gradual increase when the acceptor group is changed from Se−Cl to Se−F, consistent with the increased polarity of the Se−Cl/F bonds. The computed E_{NB} values in Table 1 reveals that N(sp^2) is a better donor than O(sp^2). This can be rationalized by considering the higher electronegativity and difficulty of ionization of the latter leading to a larger energy difference between the lone pair bearing orbital on O and the antibonding Se−Y orbital.[28] Moreover, imines and amines are generally understood to be better Brønsted and also Lewis bases than aldehydes/ketones and ethers.

The nonbonding interactions computed using the property descriptor method is compared with the corresponding values obtained with the HDR and OP methods. The correlations between these approaches are found to be reasonably good. These correlations are quite evident from the mutual agreement between the calculated $E_{NB-NICS(0)}$ values with that obtained using the HDR (Figure 2a) and OP (Figure 2b) methods at the MP2 level of theory. Similar correlations are noticed for the E_{NB} values obtained at the BHandHLYP/cc-pVDZ level of theory (Figure 3, parts a and b). The good correlations observed between different methods of quantification can be assumed to imply the reliability of the predicted relative order of nonbonding interaction. These trends convey that the presence of exocyclic nonbonding interaction directly affects the ring current of the aryl ring. It is worthwhile to note that in two-ring heterocycles the NICS values for both rings are affected by substituents in but one of them. Indeed, species **1**−**3** can be viewed as two-ring heterocycles as befits their alternative description as benzo-annulated derivatives of 2*H*-1,2-oxaselenole, 2*H*-1,2-thiaselenole, and isoselenazole in which there is a λ^3 (tricoordinated) selenium.

Another interesting correlation pertains to the E_{NB} values obtained using the NICS(0) approach at the MP2 and DFT methods. The agreement between the predicted values at the MP2, mPW1PW91, and BHandHLYP levels of theories for a range of donor−acceptor combinations (**1**−**5**) is found to be excellent.[29]

An observation which could be used as indirect evidence in support of electron delocalization as the primary factor responsible for nonbonding interaction emerges as follows. We have evaluated the strength of the Se···H interaction in **1** and **2** by suitable HDRs, where the formyl and thioformyl groups are oriented in such a way that it maintains a Se···H interaction. Interestingly, there are no evident correlations between the calculated strength of Se···H interaction with the NICS(0) value of the aryl ring.[30] This could presumably be due to the lack of delocalization where the hydrogen atom acts as an insulator preventing donor−acceptor delocalization as found with the Se⋯X nonbonding interactions. Alternatively, for these Se⋯X nonbonding interactions to provide meaningful stabilization, the X group bonded to the Se should be relatively electronegative and be negatively charged. However, hydrogen is of comparable electronegativity to Se and so the hydrogen is expected to be neutral or even slightly positive (after all, H_2Se is a weak acid), and so one should not be surprised that hydrogen fails to assist donor−acceptor interactions.

Although the usefulness of NICS as a measure of aromaticity is widely recognized, experimental verification of such predictions continues to be a challenging task. Correlations can be drawn between the extent of delocalizations, which is proportional to the NICS values, and themochemical quantities such as the ASE and HOMA. We have therefore focused on probing whether other measurable molecular properties exhibit sensitivity to the strength of the exocyclic nonbonding interaction. The guiding principle for choosing specific atoms as shown in Figure 4 is based on the fact that its electronic environment should be sufficiently perturbed depending on the relative positions of the substituents attached to the aryl ring. One such readily available choice is the isotropic shielding tensors of the carbon ortho to the donor group (C*) and the hydrogen atom (H_{peri}) attached to it.

Interestingly, the correlations between the changes in chemical shift values for C* as well as H_{peri} atoms and the computed strength of nonbonding interactions are found to be very good. The E_{NB} values computed using the ^{13}C* as well as $^{1}H_{peri}$ chemical shifts are provided in Table 3. Inspection of the correlation plots as given in Figure 5 conveys that the E_{NB} values determined through the chemical shift as a property descriptor on C* and H_{peri} agree well with the corresponding values obtained through NICS(0) approach. More interesting correlations are also identified between the E_{NB} values calculated using the property descriptor (C* chemical shifts) and the corresponding values evaluated from HDR and OP methods (Figure 6).[31] Crucial to the present thesis is the relationship between E_{NB} values, which are otherwise difficult to measure experimentally, and an experimentally measurable parameter. We anticipate that the proposed property descriptor based approach would hold good for a large variety of organometallic and organometalloid compounds possessing intramolecular nonbonding interactions. Further, the general agreement between the strength of intramolecular interactions alludes to the application of any of these methods to estimate the strength of intramolecular nonbonding interactions. It should also be noticed that the present scheme is valid only if the major factor responsible for such binding has its origin in orbital delocalizations. Therefore, situations involving intramolecular hydrogen bonding might not give such good correlations as seen in the present study.

Conclusions

The intramolecular nonbonding interaction energy in organochalcogens has been quantified using a newly developed property descriptor based method. The perturbation in the aromatic ring current as a result of changes in the exocyclic nonbonding interaction has been used as a probe to calculate the strength of nonbonding interactions in Se⋯X systems. The nucleus-independent chemical shift at the ring centroid (NICS(0)), chemical shifts at C* and H_{peri}, has been employed as the property descriptor. The reliability of property descriptor based method is established by comparing the calculated E_{NB} values obtained using other thermochemical schemes such as HDR as well as the OP method. The agreement between the quantified nonbonding interaction energies across different levels of theories such as DFT and MP2 has been in general found to be good. The proposed quantification scheme for intramolecular interaction based on experimentally measurable molecular properties would serve as a useful tool in quick estimates of nonbonding interactions in organoselenium compounds.

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Appendix

Starting from the previous eqs 3 and 4

$$\Delta E_{om} = E_{NB} + \zeta[\Delta\chi_{om}] \tag{3}$$

and

$$\Delta E_{op} = E_{NB} + \zeta[\Delta\chi_{op}] \tag{4}$$

Similarly,

$$\Delta E_{mp} = \zeta_{mp}[\Delta\chi_{mp}] \tag{a5}$$

In the current context we assume $\zeta_{om} = \zeta_{op} = \zeta_{mp}$.

Now, by definition

$$\Delta E_{om} + \Delta E_{mp} = \Delta E_{op} \tag{a6}$$

and

$$\Delta\chi_{om} + \Delta\chi_{mp} = \Delta\chi_{op} \tag{a7}$$

Therefore, if

$$\Delta E_{ij} = \zeta_{ij}[\chi_{ij}] \quad \text{(for para and meta systems)}$$

and

$$\Delta E_{ij} = \zeta_{ij}[\Delta\chi_{ij}] + E_{NB} \quad \text{(when either } i \text{ or } j \text{ is ortho)}$$

this justifies the equality of the ζ values.

However, eq 3 can also be rewritten as

$$\Delta E_{om} = E_{NB} + E_{om}[\Delta\chi_{om}] \tag{a8}$$

where E_{om} is an arbitrary function of χ (and likewise we have E_{mp} and E_{op}). When Taylor series expansion is carried out ($\Delta\chi = \chi(\text{substituent}) - \chi(\text{H})$)

$$E_{om}[\Delta\chi_{om}] = c_{om}{}^{(0)} + c_{om}{}^{(1)}[\Delta\chi_{om}] + {}^{1}\!/_{2}\,!\,\{c_{om}{}^{(2)}[\Delta\chi_{om}]^2\} \ldots$$
$$\left(E_{NB} \text{ is built into } c_{om}{}^{(0)}\right) \tag{a9}$$

and likewise for E_{mp} and E_{op}

$$E_{mp}[\Delta\chi_{mp}] = c_{mp}{}^{(0)} + c_{mp}{}^{(1)}[\Delta\chi_{mp}] + {}^{1}\!/_{2}\,!\,\{c_{mp}{}^{(2)}[\Delta\chi_{mp}]^2\} \ldots$$
$$\left(E_{NB} \text{ is absent here but } c_{mp}{}^{(0)} \text{ need not be zero}\right) \tag{a10}$$

$$E_{op}[\Delta\chi_{op}] = c_{op}{}^{(0)} + c_{op}{}^{(1)}[\Delta\chi_{op}] + {}^{1}\!/_{2}\,!\,\{c_{op}{}^{(2)}[\Delta\chi_{op}]^2\} \ldots$$
$$\left(E_{NB} \text{ is built into } c_{op}{}^{(0)}\right) \tag{a11}$$

Now $\Delta\chi_{om} + \Delta\chi_{mp} = \Delta\chi_{op}$.

Suppose we have three functions with their Taylor expansions (assuming these series converge over the same range of x)

$$f(x) = \sum_{k=0}^{\infty} a_k x^k \tag{a12}$$

$$g(x) = \sum_{i=0}^{\infty} b_k x^k \tag{a13}$$

$$h(x) = \sum_{i=0}^{\infty} c_k x^k \qquad \text{(a14)}$$

If $f(x) + g(x) = h(x)$, then $a_k + b_k = c_k$ for each power or term in the expansion k. Now if $f(x) = a_0 + a_1x$, and likewise $g(x)$ and $h(x)$ are linear functions of x then $a_0 + b_0 = c_0$ and $a_1 + b_1 = c_1$.

Equations 3 and 4 in the text assume such linearity. By doing so, we recover our primary assumption (where $x = \Delta\chi$, and all three values of ζ are equal).

In support on the equality of the proportionality constant ζ can be gathered through the relationship between ring current (RC) and resonance energy (E_{re}) in $[4n + 2]\pi$ annulenes.[32] It had been shown by Haddon that in $[4n + 2]$ annulenes RC $= (3S/\pi^2)E_{re}$ (where S stands for the area of the annulene ring). It is of importance to note that the systems considered here (**1**−**3**) are nearly of the same size as well.

Supporting Information Available: BHandHLYP optimized coordinates of all the systems, table of intramolecular H-bonding energy for systems **1** and **2**, summary of the NBO analysis at the DFT levels, correlation plot of nonbonding interaction energy evaluated using NICS(0), and δH_{peri} as the property descriptor, and full citation of ref 16. This material is available free of charge via the Internet at http://pubs.acs.org.

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(27) For 1f the ENB values obtained at the CCSD(T), MP2, and BHandHLYP levels of theories are 10.5, 10.9, and 10.3 kcal/mol, respectively. All the calculations are done using cc-pVDZ basis set. (More details are available in ref 11b.)

(28) See further details of NBO analysis in Table S1in the Supporting Information.

(29) See Figure S1 in the Supporting Information.

(30) See Table S2 in the Supporting Information for further details.

(31) See Figure S2 in the Supporting Information for correlation of ENB calculated by ^{1}H chemical shifts and HDR and OP methods.

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