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Correlations between the benzene character of acenes or helicenes and simple molecular descriptors

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Dedicated to Professor Nenad Trinajstic on his 65th birthday

Abstract—Aromatic stabilities of acenes and helicenes, which are responsible for their biological, environmental and cancerous behavior have been modeled using a newly introduced Sadhana (Sd) and A indices. The results are compared with those obtained from PI (Padmakar-Ivan) index. The regression analysis has shown that excellent results are obtained by considering acenes and helicenes as separate classes of isomeric benzenoid hydrocarbons and that A index is better index than both PI and Sd indices.

1. Introduction

It is well known that acenes and helicenes are two distinct classes of isomeric benzenoid hydrocarbons, differing due to the mode of annelation. As a result of this they exhibit different physical, chemical and biological properties. Exhaustive work is carried out on these classes of benzenoids,[1–5] even then their chemistry is still very much of interest to synthetic chemists, environmental chemists, cancer research chemists, theoretical chemists, analytical chemists, and structural chemists.[6–10]

Physicochemical properties and biological activities of acenes and helicenes are mainly due to their aromatic stabilities.[11] Helicenes are predicted to be always more stable than the corresponding acenes. It is worthy to mention that acenes (a) and helicenes (b) might include benzene and napthalene, and that these benzenoids have been arbitrarily assigned to classes a and b.

In view of the direct connection of aromatic stability with the properties and the activities mentioned above it was thought worthy to undertake topological investigations of aromatic stability of acenes and helicenes using newly introduced Sadhana (Sd)[12] and A indices and compare the results with those obtained from the related PI (Padmakar-Ivan) index.[13–15] The choice of Sadhana index (Sd) is because it is a cyclic index recently introduced[12] for benzenoid systems and very little is known about its applicability. The results as discussed below show that excellent results are obtained by considering acenes and helicenes as two distinct classes of isomeric benzenoid hydrocarbons and that A index is found to be a better index than both the PI and the Sd indices.

Randic, Gimarc and Trinajstic[18] used the conjugated circuit model to predict the aromatic stability of acenes and helicenes. The same has been adopted in the present study also. They have considered a combined set of 14 helicenes and acenes, in that acenes were introduced for comparison with helicenes. However, the methodology used by them was to consider acenes and helicenes as two different classes. In order to avoid size effect, the resonance energy (RE) was normalizing giving:

$$\mathrm{NRE} = \mathrm{RE}/\mathrm{N} \quad (1)$$

where, NRE stands for RE per π electron, while N is the number of π electrons in the conjugated molecule.

As stated above, we have attempted prediction of NRE using Sd,[12] A and PI indices.[13–15] The results obtained

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will be useful for those medicinal chemists and environmentalists who are interested in providing basis for the physiological activity and environmental behavior of acenes and helicenes.

2. Results and discussion

Our earlier results[12] have shown that Sadhana index (Sd) of acenes and helicenes can be estimated from the same formula:

$$\mathrm{Sd} = \mathrm{Sd(G)} = 2\mathrm{h}\ (5\mathrm{h} + 1) \tag{2}$$

where, h is the number of cycles (hexagon) present in the acene/helicene molecules. It means that the same formula applies for helicenes and any isomeric catacondensed system with no linearly condensed systems with rings: all such systems are isoarithmic.

In contrast to the similar expression for the calculation of Sd index, acenes and helicenes have separate expressions[14,15] for the calculation of PI (Padmakar-Ivan) index:

For acenes

$$\mathrm{PI} = 24\,\mathrm{h}^2 \tag{3}$$

For helicenes

$$\mathrm{PI} = 25\,\mathrm{h}^2 - 3\,\mathrm{h} + 2 \tag{4}$$

Here again, in eqs 3 and 4, h stands for the number of cycles (hexagon) present in the acene/helicene molecules.

The A index recommended by the referee on this paper is defined as:

$$\mathrm{A} = \mathrm{h}^{\mathrm{a}} + \mathrm{b}\,\mathrm{k}^{\mathrm{a}} \tag{5}$$

This index, therefore is based on h and the number k of kinks in dualist graph[16,17] (zero for acenes, h-2 for benzenoids that are isoarithmic with helicenes). One may try a = b = 1 or 2. It, perhaps, would have the advantage of following a single correlation for the two classes and for any other non-branched catacondensed benzenoids.

The Sd, A, and PI indices calculated for the same combined set of 14 acenes and helicenes, as was used by Randic, Gimarc, and Trinajstic[18] are presented in Table 1, alongwith their NRE and % benzene character values.

A perusal of Table 1 shows that degeneracy is present in both the PI and the Sd indices as they belong to first-generation topological indices.[19] Inspite of their degeneracy they can be used successfully for QSPR and QSAR studies.[20,21–27] In the present study also same is found to be the case. In contrast to the PI and Sd indices no degeneracy is observed in A index and is thus the most discriminating index.

Initially, we have performed QSPR for the combined set of acenes and helicenes for predicting their NRE and also % benzene character (Table 2) which gave a very poor statistics. These results show that they (acenes and helicenes) are to be considered as distinct classes of compounds.[28–32] Regressions attempted under such situation gave excellent models for modeling, monitoring, and estimating NRE. It is important to mention that the following regression expressions (models) all are at 95% confidence limit. Hence, the purpose of the introduction of A index is not fulfilled. However, this index as proposed by the referee proved better than the PI and Sd indices only when acenes and helicenes are considered as separate classes.

We first discuss the results obtained for modeling of NRE for acene molecules.

The regression analysis[33] for acenes using A, PI and Sd indices gave the following QSPR models for modeling NRE:

$$\mathrm{NRE} = 0.1620 - 0.0133\,\mathrm{A} \qquad n = 8,\ \mathrm{Se} = 0.0111,\ \mathrm{R} = -0.9532,\ \mathrm{Q} = 85.87 \tag{6}$$

$$\mathrm{NRE} = 0.1370 - 5.8 \times 10^{-5}\ \mathrm{PI} \qquad n = 8,\ \mathrm{Se} = 0.0145,\ \mathrm{R} = -0.9192,\ \mathrm{Q} = 63.39 \tag{7}$$

$$\mathrm{NRE} = 0.1380 - 0.0001\,\mathrm{Sd} \qquad n = 8,\ \mathrm{Se} = 0.0141,\ \mathrm{R} = -0.9240,\ \mathrm{Q} = 65.53 \tag{8}$$

The results obtained for modeling NRE of helicenes are found as:

$$\mathrm{NRE} = 0.1400 - 0.0003\,\mathrm{A} \qquad n = 6,\ \mathrm{Se} = 0.0003,\ \mathrm{R} = 0.9810,\ \mathrm{Q} = 3270.00 \tag{9}$$

$$\mathrm{NRE} = 0.1410 + 1.8930 \times 10^{-6}\ \mathrm{PI} \qquad n = 6,\ \mathrm{Se} = 0.0004,\ \mathrm{R} = 0.9730,\ \mathrm{Q} = 2432.50 \tag{10}$$

$$\mathrm{NRE} = 0.1400 + 6.27 \times 10^{-6}\,\mathrm{Sd} \qquad n = 6,\ \mathrm{Se} = 0.0004,\ \mathrm{R} = 0.9649,\ \mathrm{Q} = 2412.25 \tag{11}$$

The statistical characteristics of eqs 10 and 11 show that in case of helicenes, the PI index is found better than the Sd index for modeling NRE and that A index is the best for this purpose.

In addition, we have also used A, PI, and Sd indices for modeling the percentage of benzene character of both acenes and helicenes. This percentage of benzene character, according to Randic, Gimarc and Trinajstic[18] is estimated from the following expression:

$$\%\ \text{benzene character} = \frac{\text{NRE (molecule)}}{\text{NRE (benzene)}} \times 100 \qquad (12)$$

Accordingly, the percentage of benzene character (Table 1) can be used for a finer classification within an isomeric class of aromatic molecules.

For acene molecules excellent results are obtained for modeling percentage of benzene character. Using A, PI and Sd indices, the following results are obtained:

$$\%\ \text{benzene character} = 105.0 - 8.39\,\text{A}$$
$$n = 8,\ \text{Se} = 3.4008,\ \text{R} = -0.9884,\ \text{Q} = 0.2906 \qquad (13)$$

$$\%\ \text{benzene character} = 89.60 - 0.0358\,\text{PI}$$
$$n = 8,\ \text{Se} = 8.0488,\ \text{R} = -0.9336,\ \text{Q} = 0.1160 \qquad (14)$$

$$\%\ \text{benzene character} = 90.0011 - 0.0841\,\text{Sd}$$
$$n = 8,\ \text{Se} = 7.7819,\ \text{R} = -0.9380,\ \text{Q} = 0.1205 \qquad (15)$$

The statistical characteristics show that in case of acenes the Sd index is slightly better than the PI index for modeling percentage benzene character and that A index is most appropriate for this purpose.

Table 1. Acenes (a) and helicenes (b) and their NRE, PI, Sd, A indices

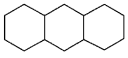
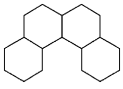
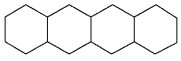
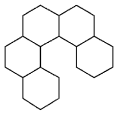
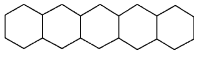
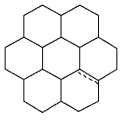
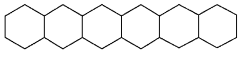
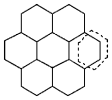
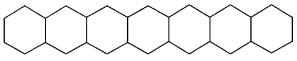
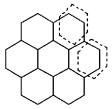
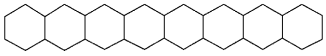
Compd	Acene/Helicene	% Benzene character	NRE	PI	Sd	A
1a		100	0.145	24	12	1
2a		91	0.133	96	44	2
3b		97	0.141	218	96	4
3a		79	0.114	216	96	3
4b		97	0.141	390	168	6
4a		68	0.099	384	168	4
5b		98	0.142	612	260	8
5a		60	0.087	600	260	5
6b		99	0.143	1206	392	12
6a		53	0.076	864	392	6
7b		99	0.144	1578	504	14
7a		47	0.069	1176	504	7
8b		99	0.144	2000	656	16
8a		43	0.062	1536	656	8

Table 2. Results for modeling NRE and % benzene characters of the combined series using A, Sd, and PI indices

S.N.	Topological indices	Property/Activity modeled			
		NRE		% Benzene character	
		R	Se	R	Se
	I Monoparametric Regression				
1	A-index	0.1268	0.0337	0.1936	22.35
2	PI-index	−0.2272	0.0330	−0.1673	22.46
3	Sd-index	−0.4177	0.0308	0.3598	21.26
	II Polynomial Regression (second polynomial)				
1	A-index	0.5704	0.0291	0.5666	19.60
2	PI-index	0.5575	0.0294	0.5145	20.40
3	Sd-index	0.4438	0.0318	0.3515	21.99

In case of helicenes, the percentage benzene character is calculated using A, PI, and Sd indices gave following results:

$$\%\ \text{benzene character} = 96.20 + 0.1960\ \text{A}$$
$$n = 6,\ \text{Se} = 0.3577,\ \text{R} = 0.9455,\ \text{Q} = 2.6432 \quad (16)$$

$$\%\ \text{benzene character} = 96.90 + 0.0013\ \text{PI}$$
$$n = 6,\ \text{Se} = 0.4520,\ \text{R} = 0.9115,\ \text{Q} = 2.0166 \quad (17)$$

$$\%\ \text{benzene character} = 96.70 + 0.0042\ \text{Sd}$$
$$n = 6,\ \text{Se} = 0.4704,\ \text{R} = 0.9038,\ \text{Q} = 1.9213 \quad (18)$$

Here, PI index is observed to be better than the Sd index for modeling percentage benzene character. Once again, A index is found superior to both PI and Sd indices.

The aforementioned differential results obtained for modeling % benzene character of acenes and helicenes may be attributed to the fact that for acenes % benzene character rapidly decreases and thus follows the decrease in the stability of acenes with the increase in the size. On the other hand % benzene character for helicenes indicates them to remain highly aromatic with increase in size.

The predictive power of the proposed models is determined by estimating quality factor Q, the largest value of which indicates highest[34,35] predictive power of the model. This quality factor Q is defined[34,35] as the ration of correlation coefficient (R) to standard deviation (Se), that is, Q= = R/Se. The values of Q for different models are given above in the respective equations.

These values show that in modeling NRE of acenes, the predictive power of the Sd index is better than the PI index. However, for helicenes reverse is the case. Also, for the estimation of % benzene characters in both the cases the models containing Sd index have better predictive power than the models based on PI index.

3. Conclusions

From the results and discussion made above we conclude that A, PI, and Sd indices can be used successfully for modeling NRE of acenes and helicenes. However, such type of results are not obtained when these indices are used for modeling % benzene character of helicenes. The new A index, as proposed by the referee, gave better results than PI and Sd indices. Results obtained herein are helpful to medicinal and environmental chemists to explain environmental behavior and physiological activities of acenes and helicenes.

4. Experimental

4.1. NRE and % benzene character

The values of NRE and % benzene characters are adopted from the literature.[18]

4.2. Topological indices

The details of the calculation of PI and Sd indices are available in the literature,[12,13–15] while the calculation of A index is given in the introduction section of this paper. However, the expressions used for their calculations are given in the Results and discussion section of this paper.

4.3. Regression analysis

The regression analysis[33] of the data set is carried out by using simple regression procedures. Since excellent results are obtained in simple regression analysis there was no need to perform multiple regression analysis. Another reason for not doing multiple regression analysis is that the data set permits only the simple regression, that is, monoparametric regression only.

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