

Correlation of the Melting Points of Potential Ionic Liquids (Imidazolium Bromides and Benzimidazolium Bromides) Using the CODESSA Program

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The melting points of several imidazolium-based ionic liquids or ionic liquid analogues were correlated using the CODESSA program in order to develop predictive tools for determination of suitable ionic liquid salts. The data set consisted of melting point data (°C) for 104 substituted imidazolium bromides divided on the basis of the N-substituents into three subsets: A-57 compounds, B-29 compounds, and C-18 compounds. The 45 benzimidazolium bromides form set D. Five-parameter correlations were obtained for (i) set A with $R^2 = 0.7442$, (ii) set B with $R^2 = 0.7517$, and (iii) set D with $R^2 = 0.6899$, while set C was correlated with a three parameter equation with $R^2 = 0.9432$. These descriptors for predicting the melting points of the imidazolium and benzimidazolium bromides were based on the size and electrostatic interactions in the cations.

INTRODUCTION

Ionic liquids (IL) have received a great deal of attention as a promising area of research for the development of new “green” technologies. IL offer a highly solvating, yet noncoordinating medium in which a number of organic and inorganic solutes may be dissolved.^{1,2}

The exciting solvent properties of IL include their potential nonvolatility, nonflammability, and high thermal stability.³ Melting points as low as $-96\text{ }^{\circ}\text{C}$ are known, thus the usable liquid range may cover that used for conventional synthetic chemistry and low-temperature extractions.⁴

Most of the recent work with IL as solvents has focused on the characterization and application of imidazolium derivatives. Nonetheless, the properties of both cation and anion are useful tools for fine-tuning the physical properties of the resulting IL for desired “solvent” characteristics.^{5–8} Clearly, many different IL may be synthesized having a wide range of physical and chemical properties.

Favored applications of IL as solvents include catalysis,^{9,10} electrochemistry,¹¹ and green chemistry. From the green chemistry perspective, the development of IL as solvent alternatives could, for example, sustain the use of liquid/liquid separations while decreasing reliance on traditional organic solvents historically used to maintain the biphasic system. Utility has been demonstrated in a variety of separations with several IL, notably those with PF_6^- or $\text{N}(\text{SO}_2\text{CF}_3)_2^-$ as the anion. These ionic liquids have solvent characteristics suitable for their incorporation in place of traditional volatile organic compounds (VOCs) in liquid/

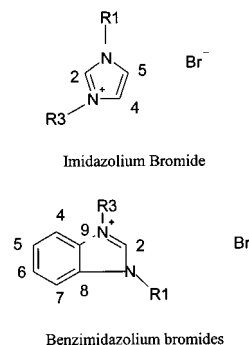


Figure 1. Structure of imidazolium bromides and benzimidazolium bromides.

liquid separations. For example, with a series of organic solutes, we have shown that the solute affinity for the IL ($[\text{C}_4\text{mim}][\text{PF}_6]$) phase increases in correlation with the solute’s 1-octanol/water log P value (a traditional hydrophobicity probe).¹²

There is currently no method available to predict the melting points (and other useful physical properties) of the approximately 10^{18} combinations of ions that could lead to useful ionic liquids. The present investigation attempts to begin the process of redressing this situation via correlating the melting point of IL with the chemical structures of substituted imidazolium bromides and benzimidazolium bromides (Figure 1) using molecular descriptors generated by the CODESSA program.

EXPERIMENTAL METHODOLOGY

The data for IL and analogues presently considered (imidazolium and benzimidazolium bromides) was obtained from the Beilstein database.¹³ The database used for cor-

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Table 1. Allocation of Imidazolium Bromides to the Subsets

subset no.	substituents of imidazolium bromides		
	1 or 3	other positions	
A	alkyl	any	$n = 57$ (Table 2)
B	OR	any	$n = 29$ (Table 3)
C	aryl	any	$n = 18$ (Table 4)

relating melting points of the imidazolium bromides ($n = 104$) was divided into three subsets. The division was based on the chemical substituents at position 1. Table 1 describes how the imidazolium bromides were allocated to the different subsets. Set C (benzimidazolium bromides) is comprised of 45 structures (Table 5).

All the data sets were prepared using ISIS/Base.¹⁴ The Hyperchem program¹⁵ was used to generate the preliminary molecular geometry optimization using molecular mechanics MM+ force fields. The final optimization was obtained using the semiempirical AM1 parametrization method¹⁶ present in the MOPAC computer program.¹⁷ The output files were used for producing constitutional, topological, electrostatic, and semiempirical descriptors by the CODESSA software package.¹⁸ The resulting descriptors were then used for multilinear scale treatment.

Our group has been actively engaged in QSPR/QSAR studies of several physicochemical and biological properties employing the CODESSA program.¹⁹ CODESSA is frequently used to provide correlations and give insight into the way in which structural features control physical properties.^{19–22}

CODESSA uses the heuristic or the best multilinear regression method (BMLR) to search for the set of best multilinear correlations: preselection of descriptors by eliminating the descriptors that are not available for structure or those having a small variation in magnitude or the descriptors having a F -test value less than 1 or t -values less than 1.5.

In the case of the heuristic method the descriptors are ordered by decreasing correlation coefficient when used in one-parameter correlations. The next step involves correlation of the given property with the top descriptor in the above list with each of the remaining descriptors and the next one with each of the remaining descriptors, etc. The best pairs, as evidenced by the highest F -values in the two-parameter correlations, are chosen and used for further inclusion of descriptors in a similar manner.

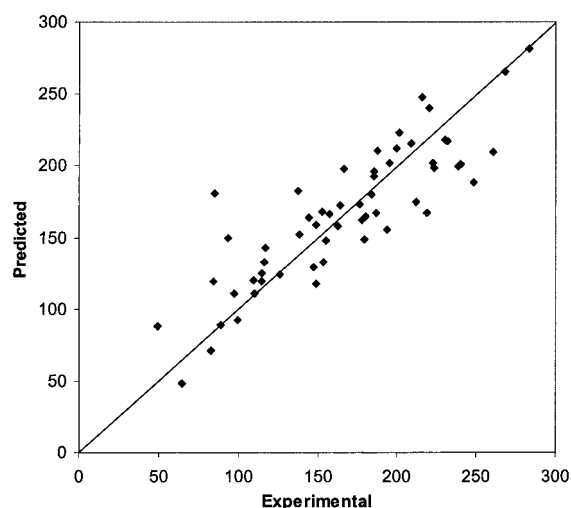
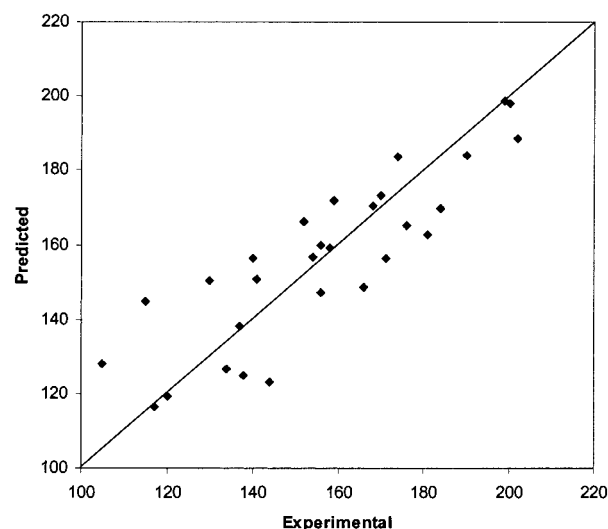
BMLR searches for the multiparameter regression with the maximum predicting ability using the following strategy.

1. All orthogonal pairs of descriptors i and j (with $R^2_{ij} < R^2_{min}$) are found in a given data set.

2. The pairs with highest regression correlation coefficient R^2 with the property are chosen for performing the higher order treatments.

3. For each descriptor pair obtained, a noncollinear descriptor scale k (with $R^2_{ik} < R^2_{nc}$, $R^2_{jk} < R^2_{nc}$) is added, and the respective three-parameter regression treatment is performed. The descriptor triples with highest R^2 are chosen for the next step.

4. For each descriptor set, chosen in the previous step, an additional noncollinear descriptor scale is added, and the respective $(n+1)$ -parameter regression treatment is performed.

**Figure 2.** Plot of experimental and calculated MP for Set A imidazolium salts (equation 1; $n = 57$; $R^2 = 0.7442$; see Table S1).**Figure 3.** Plot of experimental and calculated MP for Set B imidazolium salts (equation 2; $n = 29$; $R^2 = 0.7517$; see Table S2).

5. The final result is produced when the increase in R^2 is below a given threshold value. Otherwise step 4 is repeated.

RESULTS AND DISCUSSION

The data sets of imidazolium bromides (divided into three subsets based on the substituents at position 1) and benzimidazolium bromides were taken for correlating the melting points. The best equations were found by BMLR in all cases.

Set A was correlated using a five-parameter equation (eq 1, Table S1 and depicted in Figure 2).

$$T_m = -(62.02 \pm 6.16)E_{HOMO-LUMO} + (96.58 \pm 14.68)J + (1482.1 \pm 232.1)P_\mu + (667.4 \pm 141.7)Q_{max,N} - (8.17 \pm 1.89)E_{max,e-n,C} + (9.45 \pm 3.56) \quad (1)$$

$$R^2 = 0.7442, R^2_{cv} = 0.6853, F = 29.67, s = 29.2, n = 57$$

Table 2. Allocation of Different Structures to Set A^a

ID	exptl MP	calcd MP	1-substituent	3-substituent	other substituents
1	49.0	86.8	-CH ₃	-CH ₂ COPh	
2	64.9	65.1	-CH ₃	-C ₂ H ₅	
3	83.0	69.7	-CH=CH ₂	<i>n</i> -C ₄ H ₉	
4	84.5	126.6	<i>n</i> -C ₁₀ H ₂₁	-CH ₃	2-CH ₃
5	85.0	162.0	-CH ₃	-CH ₂ COC ₆ H ₄ (<i>m</i> -OC ₃ H ₇)	
6	88.5	87.3	-CH ₂ CH=CH ₂	-CH ₂ CHCN	
7	93.5	155.4	-CH ₃	-CH ₂ C ₆ H ₄ (<i>p</i> -COPh)	
8	97.35	105.3	-CH ₃	-CH ₂ CH ₂ OH	
9	99.5	104.4	-CH=CH ₂	-C ₂ H ₅	
10	109.5	145.7	-CH ₃	-CH ₃	
11	110.5	122.0	-CH ₃	<i>n</i> -C ₄ H ₉	5-CH ₃
12	115.0	140.1	-CH ₃	-CH ₂ C ₆ H ₄ (<i>m</i> -CH ₃)	
13	115.0	142.6	-CH ₃	-CH ₂ C ₆ H ₄ (<i>o</i> -CH ₃)	
14	116.5	140.5	<i>n</i> -C ₅ H ₁₁	-CH ₂ Ph	<i>n</i> -C ₁₁ H ₂₃
15	117.0	148.7	-CH ₃	-CH ₂ COPh	
16	126.0	143.0	-CH ₃	-CH ₂ Ph	
17	137.5	171.2	-CH ₃	-CH ₂ COC ₆ H ₄ (<i>m</i> -OC ₂ H ₅)	
18	138.5	141.4	-CH ₃	-C(CH ₃) ₂ COPh	
19	144.5	138.9	-CH ₃	-CH ₂ COC ₆ H ₄ (<i>p</i> -OC ₂ H ₅)	
20 ^a	147.0	151.1			
21	148.5	171.8	-CH ₃	-CH ₂ COC ₆ H ₄ (<i>p</i> -Cl)	
22	149.0	106.5	<i>n</i> -C ₃ H ₇	-CH ₂ COPh	
23	153.0	159.9	-CH ₃	-CH ₂ COC ₆ H ₄ (<i>o</i> -CH ₃)	
24	153.5	145.6	-C ₂ H ₅	-C ₂ H ₅	4-Ph, 5-Ph
25	155.0	138.9	-CH=CH ₂	<i>n</i> -C ₃ H ₇	
26	157.5	185.6	-CH ₃	-CH ₂ COC ₆ H ₄ (<i>p</i> -OMe)	
27	162.5	135.4	<i>n</i> -C ₃ H ₇	<i>n</i> -C ₃ H ₇	2-CH ₂ CH(CH ₃) ₂
28	164.0	148.5	-CH ₃	-CH ₂ COC ₆ H ₃ [3,4-(CH ₃) ₂]	
29	166.0	199.5	-CH ₃	-CH ₂ COC ₆ H ₄ (<i>o</i> -OCH ₃)	
30	176.0	175.4	-CH ₃	-CH ₂ COC ₆ H ₄ (<i>m</i> -Cl)	
31	178.0	161.1	-CH(CH ₃) ₂	-CH ₂ COC ₆ H ₄ (<i>m</i> -OCH ₃)	
32	179.0	174.9	-CH ₃	-CH ₂ COC ₆ H ₄ (<i>o</i> -F)	
33	180.0	155.3	-CH ₃	-CH ₂ COC ₆ H ₃ [1,3-(CH ₃) ₂]	
34	183.5	189.5	-CH ₃	-CH ₂ COC ₆ H ₃ [3,4-(Cl) ₂]	
35	185.0	196.4	-CH ₃	-CH ₂ COPh	2-CH(=CH ₂)Ph
36	185.0	163.0	-CH ₃	-(CH ₂) ₂ C ₆ H ₄ (<i>p</i> -NO ₂)	
37	186.5	168.9	-CH ₃	-CH ₂ Ph	2- <i>n</i> -C ₇ H ₁₅
38	187.5	143.6	-CH ₃	-CH ₂ COC ₆ H ₄ (<i>p</i> -NO ₂)	
39	194.0	160.4	-CH ₃	-CH ₂ Ph	<i>n</i> -C ₉ H ₁₉
40	195.5	211.8	-CH ₃	-CH ₃	5-Cl
41	200.0	177.9	-CH ₃	-CH ₂ COPh	2-CH(=CH ₂)C(CH ₃) ₃
42	201.0	228.6	-CH ₃	-CH ₂ COC ₆ H ₄ (<i>p</i> -Cl)	2-CH ₃
43	208.5	205.5	-CH ₃	-CH ₂ COC ₆ H ₃ [2,5-(OCH ₃) ₂]	
44	212.0	145.4	-CH ₃	-CH ₂ COC ₆ H ₄ (<i>p</i> -CN)	
45	216.0	216.2	-CH ₃	-CH ₂ COC ₆ H ₃ [2,3-(OCH ₃) ₂]	
46	218.5	176.3	-CH ₃	-CH ₂ COC ₆ H ₄ (<i>p</i> -Br)	
47	220.5	237.5	-CH ₃	-CH ₃	-SCN
48	222.5	180.5	-CH ₃	-CH ₂ COC ₆ H ₂ [2,4,6-(CH ₃) ₃]	
49	223.5	180.6	-CH ₃	-CH ₂ C ₆ H ₄ [2-COOC ₆ H ₄ (<i>p</i> -NO ₂)]	2-CH ₃
50 ^a	230.5	231.0			
51	231.5	204.7	-CH ₃	-CH ₂ COC ₆ H ₃ [3,4-(OCH ₃) ₂]	
52	238.5	210.2			
53 ^a	240.0	221.2	-CH ₃	-CH ₂ COC ₆ H ₃ [3,5-(OCH ₃) ₂]	
54	248.5	208.9	-CH ₃	-CH ₂ COC ₆ H ₄ (<i>p</i> -Ph)	
55	260.5	231.8	-CH ₃	-CH ₂ =CHC ₆ H ₄ OH	
56	268.0	295.2	-CH ₃	-CH ₃	2-Br, 4-Br, 5-Br
57	283.0	293.3	-CH ₃	-CH ₃	2-Ph

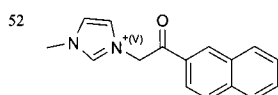
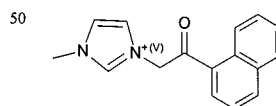
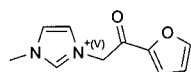
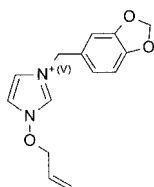
^a See the structures below:

Table 3. Allocation of Different Structures to Set B^a

ID	exptl MP	calcd MP	1-substituent	3-substituent	other substituents
1	105.0	133.5	-OCH ₂ C ₆ H ₃ [2,4-(Cl) ₂]	-CH ₂ COC ₆ H ₄ (p-Cl)	
2	115.0	138.9	-OH	-CH ₂ C ₆ H ₃ [2,4-(Cl) ₂]	
3	117.0	135.1	-OCH=CH ₂	-CH ₂ C ₆ H ₃ [2,4-(Cl) ₂]	
4	120.0	120.7	-OC ₂ H ₅	-CH ₂ C ₆ H ₄ (p-NO ₂)	
5	130.0	155.5	-OC ₂ H ₅	-CH ₂ COC ₆ H ₄ (p-Cl)	
6	134.0	108.9	-OC ₂ H ₅	-CH ₂ C ₆ H ₃ [2,4-(Cl) ₂]	
7 ^a	137.0	132.4			
8	138.0	127.3	-OCH ₂ CH ₂ Ph	-CH ₂ C ₆ H ₃ [2,5-(Cl) ₂]	
9	140.0	155.5	-OCOC (CH ₃) ₃	-CH ₂ COC ₆ H ₄ (p-Cl)	
10	141.0	147.2	-OPh	-CH ₂ COC ₆ H ₄ (p-N(CH ₃) ₂)	
11	144.0	124.2	-OCH ₂ Ph	-CH ₂ C ₆ H ₃ [2,4-(Cl) ₂]	
12	152.0	171.4	-OH	-OH	2-Br, 4-CH ₃ , 5-CH ₃
13	154.0	153.0	-OH	-OH	2-CH ₃ , 4-Br
14	156.0	162.2	-OCH ₂ C ₆ H ₃ (2,6 [Cl] ₂)	-OCH ₂ C ₆ H ₃ (2,6[Cl] ₂)	2-C ₂ H ₅
15	156.0	155.2	-OCH ₃	-CH ₂ COC ₆ H ₄ (p-Cl)	
16	158.0	159.4	-OH	-OH	2-Ph, 4-Br
17	159.0	153.7	-OCH ₂ Ph	-CH ₂ C ₆ H ₂ [3,4,5 (-OCH ₃) ₃]	2-C ₂ H ₅
18	166.0	161.9	-OCOCH (CH ₃) ₃	-CH ₂ COC ₆ H ₄ (p-Cl)	
19	168.0	174.2	-OCH ₂ C ₆ H ₄ (p-NO ₂)	-OCH ₂ C ₆ H ₄ (p-NO ₂)	2-CH ₃
20	170.0	167.9	-OCH ₂ C ₆ H ₄ (p-Br)	-OCH ₂ C ₆ H ₄ (p-Br)	2-C ₂ H ₅
21	171.0	176.1	-OPh	-CH ₂ COC ₆ H ₄ (p-Cl)	2-C ₂ H ₅
22	174.0	178.1	-OCH ₂ C ₆ H ₄ (p-Br)	-OCH ₂ C ₆ H ₄ (p-Br)	2-CH ₃
23	176.0	156.3	-OCH ₂ C ₆ H ₃ (2,4-[Cl] ₂)	-OCH ₂ C ₆ H ₃ (2,4-[Cl] ₂)	2-C ₂ H ₅
24	181.0	170.4	-OH	-OH	2-Br
25	184.0	163.5	-OCOC (CH ₃) ₃	-CH ₂ COC ₆ H ₄ (p-Cl)	2-C ₂ H ₅
26	190.0	193.6	-OH	-CH ₂ C ₆ H ₂ [3,4,5 (-OCH ₃) ₃]	
27	199.0	180.0	-OH	-CH ₂ COC ₆ H ₄ (p-Cl)	2-C ₂ H ₅
28	200.0	184.8	-OH	-CH ₂ COC ₆ H ₄ (p-Cl)	2-CH ₃
29	202.0	196.0	-OH	-CH ₂ COC ₆ H ₄ (p-Cl)	

^a See the structure below:**Table 4.** Allocation of Different Structures to Set C

ID	exptl MP	calcd MP	1-substituent	3-substituent	other substituents
1	62.5	91.6	-CH ₂ Ph	-CH ₂ Ph	
2	87.5	112.2	-CH ₂ Ph	<i>n</i> -C ₁₀ H ₂₁	2-CH ₃
3	103.0	108.1	-CH ₂ Ph	<i>n</i> -C ₁₄ H ₂₉	2-CH ₃
4	116.5	120.0	-CH ₂ Ph	<i>n</i> -C ₅ H ₁₁	2- <i>n</i> -C ₁₁ H ₂₃
5	135.0	130.9	-CH ₂ Ph	-CH ₂ Ph	4-C ₂ H ₄ OH
6	147.0	183.2	-Ph	-CH ₂ COC ₆ H ₄ (m-OCH ₃)	
7	186.5	117.1	-CH ₂ Ph	-CH ₃	2- <i>n</i> -C ₁₁ H ₂₃
8	193.0	202.5	-CH ₂ CH ₂ Ph	-CH ₂ COC ₆ H ₄ (p-Br)	2-CH ₃
9	202.0	200.6	-CH ₂ Ph	-CH ₂ COC ₆ H ₄ (p-OCH ₃)	2-CH ₃
10	205.5	201.3	-Ph	-CH ₂ COC ₆ H ₄ (p-CH ₃)	2-CH ₃
11	205.5	210.5	-C(Ph) ₃	-CH ₂ COPh	4-CH ₃
12	224.5	205.2	-CH ₂ Ph(p-OCH ₃)	-CH ₂ COC ₆ H ₄ (p-CH ₃)	2-CH ₃
13	228.5	232.6	-CH ₂ Ph	-CH ₂ COC ₆ H ₄ (p-Cl)	2-CH ₃
14	239.0	223.0	-CH ₂ Ph	-CH ₂ COPh	2-CH ₃
15	250.0	241.3	-CH ₂ C ₆ H ₄ F	-CH ₂ C ₆ H ₄ Cl	2-CH ₃ , 4-CH ₃
16	267.5	263.8	-Ph	-Ph	2-Ph, 4-NH ₂
17	282.5	300.6	-Ph	-CH ₃	2-Ph, 4-NH ₂
18	283.0	279.5	-Ph	-Ph	2-Ph, 4-NH ₂

The five-parameter correlation of the Set B was given in eq 2 (Table S2 and depicted in Figure 3).

$$T_m = -(14.04 \pm 2.07)E_{\max, e-n, C-N} + (0.905 \pm 0.138)HDSA1_{HA} + (3.69 \pm 0.71)N_H + (51.16 \pm 15.02)S - (341.5 \pm 122.2)Q_{\max, O} + (4513 \pm 655) \quad (2)$$

$$R^2 = 0.7517, R^2_{cv} = 0.6440, F = 13.93, s = 14.5,$$

$$n = 29$$

The three-parameter correlation of the Set C was given in eq 3 (Table S3 and depicted in Figure 4).

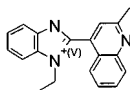
$$T_m = -(25.78 \pm 1.82)RNCS + (4.52 \pm 0.36)HDSA1_{HA} - (10.3 \pm 1.40)E_{\min, C-N} + (3027 \pm 426) \quad (3)$$

$$R^2 = 0.9432, R^2_{cv} = 0.9166, F = 77.53, s = 17.7,$$

$$n = 18$$

Table 5. Allocation of Different Structures to Set D^a

ID	exptl MP	calcd MP	1-substituent	3-substituent	other substituents
1	150.8	168.9	-(CH ₂) ₃ CN	-(CH ₂) ₂ CN	
2	163.0	199.6	-CH ₃	-CH ₂ CH=CH ₂	
3	175.5	233.8	-CH ₂ COOH	-CH ₂ COPh	
4	183.0	204.5	-CH ₂ OH	-CH ₂ COPh	
5	196.0	188.4	-CH ₃	-CH ₂ COPh	5-OCH ₃
6	198.0	198.2	-C ₂ H ₅	-CH ₂ COC ₆ H ₄ (p-Br)	
7	205.0	214.8	-CH ₂ COOCH ₃	-CH ₂ COPh	2-CH ₃
8	206.0	181.7	-C ₂ H ₅	-C ₂ H ₅	
9	208.0	244.1	-CH (CH ₃) ₂	-CH ₂ COPh	2-NH ₂
10	211.0	213.4	-CH ₂ COOCH ₃	-CH ₂ COC ₆ H ₄ (p-Br)	2-CH ₃
11	214.5	209.1	-CH ₂ COOCH ₃	-CH ₂ COC ₆ H ₄ (p-OCH ₃)	2-CH ₃
12	215.0	227.0	-CH ₂ CH=CH ₂	-CH ₂ COC ₆ H ₄ (p-Br)	
13	215.0	220.6	-CH ₂ COOC ₂ H ₅	-CH ₂ COPh	2-C ₂ H ₅
14	215.0	192.9	-CH ₃	-CH ₂ COOC ₂ H ₅	2-CH ₃
15	217.0	213.4	-CH ₂ COOCH ₃	-CH ₂ COC ₆ H ₄ (p-CH ₃)	2-CH ₃
16	223.5	220.4	-CH ₃	-CH ₂ COPh	5-NO ₂
17	226.5	246.5	-Ph	-CH ₂ COC ₆ H ₄ (p-NO ₂)	2-CH ₃
18	227.5	242.3	-C ₄ H ₉	-CH ₂ COOCH ₃	2-NH ₂
19	231.0	235.2	-(CH ₂) ₃ COOC ₂ H ₅	-CH ₂ Ph	2-CH ₃
20	231.0	230.3	-CH ₂ COOCH ₃	-CH ₂ COCH ₃	2-CH ₃
21	233.0	230.6	-C ₂ H ₅	-CH ₂ COOC ₂ H ₅	2-C ₂ H ₅
22	234.0	228.5	-CH ₂ COOCH ₃	-CH ₃	2-CH ₃
23	234.5	218.0	-CH ₂ COOC ₂ H ₅	-CH ₂ COPh	2-C ₂ H ₅
24	235.0	257.3	-(CH ₂) ₃ COOH	-CH ₂ Ph	2-CH ₃
25	235.5	246.9	-CH ₃	-CH ₂ COC ₆ H ₄ (p-NO ₂)	5-NO ₂
26	236.5	253.9	-C ₂ H ₅	-C ₂ H ₅	2-CH ₃
27	238.5	240.6	<i>n</i> -C ₁₅ H ₃₁	<i>n</i> -C ₁₅ H ₃₁	2-CH ₃
28	239.0	218.9	-CH ₃	-CH ₂ COC ₆ H ₄ (p-NO ₂)	5-OCH ₃
29	240.5	219.6	-CH ₃	-CH ₂ COOCH ₃	2-NH ₂
30	242.0	252.5	-CH ₃	-CH ₂ CN	2-CH ₃
31	246.0	279.5	<i>n</i> -C ₉ H ₁₉	<i>n</i> -C ₉ H ₁₉	2-CH ₃
32	248.0	240.8	-CH ₂ Ph	-CH ₂ COC ₆ H ₄ (p-NO ₂)	2-CH ₃
33	249.5	245.1	-CH ₂ COOC ₂ H ₅	-CH ₂ COOC ₂ H ₅	2-CH ₃
34	251.5	232.3	-CH ₃	-CH ₂ COOC ₂ H ₅	2-NH ₂
35	253.5	251.4	-C ₂ H ₅	-CH ₂ COC ₆ H ₄ (p-NO ₂)	5-CH ₃ , 6-CH ₃
36	255.0	241.0	-CH ₃	-CH(CH ₃)COOCH ₃	2-CH ₃
37	257.5	225.4	-NH ₂	-CH ₂ COPh	2-NH ₂
38	261.0	253.0	-C ₂ H ₅	-CH ₂ CN	2-CH ₃
39	264.5	255.0	-CH ₃	-CH ₂ COPh	2-CH ₃ , 5-NO ₂
40	265.0	245.4	-CH ₃	-CH ₃	2-C ₂ H ₅ , 5-NO ₂
41	270.0	250.6		-CH ₃	-C ₆ H ₄ (<i>o</i> -COOH)
42	275.0	271.0	-CH ₃	-CH ₃	5-Cl
43	279.5	256.5	-NH ₂	-CH ₂ COC ₆ H ₄ (p-OCH ₃)	2-NH ₂
44 ^a	319.0	307.9			
45	370.0	268.2	-CH ₂ C ₆ H ₄ (p-NO ₂)	-CH ₂ C ₆ H ₄ (p-NO ₂)	2-NH ₂

^a See the structure below:

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Set D was correlated using a five-parameter equation given by eq 4 (Table S4 and depicted in Figure 5).

$$T_m = -(224.4 \pm 34.3)E_{c(C-H)} + (0.74 \pm 0.15)HDSA + (45.3 \pm 9.6)E_{\min,ex(C-C)} - (12.04 \pm 2.95)RPCS - (1752 \pm 607)RE_{\max,C} + (1015 \pm 142) \quad (4)$$

$$R^2 = 0.6899, R^2_{cv} = 0.5961, F = 16.91, s = 20.0,$$

$$n = 45$$

In eqs 1–4, $E_{HOMO-LUMO}$ is the energy gap between the highest occupied molecular orbitals and the lowest unoccupied molecular orbitals which helps to estimate the relative reactivity of the molecules of a given series of compounds and is related to the activation energy of the corresponding chemical reaction. P_μ is the minimum atomic orbital elec-

tronic population and deals with the nucleophilicity of the molecule. $HDSA I_{HA}$ is the hydrogen acceptor dependent hydrogen donor surface area, $HDSA$ is the hydrogen donor surface area, $Q_{\max,N}$ and $Q_{\max,O}$ are the maximum partial charge for a N atom and O atom, respectively, and RNCS and RPCS are the relative negative charged and relative positive charged surface areas, respectively, and thus deal with the features responsible for polar interactions between molecules. J is the Balaban index, and this topological descriptor relates to the atomic connectivity in the molecule. $E_{\max,e-n,C}$ is the maximum electron–nuclear attraction for a C atom, $E_{e-n,max,C-N}$ and $E_{e-n,min,C-N}$ are the maximum and minimum electron–nuclear attraction for a C–N bond, respectively, $E_{c(C-H)}$ is the maximum Coulombic interaction for a C–H bond, $E_{\min,ex(C-C)}$ is the minimum exchange energy for a C–C bond, $RE_{\max,C}$ is the maximum electrophilic

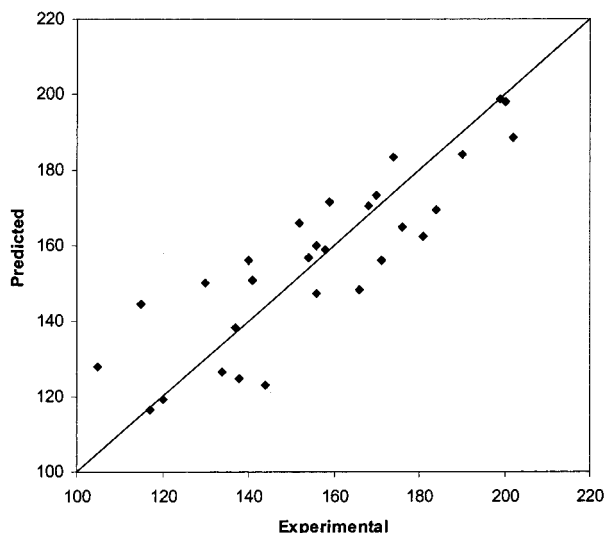


Figure 4. Plot of experimental and calculated MP for Set C imidazolium salts (equation 3; $n = 18$; $R^2 = 0.9432$; see Table S3).

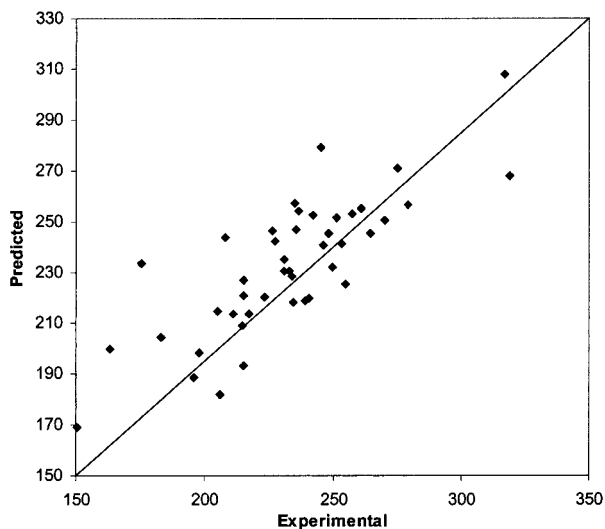


Figure 5. Plot of experimental and calculated MP for Set D benzimidazolium salts (equation 4; $n = 45$; $R^2 = 0.6899$; see Table S4).

reactivity index for a C atom, and S is the image of the Onsager-Kirkwood solvation energy. These descriptors indicate the importance of the intramolecular electronic effects on the intermolecular electrostatic interactions (including multipole interactions) of a molecule in determining the melting point of the substituted imidazoles and benzimidazoles.

The intercorrelation of descriptors is depicted in Tables S5–S8. All correlations of any single descriptor in a given model with all others in the same model had R^2 of less than 0.5.

VALIDATION OF RESULTS

The following procedure was used for the cross-validation of the five-parameter correlation eq 1. The subset A (57 compounds) was randomly divided into three groups I (1,4,7,...), II (2,5,8,...), and III (3,6,9,...) (19 in each set). The melting points of subsets I+II, I+III, and II+III were correlated using the descriptors from the five descriptor

equation for the whole dataset (eq 1). The coefficients of the descriptors for subsets I+II, I+III, and II+III were recorded. The subset I+II equation was then used for the prediction of the melting point of group III. Similarly, group II and group I melting points were predicted using the descriptor coefficients from subsets I+III and II+III, respectively. The correlation values were given in Table S9.

The predicted melting point was then correlated with the experimental values. The predicted melting points for group I, II, and III were then combined and correlated with the experimental melting point of the whole set. This cross-validation afforded a squared correlation coefficient of 0.7080 compared to that found in the original five-parameter correlation (eq 1, 0.7442).

CONCLUSION

We were able to successfully correlate the melting point of imidazolium bromides and benzimidazolium bromides containing different substituents. This was done with the help of molecular descriptors generated using the CODESSA program. The five-parameter correlation equation should be able to predict the melting point of unknown or unavailable compounds of this class. The descriptors involved in the correlations reflect directly both the intermolecular interactions and the influence of intramolecular electronic effects on those interactions. We are currently attempting to validate and refine the model by preparing new imidazolium bromide derivatives.

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Supporting Information Available: Tables S1–S4 give the correlation of the melting point of the imidazolium bromides Set A, Set B, Set C, and benzimidazolium bromides (Set D), respectively; Tables S5–S8 give the intercorrelations of descriptors for eqs 1–4, respectively; and Table S9 gives the validation of correlation for eq 1. This material is available free of charge via the Internet at <http://pubs.acs.org>.

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