COMPUTATIONAL PREDICTION AND EXPERIMENTAL CONFIRMATION OF SOLID SOLUTION FORMATION FROM DIFFERENT NITROBENZOIC ACID DERIVATIVES

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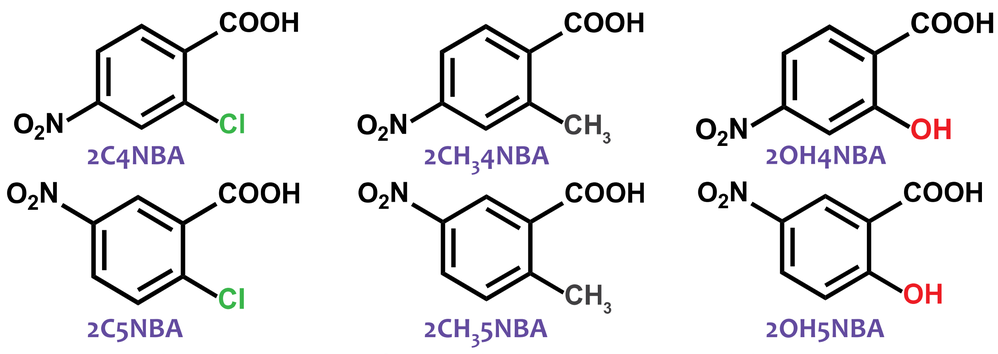
Introduction

Several nitrobenzoic acid **(NBA)** derivatives were selected as model compounds because of their availability and chemically similar structures, in which the different atom/group **(-Cl, -CH_3 or -OH)** doesn't significantly affect the dominant intermolecular interactions (see below).



Molecular structure of six studied nitrobenzoic acid derivatives

Crystal structures of nitrobenzoic acid derivatives

	2C4NBA	2$CH_3$4NBA	2OH4NBA	2C5NBA	2$CH_3$5NBA[4]	2OH5NBA[5]
Crystal system	Monoclinic	Monoclinic	Monoclinic	Monoclinic	Triclinic	Triclinic
Space group	$P2_1/c$	$P2_1/c$	$P2_1/c$	$P2_1/c$	$P\text{-}1$	$P\text{-}1$
a / Å	10.833(3)	4.9248(10)	3.8015(1)	5.8681(2)	7.636(13)	5.1231(2)
b / Å	5.8573(14)	11.8428(2)	11.6936(4)	5.1261(2)	10.426(19)	8.7759(3)
c / Å	13.497(3)	13.6012(2)	16.2761(5)	26.8664(10)	10.520(18)	9.2683(3)
α / °	90	90	90	90	89.28(3)	62.246(2)
β / °	105.734(4)	92.036(2)	94.506(2)	98.486(18)	81.80(3)	75.259(2)
γ / °	90	90	90	90	76.32(3)	82.642(2)
V / Å^3	824.32	792.76	721.28	799.31	805.25	356.60
$\rho_{calc.}$ / g cm^{-3}	1.624	1.518	1.687	1.675	1.495	1.706
Z, Z′	4, 1	4, 1	4, 1	4, 1	4, 2	2, 1

Crystallization results

Experimentally obtained crystalline phases from different nitrobenzoic acid mixtures

Substance ratio / %	Series of nitrobenzoic acid derivatives					
	2OH4NBA – 2C4NBA	**2$CH_3$4NBA – 2C4NBA**	**2OH4NBA – 2$CH_3$4NBA**	**2$CH_3$5NBA – 2C5NBA**	**2$CH_3$5NBA – 2OH5NBA**	**2C5NBA – 2OH5NBA**
0:100	2C4NBA|	2C4NBA|	2CH34NBA|	2C5NBA|	2OH5NBA|	2OH5NBA|
10:90	**Mixture**	**Mixture**	**Mixture**	SS^{2C5NBA}|	SS^{2OH5NBA}|	SS^{2OH5NBA}|
30:70	SS^{2OH4NBA}|	SS^{2CH34NBA}|	**Mixture**	**Mixture**	SS^{2OH5NBA}|	SS^{2OH5NBA}|
50:50	SS^{2OH4NBA}|	SS^{2CH34NBA}|	SS^{2OH4NBA}|	SS^{2CH35NBA}|	**Mixture**	SS^{2OH5NBA}|
70:30	SS^{2OH4NBA}|	SS^{2CH34NBA}|	SS^{2OH4NBA}|	SS^{2CH35NBA}|	SS^{2CH35NBA}|	**Mixture**
90:10	SS^{2OH4NBA}|	SS^{2CH34NBA}|	SS^{2OH4NBA}|	SS^{2CH35NBA}|	SS^{2CH35NBA}|	**Mixture**
100:0	2OH4NBA|	2CH34NBA|	2OH4NBA|	2CH35NBA|	2CH35NBA|	2C5NBA|

2OH4NBA and **2OH5NBA** = 2-hydroxy-(4/5)-nitrobenzoic acid, **2Cl4NBA** and **2Cl5NBA** = 2-chloro-(4/5)-nitrobenzoic acid, **2$CH_3$4NBA** and **2$CH_3$5NBA** = 2-methyl-(4/5)-nitrobenzoic acid, I = polymorph, SS = solid solution

Computational calculations

Lattice energies of various structures of nitrobenzoic acid derivatives

Molecule	Structure ($E_{lattice}$ / kJ mol^{-1})						
	Original	**Isostructural**			**Substituted**		
		OH	**Cl**	**CH_3**	**OH**	**Cl**	**CH_3**
2OH4NBA	-115.6	–	-121.5 ▼	-119.5 ▼	–	-117.0 ▼	-116.2 ▼
2C4NBA	-113.1	-122.1 ▼	–	-115.0 ▼	-113.9 ▼	–	-113.5 ▼
2$CH_3$4NBA	-122.4	-106.9 ▲	-113.4 ▲	–	-112.8 ▲	-112.7 ▲	–
2OH5NBA	-110.8	–	-111.5 ▼	-109.2 ▲	–	-120.0 ▼	-118.9 ▼
2C5NBA	-116.3	-106.9 ▲	–	-106.7 ▲	-113.0 ▲	–	-112.5 ▲
2$CH_3$5NBA	-116.4	-123.1 ▼	-118.4 ▼	–	-119.9 ▼	-118.4 ▼	–

Intermolecular interaction energies of various structures of nitrobenzoic acid derivatives

Molecule	Structure ($E_{int.}$ / kJ mol^{-1})						
	Original	**Isostructural**			**Substituted**		
		OH	**Cl**	**CH_3**	**OH**	**Cl**	**CH_3**
2OH4NBA	-123.7	–	-115.2 ▲	-129.3 ▼	–	-115.9 ▲	-115.5 ▲
2C4NBA	-119.5	-116.2 ▲	–	-107.4 ▲	-118.4 ▲	–	-119.8 ▼
2$CH_3$4NBA	-123.0	-112.2 ▲	-118.9 ▲	–	-117.1 ▲	-118.3 ▲	–
2OH5NBA	-125.7	–	-116.3 ▲	-113.2 ▲	–	-120.3 ▲	-119.8 ▲
2C5NBA	-115.2	-109.2 ▲	–	-117.1 ▼	-120.9 ▼	–	-120.1 ▼
2$CH_3$5NBA	-129.1	-118.4 ▲	-115.5 ▲	–	-111.5 ▲	-112.1 ▲	–

Background

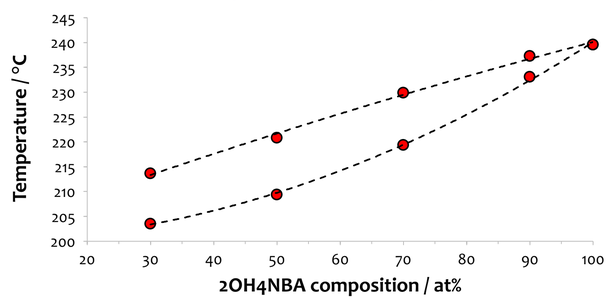
Organic solids are able to form very wide range of crystalline structures of different compositions – including polymorphs, solvates, co-crystals and solid solutions. Both geometric and chemical aspects, such as molecule dimensions, symmetry, and intermolecular interactions, are important in understanding solid state properties of all these phases.[1] In last decade research of solid solutions has increased significantly and has become common in crystal engineering. While analysing solid solutions and their molecular packing, more and more attention is paid to structural aspects that promotes and are responsible for the formation of solid solutions in two-component systems.[2]

Aims

- To perfrom crystallization experiments between binary systems of various nitrobenzoic acid derivatives to experimentally determine the information about formation of solid solutions
- To identify possible factors which could be used in prediction of the formation of solid solutions between chemically similar molecules[3]

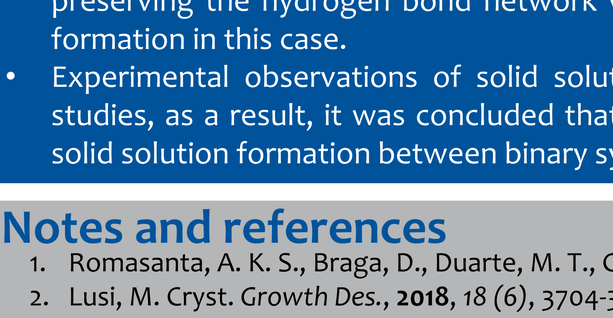
Structural aspects of nitrobenzoic acid derivative solid solutions

Melting phase diagrams



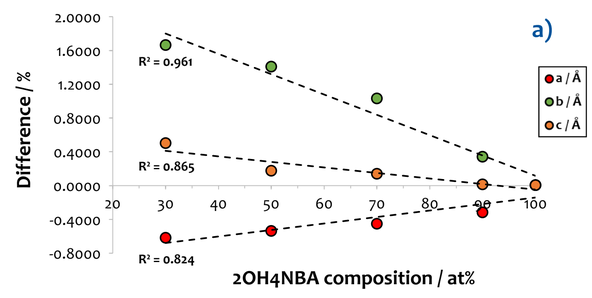
Melting points *vs.* atomic fraction of **2OH4NBA** in **2OH4NBA – 2C4NBA** solid solutions

Solid solution formation can be confirmed by means of melting phase diagram. It precisely demonstrate that the nitrobenzoic acid derivatives form solid solutions between each other.

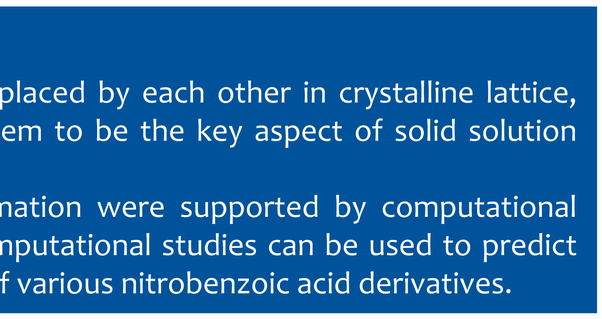


Melting points *vs.* atomic fraction of **2$CH_3$4NBA** in **2$CH_3$4NBA – 2C4NBA** solid solutions

Lattice parameters



Crystalline lattice parameters (a, b, and c) changes depending on the content of **2OH4NBA** (recrystallized from (a) – **ethanol**, (b) – **methanol**)

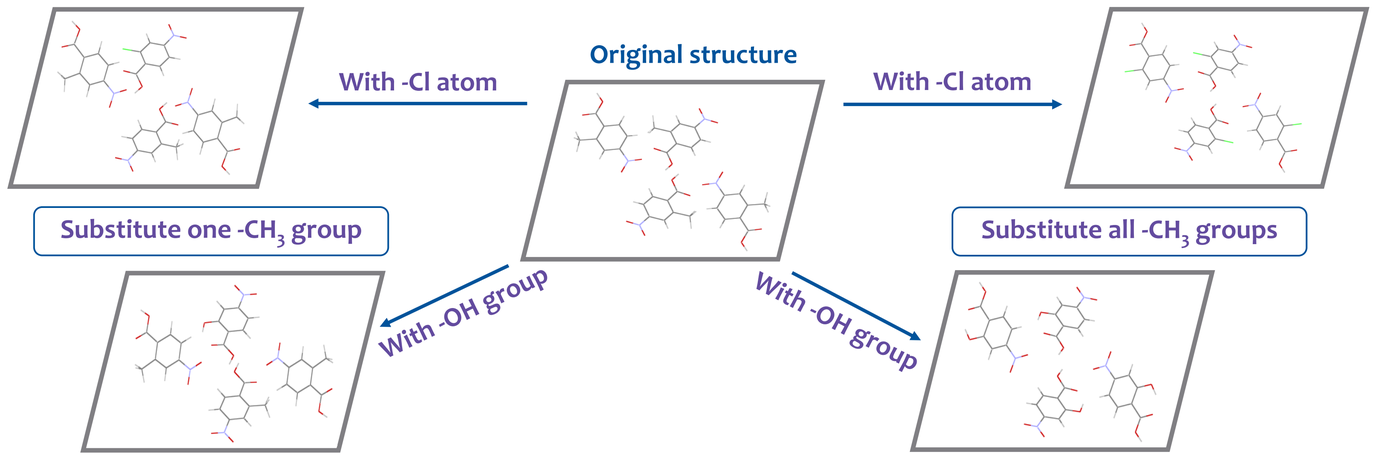


In the case of **2OH4NBA – 2C4NBA** non-solvated solid solution (both ethanol and methanol), it can be observed that the crystal lattice parameters, depending on the content of **2OH4NBA** form a monotonous function. This means that the *Vegard's Law* is fulfilled.

Characterization of intermolecular interactions

Lattice as well as intermolecular interaction energies were calculated for original, isostructural and substituted structure (detailed example see below).

Substituted structure **Isostructural structure**



Conclusions

- Nitrobenzoic acid derivative molecules can be replaced by each other in crystalline lattice, preserving the hydrogen bond network which seem to be the key aspect of solid solution formation in this case.
- Experimental observations of solid solution formation were supported by computational studies, as a result, it was concluded that the computational studies can be used to predict solid solution formation between binary systems of various nitrobenzoic acid derivatives.

Acknowledgments

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Notes and references

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