

L.A. Belyakova, D.Yu. Lyashenko, A.G. Grebenyuk, L.S. Dzyubenko, E.I. Oranskaya

Study of „ β -Cyclodextrin – Benzene Carboxylic Acid” Supramolecular Complexes

*Chuiko Institute of Surface Chemistry of National Academy of Sciences of Ukraine
17 General Naumov Str., Kyiv, 03164, Ukraine, E-mail: mila.belyakova@gmail.com, isc412@ukr.net*

The identity of “ β -cyclodextrin – benzene carboxylic acid” complexes synthesized in aqueous solutions and on the surface of highly dispersed silica was demonstrated. It was proved that obtained complexes are inclusion compounds of the “host – guest” type with equimolar ratio of 1:1. The stability constants of inclusion complexes and the thermodynamic parameters of their formation have been calculated. From the results of quantum-chemical calculations a conclusion about equal probability of “tail forward” and “head forward” inclusion complexes formation was made. The peculiarities of dehydration and thermal destruction of the inclusion complexes in comparison with individual compounds and their equimolar mixtures were revealed

Key words: silica, β -cyclodextrin, benzene carboxylic acid, supramolecular structures, inclusion complexes.

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Introduction

It is known that the solubility of many drugs and biologically active compounds, their bioavailability, as well as resistance to hydrolysis, thermal and oxidative degradation increase in the presence of cyclodextrins as a result of the formation of inclusion complexes of the “host – guest” type [1 – 5]. However, the release of these compounds is accompanied by the formation of other, more stable complexes. Therefore the process of cyclodextrins elimination from the body slows down. Accumulation of cyclodextrins markedly affects the metabolism in general. This problem can be solved by cyclodextrins fixing on the surface of solid matrices used in medicine as sorbents. Highly dispersed silica, for example, is used in medical practice as a drugs filler, as well as enterosorbent of proteins, endo- and exotoxins, pathogens, and viruses [6]. Silica with grafted cyclodextrins can be successful for preparation of drug compounds nanocapsules. Using fine silica as a carrier of such supramolecular structures should help to increase the stability of medicinal compounds to hydrolysis and oxidation, improving their bioavailability, decreasing the concentration of drugs without reducing the therapeutic effect. It is possible that these composite nanomaterials will have additional useful properties due to nanosized form of medicinal compounds. However the chemical immobilization of cyclodextrins on the surface of highly dispersed silica and preparation of inclusion complexes of grafted cyclodextrins with drug compounds are poorly understood.

In this paper the interaction of benzene carboxylic

acids (BCA) with β -cyclodextrin (β -CD) in aqueous solutions and on the surface of highly dispersed silica chemically modified with β -CD was studied. Benzoic (BA) and 2-hydroxybenzoic (salicylic, SA) acids are widely used to treat inflammatory processes of diverse etiology, heart and skin diseases [7].

I. Experimental

β -Cyclodextrin of “Fluka” and benzoic acid with the content of the basic substances at least 99 % from “Laboratorios Almiral SA” and salicylic acid “analytical pure” from “Reakhim” were used without additional purification.

UV absorption spectra of benzene carboxylic acids in water and n-hexane, and BCA aqueous solutions containing β -CD were recorded with a Specord M-40 spectrophotometer in the range of 200–350 nm using a thermostatically controlled quartz cuvettes ($l = 0.1$ cm). The temperature was determined with an accuracy of ± 0.5 o. The reflection spectra of silica modified with β -CD before and after interaction with BCA were recorded using an attachment of diffuse reflection 45/0.

IR spectra were recorded with a Thermo Nicolet NEXUS single-beam infrared spectrophotometer in the frequency range 4000–400 cm^{-1} . Plates (~ 30 mg) were pressed to IR spectra record, the pressure of compaction was 108 Pa.

Complete thermal analysis was carried out with a Q-1500 D device. Registration sensitivities are 500, 100, and 1 for the TG, DTA, and DTG curves, respectively.

The range of heating is 20–1000°C, heating rate is 10 grad·min⁻¹.

Quantum-chemical calculations were performed by the self-consistent field Hartree-Fock-Roothaan method within semiempirical PM3 approximation [8, 9] using the GAMESS program package (version 6.4) [10]. IR spectra were calculated within the harmonic approximation of rigid rotator under normal conditions.

II. Results and discussion

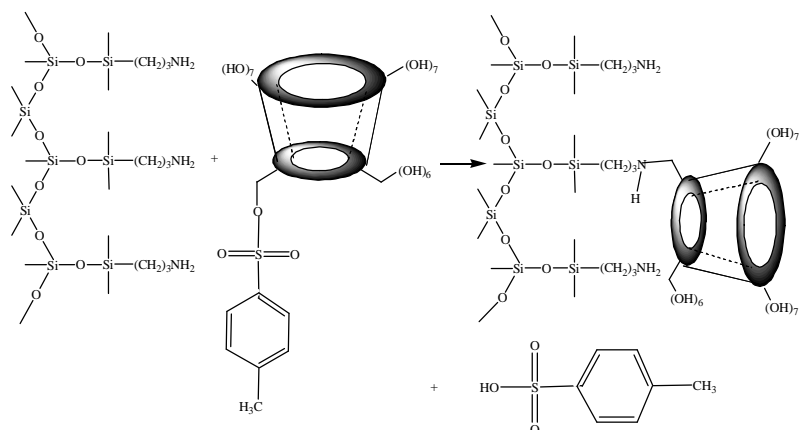
Modification of silica surface with β -CD was performed by the interaction of aminopropylsilica with mono-(toluenesulfonyl)- β -cyclodextrin (Scheme 1):

The chemically fixing molecules of β -CD on the surface of aminopropylsilica occurs at the narrow edge, and the wide edge of β -CD molecules with 14 secondary alcohol groups remains available for contact with the molecules of benzene carboxylic acids. Chemically immobilized β -cyclodextrin molecules (0.035 mmol/g) form a monolayer on the silica surface where neighboring molecules of β -CD are linked together by hydrogen bonds [11]. With the help of UV and IR spectroscopy the identity of products formed between BCA and β -CD in a solution and on the silica surface has

been proved. However, a more precise spectral pattern is observed for the individual products formed in aqueous solutions. This is understandable, since the content of BCA and β -CD on the silica surface is much smaller than that in a solution.

For aqueous solutions with concentrations of BCA from 0.1 to 1.0 mmol there are two bands $\pi \rightarrow \pi^*$ transitions of substituted benzene which are shifted to shorter wavelengths in comparison with their positions in the UV spectra of BA and SA in *n*-hexane (Table 1). This is a consequence of BCA involvement into the formation of hydrogen bonds in a polar solvent [12].

β -CD adding to aqueous solutions of BCA leads to long-wavelength shift of both benzene absorption bands (Table 1). It is due to the appearance of hydrophobic environment for BCA molecules. A similar pattern is observed for solutions of BCA in *n*-hexane (Table 1). Only the inner cavity of β -CD molecule may be a hydrophobic environment as its outer surface is hydrophilic [1]. The experimental data obtained by method of equimolar series fit the straight line in coordinates of the Benesi-Hildebrand equation for complexes of 1:1 [13] (Figure 1). Low values of stability constants K_s (Table 2) for both complexes β -CD · BCA indicate that they are likely formed through nonspecific intermolecular interactions.



Scheme 1. Chemical immobilization of β -cyclodextrin on the surface of aminopropylsilica.

Table 1

UV absorption spectra of benzene carboxylic acids

Studied system	$p \rightarrow p^*$ transitions of benzene			
	λ_1 , nm	ϵ^{λ_1} , L·mol ⁻¹ ·cm	λ_2 , nm	ϵ^{λ_2} , L·mol ⁻¹ ·cm
BA – water	224	9332	273	933
β -CD – BA – water	229	10470	275	955
BA – <i>n</i> -hexane	232	15849	275	1514
SA – water	233	6607	298	3311
β -CD – SA – water	235	6607	302	3388
SA – <i>n</i> -hexane	238	7586	307	3981
Complex of β -CD – BA onto silica surface	234	–	276	–
Complex of β -CD – SA onto silica surface	238	–	308	–

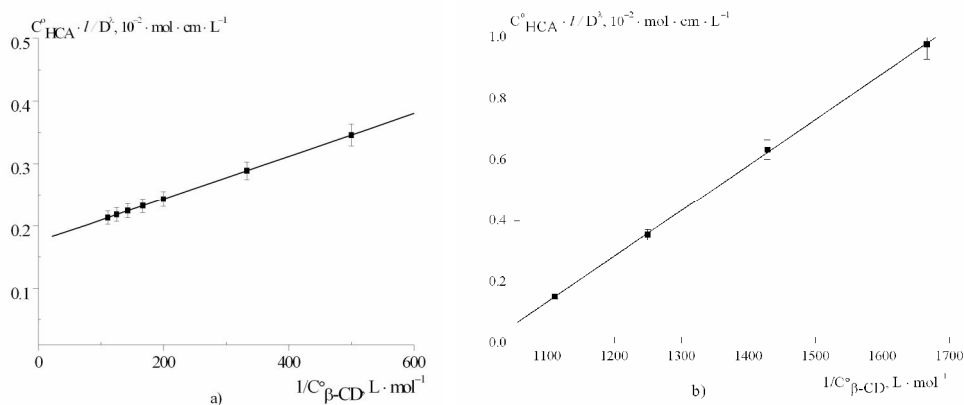


Fig. 1. Dependence of the UV spectral characteristics of benzoic (a) and salicylic (b) acids on the content of β -cyclodextrin in aqueous solution (in coordinates of the Benesi-Hildebrand equation for the complexes of 1:1).

Table 2

Stability constants K_s for complex formation between β -cyclodextrin and benzoic (or salicylic) acid with ratio 1:1

Temperature, K	K_s , L mol	
	complex " β -CD – BA"	complex " β -CD – SA"
291	124 ± 6	124 ± 6
293	120 ± 6	119 ± 6
295	114 ± 6	111 ± 6
298	108 ± 5	105 ± 5
300	104 ± 5	98 ± 5

Table 3

The wave numbers (ν) of intense absorption bands in the IR spectra of benzene carboxylic acids and their inclusion complexes with β -cyclodextrin

Benzoic acid			Inclusion complexes of β -cyclodextrin with benzoic acid		
ν , cm^{-1} (experimental data)	ν , cm^{-1} (calculated data)		ν , cm^{-1} (experimental data)	ν , cm^{-1} (calculated data)	
				complex "tail forward"	complex "head forward"
$\nu(\text{C-H})$ aromatic ring	3068	3075		3048	3054
$\nu(\text{C=O})$	1708	1793	1696	1791	1794
$\nu(\text{C=C})$	1603	1600	1603	1600	1600
	1582	1543	1580	1547	1549
	1497	1453		1459	1457
Salicylic acid			Inclusion complexes of β -cyclodextrin with salicylic acid		
ν , cm^{-1} (experimental data)	ν , cm^{-1} (calculated data)		ν , cm^{-1} (experimental data)	ν , cm^{-1} (calculated data)	
				complex "tail forward"	complex "head forward"
$\nu(\text{O-H})$ hydroxyl	3240	3223		3055	3052
$\nu(\text{C-H})$ aromatic ring	3050	3194		3017	3018
$\nu(\text{C=O})$	1675	1734	1675	1769	1771
	1664	1664	1664	1610	1616
$\nu(\text{C=C})$	1611	1609	1610	1603	1605
	1578	1594	1580	1550	1555
	1480	1527	1480	1467	1470
	1466	1430		1415	1418

Figure 2 shows the diffraction patterns of the initial compounds (β -cyclodextrin and benzene carboxylic acids), their physical mixtures and complexes with composition 1:1. Diffraction patterns of the starting compounds contain intense peaks, which confirm the individuality of the crystal structure of these compounds (Figure 2, a–c). The X-ray of physical mixtures of β -cyclodextrin with benzoic (or salicylic) acid are superposition of diffraction patterns of β -cyclodextrin and benzene carboxylic acids (Figure 2, d, e). Characteristic peaks of β -cyclodextrin, benzoic (or salicylic) acids are absent in the X-ray of interaction products of β -CD with BCA (Figure 2, f, g). The features of the diffraction patterns of β -CD · BCA complexes are the broadening of the peaks and the presence of amorphous halo. Observed decrease in crystallinity of the products of interaction between β -CD and BCA compared with their physical mixtures is due to the formation of supramolecular structures – “ β -CD – BCA” inclusion complexes of “host – guest” type, namely the entry of BCA molecules into the internal hydrophobic cavity of β -cyclodextrin.

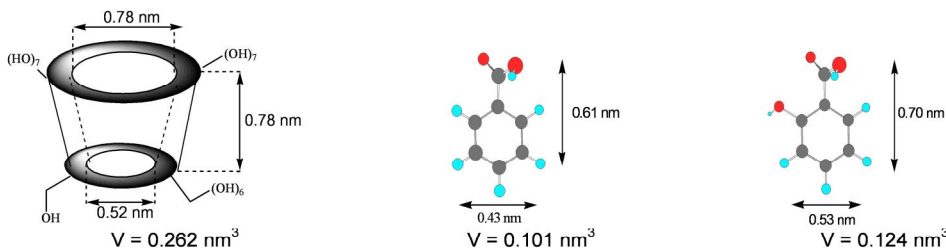
As follows from the IR spectral data (Table 3), the contribution of specific interactions to the formation of “ β -CD – BCA” complexes is really unessential. In the IR spectrum of BA the absorption bands of the valence vibrations of the C–H aromatic ring (3068 cm^{-1}), C=O carboxyl group (1708 cm^{-1}) and C=C benzene ring ($1603, 1582, 1497\text{ cm}^{-1}$) were recorded. The

IR spectrum of SA contains the bands of the valence vibrations of the O–H hydroxyl substituent (3240 cm^{-1}), C–H (3050 cm^{-1}), C=O ($1675, 1664\text{ cm}^{-1}$) and C=C ($1611, 1578, 1480, 1466\text{ cm}^{-1}$) bonds [14].

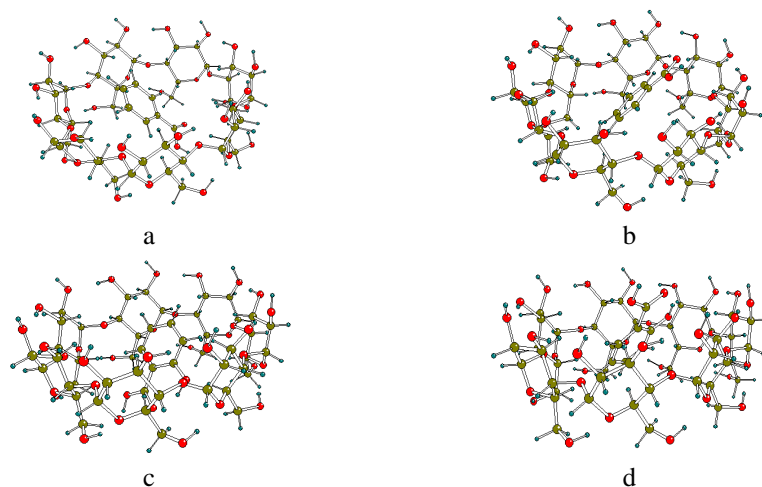
A broad band with a maximum at 3325 cm^{-1} appears in the IR spectrum of β -CD. It belongs to the valence vibrations of the O–H hydroxyl groups linked by hydrogen bonds. There are also an absorption band of the valence vibrations of the C–H bonds in the CH– and CH₂– groups (2925 cm^{-1}), the deformation vibrations of the O–H bonds in the COH groups and the water molecules (1647 cm^{-1}), and the absorption bands at $1424, 1364, 1335\text{ cm}^{-1}$ of the deformation vibrations of the C–H in the CH₂OH and CHOH groups [15–17].

In the IR spectrum of “ β -CD – BCA” complex with molecular ratio of 1:1 the band of the valence vibrations of BA carbonyl group is shifted slightly to lower frequencies (1696 cm^{-1}), and its intensity increases. Moreover, the low-frequency band of the C=C aromatic ring (1497 cm^{-1}) does not occur.

Similar changes are observed in the IR spectrum of the “ β -CD – SA” complex: no absorption bands of the C=C bond (1466 cm^{-1}) and O–H hydroxyl group (3240 cm^{-1}) of salicylic acid occur. The position of the absorption band of the valence vibrations of the C=O bond does not change, but its intensity increases. Thus, the carbonyl group of BCA does not participate in the formation of hydrogen bonds. Increased intensity of its absorption band is a consequence of BCA penetration



Scheme 2. Geometry parameters of β -cyclodextrin and benzene carboxylic acids.



Scheme 3. The spatial structures of inclusion complexes of β -cyclodextrin with benzoic (a, b) and salicylic (c, d) acids: the “tail forward”(a, c) and “head forward” (b, d).

Table 4

The calculated energy characteristics of β -cyclodextrin, benzene carboxylic acids, and their 1:1 inclusion complexes

Molecule	The heat of formation, $\text{kJ}\cdot\text{mol}^{-1}$	The energy of complex formation from molecules, $\text{kJ}\cdot\text{mol}^{-1}$	The energy of frontier orbitals, eV		Energy gap, eV
			LUM O*	HO MO*	
β -CD	-6037		1.44	-11.00	12.44
BA	-277		-0.53	-10.13	9.60
SA	-478		-0.65	-9.40	8.75
Complex β -CD – BA "tail forward"	-6360	-46	-0.89	-10.41	9.52
Complex β -CD – BA "head forward"	-6348	-33	-0.87	-10.46	9.59
Complex β -CD – SA "tail forward"	-6539	-23	-1.06	-9.81	8.75
Complex β -CD – SA "head forward"	-6548	-32	-1.00	-9.74	8.74

* Lowest unoccupied molecular orbital

** Highest occupied molecular orbital

into the inner cavity of β -CD. The absence of the band at 3240 cm^{-1} in the IR spectrum of " β -CD – SA" complex can be either a consequence of the participation of the hydroxyl group of SA in the formation of hydrogen bonds with the glycosidic oxygen atoms of β -CD, or its masking with the absorption bands of the valence vibrations of the C–H bonds of β -CD. The latter seems more probable, since the stability constants of " β -CD – BA" and " β -CD – SA" complexes are identical (Table 2).

Calculated IR spectra of benzene carboxylic acids and their inclusion complexes with β -cyclodextrin are in a good agreement with experimental data (Table 3). Thus, the synthesized of " β -CD – BCA" complexes are inclusion compounds of the "host – guest" type. The decisive role in its formation belongs to the nonspecific (dispersion and van der Waals) interactions.

Taking into account the sizes of β -CD and BCA molecules (Scheme 2), penetration of benzoic and salicylic acids into the inner cavity of β -cyclodextrin can occur. For BCA the axial "host – guest" complexes of two types can be formed.

Carboxyl group of benzene carboxylic acid is located either in the plane of the small diameter or in the plane of the large diameter of toroidal β -cyclodextrin molecule.

However, the complex, in which the carboxyl group of BCA is located in the plane of the wide edge of β -CD molecule, is the most probable and stable [18]. At the same time, in this case the formation of hydrogen bonds with secondary alcohol groups of the wide edge of β -CD is unlikely. The spatial structures of probable " β -CD – BCA" inclusion complexes are shown in Scheme 3

Interaction energy of benzene carboxylic acids with β -cyclodextrin is relatively small (Table 4). Energy characteristics of the "tail forward" and "head forward" inclusion complexes have similar values for both BA and SA. This proves equal probability of the " β -CD – BCA" inclusion complexes formation in a solution, both by BCA molecules joining into the β -cyclodextrin cavity through narrow and wide edges of β -CD molecules.

For β -cyclodextrin, chemically anchored on the silica surface (Scheme 4), only "tail-forward" complexes are formed, since BCA molecules joining into the inner cavity of β -CD through the narrow edge is impossible because of steric reasons:

Despite the high constants of distribution in the system n-octanol – water for studied benzene carboxylic acids (Table 5), the solubility of BCA in water increases more than twice due to the formation of inclusion complexes of the "host – guest" type.

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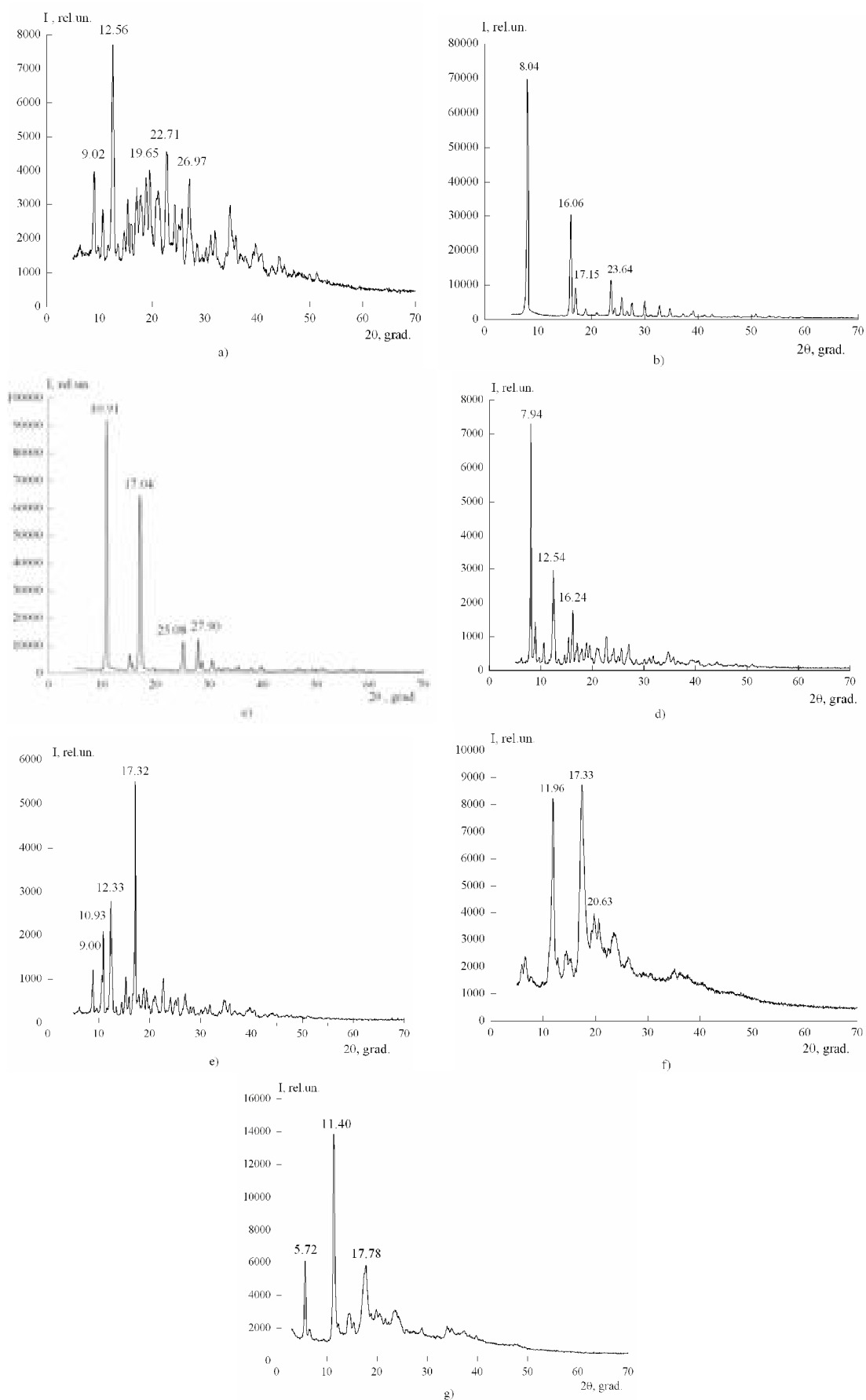
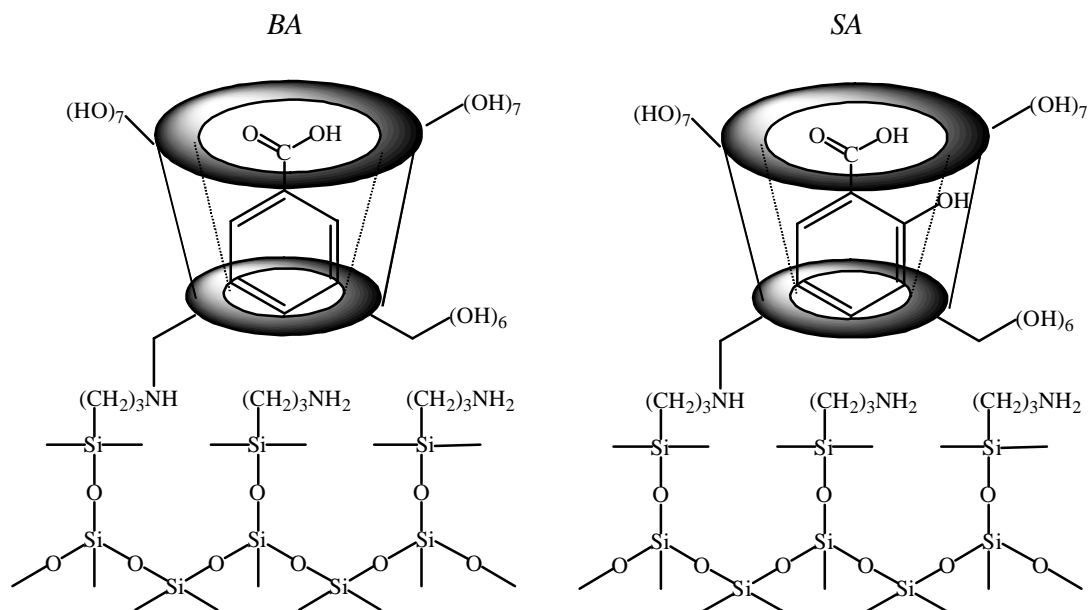


Fig. 2. Diffraction patterns of β -cyclodextrin (a), benzoic (b) and salicylic (c) acids, their equimolar physical mixtures (d, e) and “ β -CD – BCA” inclusion complexes (f, g), respectively.



Scheme 4. The surface “tail-forward” inclusion complexes of grafted β -cyclodextrin with benzene carboxylic acids.

Starting from the UV spectrophotometric experimental data, the thermodynamic parameters of “ β -CD – BCA” inclusion complexes formation were calculated (Table 6): changes in the Gibbs free energy ΔG at different temperatures – from the equation of van't Hoff $\Delta G = -RT \ln K$; enthalpy change ΔH and entropy change ΔS – graphically using the equation $R \ln K = -\Delta H/T + \Delta S$ [5, 19]. Calculated thermodynamic parameters have a negative sign indicating, firstly, that complexation in studied temperature range is a spontaneous reaction, secondly, that the formation of new nanoscale structures is an exothermic process and, thirdly, that it is associated with freedom restriction of the vibrational and rotational motions of molecule-“guest” at its penetration into the inner cavity of β -cyclodextrin. Virtually the same values of the thermodynamic parameters for both inclusion complexes indicate that their formation occurs through the same intermolecular interactions. These interactions are non-specific ones between the internal hydrophobic cavity of β -cyclodextrin and aromatic ring of benzene carboxylic acids. Functional groups of BCA do not affect the strength of formed complexes. Obtained results are in accordance with the IR spectroscopy data, and also with those of quantum-chemical calculations.

The process of thermal degradation of “ β -CD – BCA” inclusion complexes was studied using the complete thermal analysis (Figure 3). On the DTA curve of β -CD there are two endo- and one exothermic effects (Figure 3 a) accompanied by mass loss on the TG and DTG curves. Low-temperature endo effect refers to the removal of water from the cavity of β -CD. Two other thermo effects correspond to degradation of alcohol groups and destruction of glucopyranose links. The thermal destruction of β -CD, chemically grafted to the surface of aminopropylsilica, occurs similarly, except exo effect at $\sim 500^\circ\text{C}$ appearing as a shoulder of that at 550°C , which belongs to destruction of the surface amino- and iminopropyl groups of modified silica. Water adsorbed on the surface of β -cyclodextrin-containing silica is removed at $70\text{--}80^\circ\text{C}$. DTA curves for BCA have four endo and one exo effects (Figure 3 b, c). Thermal curves of “ β -CD – BCA” inclusion complexes (Fig. 3 f, g) contain thermo effects of both BCA and β -CD. In contrast to BCA and their equimolar mixtures with β -CD (Figure 3 d, e), thermo effects of BCA in the inclusion complexes are shifted to higher temperatures, and melting temperatures of BCA in the inclusion complexes increase (Table 7). These results are in accordance with

Table 5

Values of constant of distribution between *n*-octanol and water $P_{o/w}$ and solubility in water at 18°C S_w for benzene carboxylic acids

Benzene carboxylic acid	$P_{o/w}$	S_w , g L	
		without β -CD	with β -CD
BA	74	2.79	6.94
SA	172	1.58	3.56

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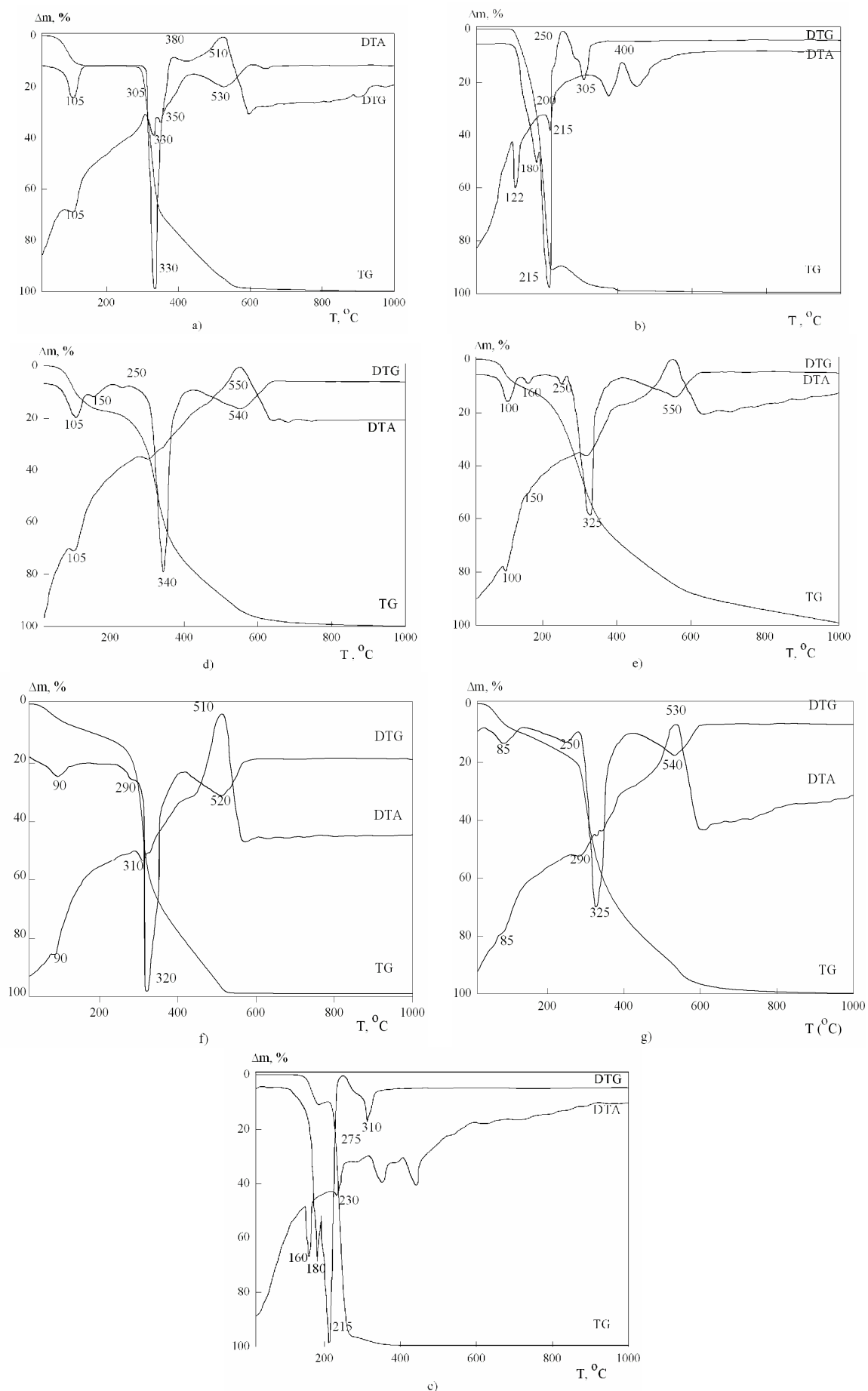


Fig. 3. Thermal curves for β -cyclodextrin (a), benzoic (b) and salicylic (c) acids, and also for their physical mixtures (d,e) and “ β -CD – BA” (f) and “ β -CD – SA” (g) inclusion complexes.

Table 6Thermodynamic parameters for complex formation between β -cyclodextrin and benzene carboxylic acids

Temperature, K	ΔG , kJ mol ⁻¹	ΔH , kJ mol ⁻¹	ΔS , J mol ⁻¹ K ⁻¹
β -CD – BA			
291	–(11.66±0.58)	–(23±1)	–(39±2)
293	–(11.66±0.58)		
295	–(11.62±0.58)		
298	–(11.60±0.58)		
300	–(11.58±0.58)		
β -CD – SA			
291	–(11.66±0.58)	–(23±1)	–(39±2)
293	–(11.64±0.58)		
295	–(11.55±0.58)		
298	–(11.53±0.58)		
300	–(11.44±0.57)		

Table 7The results of thermal analysis of β -cyclodextrin, benzene carboxylic acids and its 1:1 inclusion complexes

Compound	T_{melt}^* , °C	Content of water, molecules of water /molecule of β -CD		Volume occupied by water** in cavity of β -CD, nm ³		E_{act} dehydration, kJ mol ⁻¹
		calculation	experiment	calculation	experiment	
β -CD	258	8.7	8.0	0.261	0.240	27
BA	123					
complex “ β -CD – BA”	235	5.3	5.0	0.159	0.150	35
SA	161					
complex “ β -CD – SA”	208	4.6	4.0	0.138	0.120	41

* By capillary method

**Volume of water molecule is equal to 0.030 nm³

direct determination of melting temperatures of β -CD, BCA, and their inclusion complexes by capillary method (Table 7), as well as with the earlier results of mass-spectrometric study of “ β -CD – BCA” complexes degradation [20]: destruction of inclusion compounds begins with the removal of water molecules, at first, and then of benzene carboxylic acids from the cavity of β -CD molecules, and only after that thermal destruction of β -cyclodextrin comes.

Results of differential thermogravimetric analysis (Table 7) show that the “ β -CD – BCA” inclusion complexes contain less water than the initial β -CD. Reducing the volume occupied by water is equal to the volume of BCA molecules (Scheme 2). Consequently, only partial displacement of water from the inner cavity of β -cyclodextrin takes place during the formation of inclusion complexes with benzoic and salicylic acids. The activation energy of dehydration [21] increases with decreasing water content in the cavity of β -CD (Table 7) and increasing the volume of molecule-“guest”. Consequently, the intermolecular forces that hold the various water molecules in the β -cyclodextrin cavity are not identical.

Conclusions

With the help of UV and IR spectroscopy, as well as X-ray analysis, thermography and quantum-chemical calculations the interaction of benzoic and salicylic acids with β -cyclodextrin in aqueous solutions and on the surface of chemically modified fine silica has been studied. The identity of complexes between β -cyclodextrin and benzene carboxylic acids formed in a solution and on the silica surface has been proved. Stability constants and standard thermodynamic parameters of complexation have been calculated. It was proved that products of β -cyclodextrin interaction with benzene carboxylic acids are the inclusion complexes of the “host – guest” type with molecular ratio of 1:1. Results of quantum-chemical calculations indicate equal probability of the “tail forward” and “head forward” inclusion complexes formation. It was found partial removal of water molecules from the inner cavity of β -cyclodextrin during the formation of inclusion compounds. The activation energies of dehydration of β -

cyclodextrin and its complexes with benzene carboxylic acids have been calculated. It was demonstrated that encapsulation of benzene carboxylic acids into β -cyclodextrin increases their solubility and thermal stability. It was proved that the thermal destruction of inclusion complexes begins with the removal of water molecules from the cavity of β -cyclodextrin and then benzene carboxylic acids, followed by destruction of cyclic oligosaccharide.

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Белякова Л.О. - д.х.н., проф., заст. директора;
Ляшенко Д.Ю. - к.х.н., старший науковий співробітник;
Гребенюк А.Г. - к.х.н., старший науковий співробітник;
Дзюбенко Л.С. - к.х.н., старший науковий співробітник;
Оранська О.І. - к.х.н., старший науковий співробітник..

- [1] J. Szejtli. Introduction and general overview of cyclodextrin chemistry // *Chem. Rev.*, **98**(5), pp. 1743-1750 (1998).
- [2] A.R. Hedges. Industrial applications of cyclodextrins // *Chem. Rev.*, **98**(5), pp. 2035-2044 (1998).
- [3] K. Uekama, F. Hirayama, T. Irie. Cyclodextrin drug carrier systems // *Chem. Rev.*, **98**(5), pp. 2045-2076 (1998).
- [4] Z. Zuo, G. Kwon, B Stevenson. Flutamide-hydroxypropyl- β -cyclodextrin complex: formulation, physical characterization, and absorption studies using the caco-2 in vitro model // *J. Pharm. Pharmaceut. Sci.*, **3**(2), pp. 220-227 (2000).
- [5] N. Takisawa, K. Shirahama, I. Tanake. Interactions of amphiphilic drugs with α -, β -, and γ -cyclodextrins // *Colloid Polym. Sci.*, **271**(5), pp. 499-506 (1993).
- [6] *Medical Chemistry and Clinical Application of Silica*. Ed. by A.A. Chuiko, pp. 153-167, Naukova dumka, Kiev, (2003).
- [7] M.D. Mashkovsky. *Medicines*. New Wave, Moscow, 608 p. (2000).
- [8] J.J.P. Stewart. Optimization of parameters for semiempirical methods. I. Method // *J. Comput. Chem.*, **10**(2), pp. 209-220 (1989).
- [9] J.J.P. Stewart. Optimization of parameters for semiempirical methods. II. Applications // *J. Comput. Chem.*, **10**(2), pp. 221-264 (1989).
- [10] M.W. Schmidt, K.K. Baldridge, J.A. Boatz, S.T. Elbert, M.S. Gordon, J.H. Jensen, S. Koseki, N. Matsunaga, K.A. Nguyen, S.J. Su, T.L. Windus, M. Dupuis, J.A. Montgomery. General atomic and molecular electronic-structure system // *J. Comput. Chem.*, **14**(11), pp. 1347-1363 (1993).
- [11] L.A. Belyakova, K.A. Kazdobin, V.N. Belyakov, S.V. Ryabov, A.F. Danil de Namor. Synthesis and properties of supramolecular systems based on silica // *J. Colloid Interface Sci.*, **283**(2), pp. 488-494 (2005).
- [12] C.N.R. Rao. *Ultra-violet and Visible Spectroscopy Chemical Applications*. Butterworths, London. 164 p.(1961).
- [13] X. Wen, F. Tan, Z. Jing, Z. Liu. Preparation and study the 1:2 inclusion complex of carvedilol with β -cyclodextrin // *J. Pharm. Biomed. Analysis*, **34**(3), pp. 517-523 (2004).
- [14] *Chemical Applications of Spectroscopy*. Ed. by W. West, pp. 205-315, Inter-science, New York–London, (1956).
- [15] A.L. Smith. *Applied Infrared Spectroscopy*. John Wiley and Sons, New York. 328 p. (1982).
- [16] T.N.T. Phan, M. Bacquet, J. Laureyns, M. Morcellet. New silica gels functionalized with 2-hydroxy-3-methacryloyloxypropyl- β -cyclodextrin using coating or grafting methods // *Phys. Chem. Chem. Phys.*, **1**(22), pp. 5189-5195 (1999).
- [17] Z.-W. Gao, X.-P. Zhao. Guest-controlling effects on ER behaviors of β -cyclodextrin polymer // *J. Colloid Interface Sci.*, **289**(1), pp. 5662 (2005).
- [18] S. Jambhekar, R. Casella, T. Maher. The physicochemical characteristics and bioavailability of indomethacin from β -cyclodextrin, hydroxyethyl- β -cyclodextrin, and hydroxypropyl- β -cyclodextrin complexes // *Int. J. Pharmaceutics*, **270**(1-2), pp. 149-166 (2004).
- [19] J. Li, Y. Wei, L. Ding, C. Dong. Study on the inclusion complexes of cryptotanshinone with β -cyclodextrin and hydroxypropyl- β -cyclodextrin // *Spectrochim. Acta. A.*, **59**(12), pp. 2759-2766 (2003).
- [20] L.A. Belyakova, A.M. Varvarin, B.B. Palyanitsa, T.V. Kulik. Mass spectrometric study of the thermolysis of inclusion complexes “ β -cyclodextrin – benzen carboxylic acid” // *Mass-spectrometry*, **6**(1), pp. 47-52(2009).
- [21] G.O. Piloyan. *Theory of Thermal Analysis*. Nauka, Moscow, 232 p. (1964).

Л.О. Белякова, Д.Ю. Ляшенко, А.Г. Гребенюк, Л.С. Дзюбенко, Е.І. Оранська

Дослідження супрамолекулярних комплексів „ β -циклодекстрин – бензолкарбонова кислота”

*Інститут хімії поверхні ім. О. О. Чуйка Національної академії наук України
17, вул. Генерала Наумова, Київ, 03164, Україна. E-mail: mila.belyakova@gmail.com, isc412@ukr.net*

Встановлено ідентичність комплексів β -циклодекстрину з бензолкарбоновими кислотами, синтезованих у водних розчинах та на поверхні високодисперсного кремнезему. Доведено, що одержані комплекси відносяться до сполук включення типу “хазяїн – гість” та мають склад 1 : 1. Розраховано константи стійкості комплексів включення та стандартні термодинамічні параметри їх утворення. На основі результатів квантово-хімічних розрахунків зроблено висновок про рівноімовірність утворення комплексів включення “хвіст вперед” та “голова вперед”. Виявлено особливості дегідратації та термодеструкції комплексів включення у порівнянні з індивідуальними сполуками та їх еквімолярними сумішами.

Ключові слова: кремнезем, β -циклодекстрин, бензолкарбонова кислота, супрамолекулярні структури, комплекси включення.