

INTERACTION OF SUBSTITUTED ARYL IODIDES WITH PROTONIC ACIDS

V.K. Chaikovskii, A.A. Funk, N.S. Kozlova, T.S. Kets*

Tomsk Polytechnic University

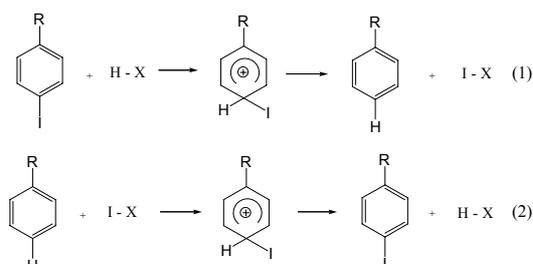
*Tomsk State Pedagogical University

E-mail: clg@mail.ru

Using GAUSSIAN'98W program package calculation of Gibbs free energy, activation enthalpy and free activation energy of direct and reverse interaction reaction of substituted aryl iodides with mineral acids has been carried out. Experimental test of the obtained theoretical results is performed. HI is shown to demonstrate a strong deiodinating affect only on the compounds with high π -electron density. HCl, H_3PO_4 and H_2SO_4 deiodinate partially only 4-iodoaniline.

In spite of considerable amount of publications on processes accompanying aryl iodides transformation under influence of protonic acids there is still much ambiguous in this field of chemistry of iododerivatives. In scientific sources rather contradictory information about the behavior of aromatic iododerivatives in acid mediums is presented. First of all, it refers to interaction of aryl iodides with hydroiodic acid. For example, until now a classical explanation of impossibility of iodination of aromatic compounds by molecular iodine is the fact that hydrogen iodide, segregating in the process of reaction, reduces formed aryl iodide [1–3]. Hence, it appears that it is necessary to remove somehow (anywise) hydroiodic acid occurring at iodination. Oxidizers which can convert HI into compounds with electropositive iodine or such substances as silver salts which remove HI from reacting medium forming silver iodide [4] are used for this purpose. On the other hand, according to the results of research of A. Kekule, carried out as early as XIX c., aryl iodides are not reduced by HI at boiling with its excess during some hours [5]. And, finally, there is an opinion that iodine substitution in iodoarenes at the presence of strong acids is nothing more than the process of electrophilic substitution of iodine by proton protodeiodination [6, 7].

For deeper understanding of iodination and deiodination processes of aromatic compounds we carried out thermochemical calculations of direct deiodination (1) and reverse (iodination) (2) reactions of interaction of 4-iodoaniline (**1a**), iodobenzene (**2a**) and 1-iodo-4-nitrobenzene (**3a**) with HI, HCl, H_3PO_4 and H_2SO_4 by a semi-empirical method PM3 using program package GAUSSIAN'98W [8] and performed the experimental test of obtained results (scheme 1).



Where: R=NH₂ (**1a,b**), H (**2a,b**), NO₂ (**3a,b**); X=I⁻, Cl⁻, H₂PO₄⁻, HSO₄⁻

Scheme 1

The calculation of Gibbs free energies (ΔG), enthalpies and free activation energies (ΔH^\ddagger , ΔG^\ddagger) of interaction reaction of compounds **1a-3a** with HI shows, table 1, reaction 1, that comparatively low energy of transient state and negative values ΔG of reaction may promote deiodination of 4-iodoaniline **1a**, but in the case of iodobenzene **2a** activation barrier increases about 1,3 times and for iodonitroarene **3a** 1,5 times that makes their deiodination more difficult. Higher activation barriers and positive values of free energy ΔG of reverse reaction for all three types of arenes show the impossibility of the process in reverse direction (2), i.e. aniline, benzene and nitrobenzene iodination by molecular iodine (table 2). When iodoaromatic compounds **1a-3a** interacting with hydrochloric, orthophosphoric and sulfuric acids reverse reaction is more probable (2) and iodoarene deiodination is less probable.

Table 1. Gibbs free energies (ΔG), enthalpies (ΔH^\ddagger) and activation free energies (ΔG^\ddagger) of deiodination reactions at aryl iodides interaction with proton acids, reaction (1), kJ/mol

R	H-X	ΔH^\ddagger	ΔG^\ddagger	ΔG
NH ₂	H-I	337,98	356,07	-111,87
H	H-I	436,48	453,00	-112,19
NO ₂	H-I	516,30	531,60	-116,07
NH ₂	H-Cl	600,53	615,89	47,38
H	H-Cl	699,03	712,82	47,07
NO ₂	H-Cl	778,85	791,42	43,18
NH ₂	H-H ₂ PO ₄	615,42	621,02	100,81
H	H-H ₂ PO ₄	713,90	717,95	100,50
NO ₂	H-H ₂ PO ₄	793,74	796,55	96,61
NH ₂	H-H ₂ SO ₄	522,89	523,64	105,96
H	H-HSO ₄	621,36	620,57	105,64
NO ₂	H-HSO ₄	701,20	699,18	101,76

For experimental verification of the obtained results we investigated compounds **1a-3a** behavior in acetic solutions of hydroiodic (57,5 %, 1,717 kg/m³), hydrochloric (34,0 %, 1,700 g/sm³), orthophosphoric (84,0 %, 1,834 g/sm³) and sulfuric (95,0 %, 1,835 g/sm³) acids.

All proton acids were used with twofold molar excess. Temperature of reaction, time and solvent were selected for maximal approximation of process conditions to the process of iodination reaction which is often carried out in acetic acid in the range of temperatures 25...120 °C. Reacting mass was boiling with backflow condenser during 5 hours.

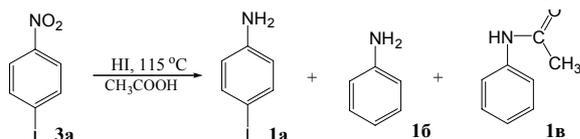
Table 2. Gibbs free energies (ΔG), enthalpies (ΔH°) and activation free energies (ΔG^\ddagger) of iodination reactions by reagents I-X, reaction (2), kJ/mol

R	I-X	ΔH°	ΔG^\ddagger	ΔG
NH ₂	I-I	444,39	467,90	111,87
H	I-I	543,50	565,19	112,19
NO ₂	I-I	626,85	647,67	116,07
NH ₂	I-Cl	541,81	568,51	-47,38
H	I-Cl	640,91	665,75	-47,07
NO ₂	I-Cl	724,27	748,24	-43,18
NH ₂	I-H ₂ PO ₄	509,66	520,21	-100,81
H	I-H ₂ PO ₄	608,76	617,45	-100,50
NO ₂	I-H ₂ PO ₄	692,12	699,94	-96,61
NH ₂	I-OSO ₃ H	415,86	417,68	-105,96
H	I-OSO ₃ H	514,96	514,93	-105,64
NO ₂	I-OSO ₃ H	598,32	597,42	-101,76

Chromatography-mass-spectrometric (GC-MS) analysis of interaction products of iodoarenes and hydroiodic acid showed that of three researched compounds only 4-iodoaniline **1a** is subjected to significant deiodination. According to the results of GC-MS **1a** substrate conversion amounted 84,03 %. Aniline (78,00 %) (**1b**) and acetanilide (6,03 %) (**1c**) appeared to become the main reaction products, table 3.

Deiodination occurred at significantly less degree when aryl amine **1a** heating with HCl or H₃PO₄. According to the data of preparative thin-layer chromatography (TLC) besides the initial substance **1a** (68...71 %) aniline **1b** (10...12 %) and acetanilide **1c** (17...19 %) were revealed in the product mixture and at the presence of H₂SO₄ besides mentioned products sulfanilic acid was preparatively isolated from the reaction mixture.

When interacting with HI iodobenzene **2a** turned into benzene (**2b**) only by 0,24 %, but 1-iodo-4-nitrobenzene **3a**, in spite of theoretical calculations, was subjected to more general conversion (2,5 %) forming 4-iodoaniline (**1a**), aniline (**1b**) and acetanilide (**1c**).



We suppose that in nitroarene **3a** nitro group had been firstly reduced and only after that deiodination of generated aryl amine **1a** occurred. When hydroiodic acid substituting for hydrochloric, sulfuric or orthophosphoric one, substrate **3a** deiodination was not recorded.

Annelated polycyclic hydrocarbon – anthracene (**4b**), in spite of its high reactivity in electrophilic substitution reactions, generates 9-iodoanthracene (**4a**) with great difficulty [9]. Polycycle **4a** is not iodinated under iodine monochloride action, but it is chlorinated [10, 11], and it mainly forms anthraquinone under the action of hypiodite character reagents [7].

Certainly, the carried out thermochemical calculations havenot answered completely all the questions concerning anthracene and its halogen derivatives, but they showed that iodoarene **4a** is more labile than iodoaniline **1a** in acid media, especially under the action of HI (Scheme 2, table 3, 4).

Table 3. Chromatography-mass-spectrometric analysis of interaction products of iodoaromatic compounds with HI in acetic acid (120 °C, 5 h)

Substrate	Reaction products	Content in a mixture, %	Mass-spectrometry data, m/z (I rel.), %
 1a	Aniline	78,00	93(M+, 100), 39(12,5), 41(5), 52(7), 63(7), 66(41), 78(3)
	Acetanilide	6,03	135(M+, 30), 43(17), 51(5), 66(16), 77(4), 93(100)
	4-iodoaniline	15,95	219 (M+, 100), 39(20), 65(60), 74(2), 92(59), 109(7)
 2a	Benzene	0,24	78(M+, 100), 15(2), 26(4), 28(3), 37(4), 39(12), 49(4), 51(23), 61(1), 63(5), 74(6), 76(6)
	Iodobenzene	99,76	204(M+, 75), 27(3), 38(3), 51(28), 77(100), 127(8)
 3a	Aniline	0,84	93(M+, 100), 39(12), 46(8), 52(5), 63(5), 66(41), 77(2), 105(5), 120(1)
	Acetanilide	0,19	135(M+, 23), 43(22), 66(18), 77(5), 93(100)
	4-iodoaniline	1,47	219 (M+, 100), 39(24), 52(9), 65(75), 74(2), 92(97), 109(12), 127(9)
	1-iodo-4-nitrobenzene	97,5	249(M+, 100), 30(7), 50(37), 76(83), 92(24), 127(5), 191(6), 203(50), 219(7)

Table 4. Gibbs free energies (ΔG), enthalpies (ΔH°) and activation free energies (ΔG^\ddagger) of deiodination reactions of 9-iodoanthracene under the action of protonic acids, kJ/mol

H-X	ΔH°	ΔG^\ddagger	ΔG
H-I	311,58	330,08	-148,88
H-Cl	574,13	589,91	10,37
H-HSO ₄	496,48	497,66	68,95

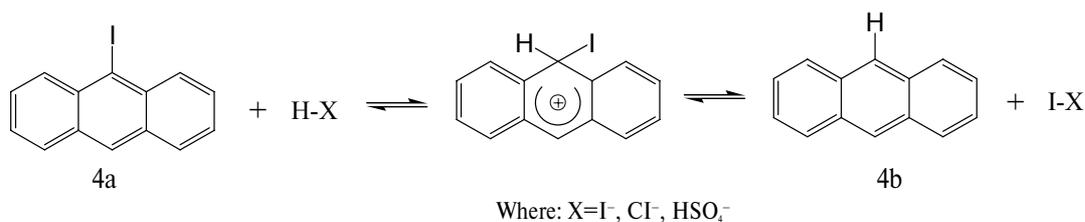
Table 5. Gibbs free energies (ΔG), enthalpies (ΔH°) and activation free energies (ΔG^\ddagger) of iodination reactions of anthracene by reagents I-X, kJ/mole

I-X	ΔH°	ΔG^\ddagger	ΔG
I-I	455,21	478,96	148,88
I-Cl	552,62	579,54	-10,37
I-OSO ₃ H	426,67	428,71	-68,95

In fact, 9-iodoanthracene heating **4a** with twofold molar excess of hydroiodic acid in acetic acid during 5 hours have turned out to result in 100 % conversion of 9-iodoanthracene into anthracene. The latter was isolated preparatively with the 95 % yield.

Experimental part

Control of reaction course and purity of obtained products was checked by TLC on the Silufol UV-254 plates. Spots were developed under UV irradiation. Hexane was used as eluent for anthracene derivatives, for other



Scheme 2

researched substrates hexane: benzene (1:1) was used. After carrying out the experiment, obtained mixtures were analyzed on chromatography-mass spectrometry HP 5972 (EI, 70 eV, column RTX-5 ms, length 15 m).

Thermochemical calculations were carried out using the computer program package GAUSSIAN'98W by the method PM3.

Substrates **1a** and **3a** of «chemically pure» grade were additionally crystallized (two times each). Iodobenzene **2a** was purified by distillation. 9-iodoanthracene was obtained by iodination of anthracene by means of tetraiodoglycoluril [9]. Hydroiodic acid was prepared by the procedure [12].

Interaction of iodoarenes 1a-4a with hydroiodic acid. 10 mmol of iodoarene **1a-3a**, 4.52 g (20 mmol) of HI and 20 ml of AcOH (for 9-iodoanthracene: 1 mmol of iodoarene **4a**, 2 mmol of HI, 5 ml of AcOH) were put into a 50 ml flask, equipped with a backflow condenser. The reacting mass was boiling during 5 hours at 120 °C and then it was cooled and diluted with 40 ml of cold water.

Preparation of samples for the analysis. 1. NaOH solution was added to the mixture of interaction products of amine **1a** and nitroarene **3a** to base media and sodium sulfite – for segregated iodine removal. Products were extracted with hexane (3×30 ml), hexane layer was

segregated, ~80 % of solvent was distilled. The obtained mixture of substances was analyzed by the method of thin-layer chromatography and GC-MS.

2. Na₂SO₃ water solution was added to the mixture of interaction products of iodobenzene **2a** with HI for segregated iodine removal. Products were extracted with hexane (3×10 ml), hexane layer was segregated, CaCl₂ was dried and GC-MS was analyzed.

Isolation and purification of anthracene (4b). After interaction of 9-iodoanthracene **4a** with HI the mixture was diluted with water and solution Na₂SO₃ was added. The product was extracted with dichloromethane (3×20 ml), the extract was dried on CaCl₂. Solvent was distilled. Anthracene was purified on a column with SiO₂ (eluent hexane). Polycycle **4b** yield is 0,169 g (95 %). m. p. 215...216 °C.

Interaction of iodoarene 1a-3a with HCl, H₃PO₄, H₂SO₄. 10 mmol of iodoarene **1a-3a**, (20 mmol) of acid and 20 ml of AcOH were put into a 50 ml flask equipped with a backflow condenser. The reacting mass was boiling during 5 hours at temperature ~120 °C. It was cooled, diluted with 40 ml of cold water and extracted with CH₂Cl₂. The extract was dried, solvent was distilled. The products were separated by the method of preparative thin-layer chromatography (SiO₂, hexane: benzene – 1:1).

REFERENCES

- Nesmeyanov A.N., Nesmeyanov N.A. Principles of organic chemistry, 2^d issue. – Moscow: Khimiya, 1974. – V. 2. – P. 48.
- Gauptman Z., Grefe Yu., Remane H. Organic chemistry. – Moscow: Khimiya, 1979. – P. 289.
- Chemical encyclopedia. – Moscow: Sovetskaya Entsiklopediya, 1990. – V. 2. – P. 497.
- Merkushev E.B. Advances in synthesis of iodoaromatic compounds // Uspekhi Khimii (in Russian). – 1984. – V. 53. – 4th issue. – P. 583–594.
- Kekule A. Untersuchungen über aromatische Verbindungen // Annalen der Chemie und Pharmacie. – 1866. – Bd. 137. – S. 129.
- Filimonov V.D., Krasnokutskaya E.A., Lesina Yu.A. Generation of electrophilic iodine from iodine monochloride in neutral media. Iodination and protodeiodination of carbazole // Russ. J. Org. Chem. – 2003. – V. 39. – № 6. – P. 875–880.
- Bartoshevich R., Mechnikovska-Stolyarchik V., Opshondek B. Methods of organic compounds reduction. – Moscow: Inostrannaya Literatura, 1960. – P. 76.
- GAUSSIAN 98W. User's Reference. Ed. E. Fritsch, M.J. Fritsch. – Pittsburgh: Gaussian Inc., 1998. – 280 p.
- Chaikovskii V.K., Filimonov V.D., Yagovkin A.Yu., Ogorodnikov V.D. 2,4,6,8-Tetraiodo-2,4,6,8-tetraazabicyclo[3.3.0]octane-3,7-dione as a mild and convenient reagent for iodination of aromatic compounds // Russ. Chem. Bull., Int. Ed. – 2003. – V. 50. – № 12. – P. 2411–2415.
- Turner D.E., O'Malley R.F., Sardella D.J., Dennis J.S., Lucio S.B., Pushkar K. The reaction of iodine monochloride with polycyclic aromatic compounds: polar and electron transfer pathways // J. Org. Chem. – 1994. – V. 59. – № 23. – P. 7335–7340.
- Chaikovskii V.K., Filimonov V.D. Iodination and chlorination of aromatic polycyclic hydrocarbons with iodine monochloride in water solution of aqueous sulfuric acid // Russ. J. Org. Chem. – 2001. – V. 37. – Issue 8. – P. 1130–1133.
- Karyakin Yu.V., Angelov I.I. Pure chemical reagents. – Moscow: Khimiya, 1974. – P. 169.

Arrived on 27.10.2006