

Oxidative Halogenation of Aromatic Compounds with Metal Halides and Sodium Bismuthate

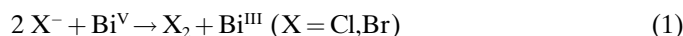
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A new mild and efficient method for aromatic halogenation with a wide variety of halides in the presence of sodium bismuthate NaBO₃ in AcOH is reported. Metal halides of groups Ia, IIa, IIIa, IVa, Va, and the first row of transition elements are suitable for this method.

There has been a growing interest in the last few years in metal halides as alternatives to molecular halogens in halogenations of aromatic compounds [1][2]. Halides of transition metals of groups I, IV, and V have received particular attention [3–6]. Generation of halogens from these metal halides requires very drastic conditions [7][8]. Other methods involve oxidation of certain halides with hardly available and expensive oxidizing agents such as peroxyacetic acid [9], lead tetraacetate [10], and nitrogen dioxide [11].

Bismuthate ion is a strong oxidizing agent, but little attention has been paid to its potential in organic synthesis [12]. It has long been known that the ion oxidizes halides to the corresponding halogen in aqueous HClO₄ [13][14]. No studies have been carried out regarding the exploitation of the reagent in the halogenation of organic compounds with metal halides.



We hereby wish to report a new method for aromatic chlorination and bromination with various halides in the presence of NaBiO₃.

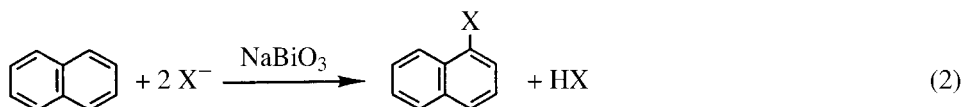
Results and Discussion. – Appropriate amounts of the aromatic substrate and the halide were allowed to react with NaBiO₃ in AcOH at room temperature. The reaction was monitored with a moist starch-iodide paper held over the reaction vessel. The blue color indicated the presence of free halogen in the reaction mixture.

All metal halides of groups Ia, IIa, IIIa, IVa, Va, and the first row of transition metals react with NaBiO₃ in AcOH and produce the corresponding halogen. The reactivity of NaBiO₃ with halides varies from metal to metal. We found that the rate of halogen production increases as we go from the top of the group to the bottom. The reactivity is also affected by the amount of H₂O present in the halide crystals. Anhydrous forms are more reactive than their hydrated forms.

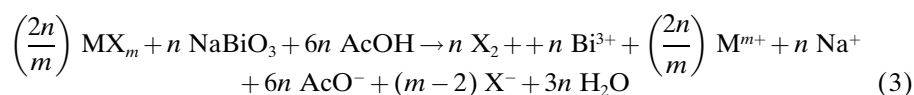
Naphthalene was chosen for a comparative study of aromatic chlorination and bromination with various metal chlorides and bromides. The results are summarized in *Tables 1* and *2*.

Table 1. Chlorination of Naphthalene with Metal Halides and NaBiO₃

Naphthalene [mmol]	MCl _m (mmol)	NaBiO ₃ [mmol]	Time [h]	1-Chloronaphthalene Yield [%]
5	NaCl (10)	5	3	68
5	KCl (10)	5	1	82
5	RbCl (10)	5	1	85
5	CsCl (10)	5	1	87
5	MgCl ₂ (5)	5	2	74
5	CaCl ₂ (5)	5	1	85
5	SrCl ₂ (5)	5	1	83
5	BaCl ₂ (5)	5	1	86
5	AlCl ₃ (5)	5	0.5	88
5	GaCl ₃ (5)	5	0.5	84
5	InCl ₃ (5)	5	1	80
5	SnCl ₂ (5)	10	3	76
5	SnCl ₄ (5)	5	0.5	88
5	PbCl ₂ (5)	10	3	78
5	SbCl ₃ (5)	10	2	75
5	SbCl ₅ (5)	5	0.5	87
5	TiCl ₄ (5)	5	0.5	85
5	CrCl ₃ (5)	5	2	72
5	MnCl ₂ (5)	10	2	82
5	FeCl ₃ (5)	5	1	85
5	CoCl ₂ (5)	5	1	83
5	NiCl ₂ (5)	5	2	78
5	Cu ₂ Cl ₂ (5)	10	1	84
5	CuCl ₂ (5)	5	1	87
5	ZnCl ₂ (5)	5	0.5	86



The general stoichiometric equation representing various metal halides, MX_m, in their reactions with bismuthate V ion to give the corresponding halogens is as follows:



It was found that metals with two valence states, like copper and tin, require 2 equiv. of NaBiO₃, one for the conversion of the metal to the higher-valence state, and the other for the generation of the halogen (Eqn. 4). It is also noted that reactions involving metals of low-valence state require longer reaction times.

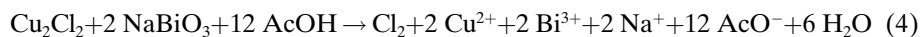
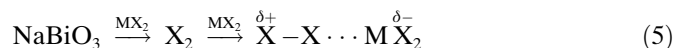


Table 2. Bromination of Naphthalene with Metal Halides and NaBiO₃

Naphthalene [mmol]	MCl _m (mmol)	NaBiO ₃ [mmol]	Time [h]	1-Bromonaphthalene Yield [%]
5	NaBr (10)	5	24	60
5	KBr (10)	5	12	70
5	CaBr ₂ (5)	5	12	73
5	BaBr ₂ (5)	5	12	71
5	AlBr ₃ (5)	5	6	86
5	SnBr ₄ (5)	5	4	83
5	SnBr ₂ (10)	10	2	81
5	SbBr ₃ (5)	10	12	78
5	MnBr ₂ (5)	10	12	76
5	FeBr ₃ (5)	5	3	77
5	CoBr ₂ (5)	5	12	73
5	Cu ₂ Br ₂ (5)	10	8	75
5	CuBr ₂ (5)	5	6	72
5	ZnBr ₂ (5)	5	6	74

The influence of the *Lewis* acid character of Sn⁴⁺, Sb⁵⁺, Al³⁺, Ti⁴⁺, and Zn²⁺ halides is apparent from the data of *Tables 1* and *2*. The high reaction rates involving these halides are expected, since they exhibit strong to moderate activity as *Friedel-Crafts* catalysts [15]. These halides may have a dual function when used in excess. The primary function is to produce halogen and the other is to act as a *Lewis* acid to activate the produced halogen.



The metal halides, which possess *Lewis* acid characteristics, vary in their levels of activity as *Friedel-Crafts* catalysts. The reactivity follows the order AlBr₃ > AlCl₃ > FeCl₃ > SbCl₅ > BF₃ > SnCl₄ > ZnCl₂ [16].

Zinc halides ZnCl₂ and ZnBr₂, although the least reactive, are very cheap, easy to handle, easy to dry, and well-soluble in acetic acid. In addition to their *Lewis* acid properties, they are capable of trapping the resulting hydrogen halide, which usually reduces the halogenation rate (*Eqns. 5* and *6*) [17].



Owing to these findings, we decided to investigate the impact of a large excess of zinc halide in the halogenation of some aromatic compounds in comparison with reactions involving 1 equiv. of the same halide. The results are summarized in *Tables 3* and *4*.

The results from *Tables 3* and *4* indicate that the excess of zinc halides enhanced the reactivity of halogens towards aromatic halogenation. The reaction with alkylbenzenes

Table 3. Chloronation of Aromatic Compounds with $ZnCl_2$ and $NaBiO_3$

Substrate	Products	Molar ratio Subst./ $ZnCl_2$ / $NaBiO_3$	Time [h]	Yield [%]
Benzene	Chlorobenzene	1 : 1 : 1	12	54
		1 : 10 : 1	5	68
Toluene	<i>o</i> - <i>p</i> -Chlorotoluene 2 : 3	1 : 1 : 1	6	73
<i>m</i> -Xylene	4-Chloro-1,3-dimethylbenzene	1 : 1 : 1	4	76
		1 : 10 : 1	2	82
Mesitylene	2-Chloromesitylene	1 : 1 : 1	1	81
		1 : 10 : 1	0.25	90
Durene	3-Chlorodurene	1 : 1 : 1	0.5	74
		1 : 10 : 1	0.25	86
Anisole	<i>o</i> - <i>p</i> -Chloroanisole 1 : 4	1 : 1 : 1	0.5	84
		1 : 10 : 1	0.25	86
Phenol	2,4,6-Trichlorophenol	1 : 1 : 1	0.5	76
Acetanilide	<i>o</i> - <i>p</i> -Chloroacetanilide 3 : 7	1 : 1 : 1	0.25	90
Aniline	2,4,6-Trichloroaniline	1 : 1 : 1	0.5	72
Naphthalene	1-Chloronaphthalene	1 : 1 : 1	0.5	86
		1 : 10 : 1	0.25	86
Anthracene	9,10-Dichloroanthracene	1 : 10 : 1	1	78
Phenanthrene	9-Chlorophenanthrene	1 : 1 : 1	0.5	76

Table 4. Bromination of Aromatic Compounds with $ZnBr_2$ and $NaBiO_3$

Substrate	Products	Molar ratio Subst./ $ZnBr_2$ / $NaBiO_3$	Time [h]	Yield [%]
Benzene	Bromobenzene	1 : 1 : 1	24	20
		1 : 10 : 1	12	38
Toluene	<i>o</i> - <i>p</i> -Bromotoluene 3 : 7	1 : 1 : 1	10	74
<i>m</i> -Xylene	4-Bromo-1,3-dimethylbenzene	1 : 10 : 1	6	80
		1 : 1 : 1	6	73
Mesitylene	2-Bromomesitylene	1 : 10 : 1	3	82
		1 : 1 : 1	2	81
Durene	3-Bromodurene	1 : 10 : 1	0.5	90
		1 : 1 : 1	2	75
Anisole	<i>o</i> - <i>p</i> -Bromoanisole 1 : 9	1 : 10 : 1	0.5	82
		1 : 1 : 1	2	78
Phenol	2,4,6-Bromophenol	1 : 1 : 1	1	86
Acetanilide	<i>o</i> - <i>p</i> -Bromoacetanilide 1 : 4	1 : 1 : 1	0.5	73
Aniline	2,4,6-Tribromoaniline	1 : 1 : 1	0.5	85
Naphthalene	1-Bromonaphthalene	1 : 1 : 1	0.5	70
		1 : 10 : 1	6	74
Anthracene	9,10-Dibromoanthracene	1 : 10 : 1	1.5	88
Phenanthrene	9-Bromophenanthrene	1 : 1 : 1	3	52
		1 : 10 : 1	2	70
		1 : 10 : 1	1	76

gave only nuclear-halogenated compounds, and no side-chain attack was observed. Furthermore, the reactivity of alkylbenzenes towards $ZnCl_2$ and $NaBiO_3$ increased with increasing number of alkyl groups.

To avoid side oxidation of reactive substrates like phenols and aniline by bismuthate ion, the halide is first allowed to react with NaBiO_3 for 15 min, then the aromatic substrate is added. Monohalogenation of phenols and anilines could not be achieved owing to their high reactivity compared with other aromatic compounds.

Experimental. – *General Procedure for Halogenation with Metal Halides and NaBiO_3 .* NaBiO_3 (1.55 g, 5.5 mmol) was added in one portion to a stirred mixture of the aromatic substrate (5 mmol) and zinc halide (50 mmol) in glacial AcOH (50 ml). The mixture was stirred vigorously for the specified time and then diluted with CH_2Cl_2 (50 ml). The resulting solid was filtered off, and the filtrate was washed successively with H_2O and aq. NaHCO_3 , and dried (Na_2SO_4). Evaporation *in vacuo* afforded the required halo compound.

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