Conversion of Nucleophilic Halides to Electrophilic Halides: Efficient and Selective Halogenation of Azinones, Amides, and Carbonyl Compounds Using Metal Halide/Lead Tetraacetate

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Abstract: $AlCl_3/Pb(OAc)_4$ and $ZnBr_2/Pb(OAc)_4$ are efficient electrophilic N- and α-C-halogenating agents. A variety of azinones, amides and carbonyl compounds were chemoselectively and regioselectively N-, or α-C-halogenated in good to excellent yield using $AlCl_3/Pb(OAc)_4$ and $ZnBr_2/Pb(OAc)_4$ in acetonitrile.

Key words: N-halogenation,, α-C-halogenation, electrophilic halogenation, selective halogenation, metal halide/lead tetraacetate

α-Halocarbonyl compounds[1–3] and *N*-halonitrogen heterocycles[4,5] are among the most versatile intermediates in organic synthesis. Direct selective halogenation of carbonyl compounds and nitrogen heterocycles is also a very important synthetic transformation technique. Electrophilic halogenating agents are useful for halogenating these carbonyl compounds and nitrogen heterocycles. In general, direct conversion of carbonyl compounds such as ketones to α-halocarbonyl compounds can be achieved by using halogenating agents such as copper(II) halides,[6] sulfuryl chloride,[7] *p*-toluenesulfonyl chloride,[8] *N*-halosuccinimide/*p*-toluenesulfonic acid,[9] Koser's reagent/magnesium halides,[10] tetraalkylammonium trihalides[11] and bromine.[12] Recently, much effort has been made to develop new efficient methods for α-halogenation of 1,3-dicarbonyl compounds.[13]

Also *N*-halo derivatives have been found to be useful and valuable compounds in organic synthesis.[4,5,14–22] For N-halogenation of nitrogen heterocycles, and amides, a relatively few reagents for N-halogenation have been described, including among others, *tert*-butyl hypochlorite,[14–16] chlorine,[23] sodium hypochlorite,[24] calcium hypochlorite,[19] Oxone®[25] and trichloroisocyanuric acids.[26] However, these methods suffer from such drawbacks as long reaction times, cumbersome work-up procedures, short shelf lifetime and emission of active oxygen. Here, we report a more convenient and effective method for the N- or α-C-halogenation of azinones, amides, and carbonyl compounds.

In our previous work on phenylation of 4,5-dichloropyridazin-3(2*H*)-one using lead tetraacetate/zinc chloride/benzene system,[27] we had found that a combination of metal chloride and lead tetraacetate (LTA) chlorinates pyridazin-3(2*H*)-ones to the corresponding *N*-chloro derivatives. This is an evidence of conversion of nucleophilic chlorine, metal chloride, to electrophilic chlorine such as AcOCl (Cl^+ equivalent). Therefore, we anticipated this reaction to go through the following mechanism:

$$Pb(OAc)_4 + MXn \rightarrow Pb(OAc)_2 + MX_{n-1}(OAc) + AcOX$$
$$AcOX + NuH \rightarrow NuX + AcOH$$

In this study, we examined the N-chlorination of 4,5-dichloropyridazin-3(2*H*)-one (**1a**) with $ZnCl_2/Pb(OAc)_4$ in refluxing organic solvents such as dichloromethane, dimethylformamide, acetonitrile, *n*-hexane and tetrahydrofuran (entries 1–5 in Table 1). Using acetonitrile as solvent, 2-chloro derivative **2a** was obtained exclusively in 78% yield (entry 2 in Table 1). Subsequently, the chlorination of **1a** was evaluated in acetonitrile using various $MX_n/Pb(OAc)_4$ systems (entries 6–18 in Table 1). Using $FeCl_3$ (1 equiv) and $AlCl_3$ (1 equiv), **2a** was obtained exclusively in excellent yields (entries 6 and 10 in Table 1). On the other hand, chlorination of **1a** with $SnCl_4/Pb(OAc)_4$ (1:1 equiv) in refluxing dichloromethane gave **2a** in 85% yield (entry 15 in Table 1), whereas **2a** was not formed at room temperature. Reaction of **1a** with $SnCl_4/Pb(OAc)_4$ (1:1 equiv) in refluxing acetonitrile for four hours gave **2a** in low yield although the reaction did not proceed completely (entry 16 in Table 1). Although the treatment of **1a** with $AlBr_3/Pb(OAc)_4$ in acetonitrile did not yield 2-bromo derivative **2b**, the compound **1a**, when reacted with $ZnBr_2/Pb(OAc)_4$ in acetonitrile at room temperature, gave **2b** in excellent yield (entry 18 in Table 1). However, treatment of **1a** with $AlI_3/Pb(OAc)_4$ or $ZnI_2/Pb(OAc)_4$ in acetonitrile did not give products. Neither did the reaction of **1a** with zinc chloride and other metal acetates such as $Zn(OAc)_2$, $Cu(OAc)_2$, $Hg(OAc)_2$, $Sn(OAc)_4$, $Pd(OAc)_2$ and $Tl(OAc)_3$ occur.

On the other hand, the chlorination of benzene derivatives with elemental chlorine has been reported to have yielded from $SnCl_4/Pb(OAc)_4$ (2:1 equiv).[28] However, when $Pb(OAc)_4/AlCl_3$ (1:2 equiv; entry 11 in Table 1) or $Pb(OAc)_4/AlCl_3$ (0.5:1 equiv; entry 12 in Table 1) were used, the reactions did not occur. Consequently, the mechanism of our system is different from the pathway described in the literature[28] although small amounts of

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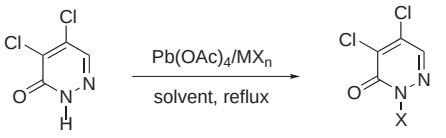
Table 1 Reaction of 4,5-Dichloropyridazin-3(2*H*)-ones (**1a**) with $Pb(OAc)_4/MX_n$



1a

2a: X= Cl
2b: X= Br

Entry	$Pb(OAc)_4$ (equiv)	MX_n (equiv)	Solvent	Conditions[a]	Product (%)[b]	
					2a	**2b**
1	1	$ZnCl_2$ (1)	CH_2Cl_2	20 h, r.t.	60[c]	–
2	1	$ZnCl_2$ (1)	MeCN	1.5 h, reflux	78	–
3	1	$ZnCl_2$ (1)	DMF	4 h, reflux	–[d]	–
4	1	$ZnCl_2$ (1)	*n*-hexane	4 h, reflux	No reaction	
5	1	$ZnCl_2$ (1)	THF	4 h, reflux	No reaction	
6	1	$FeCl_3$ (1)	MeCN	1.5 h, reflux	91	–
7	1	$TiCl_4$ (1)	MeCN	4 h, reflux	No reaction	
8	1	CuCl (1)	MeCN	5 h, reflux	30[c]	–
9	1	$CuCl_2$ (1)	MeCN	7 h, reflux	50[c]	–
10	1	$AlCl_3$ (1)	MeCN	1.1 h, reflux	93	–
11	2	$AlCl_3$ (1)	MeCN	1.1 h, reflux	92	–
12	0.5	$AlCl_3$ (1)	MeCN	1.1 h, reflux	No reaction	
13	1	$AlCl_3$ (2)	MeCN	1.1 h, reflux	No reaction	
14	1	$AlCl_3$ (0.5)	MeCN	3.7 h, reflux	48[c]	–
15	1	$SnCl_4$ (1)	MeCN	12 h, reflux	85	–
16	1	$SnCl_4$ (1)	MeCN	4 h, reflux	30[c]	–
17	1	$AlBr_3$ (1)	MeCN	10 min, r.t.	–[e]	–
18	1	$ZnBr_2$ (1)	MeCN	5 min, r.t.	–	95

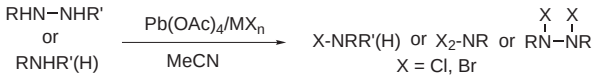
[a] Isolated yield.
[b] Unreacted **1a** was isolated.
[c] *N*-Methyl-*N*-(6-oxo-6*H*-pyridazin-1-ylmethyl)formamide was isolated in good yield.
[d] The unknown product was detected on TLC.
[e] $AlBr_3$ was reacted explosively with **1a** under this condition to some unknown products.

chlorine or bromine were detected at the initial step. Based on the experiments for five different mole ratios of $Pb(OAc)_4/AlCl_3$ (entries 10–14 in Table 1), the optimum molar ratio is 1:1 equivalent of $Pb(OAc)_4/AlCl_3$ (entry 10 in Table 1). However, treatment of **1a** with zinc chloride or chlorine in the absence of lead tetraacetate in acetonitrile did not give trichloro compound **2a**. Neither did the reaction of **1a** with $Zn(OAc)_2/Br_2$ occur. These results are strongly suggestive of the conversion of nucleophilic chloride such as zinc chloride to an electrophilic chloride of AcOCl (Cl^+ equivalent) in our system. Lead tetraacetate is a good acetoxylation agent.[29] Reaction of lead tetraacetate with iodide affords AcOI.[30] If AcOX were to be formed by the reaction of lead tetraacetate with X_2, two equivalents of lead tetraacetate would be required. However, when one equivalent of $Pb(OAc)_4$ (entry 10 in Table 1) was used, the N-halogenation proceeded completely. On the other hand, when excess $AlCl_3$ was used (entries 12, 13 in Table 1), no reaction occurred.

For detailed comparison with a panel of representative azinones and amides, two reaction systems, i.e., $AlCl_3/Pb(OAc)_4$/MeCN and $ZnBr_2/Pb(OAc)_4$/MeCN were selected. N-Chlorination of benzotriazole, nicotinamide, isoindole-1,3-dione and saccharin with $AlCl_3/Pb(OAc)_4$ (1:1 equiv) in acetonitrile gave the corresponding *N*-monochlorides in good to excellent yields, respectively

(entries 1, 3, 7, 11, 15 and 17 in Table 2),[31] whereas 2-pyridone was found to be unreactive under the identical condition. The reaction of toluene-4-sulfonamide and 2,3-dihydrophthalzine-1,4-dione with $AlCl_3/Pb(OAc)_4$ (2:2 equiv) in acetonitrile gave the corresponding *N*,*N*-dichlorides in 88% and 94% yields, respectively (entries 5 and 9 in Table 2). On the other hand, N-bromination of isoindole-1,3-dione, 2,3-dihydrophthalzine-1,4-dione, saccharin, pyrrolidine-2,5-dione and azepan-2-one with $ZnBr_2/Pb(OAc)_4$ in MeCN gave the corresponding *N*-bromo derivatives (entries 8, 12, 16 and 18 in Table 2)[32] and *N*,*N*-dibromo derivative (entries 10 in Table 2).[32]

Table 2 N-Chlorination of Azaheterocycles and Amides Using $Pb(OAc)_4/MX_n$ in Acetonitrile[a]



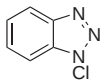
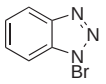
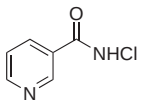
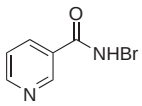
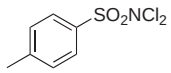
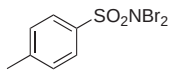
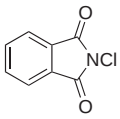
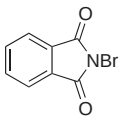
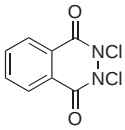
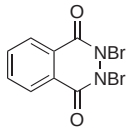
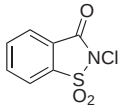
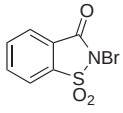
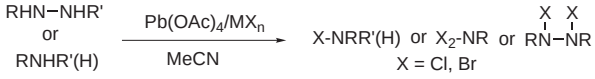
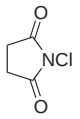
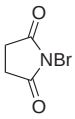
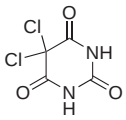
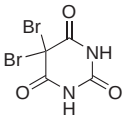
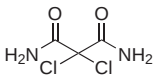
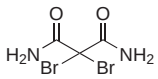
Entry	MX_n	Time	Method [b]	Product	Yield (%)[c]
1	$AlCl_3$	1 h	A		96
2	$ZnBr_2$	1.1 h	A		No reaction
3	$AlCl_3$	1 h	A		86
4	$ZnBr_2$	1.3 h	A		No reaction
5	$AlCl_3$	6 h	B		88
6	$ZnBr_2$	50 min	B		No reaction
7	$AlCl_3$	3 h	A		88
8	$ZnBr_2$	5 min	A		86
9	$AlCl_3$	45 min	B		94
10	$ZnBr_2$	1 h	B		41
11	$AlCl_3$	30 min	A		91
12	$ZnBr_2$	55 min	A		82

Table 2 N-Chlorination of Azaheterocycles and Amides Using $Pb(OAc)_4/MX_n$ in Acetonitrile[a] (continued)

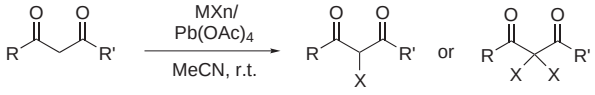


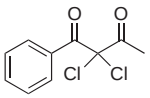
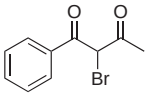
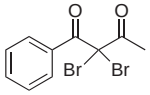
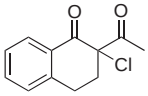
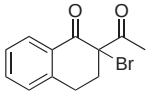
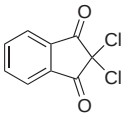
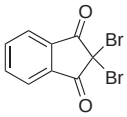
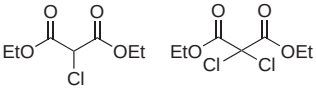
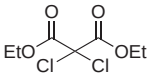
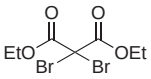
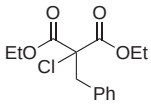
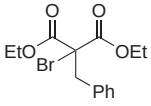
Entry	MX_n	Time	Method [b]	Product	Yield (%)[c]
13	$AlCl_3$	7 h	A		No reaction
14	$ZnBr_2$	3 h	A		Unknown product
15	$AlCl_3$	1.3 h	A		95
16	$ZnBr_2$	1 h	A		93
17	$AlCl_3$	45 min	A		90
18	$ZnBr_2$	1 h	B		84
19	$AlCl_3$	15 min[d]	B		97
20	$ZnBr_2$	20 min	B		94
21	$AlCl_3$	55 min[d]	B		95
22	$ZnBr_2$	15 min	B		85

[a] Reaction temperature: at reflux temperature for the chlorination; at room temperature for the bromination.
[b] Method A: MXn/ $Pb(OAc)_4$ = 1:1 equiv. Method B: MXn/$Pb(OAc)_4$ = 2:2 equiv.
[c] Isolated yield.
[d] Reflux temperature.

Furthermore, α-chlorination of 2-acetyl-3,4-dihydro-2*H*-naphthalen-1-one and 2-benzylmalonic acid diethyl ester with $AlCl_3/Pb(OAc)_4$ (1:1 equiv) in acetonitrile gave exclusively the corresponding α-monochlorides in excellent yields (entries 4 and 11 in Table 3), whereas malonic acid diethyl ester was reacted under identical condition to afford 2-chloro (60%) and 2,2-dichloro derivative (24%, entry 8 in Table 3).[31] Treatment of 1-phenylbutane-1,3-dione, indan-1,3-dione, and malonic acid diethyl ester with $AlCl_3/Pb(OAc)_4$ (2:2 equiv) in acetonitrile afforded the corresponding α,α-dichlorides in good to excellent yields, respectively (entries 1, 6 and 9 in Table 3).[31] Bromination of 1-phenylbutane-1,3-dione, 2-acetyl-3,4-dihydro-2*H*-naphthalen-1-one and 2-benzylmalonic acid diethyl ester with $ZnBr_2/Pb(OAc)_4$ (1:1 equiv) in MeCN furnished the corresponding α-monobromides in good to excellent yields, respectively (entries 2, 5 and 12 in Table 3).[32] In addition, reaction of 1-phenylbutane-1,3-dione, indan-1,3-dione and malonic acid diethyl ester with $ZnBr_2/Pb(OAc)_4$ (2:2 equiv) in MeCN afforded the corresponding α,α-dibromides in good yields, respectively (entries 3, 7 and 10 in Table 3).[32]

Table 3 α-Chlorination of Carbonyl Compounds **7** with $MX_n/Pb(OAc)_4$ (1:1 equiv) in Acetonitrile at Room Temperature



Entry	MXn	Time	Method[a]	Product	Yield (%)[b]
1	$AlCl_3$	6 h	B		97
2	$ZnBr_2$	20 min	A		75
3	$ZnBr_2$	5.3 h	B		85
4	$AlCl_3$	5 min	A		97
5	$ZnBr_2$	10 min	A		97
6	$AlCl_3$	3 h	B		88
7	$ZnBr_2$	30 min	B		86
8	$AlCl_3$	2 h	A		60/24
9	$AlCl_3$	15 min	B		88
10	$ZnBr_2$	3.5 h	B		86
11	$AlCl_3$	7 h	A		98
12	$ZnBr_2$	18 h	A		80

[a] Method A: molar ratio of azinone/MXn/$Pb(OAc)_4$ = 1:1:1 equiv. Method B: molar ratio of azinone/MXn/$Pb(OAc)_4$ = 1:2:2 equiv.
[b] Isolated yield.

On the other hand, halogenation of barbituric acid or malonamide using $AlCl_3/Pb(OAc)_4$ (2:2 equiv) and $ZnBr_2/Pb(OAc)_4$ (2:2 equiv) in MeCN gave the corresponding C_α,C_α-dihalo derivatives chemoselectively in excellent yields, respectively (entries 19–22 in Table 2).

In summary, metal halide/lead tetraacetate [$MX_n/Pb(OAc)_4$] is proven to be a good system for converting of nucleophilic halogen (X^-) to electrophilic halogen (X^+ equivalent). The systems $AlCl_3/Pb(OAc)_4$ and $ZnBr_2/Pb(OAc)_4$ are efficient electrophilic halogenating agents for azinones, amides, and 1,3-dicarbonyl compounds. A variety of azinones and amides were chemoselectively

N-halogenated in good to excellent yield using $AlCl_3$/$Pb(OAc)_4$ and $ZnBr_2$/$Pb(OAc)_4$ in acetonitrile. In addition, α-halogenation of some 1,3-dicarbonyl compound with $AlCl_3$/$Pb(OAc)_4$ and $ZnBr_2$/$Pb(OAc)_4$ in acetonitrile afforded α-monohalides or α,α-dihalides selectively in good to excellent yields. The halogenation of barbituric acid or malonamide involving 1,3-dicarbonyl and amide NH chemoselectively afforded the corresponding C_α,C_α-dihalo derivatives in excellent yields. We believe that these systems will also be applicable particularly to halogenation of various nitrogen heterocycles, amides, and active methylene/methyne compounds.

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(31) **Typical N-Chlorination of Azinones, Amides and Carbonyl Compounds.**
$Pb(OAc)_4$ (2.0 or 4.0 mmol) was dissolved in MeCN (20 mL). $AlCl_3$ or $ZnCl_2$ (2.0 or 4.0 mmol) was added to the MeCN solution, and the mixture was stirred for 5 min at r.t. After adding the nitrogen heterocycle (2 mmol) or carbonyl compound (2 mmol) to the above solution, the resulting mixture was refluxed until nitrogen heterocycle or carbonyl compound was disappeared. After evaporating the solvent under reduced pressure, the resulting residue was applied to the top of an open-bed silica gel column (3.0 × 7 cm). The column was eluted with CH_2Cl_2 or CH_2Cl_2–*n*-hexane (1:1). Fractions containing the product were combined and evaporated under reduced pressure to give monochlorides and/or dichlorides.
Selected Analytical Data.
2,4,5-Trichloropyridazin-3(2*H*)-one: colorless crystals (CH_2Cl_2); mp 146–147 °C (lit.[21] 146–147 °C). TLC (CH_2Cl_2): R_f = 0.5. IR (KBr): 3100, 1700, 1600, 1580, 1360, 1260, 1180, 1160, 960 cm^{-1}. ^1H NMR ($CDCl_3$): δ = 7.76 (s, 1 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 134.8, 137.0, 137.5, 153.8 ppm. Anal. Calcd for $C_4HCl_3N_2O$: C, 24.09; H, 0.51; N, 14.05. Found: C, 24.10; H, 0.53; N, 14.07.
***N*-Chloroisoindole-1,3-dione**: colorless crystals (CH_2Cl_2); mp 184–185 °C. TLC (CH_2Cl_2): R_f = 0.73. IR (KBr): 3070, 2950, 2880, 1750, 1720, 1620, 1510, 1470, 1360, 1310, 1080, 860 cm^{-1}. ^1H NMR ($CDCl_3$): δ = 7.82–7.84 (m, 2 H), 7.89–7.93 (m, 2 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 123.9, 131.0, 134.7, 163.3 ppm. Anal. Calcd for $C_8H_4ClNO_2$: C, 52.92; H, 2.22; N, 7.71. Found: C, 52.98; H, 2.24; N, 7.79.
***N,N*-Dichlorotoluene-4-sulfonamide**: colorless crystals (CH_2Cl_2); mp 130–131 °C. TLC (CH_2Cl_2): R_f = 0.57. IR (KBr): 3100, 3070, 1860, 1770, 1600, 1470, 1360, 1250, 1100, 910 cm^{-1}. ^1H NMR ($CDCl_3$): δ = 7.91–7.95 (m, 2 H), 8.02–8.06 (m, 2 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 125.7, 131.3, 136.1, 162.8 ppm. Anal. Calcd for $C_8H_4Br_2N_2O_2$: C, 30.03; H, 1.26; N, 8.76. Found: C, 30.11; H, 1.30; N, 8.82.

2-Acetyl-2-chloro-3,4-dihydro-2*H*-naphthalen-1-one: colorless crystals (CH_2Cl_2–*n*-hexane = 1:1); mp 49–50 °C (lit.[21] mp 48–50 °C). TLC (CH_2Cl_2–*n*-hexane = 1:1): R_f = 0.51. IR (KBr): 2950, 1720, 1680, 1600, 1460, 1420, 1360, 1300, 1240, 1200, 900, 850, 750, 720 cm^{-1}. ^1H NMR ($CDCl_3$): δ = 2.42 (s, 3 H), 2.45–2.51 (m, 1 H), 2.90–2.99 (m, 1 H), 3.05–3.08 (m, 1 H), 3.12–3.16 (m, 1 H), 7.41–7.46 (m, 2 H), 7.63–7.69 (m, 1 H), 7.95 (d, 1 H, *J* = 7.8 Hz) ppm. ^{13}C NMR ($CDCl_3$): δ = 25.0, 26.6, 30.0, 75.9, 127.3, 127.7, 129.2, 129.5, 134.7, 142.9, 189.3, 201.0 ppm. Anal. Calcd for $C_{12}H_{11}ClO_2$: C, 64.73; H, 4.98. Found: C, 64.75; H, 4.99.

2,2-Dichloro-1-phenylbutane-1,3-dione: colorless crystals (CH_2Cl_2–*n*-hexane = 1:2); mp 75–76 °C (lit.[21] mp 75–76 °C). TLC (CH_2Cl_2–*n*-hexane = 1:2): R_f = 0.50. IR (KBr): 3070, 2930, 2880, 1760, 1730, 1710, 1680, 1600, 1580, 1510, 1450, 1360, 1250, 1230, 840, 780, 690, 660, 580 cm^{-1}. ^1H NMR ($CDCl_3$): δ = 2.47 (s, 3 H), 7.46–7.54 (m, 2 H), 7.61–7.67 (m, 1 H), 8.06–8.10 (m, 2 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 24.9, 86.5, 128.7, 130.6, 130.9, 134.5, 185.9, 192.2 ppm. Anal. Calcd for $C_{10}H_8Cl_2O_2$: C, 51.98; H, 3.49. Found: C, 51.99; H, 3.52.

2,2-Dichloroindan-1,3-dione: colorless crystals (CH_2Cl_2–*n*-hexane = 1:1); mp 125–126 °C. TLC (CH_2Cl_2–*n*-hexane = 1:1): R_f = 0.63. IR (KBr): 3100, 3060, 2930, 2880, 1780, 1740, 1600, 1260, 1160, 870, 810, 780, 650 cm^{-1}. ^1H NMR ($CDCl_3$): δ = 8.07–8.11 (m, 2 H), 8.13–8.17 (m, 2 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 72.8, 125.8, 137.0, 138.1, 186.4 ppm. Anal. Calcd for $C_8H_4Cl_2O_2$: C, 50.27; H, 1.87. Found: C, 50.29; H, 1.91.

(32) **Typical N-Bromination of Azinones, Amides and Carbonyl Compounds.**

$Pb(OAc)_4$ (2.0 or 4.0 mmol) was dissolved in MeCN (20 mL). $ZnBr_2$ (2.0 or 4.0 mmol) was added to the MeCN solution, and the mixture was stirred for 5 min at r.t. The nitrogen heterocycle (2 mmol) or carbonyl compound (2 mmol) was added to the resulting solution. The resulting mixture was stirred at r.t. until nitrogen heterocycle or carbonyl compound disappeared. After evaporating the solvent under reduced pressure, the resulting residue was applied to the top of an open-bed silica gel column (3.0 × 7 cm). The column was eluted with CH_2Cl_2 or CH_2Cl_2–*n*-hexane (1:1). Fractions containing the product were combined and evaporated under reduced pressure to give monobromides or dibromides.

Selected Analytical Data.

2-Bromo-3,4-dichloropyridazin-3(2*H*)-one: colorless crystals (CH_2Cl_2); mp 169 °C. IR (KBr): 3100, 1690, 1600, 1460, 1400, 1300, 1260, 1120, 960 cm^{-1}. ^1H NMR ($CDCl_3$): δ = 7.50 (s, 1 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 132.3, 136.2, 154.7, 168.0 ppm. Anal. Calcd for $C_4HBrCl_2N_2O$: C, 19.70; H, 0.41; N, 11.49. Found: C, 19.76; H, 0.43; N, 11.51.

***N*-Bromoisoindole-1,3-dione**: colorless crystals (CH_2Cl_2); mp 199–200 °C (lit.[33] mp 198–202 °C). TLC (CH_2Cl_2): R_f = 0.76. IR (KBr): 3090, 3050, 1775, 1730, 1690, 1610, 1460, 1350, 1290, 1100, 1070, 860, 800, 700 cm^{-1}. ^1H NMR ($CDCl_3$): δ = 7.73–7.77 (m, 2 H), 7.88–7.91 (m, 2 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 123.8, 131.9, 134.3, 165.0 ppm. Anal. Calcd for $C_8H_4BrNO_2$: C, 42.51; H, 1.78; N, 6.20. Found: C, 42.59; H, 1.84; N, 6.27.

2,3-Dibromophthalazine-1,4-dione: colorless crystals (CH_2Cl_2); mp 130–131 °C. TLC (CH_2Cl_2): R_f = 0.57. IR (KBr): 3100, 3070, 1860, 1770, 1600, 1470, 1360, 1250, 1100, 910 cm^{-1}. ^1H NMR ($CDCl_3$): δ = 7.91–7.95 (m, 2 H), 8.02–8.06 (m, 2 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 125.7, 131.3, 136.1, 162.8 ppm. Anal. Calcd for $C_8H_4Br_2N_2O_2$: C, 30.03; H, 1.26; N, 8.76. Found: C, 30.11; H, 1.30; N, 8.86.

2-Bromo-1-phenylbutane-1,3-dione: colorless oil. TLC (CH_2Cl_2): R_f = 0.52. IR (KBr): 3080, 2970, 2940, 1720, 1680, 1600, 1450, 1360, 1300, 1230, 1190, 1000, 760, 690, 550 cm^{-1}. ^1H NMR ($CDCl_3$): δ = 2.44 (s, 3 H), 5.67 (s, 1 H), 7.46–7.52 (dd, 2 H, *J* = 7.87, 7.41 Hz), 7.50–7.65 (m, 1 H), 7.95–7.98 (m, 2 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 27.2, 53.0, 128.6, 129.0, 129.2, 134.5, 190.0, 198.1 ppm. Anal. Calcd for $C_{10}H_8BrO_2$: C, 49.82; H, 3.76. Found: C, 49.84; H, 3.80.

2,2-Dibromomalonic Acid Diethyl Ester: colorless oil. TLC (CH_2Cl_2–*n*-hexane = 1:1): R_f = 0.50. IR (KBr): 2980, 2930, 2890, 1760, 1740, 1465, 1445, 1390, 1365, 1290, 1240, 1200 cm^{-1}. ^1H NMR ($CDCl_3$): δ = 1.32–1.37 (t, 6 H, *J* = 7.13 Hz), 4.33–4.41 (q, 4 H, *J* = 7.13 Hz) ppm. ^{13}C NMR ($CDCl_3$): δ = 13.7, 50.7, 64.7, 163.1 ppm. Anal. Calcd for $C_7H_{10}Br_2O_4$: C, 26.44; H, 3.17. Found: C, 26.50; H, 3.20.

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