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## Graphical Abstract

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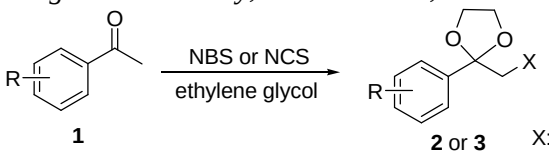


**1** **2** or **3** X: **2** -Br; **3** -Cl.

R : H, *p*-Br, *p*-Cl, *p*-F, *m*-Br, *o*-Cl, *p*-$CF_3$, *p*-$NO_2$, *m*-$NO_2$, 2,4-Cl, 3,4-Cl, biphenyl, 4'-Br-biphenyl, *p*-Me, *p*-MeO.
cyclohexanone, 3-pentanone, 2-pentanone, methyl-2-thienyl ketone

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# One-step for the preparation of α-haloacetal of ketones with N-bromosuccinimide/N-chlorosuccinimide (NBS/NCS) and ethylene glycol

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ABSTRACT

A new process that could directly prepare α-haloacetal of ketones from various ketones with N-halosuccinimide (NBS/NCS) and ethylene glycol in one step without any other catalysts was reported. The effects of solvents, NBS/NCS and reaction temperature were investigated. Under the optimal condition, most of α-haloacetals of ketones were obtained in 90–100% yield.



## 1. Introduction

Simultaneous installation of two different functional groups in one-step into the organic framework is a remarkable fundamental process in organic synthesis.[1,2] Halogenation and acetalization are two kinds of important process in organic synthesis.[3-9] α-haloacetals of ketones are valuable synthetic intermediates used for medicine and agriculture, particularly in triazole fungicides[10], α,β-unsaturated ketones[11-16], and enol ethers[14]. Previous methods to prepare α-haloacetals of ketones are always based on two separate steps, sequences on α-halogenation of ketones followed by acetalization of the α-halogenation products. One of the effective methods for preparation of α-haloacetals of ketones is one-step α-haloacetalization of ketones with halogenating reagent and alcohol or glycol. There are a few examples have been previously reported solving this challenge,[17-19] employing compounds, such as liquid bromine[20], copper(II) bromide[21], poly(diallyldimethylammonium chloride)[22], iodobenzene dichloride[23] and 1,3-dihalo-5,5-dimehtylhydantoin (DBDMH/DCDMH)[24,25]. However, most of the studies suffer for one or more disadvantages such as use of hazardous reagents, cost of metallic or strongly acids as catalyst, work up procedures, and moderate yields. Hence, the development of a safer, greener, and efficient procedure for α-haloacetalization of ketones with excellent yields remains a major challenge for synthetic organic chemists.

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N-Halosuccinimides represent an important class of halogenating reagents, especially N-bromosuccinimide (NBS), which has been widely researched in bromination of ketones to prepare α-bromoketones with various reaction conditions.[26-32] The halogenation would be not reactive enough without a Lewis acid or a Bronsted acid as catalyst.[30] *a*-Monohalogenated ketals could always be found as by-products when acetophenones with an electron-withdrawing groups(-$NO_2$) on the benzene ring was refluxed with halogenating reagents and acidic catalysts in methanol during our research.[24,33]

Herein, we decided to develop and optimize a one-step method for preparation of α-haloacetalization of ketones with NBS/NCS in glycol without any other catalysts based on our studies.

## 2. Results and discussion

In the preliminary experiments, acetophenone **1a** which is the simplest aromatic ketone was chosen as a model for α-bromoacetalization with various alcohol or glycol in one step. Compound **1a** was treated with 2.3 equiv of NBS in 6 mL of various alcohols or glycols, and the results were summarized in Table 1. When ethylene glycol was used as a reagent and solvent without any other catalyst, the α-bromoacetal of acetophenone(2-bromomethyl-2-phenyl-1,3-dioxolane, **2a**) could be precipitated from the reaction system as a white solid. After filtration, the yield of **2a** could reach 98% (entry 1, Table 1). When 1,2-propanediol was selected, the two isomers of 2-bromomethyl-4-methyl-2-phenyl-1,3-dioxolane could also be obtained with 96% yield(entry 2, Table 1), and the ratio determined by $^1$H NMR was

3:2. When the reaction performed in 1,3-propanediol, bromination of **1a** was the main reaction, and the α-bromoacetal product determined by GC was only 20%(entry 3, Table 1). Both α-bromoacetalization and bromination could not take place any more in methanol or ethanol at room temperature (entries 4, and 5, Table 1); however, when the reaction was performed under reflux in methanol, the main product was 2-bromo-1-phenylethanone and the yield could reach 80%[32](entry 6, Table 1). So, ethylene glycol was the first choice for the acetalization.

**Table 1** Effect of various solvents on the α-bromoacetalization of **1a** with NBS [a]

| Entry | Solvent | Time(h) | yield (%) |
|---|---|---|---|
| 1 | ethylene glycol | 24 | 98[b] |
| 2 | 1,2-propanediol | 24 | 96 |
| 3 | 1,3-propanediol | 24 | 20[c] |
| 4 | methanol | 8 | 0 |
| 5 | ethanol | 8 | 0 |
| 6 | methanol | 8 | 0(80[d]) |

[a] The reaction was performed with 2 mmol of acetophenone(**1a**), 4.6 mmol of NBS(2.3 equiv), and 6 mL of alcohols or glycols at room temperature;
[b] α-bromoacetal of acetophenone(**2a**) was filtrated directly from the reaction system as a white solid;
[c] The ratio of α-bromoacetal product was determined by GC;
[d] 2-bromo-1-phenylethanone was obtained with 80% yield.

**Table 2** Effect of NBS on α-bromoacetalization of **1a** with ethylene glycol [a]

| Entry | NBS (mmol) | Yield[b] (%) |
|---|---|---|
| 1 | 3.0 | 40 |
| 2 | 4.0 | 85 |
| 3 | 4.6 | 98 |
| 4 | 5.0 | 93 |
| 5 | 5.5 | 90 |

[a] The reaction was performed with 2 mmol of acetophenone(**1a**), and 6 mL of ethylene glycol at room temperature for 24 h;
[b] the α-bromoacetal of acetophenone(**2a**) was filtrated directly from the reaction system as a white solid.

**Table 3.** Effect of the dosage of ethylene glycol on α-bromoacetalization of **1a** [a]

| Entry | Ethylene glycol (mL) | Yield[b] (%) |
|---|---|---|
| 1 | 2 | 79 |
| 2 | 3 | 90 |
| 3 | 4 | 92 |
| 4 | 5 | 95 |
| 5 | 6 | 98 |
| 6 | 7 | 98.7 |

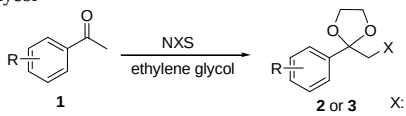
[a] The reaction was performed with 2 mmol of acetophenone(**1a**), and 4.6 mmol of NBS(2.3 equiv) at room temperature for 24 h.
[b] isolated yield.

**Table 4** Effect of NCS on α-chloroacetalization of **1a** with ethylene glycol [a]

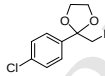
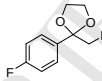
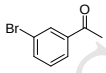
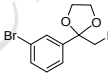
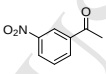
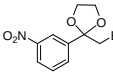
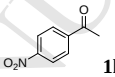
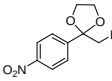
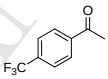
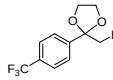
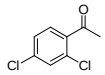
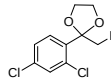
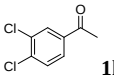
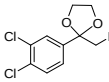
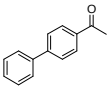
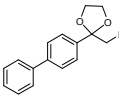
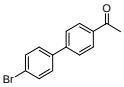
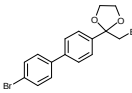
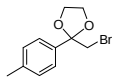
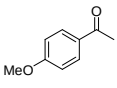
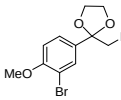
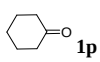
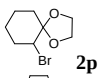
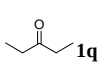
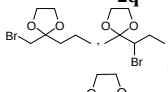
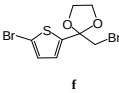
| Entry | NCS (mmol) | Ratio of **3a** [b] (%) |
|---|---|---|
| 1 | 4.6 | 62 |
| 2 | 6.0 | 73 |
| 3 | 7.0 | 79 |
| 4 | 8.0 | 90 |
| 5 | 9.0 | 89 |

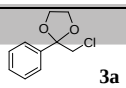
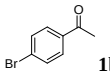
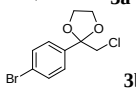
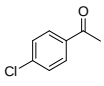
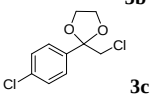
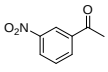
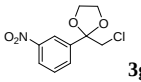
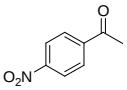
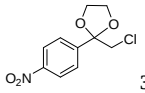
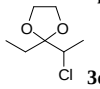
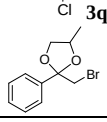
[a] The reaction was performed with 2 mmol of acetophenone(**1a**), and 6 mL of ethylene glycol at room temperature for 24 h;
[b] The ratio of α-chloroacetal product was determined by GC.

**Table 5** α-haloacetalization of various acetophenones with DBDMH/DCDMH in ethylene glycol [a]




**1** **2** or **3** X: **2** -Br; **3** -Cl.

| Entry | Substrate | Product | Yield[b](%) |
|---|---|---|---|
| 1 |  **1a** |  **2a** | 98 |
| 2 |  **1b** |  **2b** | 99 |
| 3 |  **1c** |  **2c** | 96 |
| 4 |  **1d** |  **2d** | 92 |
| 5 |  **1e** |  **2e** | 91 |
| 6 |  **1f** |  **2f** | 93 |
| 7 [c] |  **1g** |  **2g** | ~100 |
| 8 [c] |  **1h** |  **2h** | 98 |
| 9 [c] |  **1i** |  **2i** | 97 |
| 10 [c] |  **1j** |  **2j** | 96 |
| 11 |  **1k** |  **2k** | 94 |
| 12 |  **1l** |  **2l** | 91 |
| 13 |  **1m** |  **2m** | 92 |
| 14 |  **1n** |  **2n** | 85 |
| 15 |  **1o** |  **2o** | 52 [d] |
| 16 |  **1p** |  **2p** | 96 |
| 17 |  **1q** |  **2q** | 82 |
| 18 |  **1r** |  **2r** | 87[e] |
| 19 |  **1s** |  **2s** | 45 |
| 20 |  **1t** | -[f] | - |
| 21 |  **1u** | -[f] | - |
| 22 |  **1v** |  | 20, 43 |

| | | | |
|---|---|---|---|
| 23 |  **1a** |  **3a** | 90 |
| 24 |  **1b** |  **3b** | 91 |
| 25 |  **1c** |  **3c** | 95 |
| 26 [c] |  **1g** |  **3g** | ~100 |
| 27 [c] |  **1h** |  **3h** | 97 |
| 28 |  **1p** |  **3p** | 92 |
| 29 |  **1q** |  **3q** | 76 |
| 30 |  |  | 96 |

[a] The reaction was performed with 2 mmol of ketone, 4.6 mmol (2.3 equiv) of NBS(entries 1-15) or 8.0 mmol (4.0 equiv) of NCS(entries 14-20), and 6 mL of ethylene glycol at room temperature for 24 h;

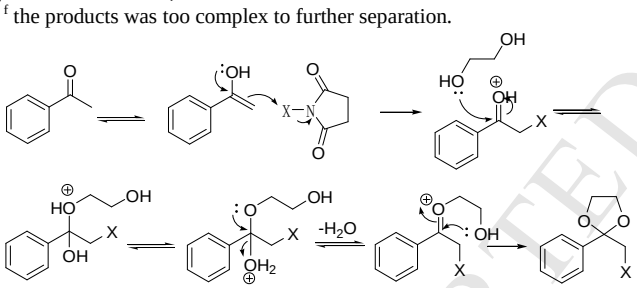
[b] isolated yield;

[c] the reaction was carried at 45℃;

[d] 2-bromomethyl-2-(3-bromo-4-methoxyphenyl)-1,3-dioxolane(**2m**) was isolated as the main product;

[e] a mixture of 2-(bromomethyl)-2-propyl-1,3-dioxolane and 2-(1-bromopropyl)-2-methyl-1,3-dioxolane was obtained, and the ratio determined by $^1$H NMR was 3 : 2;

[f] the products was too complex to further separation.



**Scheme 1** Possible mechanism for one-step α-haloacetalization of acetophenone with NXS in glycol.

Secondly, the effect of NBS on the α-bromoacetalization of **1a** was further investigated (Table 2). When 3.0 mmol (1.5 equiv) of NBS was added to the reaction system, **2a** was obtained with only 40% yield(entry 1, Table 2). Increased the amount of NBS to 4.6mmol (1.5 equiv) could result in an increase of the yield to 98%(entry 3, Table 2). However, larger amount of NBS was not necessary and helpful for the reaction.

Effect of the dosage of ethylene glycol on α-bromoacetalization of **1a** was also investigated (Table 3). Less amount of ethylene glycol (2 mL) resulted low yield of **2a**(79%)(entry 1, Table 3). When the amount of ethylene glycol was increased to 6 mL, the yield could also increase to 98%( entry 5, Table 3). The major reason may be attributed to the dilution of ethylene glycol on the water formed in the acetalization process.

The optimal reaction condition in terms of yield required 2 mmol of **1a**, 4.6 mmol of NBS, 6 mL of ethylene glycol at room temperature for 24h. To further examine the scope of this protocol, the optimized conditions were then applied to the synthesis of a variety of α-bromoacetal of substituted ketones, such as acetophenones, aliphatic ketones, acetylthiophene, and acetylfuran. The results were listed in Table 5. When **1b**, **1c**, and **1d** with a halogen atom on the *para*-position of benzene ring were selected, the yields of **2b**, **2c**, and **2d** were 99%, 96%, and 92%(entries 2, 3, and 4, Table 5), respectively. When 2-chloroacetophenone (**1e**) and 3-bromoacetophenone (**1f**) were used as the tested substrates, the yields were also good, could reach 91% and 93%(entries 5, and 6, Table 5), respectively. However, when **2g** was prepared at room temperature from **1g** with a strong electron-withdrawing group (-$NO_2$) on the benzene ring, the yield was only 76%; when the reaction temperature was increased to 45℃, **2g** could be obtained with excellent yields (~100%)(entry 7, Table 5); the same process was also used to prepared **2h**, **2i** and **2j**, the yields were 98%, 97%, and 96%(entries 8, 9, and 10, Table 5), respectively. When **1l**, and **1m** with bulky groups on the benzene ring were tested, the yields of **2l** and **2m** could also reach 91% and 92%(entries 12 and 13, Table 5), respectively. The yield of **2n** with a methyl on the benzene ring was 85% (entry 14, Table 5). Substrates with a strong electron-donation group (-$OCH_3$), such as **1o**, 2-bromomethyl-2-(3-bromo-4-methoxyphenyl)-1,3-dioxolane(**2o**) was isolated as the main product and the yield was only 52%(entry 15, Table 5). In our new chemical process of a-bromination and acetalization in one-step, acetophenones with electron-withdrawing groups on the benzene ring seem to offer products with excellent yields, and the yields of the substrates with strong electron-donating groups were less than others. Aliphatic ketones, cyclohexanone(**1p**), 3-pentanone(**1q**), and 2-pentanone(**1r**) were selected as test substrates, **2p**, **2q**, and **2r** could be obtained with 96%, 82%, and 87% yields(entry 16, 17 and 18, Table 5), respectively. **2r** was a mixture of 2-(bromomethyl)-2-propyl-1,3-dioxolane and 2-(1-bromopropyl)-2-methyl-1,3-dioxolane, and the ratio determined by $^1$H NMR was 3 : 2. When 2-acetylthiophene(**1s**) was tested, 2-(bromomethyl)-2-(5-bromothiophen-2-yl)-1,3-dioxolane(**2s**) was obtained with only 45% yield(entry 19, Table 5). However, the α-bromoacetalization of 2-acetylfuran(**1t**) and 4-acetylpyridine(**1u**) was too complex to further separation(entry 20, and 21, Table 5). When 1-phenylpropan-1-one(**1v**) was selected, 2-bromo-1-phenylpropan-1-one and 2,2-dibromo-1-phenylpropan-1-one were obtained with 20% and 43% yields(entry 22, Table 5), respectively.

N-Chlorosuccinimide (NCS) which is an analogue of NBS could be used as a chlorinated reagent to produce α-chloroacetal of acetophenone and other conditions remained. The conversion of **1a** could reach 100%, the yield of **3a** was only 62% (entry 1, Table 4), and α-chloroacetophenone was the main by-product with 38% yield. When the dosage of NCS was adjusted to 8.0 mmol, the yield of **3a** could increase to 90% (entry 4, Table 4). When **1b** and **1c** were tested, **3b** and **3c** could be obtained with 91% and 95% (entries 24, and 25, Table 5), respectively. The α-chloroacetalization of **1g** and **1h** must be carried at 45℃, the yields of **3g** and **3h** were 100% and 97% (entry 26, and 27, Table 5) , respectively. Cyclohexanone(**1p**), and 3-pentanone(**1q**) were tested, **3p**, and **3q** could be obtained in 92%, and 76% yields, respectively(entry 28, and 29, Table 5). When N-iodosuccinimide (NIS) was selected to replace NBS or NCS, no iodoacetalization was detected.

## 3. Conclusion

In summary, we developed a simple and efficient method to synthesis α-haloacetal of ketones directly from various ketones in one-step by the application of NBS/NCS in glycols as reaction reagent and solvent under mild reaction without any other catalysts. Chen et al. suggested the mechanism of keto-enol tautomerism in the process of the chlorination of acetophenones using DCDMH.[24,33] Analogously, we proposed the following

haloacetalization mechanism. In the proposed system, the α-halogenation of ketone generates acid in situ, which catalyzes the ketals formation (**Scheme 1**). Major advantageous of the present protocol include a wide range of substrates, mild reaction conditions, ease and safety of operation, and high yields, which have provided a novel route to α-haloacetal of ketones in the methodology of organic synthesis.

## 4. Experimental

### 4.1. General

All required chemicals were used directly without purification unless mentioned. Melting points (mp) were recorded on a Yanano MP500 apparatus and are uncorrected. $^1$H NMR spectra were recorded on a Varian INOVA-500 (500 MHz) spectrometer with $CDCl_3$ as the solvent and TMS as the internal standard. Capillary GC was performed on GC2014 with a RTX-1 (Restek, ø 0.25 mm–30 m) column (Inj. 250 ℃, Det. 250 ℃).

### 4.2. General procedure for preparation of α-haloacetal of acetophenones from acetophenons

A mixture of 2 mmol of substrate, and 6 mL ethylene glycol was stirred for 5 min, and then 4.6 mmol of NBS or 8 mmol of NCS was added by 5 times in one hour, and the mixture was stirred 24 h at room temperature or 45℃. Afterward, the mixture was extracted with ether(10 mL × 3). The combined organic layer was washed twice by water(20 mL), and dried over anhydrous $Na_2SO_4$. After filtration, the solvent was removed under reduced pressure, and the residual was treated with alumina chromatography (Petroleum ether/AcOEt=20/1,V/V) to generate the product.

#### 4.2.1. 2-bromomethyl-2-phenyl-1,3-dioxolane(2a)[22]

Yield 98%, white solid, m.p.: 56-58 ℃, $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 3.66 (s, 2H, $CH_2Br$), 3.88-3.91(m, 2H, $OCH_2CH_2O$), 4.17-4.20(m, 2H, $OCH_2CH_2O$), 7.32-7.38(m, 3H, ArH), 7.52(d, 2H, $J$ = 7.5 Hz, ArH); $^{13}$C NMR (125 MHz, $CDCl_3$) $\delta$ 38.2, 65.8, 107.3, 126.0, 128.3, 128.7, 139.8. IR (KBr, cm$^{-1}$): 3011, 2885, 1627, 1485, 1470, 1447, 1220, 1169, 1039, 1029, 997.

#### 4.2.2. 2-bromomethyl-2-(4-bromophenyl)-1,3-dioxolane (2b)[25]

Yield 99%, white solid, m.p.: 67-70 ℃,$^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 3.63 (s, 2H, $CH_2Br$), 3.89-3.90(m, 2H, $OCH_2CH_2O$), 4.18-4.21(m, 2H, $OCH_2CH_2O$), 7.40(d, 2H, $J$ = 8.5 Hz, ArH), 7.51(d, 2H, $J$ = 8.5 Hz, ArH); $^{13}$C NMR(125 MHz, $CDCl_3$) $\delta$ 37.8, 65.9, 107.0, 123.1, 127.9, 131.5, 138.8. IR (KBr, cm$^{-1}$): 2957, 2874, 1585, 1481, 1413, 1221, 1171, 1039, 831.

#### 4.2.3 2-bromomethyl-2-(4-chlorophenyl)-1,3-dioxolane (2c)[25]

Yield 96%, white solid, m.p.: 56-59 ℃, $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 3.64 (s, 2H, $CH_2Br$), 3.90-3.91(m, 2H, $OCH_2CH_2O$), 4.18-4.21(m, 2H, $OCH_2CH_2O$), 7.35(d, 2H, $J$ = 8.5 Hz, ArH), 7.46(d, 2H, $J$ = 8.5 Hz, ArH); $^{13}$C NMR(125 MHz, $CDCl_3$) $\delta$ 37.9, 65.9, 107.0, 127.6, 128.5, 134.8, 138.3.

#### 4.2.4. 2-bromomethyl-2-(4-fluorophenyl)-1,3-dioxolane (2d)[25]

Yield 92%, colorless oil; $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 3.65 (s, 2H, $CH_2Br$), 3.90-3.92(m, 2H, $OCH_2CH_2O$), 4.19-4.22(m, 2H, $OCH_2CH_2O$), 7.04-7.09(m, 2H, ArH), 7.49-7.53(m, 2H, ArH); $^{13}$C NMR(125 MHz, $CDCl_3$) $\delta$ 38.1, 65.9, 107.0, 115.1, 115.3, 128.0, 135.6. IR (KBr, cm$^{-1}$): 2969, 2893, 1600, 1560, 1412, 1222, 1160, 1042, 839.

#### 4.2.5. 2-bromomethyl-2-(2-chlorophenyl)-1,3-dioxolane(2e)[25]

Yield 91%, colorless oil; $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 3.93-3.96(m, 2H, $OCH_2CH_2O$), 3.97 (s, 2H, $CH_2Br$), 4.22-4.25(m, 2H, $OCH_2CH_2O$), 7.28-7.31(m, 2H, ArH), 7.41-7.43(m, 1H, ArH), 7.71-7.72(m, 1H); $^{13}$C NMR(125 MHz, $CDCl_3$) $\delta$ 36.2, 65.9, 107.2, 126.7, 128.7, 130.2, 131.5, 132.1, 136.3. IR (KBr, cm$^{-1}$): 3065, 2892, 1591, 1466, 1434, 1210, 1177, 1037, 762.

#### 4.2.6. 2-bromomethyl-2-(3-bromophenyl)-1,3-dioxolane (2f)[25]

Yield 93%, colorless oil; $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 3.63 (s, 2H, $CH_2Br$), 3.90-3.91(m, 2H, $OCH_2CH_2O$), 4.17-4.20(m, 2H, $OCH_2CH_2O$), 7.23-7.28(m, 1H, ArH), 7.45-7.48(m, 2H, ArH), 7.68(s, 1H, ArH); $^{13}$C NMR(125 MHz, $CDCl_3$) $\delta$ 37.8, 66.0, 106.7, 122.5, 124.8, 129.2, 129.9, 131.9, 142.2. IR (KBr, cm$^{-1}$): 3026, 2892, 1566, 1466, 1426, 1211, 1030.

#### 4.2.7. 2-bromomethyl-2-(3-nitrophenyl)-1,3-dioxolane (2i)[25]

Yield 100%, white solid, m.p.: 84-86 ℃, $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 3.63(s, 2H, $CH_2Br$), 3.90-3.93(m, 2H, $OCH_2CH_2O$), 4.21-4.24(m, 2H, $OCH_2CH_2O$), 7.55(dd, 1H, $J_1$ = 7.7 Hz, $J_2$ = 8.2 Hz, ArH), 7.85(d, 1H, $J$ = 7.7 Hz, ArH), 8.20(d, 1H, $J$ = 8.2 Hz, ArH), 8.38(s, 1H, ArH); $^{13}$C NMR(125 MHz, $CDCl_3$) $\delta$ 37.2, 66.1, 106.7, 121.4, 123.7, 129.3, 132.2, 142.2, 148.4. IR (KBr, cm$^{-1}$): 3026, 2880, 1616, 1525, 1474, 1349, 1227, 1142, 1042.

#### 4.2.8. 2-bromomethyl-2-(4-nitrophenyl)-1,3-dioxolane (2h)[22]

Yield 98%, white solid, m.p.: 126-129 ℃,$^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 3.62 (s, 2H, $CH_2Br$), 3.89-3.93(m, 2H, $OCH_2CH_2O$), 4.21-4.23(m, 2H, $OCH_2CH_2O$), 7.71 (d, 2H, $J$ = 8.5 Hz, ArH), 8.21 (d, 2H, $J$ = 8.5 Hz, ArH); $^{13}$C NMR(125 MHz, $CDCl_3$) $\delta$ 37.1, 66.1, 106.9, 123.5, 127.3, 146.7, 148.4. IR (KBr, cm$^{-1}$): 3109, 2897, 1608, 1519, 1473, 1347, 1220, 1171, 1038, 854.

#### 4.2.9. 2-bromomethyl-2-(4-trifluoromethylphenyl)-1,3-dioxolane (2g)[25]

Yield 97%, colorless oil; $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 3.66 (s, 2H, $CH_2Br$), 3.91-3.93(m, 2H, $OCH_2CH_2O$), 4.21-4.24(m, 2H, $OCH_2CH_2O$), 7.64-7.68(m, 4H, ArH); $^{13}$C NMR(125 MHz, $CDCl_3$) $\delta$ 37.6, 66.0, 106.9, (120.73, 122.90, 125.06, 127.22, q ), (125.27, 125.30,125.33, 125.36, q), 126.58, (130.60, 130.86, 131.12, 131.38, q), 143.7. IR (KBr, cm$^{-1}$): 2970, 2895, 1619, 1409, 1326, 1222, 1167, 1043, 847.

#### 4.2.10. 2-bromomethyl-2-(2,4-dichlorophenyl)-1,3-dioxolane (2j)

Yield 96%, white solid, m.p.: 57-58℃; $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 3.90-3.93(m, 4H, $CH_2Br$, $OCH_2CH_2O$), 4.18-4.25(m, 2H, $OCH_2CH_2O$), 7.26(d, 2H, $J$ = 8.5 Hz, ArH), 7.42(s, 1H, ArH), 7.63(d, 1H, $J$ = 8.5 Hz, ArH); $^{13}$C NMR(125 MHz, $CDCl_3$) $\delta$ 35.8, 65.9, 107.0, 126.9, 129.9, 131.2, 132.0, 135.1, 135.4.

#### 4.2.11. 2-bromomethyl-2-(3,4-dichlorophenyl)-1,3-dioxolane (2k)[25]

Yield 86%, colorless oil;$^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 3.62 (s, 2H, $CH_2Br$), 3.91-3.93(m, 2H, $OCH_2CH_2O$), 4.19-4.22(m, 2H, $OCH_2CH_2O$), 7.35-7.37(dd, 1H, $J_1$ = 8.3Hz, $J_2$ = 2.0 Hz, ArH), 7.46(d, 1H, $J_1$ = 8.3 Hz, ArH), 7.62(d, 1H, $J$ = 2.0 Hz, ArH); $^{13}$C NMR(125 MHz, $CDCl_3$) $\delta$ 37.5, 66.0, 106.5, 125.6, 128.3, 130.4, 132.6, 133.0, 140.1. IR (KBr, cm$^{-1}$): 3068, 2893, 1585, 1561, 1468, 1416, 1379, 1216, 1174, 1035, 822.

#### 4.2.11. 2-bromomethyl-2-(4-biphenylyl)-1,3-dioxolane(2l)

Yield 91%, white solid, m.p.: 74-76℃; $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 3.74(s, 2H, $CH_2Br$), 3.96-4.00(m, 2H, $OCH_2CH_2O$), 4.21-4.28(m, 2H, $OCH_2CH_2O$), 7.38(t, 1H, $J$ = 7.3 Hz, ArH), 7.47(t, 2H, $J_1$ = 7.5 Hz, $J_2$ = 7.7 Hz, ArH), 7.60-7.63(m, 6H, ArH); $^{13}$C NMR(125 MHz, $CDCl_3$) $\delta$ 39.2, 65.9, 107.3, 126.5, 127.12, 127.17, 127.6, 128.8, 138.6, 140.5, 141.8.

**4.2.13. 2-bromomethyl-2-[4-(4-bromophenyl)phenyl]-1,3-dioxolane(2m)** [25]

Yield 92%, white solid, m.p.: 91-95 ℃,$^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 3.69 (s, 2H, $CH_2Br$), 3.92-3.95(m, 2H, $OCH_2CH_2O$), 4.20-4.23(m, 2H, $OCH_2CH_2O$), 7.44-7.45(m, 2H, ArH), 7.54-7.59(m, 6H, ArH); $^{13}$C NMR(125 MHz, $CDCl_3$) $\delta$ 38.0, 65.9, 107.3, 121.8, 126.6, 126.9, 128.7, 131.9, 139.1, 139.5, 140.5. IR (KBr, $cm^{-1}$): 3021, 2891, 1671, 1479, 1384, 1224, 1167, 1072, 1039, 817.

**4.2.14. 2-bromomethyl-2-(4-methylphenyl)-1,3-dioxolane(2n)** [25]

Yield 85%, colorless oil; $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 2.38 (s, 3H, $CH_2Br$), 3.61 (s, 2H, $CH_3$), 3.90-3.92(m, 2H, $OCH_2CH_2O$), 4.18-4.21(m, 2H, $OCH_2CH_2O$), 7.20(d, 1H, $J$ = 7.9 Hz, ArH), 7.42(d, 1H, $J$ = 7.9 Hz, ArH); $^{13}$C NMR(125 MHz, $CDCl_3$) $\delta$ 21.2, 38.3, 65.8, 107.3, 125.9, 129.4, 136.7, 138.7. IR (KBr, $cm^{-1}$): 3029, 2891, 1606, 1412, 1226, 1182, 1043, 819.

**4.2.15 2-bromomethyl-2-(4-methoxyphenyl)-1,3-dioxolane (2o)** [25]

Yield 52%, mushy oil; $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 3.61 (s, 2H, $CH_2Br$), 3.87-3.90(m, 5H, $OCH_2CH_2O$, $OCH_3$), 4.16-4.18(m, 2H, $OCH_2CH_2O$), 6.88(d, 1H, $J$ = 8.5 Hz, ArH), 7.41(d, 1H, $J$ = 8.5 Hz, ArH), 7.69(s, 1H, ArH); $^{13}$C NMR(125 MHz, $CDCl_3$) $\delta$ 38.0, 56.3, 65.9, 106.6, 111.5, 126.4, 131.1, 133.3, 135.4, 156.2. IR (KBr, $cm^{-1}$): 3068, 2894, 1596, 1495, 1252, 1182, 1049, 814.

**4.2.16 2-bromocyclohexanone ethylene glycol ketal(2p)**

Yield **96%**, colorless oil; $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 1.35-1.38 (m, 1H), 1.51-1.64(m, 4H, $CH_2CH_2$), 1.98-2.05(m, 2H, $CH_2$), 2.18-2.25(m, 1H), 3.97-4.00(m, 2H, $OCH_2CH_2O$), 4.09-4.15(m, 3H, $OCH_2CH_2O$, CHBr); $^{13}$C NMR(125 MHz, $CDCl_3$) $\delta$ 23.1, 34.9, 57.2, 65.5, 65.7, 107.9.

**4.2.17. 2-(1-bromoethyl)-2-ethyl-1,3-dioxolane(2q)**

Yield **82%**, colorless oil; $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 0.92(t, 3H, $J$ = 7.4 Hz, $CH_3$), 1.68(d, 3H, $J$ = 6.9 Hz, $CH_3$), 1.75-1.82(m, 1H, $CH_2$), 1.95-2.03(m, 1H, $CH_2$), 4.00-4.05(m, 4H, $OCH_2CH_2O$), 4.17(q, 1H, $J$ = 6.9 Hz, CHBr); $^{13}$C NMR(125 MHz, $CDCl_3$) $\delta$ 7.3, 20.8, 27.2, 52.7, 66.3, 111.48.

**4.2.18. 2-(bromomethyl)-2-propyl-1,3-dioxolane and 2-(1-bromopropyl)-2-methyl-1,3-dioxolane(2r)**

Yield **86%**, colorless oil; $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 0.94(t, 2H, $J$ = 7.4 Hz, $CH_3$), 1.09(m, 1.2H, $CH_3$), 1.39-1.43(m, 1.35H, $CH_2$), 1.48(s, 1.2H, $CH_3$), 1.66-1.74(m, 0.66H, $CH_2$), 1.79-1.82(m, 1.35H, $CH_2$), 2.04-2.08(m, 0.85H, $CH_2$), 3.98-4.08(m, 5H, $OCH_2CH_2O$, CHBr); $^{13}$C NMR(125 MHz, $CDCl_3$) $\delta$ 12.9, 14.2, 16.7, 20.7, 27.0, 35.7, 38.2, 62.6, 65.4, 65.7, 109.1, 109.9.

**4.2.19. 2-(bromomethyl)-2-(5-bromothiophen-2-yl)-1,3-Dioxolane(2s)**

Yield **45%**, colorless oil; $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 4.02-4.08(m, 2H, $OCH_2CH_2O$), 4.16-4.23(m, 2H, $OCH_2CH_2O$), 4.30(s, 2H, $CH_2Br$), 6.88(d, 1H, $J$ = 7.4 Hz, cyclo-H), 6.95(s, 1H, $J$ = 7.4 Hz, cyclo-H); $^{13}$C NMR(125 MHz, $CDCl_3$) $\delta$ 37.2, 66.3, 105.6, 126.0, 131.3, 132.6, 146.0.

**4.2.20 2-bromo-1-phenylpropan-1-one and 2,2-dibromo-1-phenylpropan-1-one**

2-bromo-1-phenylpropan-1-one: Yield **20%**, colorless oil; $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 1.89(d, 3H, $CH_3$), 5.30(q, 1H, CHBr), 7.43-7.49(m, 3H, ArH), 8.01-8.03(m, 2H, ArH);

2,2-dibromo-1-phenylpropan-1-one: Yield **43%**, colorless oil; $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 3.02(s, 3H, $CH_3$), 7.34-7.39(m, 5H, ArH).

**4.2.21. 2-chloromethyl-2-phenyl-1,3-dioxolane(3a)** [25]

Yield 90%, white solid, m.p.: 62-64 ℃, $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 3.76 (s, 2H, $CH_2Cl$), 3.90-3.93(m, 2H, $OCH_2CH_2O$), 4.17-4.20(m, 2H, $OCH_2CH_2O$), 7.32-7.39(m, 3H, ArH), 7.52(d, 2H, $J$ = 7.3 Hz, ArH); $^{13}$C NMR(125 MHz, $CDCl_3$) $\delta$ 49.4, 65.8, 107.9, 126.0, 128.2, 128.7, 139.8. IR (KBr, $cm^{-1}$): 3066, 2887, 1481, 1467, 1446, 1225, 1179, 1024.

**4.2.22. 2-chloromethyl-2-(4-bromophenyl)-1,3-dioxolane(3b)** [25]

Yield 91%, white solid, m.p.: 58-61 ℃, $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 3.72 (s, 2H, $CH_2Cl$), 3.90-3.92(m, 2H, $OCH_2CH_2O$), 4.17-4.20(m, 2H, $OCH_2CH_2O$), 7.40(d, 2H, $J$ = 8.6 Hz, ArH), 7.51(d, 2H, $J$ = 8.6 Hz, ArH); $^{13}$C NMR(125 MHz, $CDCl_3$) $\delta$ 49.1, 65.9, 107.6, 123.1, 127.9, 131.5, 138.8.

**4.2.23 2-chloromethyl-2-(4-chlorophenyl)-1,3-dioxolane(3c)** [25]

Yield 95%, white solid, m.p.: 54-58 ℃, $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 3.71 (s, 2H, $CH_2Cl$), 3.88-3.91(m, 2H, $OCH_2CH_2O$), 4.15-4.18(m, 2H, $OCH_2CH_2O$), 7.33(d, 2H, $J$ = 8.3 Hz, ArH), 7.45(d, 2H, $J$ = 8.3 Hz, ArH); $^{13}$C NMR(125 MHz, $CDCl_3$) $\delta$ 49.1, 65.8, 107.6, 127.6, 128.5, 134.8, 138.3. IR (KBr, $cm^{-1}$): 2982, 1592, 1488, 1431, 1220, 1178, 1090, 1034, 833, 761.

**4.2.24. 2-chloromethyl-2-(3-nitrophenyl)-1,3-dioxolane(3g)** [25]

Yield 100%, white solid, m.p.: 78-80 ℃, $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 3.74 (s, 2H, $CH_2Cl$), 3.92-3.95(m, 2H, $OCH_2CH_2O$), 4.20-4.23(m, 2H, $OCH_2CH_2O$), 7.55(dd, 1H, $J_1$ = 7.7 Hz, $J_2$ = 8.2 Hz, ArH), 7.85(d, 1H, $J$ = 7.7 Hz, ArH), 8.20(d, 1H, $J$ = 8.2 Hz, ArH), 8.39(s, 1H, ArH); $^{13}$C NMR(125 MHz, $CDCl_3$) $\delta$ 27.4, 66.1, 107.3, 121.4, 123.7, 129.3, 132.3, 142.1, 148.4. IR (KBr, $cm^{-1}$): 3075, 2890, 1615, 1525, 1475, 1422, 1353, 1229, 1042.

**4.2.25. 2-chloromethyl-2-(4-nitrophenyl)-1,3-dioxolane (3h)**

Yield 97%, white solid, m.p.: 103-105℃; $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 3.75(s, 2H, $CH_2Cl$), 3.92-3.97(m, 2H, $OCH_2CH_2O$), 4.19-4.27(m, 2H, $OCH_2CH_2O$), 7.26(d, 2H, $J$ = 8.7 Hz, ArH), 8.24(d, 2H, $J$ = 8.7 Hz, ArH); $^{13}$C NMR(125 MHz, $CDCl_3$) $\delta$ 48.8, 66.1, 107.4, 123.5, 127.4, 146.6, 148.3.

**4.2.26 2-chlorocyclohexanone ethylene glycol ketal(3p)**

Yield **92%**, colorless oil; $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 1.13-1.47 (m, 6H), 1.68-1.92(m, 2H), 3.73-3.97(m, 5H, $OCH_2CH_2O$, CHBr); $^{13}$C NMR(125 MHz, $CDCl_3$) $\delta$ 22.96, 23.07, 33.7, 33.9, 63.4, 65.5, 107.9.

**4.2.27 2-(1-chloroethyl)-2-ethyl-1,3-dioxolane(3q)**

Yield **76%**, colorless oil; $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 0.74-0.83(m, 3H), 1.32-1.39(m, 3H), 1.46-1.60(m, 2H), 1.73-1.82(m, 1H), 3.83-3.92(m, 5H, $OCH_2CH_2O$, CHBr); $^{13}$C NMR(125 MHz, $CDCl_3$) $\delta$ 7.00, 19.5, 26.7, 60.0, 66.2, 111.5.

**4.2.28. *cis* and *trans*-2-bromomethyl-4-methyl-2-phenyl-1,3-dioxolane** [25]

Yield 96%, colorless oil; $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 1.22 (d, 0.64 H, $J$ = 6.0 Hz, $CH_3$), 1.40 (d, 0.90, $J$ = 6.0 Hz, $CH_3$), 3.35-3.38(m, 0.23 H), 3.60-3.64 (m, 1.01 H), 3.66-3.71(m, 0.34 H), 4.00-4.03 (m, 0.32 H), 4.13-4.17 (m, 0.32 H), 4.26-4.27 (m, 0.24 H), 4.51-4.58 (m, 0.21H), 7.32-7.37 (m, 1.44 H), 7.50-7.55 (m, 1.00 H); $^{13}$C NMR(125 MHz, $CDCl_3$) $\delta$ 17.7, 18.2, 38.6, 38.9, 71.8, 72.2, 72.8, 74.9, 125.91, 125.94, 128.2, 128.3, 128.6, 128.7, 140.1, 140.9.

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