Reactions of *N*-phenylamide and phenyl (thio)esters of 3-phenylpropiolic acid with benzene under superelectrophilic activation

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N-Phenylamide and phenyl (thio)esters of 3-phenylpropiolic acid add benzene in the presence of CF_3SO_3H or AlX_3 (X = Cl, Br) to give 4,4-diphenyl-3,4-dihydroquinolin-2-one, 4,4-diphenyl-3,4-dihydrocoumarin, and 4,4-diphenyl-3,4-dihydrothiocoumarin, respectively.

Key words: 3-phenylpropiolic acid, carbocations, superelectrophilic activation, quinolines, coumarins, thiocoumarins.

Quinoline and coumarin derivatives are of great practical importance. They are generally applied in chemistry, biology, medicine, and nanotechnology.[1—4] Such heterocyclic systems are the key fragments of many natural and synthetic biologically active compounds, they exhibit phosphorescent properties and are used in organic light-emitting diodes (OLEDs).[4] Thiocoumarins are poorly studied class of organic compounds, which may possess valuable practical properties. Development of novel synthetic procedures towards derivatives of quinoline, coumarin, and thiocoumarin is a topical task of organic chemistry.

Superelectrophilic activation is one of the promising strategies in organic synthesis. It involves generation of reactive species with two or more cationic centers either by protonation of the basic centers of organic compounds in the Brønsted superacids of low nucleophilicity or by coordination of aforementioned centers to strong Lewis acids.[5] In the alkyne chemistry, superelectrophilic activation opens access to various unsaturated compounds, carbo- and heterocycles.[6]

Earlier, we used superelectrophilic activation by the Brønsted superacids (CF_3SO_3H, HSO_3F) or strong Lewis acids ($AlCl_3$, $AlBr_3$) for the intramolecular cyclization of *N*-arylamides, phenyl esters and thioesters of 3-arylpropiolic acids into 4-arylquinolin-2-ones,[7] 4-phenylcoumarins,[8] and 4-phenylthiocoumarins,[9] respectively.

The aim of the present work is studying the reactions of *N*-phenylamide and phenyl (thio)esters of 3-phenylpropiolic acid with benzene under superelectrophilic activation.

Either protonation of 3-phenylpropiolic acid derivatives **1a—c** in the Brønsted superacids at the oxygen atom of the carbonyl group C=O and the carbon atom of the triple C≡C bond or coordination of these basic centers to strong Lewis acids produced superelectrophilic dications **2a—c** (Scheme 1). The latter can further be transformed by several competing routes. The first route is intramolecular cyclization to give compounds **3a—c** (see Refs 7—9) arising from interaction of vinyl cationic center with the internal π nucleophile, namely, the phenyl ring of the XPh (X = NH, O, S) moiety (route *A*). The second route is intermolecular addition of the superacid CF_3SO_3H molecules or a chloride ion to yield vinyl triflates[7] or vinyl chlorides[9] **4a—c** (route *B*). In the presence of benzene (external π nucleophile), the third competing reaction involving akenylation of benzene to afford compounds **5a—c** is possible (route *C*). The latter under the reaction conditions can undergo intramolecular cyclization into compounds **6a—c**. These results are summarized in Table 1.

Compound **1a** in CF_3SO_3H gave reaction products following all three routes, *viz.*, 4-phenylquinolin-2-one (**3a**), 4,4-diphenyl-3,4-dihydroquinolin-2-one (**6a**), and vinyl triflate (**4a**) in a low yield of 10% (see Table 1, entry *1*). The ratio of products **3a** and **6a** reflects the contribution of the different pathways of the reaction of dication **2a** with π nucleophiles, namely, intramolecular reaction with the PhNH fragment (see Scheme 1, route *A*) and intermolecular reaction with benzene (route *C*). Similar yields of compounds **3a** (48%) and **6a** (40%) indicate that probability of transformation of dication **2a** *via* these routes is approximately equal.

Electrophilic activation of compound **1a** by $AlCl_3$ favored the intermolecular route *C*. Thus, the yield of dihydroquinolinone **6a** (91%) is higher than the yield of

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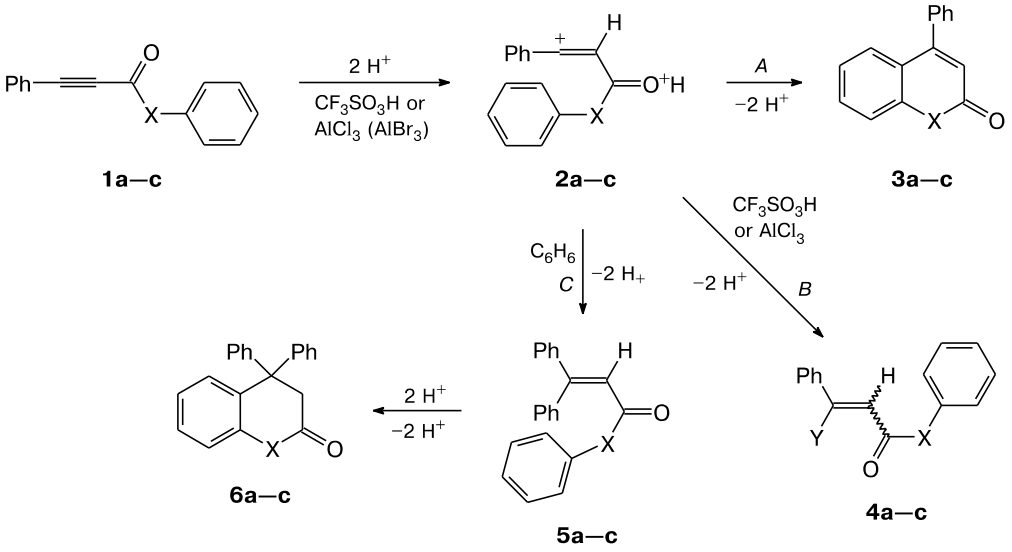
Scheme 1



1—6: X = NH (**a**), O (**b**), S (**c**); Y = TfO (**4a**), Cl (**4b**,**c**)

Table 1. Transformations of 3-phenylpropiolic acid derivatives on treatment with CF_3SO_3H or AlX_3 (X = Cl, Br) in the presence of benzene (see Scheme 1)

Entry	Starting compound	Reaction conditions	Products (Yield (%))
1	**1a**	CF_3SO_3H, C_6H_6, 20 °C, 75 h	**3a** (48), **6a** (40), **4a** (10)
2	**1a**	$AlCl_3$, C_6H_6, 80 °C, 1 h	**3a** (8), **6a** (91)
3	**1a**	$AlBr_3$, C_6H_6, 80 °C, 1 h	**3a** (65), **6a** (34)
4	**1b**	CF_3SO_3H, C_6H_6, 20 °C, 0.5 h	**6b** (13), 3,3-diphenylindan-1-one (**7**) (63)
5	**1b**	$AlCl_3$, C_6H_6, 20 °C, 2 h	**4b** (28), **6b** (13), **7** (52)
6	**1b**	$AlBr_3$, C_6H_6, 20 °C, 2 h	**3b** (59), **6b** (8), **7** (24)
7	**1b**	$AlBr_3$, C_6H_6, 20 °C, 10 h	**3b** (64), **6b** (25), **7** (7)
8	**1c**	CF_3SO_3H, C_6H_6, 20 °C, 1 h	**3c** (90), **7** (8)
9	**1c**	$AlCl_3$, C_6H_6, 20 °C, 2 h	**3c** (44), *E*-**4c** (19), *Z*-**4c** (12), **6c** (26)
10	**1c**	$AlBr_3$, C_6H_6, 20 °C, 2 h	**3c** (60), **6c** (37)
11	**1c**	$AlBr_3$, C_6H_6, 20 °C, 8 h	**3c** (70), **6c** (28)
12	**1c**	$AlBr_3$, C_6H_6, 80 °C, 1 h	**3c** (55), **6c** (37), **7** (7)

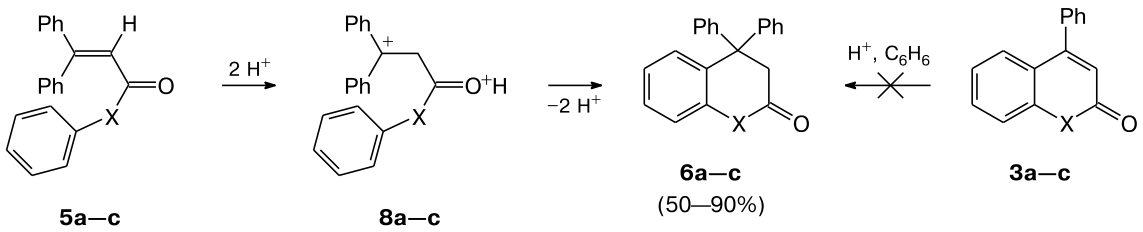
quinolinone **3a** (8%) (see Table 1, entry *2*). On the contrary, the use of $AlBr_3$ for superelectrophilic activation facilitated intramolecular cyclization of dication **2a** into quinolinone **3a** (65%), while the yield of compound **6a** was 34% (see Table 1, entry *3*).

Reaction of ester **1b** with benzene in CF_3SO_3H furnished 4,4-diphenyl-3,4-dihydrocoumarin (**6b**) (13%) and 3,3-diphenylindan-1-one (**7**) (63%) (see Table 1, entry *4*). The latter is a result of addition of two benzene molecules to the triple bond of compound **1b** followed by intramolecular acylation as it have been described earlier.[8] When $AlCl_3$ was used (see Table 1, entry *5*), vinyl chloride **4b** is additionally formed (see Scheme 1, route *B*). On going to $AlBr_3$, the major product is 4-phenylcoumarin **3b** (see Table 1, entries *6* and *7*) (route *A* is favored). The highest yield of dihydrocoumarin **6b** (25%) was achieved with $AlBr_3$—C_6H_6 mixture at 20 °C for 10 h (see Table 1, entry *7*).

In the reaction under consideration, thioester **1c** gave rise to a set of products **3c**, **4c**, and **6c** (see Table 1, entries *8—12*), which are structurally related to the compounds obtained from phenyl ester **1b**. Superelectrophilic activation of compound **1c** by CF_3SO_3H, $AlCl_3$, and $AlBr_3$ favored the formation of 4-phenylthiocoumarin (yields 44—90%) (see Scheme 1, route *A*). Catalysis with $AlBr_3$ provided the highest yield of dihydrothiocoumarin **6c** (37%) (entries *10—12*).

Formation of competing reaction products **3a—c** and **6a—c** in different electrophilic systems (CF_3SO_3H or AlX_3

Scheme 2



5a—c **8a—c** **6a—c** (50—90%) **3a—c**

X = NH (**a**), O (**b**), S (**c**)

(X = Cl, Br)) is the result of different activation degree of compounds **1a—c** (amount of positive charge on species **2a—c**) in these systems and nucleophilicity of the reaction media as well. The results obtained (see Table 1) indicate that in the vast majority of cases, activation of acetylene derivatives **1a—c** by the Lewis acids AlX_3 (X = Cl, Br) provided dehydro derivatives **6a—c** in higher yields as compared with activation by the Brønsted superacids CF_3SO_3H (*cf.* yields of **6a** in entries *1* and *2*; yields of **6b** in entries *4* and *7*; and yields of **6c** in entries *8—12*).

Formation of compounds **6a—c** precisely *via* route *C* (see Scheme 1) was confirmed by cyclization of the preliminary synthesized derivatives of 3,3-diphenylacrylic acid **5a—c** on treatment with CF_3SO_3H or $AlCl_3—CH_2Cl_2$ (Scheme 2). Intermediate formation of dications **8a—c** was assumed. A possible alternative pathway towards dihydro derivatives **6a—c** starting from compounds **3a—c** was not confirmed. Thus, no formation of compounds **6a—c** was observed upon keeping compounds **3a—c** in $CF_3SO_3H—C_6H_6$ or $AlCl_3—C_6H_6$ mixtures, the starting **3a—c** were recovered quantitatively.

In summary, under superelectrophilic activation by the Brønsted superacid CF_3SO_3H or strong Lewis acids AlX_3 (X = Cl, Br), derivatives of 3-phenylpropiolic acid **1a—c** react with benzene to give products of the competing reactions, *viz.*, compounds **3a—c**, **5a—c** or **6a—c**, the product ratios in every specific case is determined by both the structure of the staring compound **1a—c** and the type of acid used for the activation (CF_3SO_3H or AlX_3).

Experimental

^1H and ^{13}C NMR spectra were run on a Bruker AM-500 (at working frequencies of 500 and 125 MHz, respectively) in $CDCl_3$. IR spectra (neat) were obtained on a FSM-1201 instrument. Mass spectra (EI) were recorded on a MX-1321 instrument. Gas chromatography/mass spectrometry (GC/MS) was performed on a G 2570A GC/MSD (Agilent Technologies 6850c) instrument, capillary column HP-5MS (3 m × 0.25 mm), thickness of the stationary phase was 0.25 μm, helium was used as a carrier gas.

N,3-Diphenylpropiolamide (**1a**),[7] phenyl 3-phenylpropiolate (**1b**),[8] and *S*-phenyl 3-phenylprop-2-ynethioate (**1c**)[9] were synthesized according to the known procedure[10] by the reactions of 3-phenylpropiolic acid with aniline, phenol, and thiophenol, respectively. *N*,3,3-Triphenylacrylamide (**5a**), phenyl 3,3-diphenylpropenoate (**5b**), and *S*-phenyl 3,3-diphenylprop-2-enethioate (**5c**) by the known procedure[10] by the reactions of 3,3-diphenylpropenic acid with aniline, phenol, and thiophenol, respectively.

***N*,3,3-Triphenylacrylamide (5a).** Yield 27%, m.p. 130—132 °C (*cf.* Ref. 11: m.p. 129—130 °C). ^1H NMR ($CDCl_3$), δ: 6.50 (s, 1 H, =CH—); 6.84 (br.s, 1 H, H arom.); 7.01 (t, 1 H, H arom., J = 7.5 Hz); 7.08 (d, 2 H, H arom., J = 8.2 Hz); 7.20 (d, 2 H, H arom., J = 7.5 Hz); 7.31—7.36 (m, 7 H, H arom.); 7.47—7.48 (m, 2 H, H arom.); 7.47 (s, 1 H, NH) (*cf.* Ref. 11).

Phenyl 3,3-diphenylpropenoate (5b). Yield 76%, m.p. 120—122 °C (*cf.* Ref. 12: m.p. 122—123 °C). ^1H NMR ($CDCl_3$), δ: 6.57 (s, 1 H, =CH—); 6.98 (d, 2 H, H arom., J = 7.8 Hz); 7.15 (t, 1 H, H arom., J = 7.8 Hz); 7.27—7.31 (m, 4 H, H arom.); 7.35—7.39 (m, 8 H, H arom.) (*cf.* Ref. 13). GC-MS, *m/z* (I_{rel} (%)): 300 $[M]^+$ (10), 207 (100), 178 (45), 152 (8), 105 (9).

***S*-Phenyl 3,3-diphenylprop-2-enethioate (5c).** Yield 86%, m.p. 145—146 °C. ^1H NMR ($CDCl_3$), δ: 6.66 (s, 1 H, =CH—); 7.23—7.24 (m, 2 H, H arom.); 7.31—7.39 (m, 13 H, H arom.). GC-MS, *m/z* (I_{rel} (%)): 315 $[M]^+$ (10), 207 (100), 178 (45), 152 (8), 105 (9). Found (%): C, 79.67; H, 5.14. $C_{21}H_{16}OS$. Calculated (%): C, 79.71; H, 5.10.

Transformations of compounds 1a—c and 5a—c on treatment with CF_3SO_3H in the presence of benzene (general procedure). To a mixture of CF_3SO_3H (2 mL) and benzene (1 mL), compound **1a—c** or **5a—c** (1.0 mmol) was added, the mixture was stirred at 20 °C for 0.5—75 h (see Table 1, entries *1*, *4*, *8*), poured into water (50 ml), and extracted with $CHCl_3$ (3×50 mL). The combined organics were washed with water, saturated aqueous $NaHCO_3$, again with water, and dried with Na_2SO_4. The solvent was removed *in vacuo*, the product was purified by column chromatography (silica gel, elution with petroleum ether—ethyl acetate).

Transformations of compounds 1a—c and 5a—c on treatment with aluminum halides in the presence of benzene (general procedure). To a mixture of $AlBr_3$ or $AlCl_3$ (5.0 mmol) in benzene (10 mL), compound **1a—c** or **5a—c** (1.0 mmol) was added, the mixture was stirred at 20—80 °C for 1—10 h (see Table 1, entries *2*, *3*, *5—7*, and *9—12*). The products were isolated as described above.

Physicochemical parameters of 4-phenylquinolin-2-one (**3a**)[7], 4-phenylcoumarin (**3b**)[8], 4-phenylthiocoumarin (**3c**)[9], (*Z*)-3-oxo-1-phenyl-3-(phenylamino)prop-1-enyl trifluoromethanesulfonate (**4a**)[8], *S*-phenyl (*E*/*Z*)-3-chloro-3-phenyl-

prop-2-enethioate (**4c**),[9] and 3,3-diphenylindan-1-one (**7**)[14] were published earlier.

Phenyl 3-chloro-3-phenylprop-2-eneoate (4b) (exact *E*- or *Z*-configuration was not established) was synthesized in the mixture with compound **3b**, oil. ^{1}H NMR (signals of compound **4b** in the mixture), δ: 5.99 (s, 1 H, =CH—); 7.16—7.92 (m, 10 H, H arom.). GC-MS, m/z (I_{rel} (%)) : 258 $[M]^+$ (8), 222 (5), 194 (7), 165 (100), 137 (10), 102 (25).

4,4-Diphenyl-3,4-dihyroquinolin-2-one (6a). M.p. 250—252 °C. IR, ν/cm^{-1}: 3300 (N—H), 1682 (C=O). ^{1}H NMR, δ: 3.40 (s, 2 H, CH_2); 6.77, 6.84 (both d, 1 H each, H_{Ar}, J = 8.4 Hz); 6.99 (t, 1 H, H_{Ar}, J = 7.4 Hz); 7.05 (d, 4 H, H_{Ar}, J = 7.4 Hz); 7.23 (t, 2 H, H_{Ar}, J = 8.4 Hz); 7.28—7.35 (m, 5 H, H_{Ar}); 7.68 (s, 1 H, NH). ^{13}C NMR, δ: 44.46, 51.79, 116.14, 123.02, 127.03, 128.18, 128.33, 128.57, 129.41, 131.27, 136.92, 143.59, 173.11. MS (EI, 70 eV), m/z (I_{rel} (%)): 299 $[M]^+$ (69), 256 (24), 222 (100), 204 (28), 106 (28). Found (%): C, 84.30; H, 5.68; N, 4.65. $C_{21}H_{17}NO$. Calculated (%): C, 84.25; H, 5.72; N, 4.68.

4,4-Diphenyl-3,4-dihydrocoumarin (6b). M.p. 150—151 °C (*cf.* Ref. 15: m.p. 150—151 °C). ^{1}H NMR, δ: 3.56 (s, 2 H, CH_2); 7.12—7.51 (m, 14 H, H_{Ar}). GC-MS, m/z (I_{rel} (%)): 300 $[M]^+$ (70), 272 (10), 257 (100), 223 (24), 181 (35), 165 (20), 152 (15).

4,4-Diphenyl-3,4-dihydrothiocoumarin (6c). Oil. ^{1}H NMR, δ: 3.68 (s, 2 H, CH_2); 6.78 (d, 1 H, H_{Ar}, J = 7.8 Hz); 6.97 (d, 4 H, H_{Ar}, J = 5.5 Hz); 7.15 (td, 1 H, H arom., J = 2.2 Hz, J = 7.8 Hz); 7.27—7.30 (m, 8 H, H arom.). GC-MS, m/z (I_{rel} (%)): 316 $[M]^+$ (60), 288 (30), 273 (70), 239 (15), 211 (45), 197 (100), 178 (25), 165 (23). Found (%): C, 79.76; H, 5.04. $C_{21}H_{16}OS$. Calculated (%): C, 79.71; H, 5.10.

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