Catal Lett (2007) 119:296–303
DOI 10.1007/s10562-007-9234-2

Fused Polycyclic Hydrocarbons Through Superacid-Induced Cyclialkylation of Aromatics

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Received: 25 June 2007 / Accepted: 30 July 2007 / Published online: 7 September 2007

Abstract Benzene and substituted derivatives (toluene, *ortho*-xylene, 1,2,3-trimethylbenzene, 1,2,4-trimethylbenzene, anisole), when applied in large excess, react with 1,4 diols (pentan-1,4-diol, hexan-2,5-diol, and 2,5-dimethylhexan-2,5-diol) or an oxolane (2,2,5,5-tetramethyltetra hydrofuran) in the presence of the Brønsted superacid trifluoromethanesulfonic acid (triflic acid, TFSA) to afford substituted tetralins in excellent yields with high selectivity. Reacting benzene with a small excess of alkylating agents yields octahydroanthracenes. The transformation of naphthalene with oxolane leads to a partially saturated octamethyloctahydrotetracene under similar conditions. Product formation is interpreted by intermolecular Friedel-Crafts alkylation followed by cyclialkylative ring closure.

Keywords Alkylation · Cyclialkylation · Arenes · Carbocations · Superacid

1 Introduction

Superacid-catalyzed transformations of organic compounds are still attracting considerable interest. Although basic knowledge of superacid chemistry was established in the 1960s and 1970s [1], numerous new observations with respect to both mechanistic studies and synthetic applications are reported. Superacidic trifluoromethanesulfonic acid (triflic acid), in particular, has been used very often. This is primarily due to its particularly useful and attractive properties, namely, its considerably high acidity ($H_0 = -14.1$) and the lack of any side-reaction such as sulfonation and oxidation which may be observed using certain other superacids. This high and renewed interest is also attributed to the fact that the involvement of superelectrophilic species [2] in triflic acid-mediated transformations has been often implicated and, in fact, superelectrophiles have been detected by ^{1}H and ^{13}C NMR spectroscopy [3–5]. Triflic acid has been proved to be particularly useful in various alkylation processes [6–10] and in varied cyclization reactions including the synthesis of carbocyclic [9, 11–14] and heterocyclic multiple ring systems [3, 10, 15, 16]. These results have considerably widened the scope of the use of triflic acid in synthetic processes and resulted in a better understanding of the mechanistic background of the catalyzed transformations.

We have explored the use of diols and cyclic ethers as reagents in Friedel-Crafts alkylation focusing on the use of benzene in two previous papers [17, 18]. With respect to the topic of the present article, we found that 1,4-diols and oxolanes, particularly 2,2,5,5-tetramethyltetrahydrofuran, proved to be excellent reagents to form bicyclic and tricyclic partially saturated naphthalene and anthracene derivatives. On the basis of these observations and in continuation of our interest in electrophilic catalysis we have performed a detailed study with the aim of exploring the use of these uncommon alkylating agents in the alkylation of varied aromatic compounds to obtain partially saturated fused polycyclic hydrocarbons.

2 Experimental

All reagents were obtained from Aldrich and used without further purification. For quantitative GC analysis decane and hexadecane were used as internal standard. Individual

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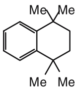
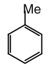
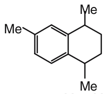
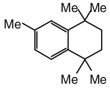
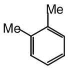
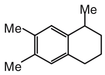
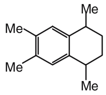
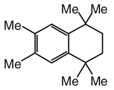
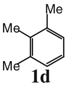
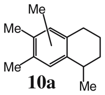
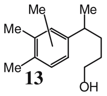
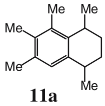
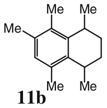
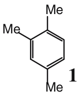
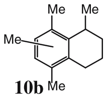
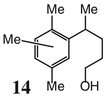
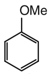
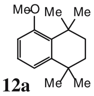
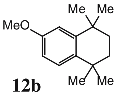
products were isolated by column chromatography (Merck silica gel 60, 230–400 mesh, hexane/ethyl acetate 7:3). ^{1}H, ^{13}C and 2D NMR spectra were recorded on Bruker Avance 500 MHz (11.7 T) and 400 MHz (9.4 T) spectrometers in CDCl$_3$ using TMS as internal standard. Analysis and further characterization were performed by GC (HP 5890 equipment, HP-1 capillary column, flame ionization detector) and GC–MS [HP 5890 Series II GC (60 m DB-1 column) coupled with an HP 5970 mass selective detector]. HR mass spectra were recorded with a Finnigan MAT95 instrument. Melting points are uncorrected (Kofler hot-plate microscope apparatus).

2.1 Spectral Data of Selected Compounds

2.1.1 Tetralin Derivatives

1,1,4,4-Tetramethyl-1,2,3,4-tetrahydronaphthalene (**4**): Typical procedure for the synthesis of tetralins. TFSA (10 mmol, 880 μL) was added in 5 min to a magnetically stirred mixture of benzene (**1a**, 100 mmol, 8.9 mL) and 2,2,5,5-tetramethyltetrahydrofuran (**3**, 1 mmol, 158 μL) kept at 0 °C under a dry nitrogen atmosphere. The mixture was allowed to warm up to room temperature and the stirring was continued for 1 h (see also Tables 1 and 2). The

Table 1 Formation of substituted tetralins in the alkylation of aromatics[a]

Entry	Aromatics	Alkylating agent	Product	Yields (%)[b]
1	 **1a**	**2c**	 **4**	93
2		**3**	**4**	94
3	 **1b**	**2b**	 **5**	51[c]
4		**2c**	 **6**	95
5		**3**	**6**	94
6	 **1c**	**2a**	 **7**	75
7		**2b**	 **8**	95
8		**2c**	 **9**	90
9		**3**	**9**	95
10	 **1d**	**2a**	 **10a**  **13**	73[d]
11		**2b**	 **11a**  **11b**	44[e]
12	 **1e**	**2a**	**10a+13**  **10b**  **14**	69[f]
13		**2b**	**11a+11b**	75[g]
14	 **1f**	**2c**	 **12a**  **12b**	59[h]
15		**2c**	**12a+12b**	56[i]
16		**3**	**12a+12b**	78[j]
17		**3**	**12a+12b**	78[k]

[a] Aromatic/alkylating agent/TFSA = 100:1:10. Reaction time = 1 h

[b] Yield of isolated, chromatographically pure compounds

[c] Reaction time = 5 min; [d]Reaction time = 30 min. Combined yield, **10a/13** selectivity = 77/23

[e] Reaction time = 30 min. Combined yield, **11a/11b** selectivity = 60/40

[f] Reaction time = 30 min. Combined yield, (**10a+10b**)/(**13** + **14**) selectivity = 63/37

[g] Combined yield, **11a/11b** selectivity = 71/29

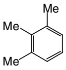
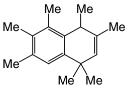
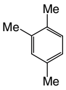
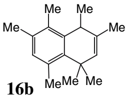
[h] Combined yield, **12a/12b** selectivity = 72/28

[i] **1f/2c**/TFSA = 0.5:1:10 mmol. Combined yield, **12a/12b** selectivity = 91/9

[j] Combined yield, **12a/12b** selectivity = 59/41

[k] **1f/3**/TFSA = 0.5:1:10 mmol. Combined yield, **12a/12b** selectivity = 93/7

Table 2 Formation of substituted dihydronaphthalenes in the alkylation of 1,2,3-trimethylbenzene (**1d**) and 1,2,4-trimethylbenzene (**1e**)[a]

Entry	Aromatics	Alkylating agent	Product	Yields (%)[b]
1	 **1d**	**2c**	 **16a**	68[c]
2		**3**	**16a**	80[d]
3	 **1e**	**2c**	**16a** +  **16b**	71[e]
4		**2c**	**16a** + **16b**	73[f]
5		**2c**	**16a** + **16b**	79[g]

[a] Aromatic/alkylating agent/TFSA = 100:1:10

[b] Yield of isolated, chromatographically pure compounds

[c] Reaction time = 5 min

[d] Reaction time = 3 h

[e] Reaction time = 5 min. Combined yield, **16a/16b** selectivity = 18/82

[f] Reaction time = 1 h. Combined yield, **16a/16b** selectivity = 67/33

[g] Reaction time = 1 h. Combined yield, **16a/16b** selectivity = 56/44

mixture was poured over ice (20 g), extracted with CH_2Cl_2 (3 × 15mL) and the organic layer was washed with brine (15 mL). The resulting product (176 mg, 94%) after drying (Na_2CO_3) and evaporation was subjected to GC, GC–MS and NMR analysis. Mp 115–120 °C (6.5–7 °C) [19]; ^{1}H NMR (400 MHz): 7.55 (m, Ar-*H*, 2H), 7.35 (m, Ar-*H*, 2H), 1.93 (s, 4H, *CH_2*), 1.53 (s, 12H, *CH_3*). MS *m/e* (%): 188 (M^+, 26), 173 (97), 141 (15), 131 (100), 128 (32), 117(29); HRMS: calcd. for $C_{14}H_{20}$ 188.1565; found 188.1564.

5-Methoxy-1,1,4,4-tetramethyl-1,2,3,4-tetrahydronaphthalene (**12a**): isolated after column chromatography as an oil. ^{1}H NMR (500 MHz): 7.22 (d, J = 8.67 Hz, 1H, Ar-*H*); 6.83 (d, J = 2.7 Hz, 1H, Ar-*H*); 6.70 (dd, J_1 = 2.7 Hz, J_2 = 8.7 Hz, 1H, Ar-*H*); 3.78 (s, 3H, O-*CH_3*); 1.66 (d, J = 8.1Hz, 4H, *CH_2*); 1.27 (s. 6H, *CH_3*); 1.25 (s, 6H, *CH_3*). MS *m/e* (%): 218 (M^+, 19), 203 (100), 161 (35), 146 (10), 128 (16), 115 (17); HRMS: calcd. for $C_{15}H_{22}O$ 218.1667; found 218.1670.

6-Methoxy-1,1,4,4-tetramethyl-1,2,3,4-tetrahydronaphthalene (**12b**): isolated after column chromatography as a solid. Mp 40–42 °C (40–42 °C) [20]; ^{1}H NMR (500 MHz): 7.13 (d, J = 8.6 Hz, 1H, Ar-*H*); 6.86 (s, 1H, Ar-*H*); 6.76 (d, J = 8.6 Hz, 1H, Ar-*H*); 3.76 (s, 3H, O-*CH_3*); 2.0–0.6 (m, 16H, *CH_2*, *CH_3*). MS *m/e* (%): 218 (M^+, 8), 175 (100), 160 (14), 145 (11), 128 (10), 115 (15); HRMS: calcd. for $C_{15}H_{22}O$ 218.1667; found 218.1670.

2.1.2 Substituted 1,4-Dihydronaphthalenes

1,1,3,4,5,6,7-Heptamethyl-1,4-dihydronaphthalene (**16a**): ^{1}H NMR (500 MHz): 7.00 (s, 1H, Ar-*H*), 6.00 (s, 1H, olefinic *H*); 3.16 (m, 1H, benzyl *H*); 2.48 (s, 3H, C = C-*CH_3*); 2.35–2.15 (s, 9H, Ar-*CH_3*); 1.24 (s, 6H, *CH_3*); 1.23 (d, 3H, *CH_3*). MS *m/e* (%): 228 (M^+, 39), 213 (13), 198 (15), 186 (35), 185 (100), 170 (33), 165 (11), 155 (16); HRMS: calcd. for $C_{17}H_{24}$ 228.1879; found 228.1878.

1,1,3,4,5,6,8-Heptamethyl-1,4-dihydronaphthalene (**16b**): ^{1}H NMR (500 MHz): 6.84 (s, 1H, Ar-*H*); 5.90 (s, 1H, olefinic *H*); 3.10 (m, 1H, benzyl *H*); 2.50 (s, 3H, C = C-*CH_3*); 2.34–2.14 (s, 9H, Ar-*CH_3*); 1.38 (s, 9H, *CH_3*) 1.21 (d, 3H, *CH_3*). MS *m/e* (%): 228 (M^+, 34), 213 (10), 198 (15), 185 (100), 170 (30), 155 (12); HRMS: calcd. for $C_{17}H_{24}$ 228.1879; found 228.1878.

2.1.3 Octahydroanthracenes

1,1,4,4,5,5,8,8-Octamethyl-1,2,3,4,5,6,7,8-octahydroanthracene (**20**): Typical procedure for the synthesis of octahydroanthracenes. TFSA (45 mmol, 4 ml) was added in 5 min to a magnetically stirred mixture of benzene (**1a**, 1 mmol, 89 μl) and 2,2,5,5-tetramethyltetrahydrofuran (**3**, 2 mmol, 316 μL) kept at 0 °C under dry nitrogen atmosphere. The mixture was allowed to warm up to room temperature and the stirring was continued for 30 min. The work-up procedure is the same as described for compound **4**. Yield = 292 mg, 98%, mp 210 °C (205–210 °C) [21]; ^{1}H NMR (400 MHz): 7.20 (s, 2H, Ar-*H*), 1.68 (s, 8H, *CH_2*), 1.29 (s, 24H, *CH_3*). MS *m/e* (%): 298 (M^+, 15), 283 (100), 225 (16), 111 (37); HRMS: calcd. for $C_{22}H_{34}$ 298.2660; found 298.2660.

2.1.4 Octahydrotetracene

1,1,4,4,7,7,10,10-Octamethyl-1,2,3,4,7,8,9,10-octahydrotetracene (**21**): TFSA (10 mmol, 880 μL) was added in 5 min to a magnetically stirred mixture of naphthalene (**1i**, 1 mmol, 0.128 g) and 2,2,5,5-tetramethyltetrahydrofuran (**3**, 2 mmol, 316 μL) kept at 0 °C under dry nitrogen atmosphere. The mixture was allowed to warm up to room temperature and the stirring was continued for 3 h. The work-up procedure was the same as described for compound **4**. Yield = 306 mg, 88%, mp 319–320 °C (320 °C) [22]; ^{1}H NMR (500 MHz): 7.69 (s, 4H, Ar-*H*); 1.76 (s, 8H, *CH_2*); 1.39 (s, 24H, *CH_3*). MS *m/e* (%): 352 (M^+, 25), 282 (28), 281 (100), 234 (5), 210 (13), 195 (12); HRMS: calcd. for $C_{26}H_{36}$ 348.2817; found 348.2817.

3 Results and Discussion

The first general and important conclusion of the present study is that only benzene, naphthalene, and substituted benzene derivatives with activating substituents undergo alkylation under the reaction conditions applied. Other substituted benzene derivatives, namely, bromobenzene and trifluoromethylbenzene bearing deactivating substituents, did not react to give the expected tetralin products in reasonable yields. A similar observation could be made with acetanilide. Further information found in attempted alkylations is given in the last part of this subsection.

As found in Experimental, all reactions were performed in a high excess of triflic acid (usually 10 molar excess to the alkylating agent). It is well-known that even small amounts of water affect significantly the acidity of triflic acid (–14.1 neat). Since in the reactions studied water is formed as a byproduct (two equivalents with diols as alkylating agents and one equivalent using 2,2,5,5-tetramethyltetrahydrofuran) a large excess of triflic acid is required to maintain the necessary acidity level to run the reactions smoothly and efficiently.

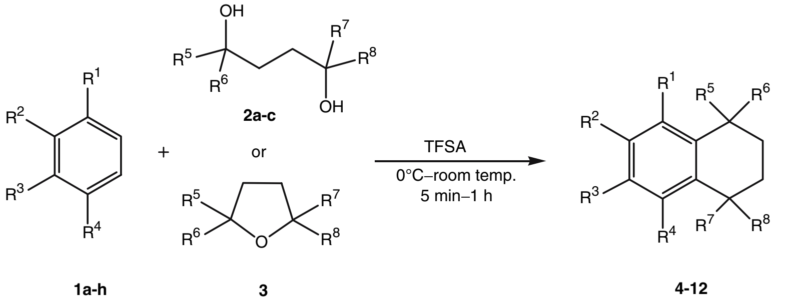
3.1 Formation of Substituted Tetralins and Dihydronaphthalenes

The alkylation of benzene (**1a**) and substituted benzene derivatives with activating methyl groups or a methoxy substituent (**1b–h**) was performed with 1,4-diols [1,4-pentanediol (**2a**), 2,5-hexandiol (**2b**), and 2,5-dimethyl-2,5-hexandiol (**2c**)], and the cyclic ether 2,2,5,5-tetramethyltetrahydrofuran (**3**) (Scheme 1). Under appropriately selected reaction conditions, namely, working with a high excess of the corresponding aromatic reactant (ratio of aromatics to alkylating agent = 100:1), substituted tetralins (compounds **4–12**) can be prepared, in most cases, in highly selective reactions (Table 1).

Benzene (**1a**) and toluene (**1b**) give single product (**4–6**) with each alkylating agent in excellent yields (entries 1, 2 and 3–5). Among the isomeric dimethylbenzenes only *ortho*-xylene (**1c**) produces the corresponding tetralin derivatives (**7**, **8** a diastereomeric mixture, and **9**). The high selectivity and the structure of the products (entries 6–9) clearly indicate that steric interaction is the sole factor playing a determining role in alkylation. According to the plausible mechanism illustrated for the reaction with 2,5-dimethyl-2,5-hexandiol (**2c**) the first, intermolecular alkylation step involves the 1,4-dicationic alkylating agent formed on the action of triflic acid (Scheme 2). Carbodications are known to be stable entities when separated by at least two methylene groups [23]. Attack to the positions C(4) or C(5) of the aromatic ring yields a single intermediate σ-complex and the corresponding 1,2-dimethyl-4-alkyl intermediate. An intramolecular alkylation step then follows to give products **7–9**. Obviously, steric crowding prevents the ring positions *ortho* to either methyl groups [C(3) or C(6) of the aromatic ring] to participate in either alkylation step. The other two dimethyl-substituted benzene isomers yield a mixture of products.

Isomeric trimethylbenzenes (1,2,3-trimethylbenzene **1d**, 1,2,4-trimethylbenzene **1e**) afford regioisomers with diols **2a** and **2b**, in contrast to the selective transformations of benzene derivatives discussed above. The reaction of both trimethylbenzenes with the diol **2a** provides a mixture of the corresponding tetralin regioisomers (**10a**, **10b**, entries 10 and 12). Furthermore, two isomeric primary alcohols (**13**, **14**) were also detected with the main products being

Scheme 1 Synthesis of substituted tetralin derivatives (in products **4**–**12** only substituents other than hydrogen are indicated)

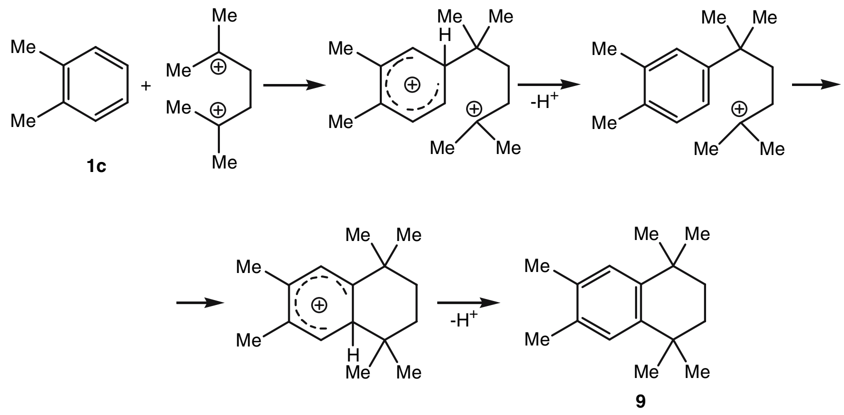


1a: R^1, R^2, R^3, R^4 = H
1b: R^1 = Me, R^2, R^3, R^4 = H
1c: R^1, R^4 = H, R^2, R^3 = Me
1d: R^1, R^2, R^3 = Me, R^4 = H
1e: R^1, R^2, R^4 = Me, R^3 = H
1f: R^1 = MeO, R^2, R^3, R^4 = H
1g: R^2, R^4 = H, R^1, R^3 = Me
1h: R^2, R^3 = H, R^1, R^4 = Me

2a: R^5 = Me, R^6, R^7, R^8 = H
2b: R^5, R^7 = Me, R^6, R^8 = H
2c: R^5, R^6, R^7, R^8 = Me
3: R^5, R^6, R^7, R^8 = Me

4: R^5, R^6, R^7, R^8 = Me
5: R^2, R^5, R^7 = Me
6: R^2, R^5, R^6, R^7, R^8 = Me
7: R^2, R^3, R^5 = Me
8: R^2, R^3, R^5, R^7 = Me
9: R^2, R^3, R^5, R^6, R^7, R^8 = Me
10a: R^1 or R^4, and R^2, R^3 = Me
10c: R^2 or R^3, and R^1, R^4 = Me
11a: R^1, R^2, R^3, R^5, R^7 = Me
11b: R^1, R^2, R^4, R^5, R^7 = Me
12a: R^1 = MeO, R^5, R^6, R^7, R^8 = Me
12b: R^2 = MeO, R^5, R^6, R^7, R^8 = Me

Scheme 2 Alkylation and cyclialkylation part steps in the transformation of *ortho*-xylene (**1c**) with 2,5-dimethylhexanediol and 2,2,5,5-tetramethyltetrahydrofuran to form 1,1,4,4,6,7-Hexamethyl-1,2,3,4-tetrahydronaphthalene (**9**)

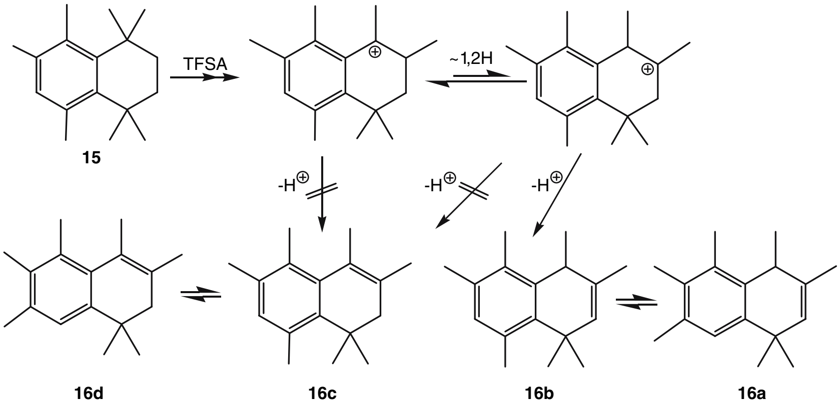


always the tetralin derivatives. The isolation of alcohols in such alkylation reactions is not unprecedented as already shown in a previous work [18]. The reaction of **1d** or **1e** with **2b** yields two isomeric tetralins (**11a**, **11b**) differing in the position of one of the methyl groups of the aromatic ring (entries 11 and 13). The main product is always the derivative with the three methyl groups of the aromatic ring in vicinal positions. Obviously, either trimethylbenzene isomer forms an equilibrium mixture by the migration of a methyl group of the aromatic ring. Since Friedel–Crafts alkylations are known to be reversible processes, this isomerization is not unexpected.

Anisole (**1f**) reacting with 1,4-pentanediol (**2a**) and 2,5-hexandiol (**2b**) produces a single regioisomer in very low yields (not shown in Table 1). More informative are the reactions with the tetramethyl alkylating derivatives (**2c** and **3**) yielding regioisomers **12a** and **12b**, with isomer **12a** being always the main product (entries 14–17). The transformation shows strong acidity dependence. Reactions in large excess of the acid afford almost exclusively isomer **12a** (entries 15 and 17), whereas the yield of isomer **12b** increases significantly when anisole is used in a large excess (entries 14 and 16). Phenols and ethers are known to yield *meta*-substituted products under superacidic conditions as a result of the attack of the electrophile to the *O*-protonated substrate [24]. The acidity dependence appears to indicate that isomer **12a** is formed through a primary *meta* attack to the *O*-protonated anisole. Formation of isomer **12b**, in turn, starts with the alkylation of the carbon in *para* position of non-protonated anisole.

The transformations of 1,2,3- and 1,2,4-trimethylbenzene with 2,5-dimethyl-2,5-hexandiol (**2c**) and 2,2,5,5-tetramethyltetrahydrofuran (**3**) yield dihydronaphthalenes instead of the expected tetralin derivatives (Table 2). This behavior is due to the easy superacidic activation of primary product **15** through hydride abstraction and the significant steric crowding induced by the three methyl groups in positions 1 and 8 (Scheme 3). The two stable tertiary carbocationic intermediates may be stabilized by proton loss to give dihydronaphthalenes **16a** and **16c**. Both products may undergo rearrangement, that is the migration of the corresponding aromatic ring methyl groups, to yield regioisomers **16b** and **16d**, respectively. Compounds **16c** and **16d** were, however, not found in the reaction mixtures. The almost exclusive formation of isomers **16a** and **16b** can be attributed to the steric interaction between methyl groups in *peri* position: the 1-methyl and 8-methyl groups are attached to sp^2 hybridized carbon atoms in isomers **16c** and **16d**. Proton loss of the intermediate carbocations to

Scheme 3 Formation of substituted dihydronaphthalenes in the superacidic activation of primary product **15** formed in the reaction of 1,2,3-trimethylbenzene (**1d**) with 2,2,5,5-tetramethyltetrahydrofuran (**3**)



form isomer **16c**, therefore, does not take place despite the fact that **16c** contains a more substituted, that is, more stable double bond.

For the sake of simplicity, the interpretation in Scheme 3 is given for compound **1d** but it is also valid for compound **1e**. The easy transformation of the various intermediates involved is well illustrated by the change in product composition in the reaction of compounds **1e** and **2c** (Table 2). At short reaction time isomer **16b** with the substitution pattern of the aromatic ring intact (entry 3) predominates, whereas isomer **16a** becomes the main product at longer reaction time (entry 4). This also shows that dehydrogenation as illustrated in Scheme 3 precedes migration of the methyl substituent of the aromatic ring.

3.2 Formation of Substituted Octahydroanthracenes and Octahydrotetracenes

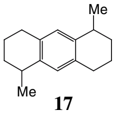
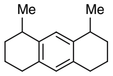
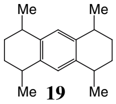
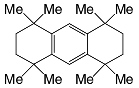
On the basis of our earlier observations [17, 18] we attempted to perform double cyclialkylations to synthesize three- and four-membered ring systems. Indeed, when the ratio of the reactants is changed to have a small excess of the alkylating agent (ratio of benzene to alkylating agent = 1:2–5), double cyclialkylation occurs to afford symmetrically substituted octahydroanthracenes (**17–20**) (Table 3).

Double cyclialkylation can also be achieved with a similar strategy working with naphthalene (**1i**) and oxolane **3**. The reaction results in the formation of the **21** symmetrically substituted octahydrotetracene in 88% yield (Scheme 4).

Double cyclialkylations, however, could not be achieved with any of the substituted benzene derivatives. This, however, is not surprising when product selectivities of the cyclialkylation reactions (summarized in Table 1) are considered. The precondition for the second alkylation (cyclialkylation) reaction is to have two additional non-substituted vicinal positions on the aromatic ring. The structure of products **4–12** reveals that, in addition to compound **4**, only the tetralin derivatives of toluene and anisole are able to yield tricyclic compounds. However, the selective formation of compounds **5** and **6** (Table 1, entries 3–5) indicates that alkylation occurs through the exclusive attack of the alkylating agent to the *para* position. The attack to *ortho* is, obviously, sterically hindered (compare also to the results with *ortho*-xylene). It follows, that all three positions of the aromatic ring in compounds **5** and **6** are similarly hindered, thereby preventing further reactions. Scheme 5

With respect to anisole, unexpected results were observed under reaction conditions favoring double cyclialkylation for benzene and naphthalene. Instead of the formation of tricyclic products (isomeric methoxyoctahydroanthracenes), isomeric methoxytetralins were formed with isomer compositions shifted to have a large excess of

Table 3 Formation of substituted octahydroanthracenes in the alkylation of benzene[a]

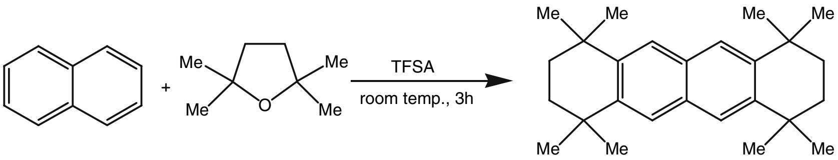
Entry	Aromatic compound	Alkylating agent	Products	Yields (%)[b]
1	 **1a**	**2a**	 **17**  **18**	94[c]
2		**2b**	 **19**	55
3		**2c**	 **20**	95
4		**3**	**20**	98

[a] Benzene/alkylating agent/TFSA = 1 : 2 : 45. Reaction time = 30 min

[b] Yield of isolated, chromatographically pure compounds

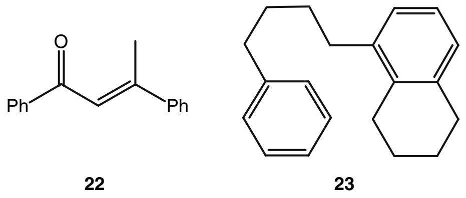
[c] Combined yield, **17/18** selectivity = 71/29

Scheme 4 Formation of octamethyloctahydrotetracene in the alkylation of naphthalene



1i **3** **21**

88% yield



Scheme 5 Products formed in the transformation of acetophenone (**22**) and tetralin (**23**)

12a relative to **12b** (Table 1, entries 15 and 17). This can be accounted for by considering the altered reaction conditions having an increased amount of the alkylating agent relative to the aromatic, and a large excess of TFSA. As mentioned before, the participation of non-protonated anisole results in the primary *para* attack. Since most of the anisole molecules are protonated under these conditions, *para* attack that is formation of isomer **12b** diminishes. The lack of tricyclic products is also attributed to the high acid concentration, which may induce polymerization of the alkylating agent instead of reaction in a second alkylation step.

3.3 Transformation of *meta*- and *para*-Xylene

In contrast to the selective transformation of *ortho*-xylene producing the corresponding substituted tetralin derivatives with all four alkylating agents, the other two isomeric dimethylbenzenes, *meta*-xylene (**1g**) and *para*-xylene (**1h**) give a complex mixture of various methyl-substituted tetralin and dihydronaphthalene derivatives as the main products. The effect of the ratio of the three-component reaction mixture and the reaction time on product composition were studied. It was found that at short reaction time (5 min) 1,1,4,4,5,8-hexamethyltetralin the primary alkylated derivative is the main product formed, however, in low yield. This easily rearranges through migration of one of the methyl groups of the aromatic ring to form the isomeric hexamethyltetralin. With increasing reaction time the relative amount of tetralins decreases and the fraction of secondary products increases: isomeric dihydronaphthalenes are formed by dehydrogenation as illustrated already in Scheme 3. In prolonged reactions other secondary products are formed and become dominant. Further studies were not pursued.

3.4 Further Observations

Two other aromatic compounds were also treated under the usual alkylation conditions in order to prepare substituted polycyclic derivatives. In an attempted alkylation of acetophenone, however, a single compound, 1,3-diphenylbut-2-en-1-one (**22**) was isolated. Since acetophenone, existing in the *O*-protonated form under these conditions, is a deactivated aromatic compound and unreactive in alkylation it undergoes the known self-aldol condensation [25]. In the case of tetralin, compound **23** is formed. This self-alkylation induced by various metal salts such as $AlCl_3$ was already described [26]. Tetralin appears to be more easily activated than the alkylating agents used in the present study.

4 Conclusions

The transformation of 1,4-diols (1,4-pentanediol, 2,5-hexandiol, and 2,5-dimethyl-2,5-hexandiol) and an oxolane (2,2,5,5-tetramethyltetrahydrofuran) with various aromatics in the presence of superacidic trifluoromethanesulfonic acid (TFSA) is a synthetically useful method to produce fused polycyclic hydrocarbons. Product formation is interpreted by intermolecular Friedel–Crafts alkylation followed by cyclialkylative ring closure with the involvement of carbocationic intermediates.

1. Benzene and substituted derivatives (toluene, *ortho*-xylene, 1,2,3-trimethylbenzene, 1,2,4-trimethylbenzene, anisole) applied in large excess react with the alkylating agents to afford substituted tetralins in excellent yields with high selectivity.
2. The transformation of benzene and naphthalene with the alkylating agents being in a small excess leads to octahydroanthracenes and a partially saturated octamethyltetracene, respectively, as a result of double cyclialkylation.
3. The alkylated products formed in the transformation of other isomeric dimethylbenzenes (*meta*- and *para*-xylene) and isomeric trimethylbenzenes with 2,5-dimethyl-2,5-hexandiol and 2,2,5,5-tetramethyltetrahydrofuran undergo carbocationic rearrangements and dehydrogenation to yield dihydronaphthalenes.

References

1. Olah GA, Prakash GKS, Sommer J (1985) Superacids. Wiley-Interscience, New York
2. Olah GA (1993) Angew Chem Int Ed Engl 32:767
3. Coustard J-M (1996) Tetrahedron 52:9509
4. Klumpp DA, Rendy R, Zhang Y, Gomez A, McElrea A (2004) Org Lett 6:1789
5. Klumpp DA, Zhang Y, Kindelin PJ, Lau S (2006) Tetrahedron 62:5915
6. Klumpp DA, Yeung KY, Prakash GKS, Olah GA (1998) J Org Chem 63:4481
7. Klumpp DA, Sanchez GV Jr, Aguirre SL, Zhang Y, de Leon S (2002) J Org Chem 67:5028

8. Zhang Y, McElrea A, Sanchez GV Jr, Do D, Gomez A, Aguirre SL, Rendy R, Klumpp DA (2003) J Org Chem 68:5119
9. Klumpp DA, Lau S, Garza M, Schick B, Kantardjieff K (1999) J Org Chem 64:7635
10. Klumpp DA, Rendy R, Zhang Y, McElrea A, Gomez A, Dang H (2004) J Org Chem 69:8108
11. Prakash GKS, Yan P, Török B, Olah GA (2003) Catal Lett 87:109
12. Klumpp DA, Baek DN, Prakash GKS, Olah GA (1997) J Org Chem 62:6666
13. Vasilyev AV, Walspurger S, Pale P, Sommer J (2004) Tetrahedron Lett 45:3379
14. Vasilyev AV, Walspurger S, Haouas M, Sommer J, Pale P, Rudenko AP (2004) Org Biomol Chem 2:3483
15. Zhang Y, Kindelin PJ, deSchepper DJ, Zheng C, Klumpp DA (2006) Synthesis 1775
16. Coustard J-M, Soro Y, Siaka S, Bamba F, Cousson A (2006) Tetrahedron 62:3320
17. Molnár Á, Török B, Bucsi I, Földvári A (1998) Topics Catal 6:9
18. Molnár Á, Ledneczki I, Bucsi I, Bartók M (2003) Catal Lett 89:1
19. Wood TF, Easter WM Jr, Carpenter MS, Angiolini J (1963) J Org Chem 28:2248
20. Boehm MF, Zhang L, Badea BA, White SK, Mais DE, Berger E, Suto CM, Goldman ME, Heyman RA (1994) J Med Chem 37:2930
21. Myhre PC, Schubert WM (1960) J Org Chem 25:708
22. Bruson HA, Kroeger JW (1940) J Am Chem Soc 62:36
23. Olah GA, Prakash GKS, Sommer J (1985) Superacids. Wiley-Interscience, New York, p. 106
24. Olah GA, Prakash GKS, Sommer J (1985) Superacids. Wiley-Interscience, New York, p. 310
25. Blau K, Burgemeister I, Grasnick J, Voerckel V (1991) J Prakt Chem 333:445
26. Korda A, Tyrlik S (1986) J Mol Catal 37:339