

# First examples of the selective carbonylation of C<sub>6</sub>–C<sub>10</sub> linear alkanes to tertiary carbonyl-containing compounds

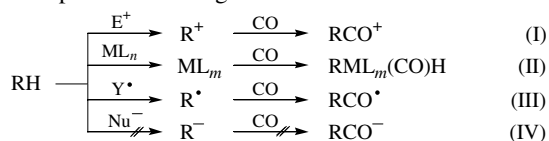
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10.1070/MC2002v012n05ABEH001661

The carbonylation of C<sub>6</sub>–C<sub>10</sub> *n*-alkanes with CO in the presence of CBr<sub>4</sub>·2AlBr<sub>3</sub> at –40 °C and 1 atm CO leads to the products of non-destructive carbonylation, *i.e.*, the esters of tertiary carboxylic acids, R<sup>1</sup>C(Me)<sub>2</sub>COOR and R<sup>2</sup>(Et)C(Me)COOR, after the workup of reaction mixtures with ROH.

Selective reactions of available alkanes and cycloalkanes with CO are of a great synthetic potential as a direct way to valuable carbonyl-containing products. Alkanes and carbon monoxide are not reactive by themselves. Powerful electrophiles, active metal complexes or free radicals are required to generate active species capable of reacting with CO:



Scheme 1

Electrophilic (I),<sup>1</sup> organometallic (II),<sup>2</sup> free-radical (III),<sup>3</sup> but not nucleophilic (IV) carbonylations were performed stoichiometrically and, in rare cases, catalytically. However, the selectivity of alkane carbonylation is generally very poor; particularly, it is low for higher homologues containing different types of C–H bonds similar in reactivity. Besides, higher alkanes easily undergo destructive carbonylation. It is due to the increased liability of R<sup>+</sup>, R–ML<sub>n</sub> and R<sup>•</sup> species for higher homologues, which are the key intermediates of reactions (I)–(III). It is a reason why selective reactions with CO are restricted by C<sub>1</sub>,<sup>2(c),(d),3(b)</sup> C<sub>2</sub>,<sup>1(f),2(c)</sup> C<sub>3</sub>,<sup>1(b),(g)</sup> C<sub>4</sub>–C<sub>5</sub><sup>1(h)</sup> alkanes described in the last years, although the investigations on alkane carbonylation have been started<sup>4</sup> since early the 1930s. The carbonylation of C<sub>6</sub>–C<sub>8</sub> alkanes in proton superacid media occurs non-selectively. At 30 °C and an alkane:SbF<sub>5</sub>:HF molar ratio of 1:2:10, hexane forms a complex mixture from *tert*-C<sub>6</sub>H<sub>13</sub>COOH (15% on hexane), *sec*-C<sub>6</sub>H<sub>13</sub>COOH (29%), and a series of destructive carbonylation products, C<sub>3</sub>–C<sub>6</sub> alkane carboxylic acids (24%), after hydrolysis of the reaction mixture. Under these conditions, heptane and octane form only products of destructive carbonylation.<sup>1(e)</sup> Heptane produces C<sub>4</sub>–C<sub>5</sub> acids in comparable amounts, while *n*-octane yields predominantly C<sub>5</sub> acids. In the presence of an olefin or an alcohol in H<sub>2</sub>SO<sub>4</sub> or H<sub>2</sub>SO<sub>4</sub>/Ag<sup>+</sup> serving as alkane hydride acceptors, the carbonylations of *n*-hexane<sup>5(a)</sup> and *n*-octane<sup>5(b)</sup> were failed: the reactions resulted in the products of only olefin or alcohol carbonylation. In the presence of Cu<sup>I</sup> in HSO<sub>3</sub>F–SbF<sub>5</sub> or HF–SbF<sub>5</sub> media, *n*-octane<sup>5(c)</sup> reacts with CO to yield Bu<sup>t</sup>COOH.

We report here the first examples of carbonylation of linear hexane, heptane, octane, nonane, and decane leading to the products of non-destructive carbonylation, *i.e.*, derivatives of *tert*-RCOOH acids (where R = C<sub>6</sub>H<sub>13</sub>, C<sub>7</sub>H<sub>15</sub>, C<sub>8</sub>H<sub>17</sub>, C<sub>9</sub>H<sub>19</sub> or C<sub>10</sub>H<sub>21</sub>). The reactions were carried out at –60 to –20 °C under atmospheric CO pressure in the presence of the CBr<sub>4</sub>·2AlBr<sub>3</sub> superelectrophilic system in CH<sub>2</sub>Br<sub>2</sub>. The workup of the reaction mixtures with H<sub>2</sub>O or Pr<sup>i</sup>OH (MeOH) led to corresponding tertiary carboxylic acids or their esters with of 88–100% selectivities. The reactions proceeded even at –60 °C. At –40 °C, the yields of esters amounted 74–95% for 1–2 h (C<sub>6</sub>–C<sub>9</sub>) and 54% for 2 h (C<sub>10</sub>) (Table 1). The structures of esters **1**–**10**, **12**, **13** were proved by <sup>13</sup>C NMR spectroscopy and those of esters **1**–**15** were supported by mass spectrometry.<sup>†</sup>

Ester **4** is identical to the product of cyclohexane carbonylation in the presence of CBr<sub>4</sub>·2AlBr<sub>3</sub> at –40 °C for 1 h.<sup>6</sup> Small

amounts of isomeric bromides RBr were formed as by-products. At both –40 and –60 °C, the isomeric mixtures of two esters were formed preferably with their content being 76–100% of the total carbonyl-containing products after Pr<sup>i</sup>OH treatment of the reaction mixtures. They were Alk<sup>1</sup>C(Me)<sub>2</sub>COOPr<sup>i</sup> (**A**: esters **1**, **5**, **7**, **9** and **12**) and Alk<sup>2</sup>C(Me)EtCOOPr<sup>i</sup> (**B**: esters **2**, **6**, **8**, **10** and **13**) with the ratio **A**/**B** (1.6–1.5):1. Practically no other isomeric esters were found in the products of C<sub>6</sub>–C<sub>8</sub> alkane carbo-

<sup>†</sup> Typical procedure for alkane carbonylation. A solution of tetrabromomethane and anhydrous aluminium bromide in a molar ratio of 1:2 in methylene bromide (2 ml per gramme of AlBr<sub>3</sub>) was cooled to –40 °C (–20 or –60 °C), and the reaction flask was filled with gaseous CO. Then, an alkane was added, and the mixture was stirred under a CO atmosphere at –40 °C (or other constant temperature) for 0.5–2 h. Then, an excess of Pr<sup>i</sup>OH was carefully added, the reaction mixture was left to warm up to room temperature and additionally stirred for 30 min. After water workup, extraction with diethyl ether and drying with MgSO<sub>4</sub>, the reaction products were analysed by GC and GC–MS. For NMR studies, ether and other light products were distilled from ether extracts.

## Selected spectral data.

**1**, R = Me: MS, *m/z* (%): 129 (1), 115 (9), 113 (5), 103 (5), 102 (85), 87 (18), 86 (10), 85 (100), 84 (20), 73 (12), 70 (9), 69 (22), 59 (18), 57 (34), 56 (14). **1**, R = Pr<sup>i</sup>: <sup>13</sup>C NMR (CDCl<sub>3</sub>, δ from TMS): 14.26 (Me, 1), 21.38 (Me, 2, ether), 24.87 (Me, 2), 17.85 (CH<sub>2</sub>, 1), 42.75 (CH<sub>2</sub>, 1), 66.76 (CH, 1, ether), 37.49 (C, 1), 177.71 (CO, 1). MS, *m/z* (%): 130 (19), 115 (2), 113 (9), 101 (5), 89(2), 88 (37), 87 (4), 86 (8), 85 (100), 84 (15), 73 (4), 70 (7), 67 (4), 57 (24), 56 (25), 55 (15).

**2**, R = Pr<sup>i</sup>: <sup>13</sup>C NMR: 8.50 (Me, 2), 19.68 (Me, 1), 21.47 (Me, 2, ether), 31.29 (CH<sub>2</sub>, 2), 66.69 (CH, 1, ether), 41.77 (C, 1), 177.29 (CO, 1). MS, *m/z* (%): 144 (8), 130 (1), 115 (1), 113 (5), 102 (8), 101 (5), 87 (3), 86 (7), 85 (100), 84 (26), 70 (3), 69 (28), 67 (5), 59 (5), 57 (23), 56 (11), 55 (25).

**3**, R = Pr<sup>i</sup>: MS, *m/z* (%): 131 (3), 130 (18), 115 (4), 113 (8), 89 (3), 88 (77), 87 (3), 86 (6), 85 (100), 84 (18), 73 (13), 70 (13), 69 (32), 67(5), 57 (23), 55 (14), 53 (5).

**4**, R = Pr<sup>i</sup>: MS, *m/z* (%): M<sup>+</sup> 170 (1), 129 (6), 128 (16), 113 (6), 111 (9), 87 (11), 84 (6), 83 (100), 82 (28), 81 (13), 80 (6), 79 (10), 77 (4), 69 (4), 67 (41), 65 (3), 59 (4), 56 (4), 55 (56), 54 (5).

**5**, R = Me: MS, *m/z* (%): 156 (0.06), 143 (0.15), 129 (0.3), 127 (0.5), 115 (2), 103 (3), 102 (39), 101 (4), 99 (18), 98 (3), 87 (7), 83 (4), 73 (4), 70 (7), 69 (9), 67 (1), 59 (7), 58 (6), 57 (100), 56 (13), 55 (17), 54 (5), 53 (3). **5**, R = Pr<sup>i</sup>: <sup>13</sup>C NMR: 13.38 (Me, 1), 21.11 (Me, 2, ether), 24.51 (Me, 2), 22.59 (CH<sub>2</sub>, 1), 26.53 (CH<sub>2</sub>, 1), 39.79 (CH<sub>2</sub>, 1), 66.24 (CH, 1, ether), 40.89 (C, 1), 176.29 (CO, 1).

**6**, R = Me: MS, *m/z* (%): 130 (3), 129 (2), 116 (15), 103 (5), 102 (4), 101 (11), 99 (19), 98 (6), 74 (2), 69 (13), 59 (9), 57 (100). **6**, R = Pr<sup>i</sup>: <sup>13</sup>C NMR: 8.25 (Me, 1), 14.07 (Me, 1), 19.88 (Me, 1), 21.22 (Me, 2, ether), 17.26 (CH<sub>2</sub>, 1), 31.43 (CH<sub>2</sub>, 1), 40.32 (CH<sub>2</sub>, 1), 66.19 (CH, 1, ether), 41.32 (C, 1), 175.66 (CO, 1).

**7**, R = Me: MS, *m/z* (%): 115 (8), 113 (19), 112 (4), 102 (89), 101 (7), 97 (2), 95 (2), 87 (12), 83 (2), 73 (6), 71 (64), 69 (21), 59 (9), 58 (5), 57 (100), 56 (28), 55 (30). **7**, R = Pr<sup>i</sup>: <sup>13</sup>C NMR: 13.46 (Me, 1), 21.14 (Me, 2, ester), 24.55 (Me, 2), 22.00 (CH<sub>2</sub>, 1), 24.02 (CH<sub>2</sub>, 1), 31.82 (CH<sub>2</sub>, 1), 40.12 (CH<sub>2</sub>, 1), 66.25 (CH,1, ether), 41.32 (C).

**8**, R = Me: MS, *m/z* (%): 144 (4), 129 (2), 116 (33), 115 (4), 113 (26), 112 (7), 102 (9), 101 (26), 97 (3), 87 (4), 84 (3), 83 (9), 71 (75), 70 (16), 69 (14), 68 (3), 67 (5), 59 (19), 58 (6), 57 (100), 56 (13), 55 (50). **8**, R = Pr<sup>i</sup>: <sup>13</sup>C NMR: 8.29 (Me, 1), 17.23 (Me, 1), 21.28 (Me, 2, ether), 26.23 (Me, 1), 19.93 (CH<sub>2</sub>, 1), 22.71 (CH<sub>2</sub>, 1), 31.46 (CH<sub>2</sub>, 1), 38.23 (CH<sub>2</sub>, 1), 66.18 (CH, 1, ether), 41.99 (C, 1).

**Table 1** Carbonylation of C<sub>6</sub>–C<sub>10</sub> *n*-alkanes by CO in the presence of CBr<sub>4</sub>·2AlBr<sub>3</sub> (S) in a CH<sub>2</sub>Br<sub>2</sub><sup>a</sup> solution for 1 h.

| Entry          | <i>n</i> -Alkane | <i>T</i> /°C | Total yield of R'COOPri (%) | R'COOPri, isomeric content (%) |                             |                   |  |
|----------------|------------------|--------------|-----------------------------|--------------------------------|-----------------------------|-------------------|--|
|                | Hexane           |              |                             | PrC(Me) <sub>2</sub> COOPri    | Et <sub>2</sub> C(Me)COOPri | PrCH(Et)COOPri    | 1,1-(Me)(COOPri)- <i>c</i> -C <sub>3</sub> H <sub>8</sub> by-product |
| 1 <sup>b</sup> |                  | –20          | 100                         | 60                             | 20                          | 20                | 0  |
| 2              |                  | –40          | 95                          | 67                             | 20                          | 0                 | 13   |
| 3              |                  | –60          | 26                          | 55                             | 27                          | 0                 | 18   |
|                | Heptane          |              |                             | BuC(Me) <sub>2</sub> COOPri    | PrC(Et)(Me)COOPri           |                   |  |
| 4              |                  | –40          | 83                          | 58                             | 42                          |                   |  |
| 5              |                  | –60          | 10                          | 81                             | 19                          |                   |  |
|                | Octane           |              |                             | AmC(Me) <sub>2</sub> COOPri    | BuC(Et)(Me)COOPri           |                   |  |
| 6              |                  | –40          | 74                          | 66                             | 34                          |                   |  |
|                | Nonane           |              |                             | HexC(Me) <sub>2</sub> COOPri   | AmC(Et)(Me)COOPri           | BuC(Pr)(Me)COOPri |  |
| 7              |                  | –40          | 75                          | 48                             | 37                          | 15                |  |
|                | Decane           |              |                             | HeptC(Me) <sub>2</sub> COOPri  | HexC(Et)(Me)COOPri          | AmC(Pr)(Me)COOPri | BuC <sub>2</sub> C(Me)COOPri   |
| 8              |                  | –40          | 54                          | 42                             | 34                          | 17                | 7  |

<sup>a</sup>[RH]/[S] = (1.2–8):1. <sup>b</sup>For 0.5 h.

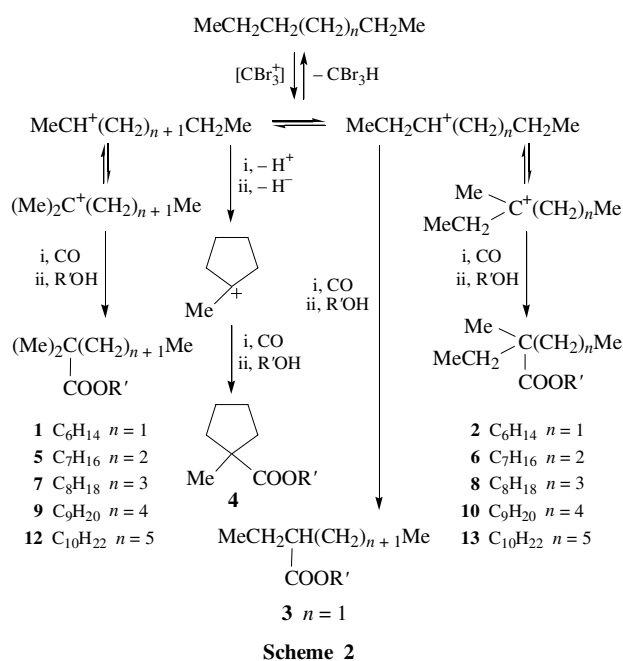
nylations or their yields under these conditions were very low, while small amounts of other *tert*-RCOOPri esters (15–37%) were produced in the reactions of C<sub>5</sub>–C<sub>10</sub> alkanes.

In the case of hexane, at –40 and –60 °C, in addition to **1** and **2**, 1-methylcyclopentane carboxylic acid ester **4** in 13–18% yield was also formed. A decrease in the temperature enhanced the formation of **4**. At –20 °C, instead of **4**, an ester of secondary acid, *sec*-C<sub>6</sub>H<sub>13</sub>COOPri **3** was formed in amounts comparable to **2**.

The formation of the main products of alkane carbonylations can be illustrated by Scheme 2.

Scheme 2 involves the formation of the active superelectrophilic complex<sup>7</sup> CBr<sub>3</sub><sup>+</sup>Al<sub>2</sub>Br<sub>7</sub><sup>–</sup>, the generation of carbocations from alkanes followed by their isomerization into stable tertiary cations, trapping CO molecules to form acyl cations, and, finally, the corresponding esters. The bypath of cyclohexane carbonylation is probably a multi-step process starting from deprotonation and cyclization of the 1-methylpentyl cation. Thus formed 1-methylcyclopentane generates the 1-methylcyclopentyl cation and, finally, compound **4**.

The polyhalomethane–aluminium bromide superelectrophiles are unique systems, which are capable of transforming linear C<sub>4</sub>–C<sub>10</sub> alkanes by CO exclusively into tertiary carbonyl-containing products. It is significant that destructive carbonylations are completely suppressed in these cases. These properties of these powerful superelectrophiles are due to their capability to

**Scheme 2**

initiate rapid generation of carbocations and their isomerization into stable *tert*-R<sup>+</sup>. As a result, the accumulation of the most stable *tert*-R<sup>+</sup> and then *tert*-RCO<sup>+</sup> cations occurs. Importantly, at –40 °C, *tert*-R<sup>+</sup> are stable to fragmentation and *tert*-RCO<sup>+</sup> are resistant to decarbonylation.

In conclusion, with polyhalomethane-based superelectrophiles, additionally to the earlier reported<sup>1(f)–(h)</sup> selective carbonylations of C<sub>2</sub>–C<sub>5</sub> alkanes and C<sub>5</sub>–C<sub>8</sub> cycloalkanes, reactions of C<sub>6</sub>–C<sub>10</sub> *n*-alkanes with CO leading to tertiary carbonyl-containing compounds were performed. Taking into account considerable interest in tertiary carboxylic acids (or their derivatives), both individual or as mixtures, for practice,<sup>1(i)</sup> the first examples of their selective preparation from alkanes are of interest.

We are grateful to Dr. A. V. Orlinkov for his help. This work was supported by the Russian Foundation for Basic Research (grant no. 99-03-30006).

## References

- (a) G. A. Olah and G. K. S. Prakash, in *The Chemistry of Alkanes and Cycloalkanes*, eds. S. Patai and Z. Rappoport, Wiley, Chichester, 1992, part 13; (b) J. Sommer and J. Bukala, *Acc. Chem. Res.*, 1993, **26**, 370; (c) I. S. Akhrem, *Top. Catal.*, 1998, **6**, 27; (d) R. Paatz and G. Weisgerber, *Chem. Ber.*, 1967, **100**, 984; (e) N. Yoneda, Y. Takahashi, T. Fukuhara and A. Suzuki, *Bull. Soc. Chem. Jpn.*, 1986, **59**, 2819; (f) A. V. Orlinkov, I. S. Akhrem and S. V. Vitt, *Mendeleev Commun.*, 1999, 198; (g) I. S. Akhrem, A. V. Orlinkov, L. V. Afanas'eva and M. E.

**9**, R = Pri. <sup>13</sup>C NMR: 13.69 (Me, 1), 21.43 (Me, 2, ester), 24.76 (Me, 2), 22.87 (CH<sub>2</sub>, 1), 24.53 (CH<sub>2</sub>, 1), 29.49 (CH<sub>2</sub>, 1), 31.69 (CH<sub>2</sub>, 1), 40.40 (CH<sub>2</sub>, 1), 66.55 (CH, 1 ether), 38.75 (C, 1), 176.94 (CO, 1). MS, *m/z* (%): 130 (50), 127 (37), 115 (4), 111 (4), 88 (100), 87 (5), 65 (51), 69 (49), 57 (94), 56 (69), 55 (52).

**10**, R = Pri. <sup>13</sup>C NMR: 8.46 (Me, 1), 13.76 (Me, 1), 20.68 (Me, 1), 21.36 (Me, 2, ether), 22.27 (CH<sub>2</sub>, 1), 22.92 (CH<sub>2</sub>, 1), 26.40 (CH<sub>2</sub>, 1), 31.41 (CH<sub>2</sub>, 1), 38.84 (CH<sub>2</sub>, 1), 66.63 (CH, 1, ether), 41.70 (C, 1), 176.33 (CO, 1). MS, *m/z* (%): 186 (0.3), 144 (23), 127 (27), 115 (4), 102 (45), 87 (11), 85 (42), 83 (11), 71 (100), 70 (44), 57 (91), 56 (20), 55 (81).

**11**, R = Pri. MS, *m/z* (%): 172 (7), 158 (11), 130 (22), 127 (33), 116 (28), 87 (31), 85 (59), 84 (20), 83 (15), 71 (100), 57 (99), 56 (67), 55 (99).

**12**, R = Pri. <sup>13</sup>C NMR: 13.81 (Me, 1), 21.53 (Me, 2, ether), 24.91 (Me, 2), 22.46 (CH<sub>2</sub>, 1), 24.74 (CH<sub>2</sub>, 1), 28.99 (CH<sub>2</sub>, 1) 29.91 (CH<sub>2</sub>, 1), 31.81 (CH<sub>2</sub>, 1), 40.53 (CH<sub>2</sub>, 2), 66.79 (CH, 1, ether), 38.92 (C, 1), 177.33 (CO, 1). MS, *m/z* (%): 186 (2), 141 (20), 130 (36), 115 (2), 112 (2), 101 (7), 99 (5), 88 (78), 85 (51), 71 (52), 70 (11), 69 (31), 67 (8), 57 (100), 56 (48), 55 (41).

**13**, R = Pri. <sup>13</sup>C NMR: 8.62 (Me, 1), 13.85 (Me, 1), 21.60 (Me, 2, ether), 24.88 (Me, 1) 23.00 (CH<sub>2</sub>, 1), 24.74 (CH<sub>2</sub>, 1), 25.23 (CH<sub>2</sub>, 1), 29.68 (CH<sub>2</sub>, 1), 31.63 (CH<sub>2</sub>, 1), 39.94 (CH<sub>2</sub>, 1), 66.87 (CH, 1, ether), 41.88 (C, 1), 176.71 (CO, 1). MS, *m/z* (%): 199 (0.7), 158 (3), 144 (33), 141 (24), 111 (9), 102 (58), 99 (12), 87 (9), 85 (44), 83 (18), 71 (64), 57 (100), 56 (20), 55 (61).

**14**, R = Pri. MS, *m/z* (%): 186 (9), 158 (15), 144 (11), 141 (21), 116 (27), 97 (14), 87 (21), 70 (9), 69 (24), 67 (10), 57 (100), 56 (45), 55 (54).

**15**, R = Pri. MS, *m/z* (%): 186 (3), 172 (20), 141 (29) 140 (12), 130 (33), 99 (11), 71 (61), 70 (21), 69 (20), 57 (100), 56 (54), 55 (61).

- Vol'pin, *Izv. Akad. Nauk, Ser. Khim.*, 1996, 1214 (*Russ. Chem. Bull.*, 1996, **45**, 1154); (h) I. S. Akhrem, A. V. Orlinkov and S. V. Vitt, *Tetrahedron Lett.*, 1999, **40**, 5897; (i) H. Bahrmann, in *Koch Reactions in New Syntheses with Carbon Monoxide*, ed. J. Falbe, Springer-Verlag, Berlin, 1980, ch. 5.
- 2 (a) T. Sakakura, T. Sodeyama, K. Sasaki and K. Wada, *J. Am. Chem. Soc.*, 1990, **112**, 7221; (b) P. Margl, T. Ziegler and P. Blochl, *J. Am. Chem. Soc.*, 1996, **118**, 5412; (c) Y. Fujiwara, K. Takaki and Y. Taniguchi, *Synlett.*, 1996, 591; (d) M. Lin, T. E. Hogan and A. Sen, *J. Am. Chem. Soc.*, 1996, **118**, 4574.
- 3 (a) C. L. Hill, *Synlett.*, 1995, 127; (b) I. Ryu and M. Soneda, *Angew. Chem., Int. Ed. Engl.*, 1996, **35**, 1050; (c) M. Lin and A. Sen, *J. Chem. Soc., Chem. Commun.*, 1992, 892; (d) W. T. Boese and S. Goldman, *Tetrahedron Lett.*, 1992, **33**, 2119; (e) W. T. Boese and S. Goldman, *J. Am. Chem. Soc.*, 1992, **114**, 350; (f) C. L. Hill and B. S. Jaynes, *J. Am. Chem. Soc.*, 1995, **117**, 4704; (g) R. R. Ferguson and R. H. Crabtree, *J. Org. Chem.*, 1991, **56**, 5503.
- 4 H. Hopff, C. D. Nenitzescu, D. A. Isacescu and I. P. Cantuniari, *Ber. Dtsch. Chem. Ges.*, 1936, **69**, 2244.
- 5 (a) W. Haaf and H. Koch, *Liebigs Ann. Chem.*, 1960, **638**, 122; (b) Y. Souma and H. Sano, *Bull. Chem. Soc. Jpn.*, 1974, **47**, 1717; (c) Q. Xu and Y. Souma, *Top. Catal.*, 1998, **6**, 17.
- 6 S. Z. Bernadyuk, I. S. Akhrem and M. E. Vol'pin, *Mendeleev Commun.*, 1994, 183.
- 7 (a) I. Akhrem, A. Orlinkov and M. Vol'pin, *J. Chem. Soc., Chem. Commun.*, 1993, 671; (b) I. S. Akhrem and A. V. Orlinkov, *Izv. Akad. Nauk, Ser. Khim.*, 1998, 771 (*Russ. Chem. Bull.*, 1998, **47**, 740).

Received: 19th August 2002; Com. 02/1988