

## A New C–C Bond-forming Free Radical Rearrangement

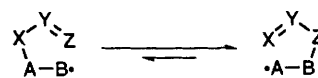
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On treatment with tributyltin hydride and azoisobutyronitrile in benzene at reflux  $\alpha$ -aryl- $\beta$ -bromoalkyl vinyl ethers rearrange in moderate yield to  $\delta$ -aryl ketones: possible mechanistic rationales are discussed for this novel C–C bond-forming process.

The formalism of Scheme 1 conveniently describes a number of free radical 2,3-shifts. These are the well known acyloxy migration (A = B = Y = carbon, X = Z = oxygen)<sup>1</sup> and the allylperoxy migration (A = B = oxygen, X = Y = Z = carbon)<sup>2</sup> together with the more recent phosphonooxy migration [A = B = carbon, X = Z = oxygen, Y = phosphorus(v)]<sup>3</sup> and a number of other related migrations.<sup>4,5</sup>

Each of these rearrangements, which involve the making and breaking of carbon–heteroatom bonds, is of considerable mechanistic interest but has only limited synthetic utility.<sup>6,7</sup> We were intrigued by, and report here on the possibility of using Scheme 1 as a framework for the design of related



Scheme 1

migrations that would occur with formation of a C–C bond (*i.e.* in which at least B = Z = carbon) and so a synthetically useful process.

The concept was readily put into practice. Reaction of the Tebbe reagent<sup>8</sup> with styrene bromohydrin acetate gave the enol ether **1** which on treatment in benzene at reflux with

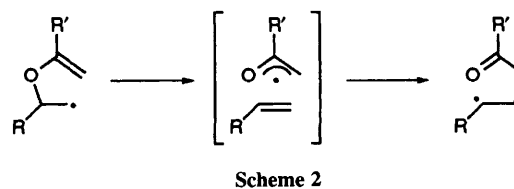
Table 1

Entry	Substrate	Products (% Yield) <sup>a</sup>
1		Ph(CH <sub>2</sub> ) <sub>3</sub> COMe <b>2</b> <sup>17</sup> 32 (50) + <b>3</b> (50)
2		Ph(CH <sub>2</sub> ) <sub>3</sub> COEt <b>5</b> <sup>17</sup> 28 (53) + <b>6</b> (47)
3		<i>p</i> -MeO-C <sub>6</sub> H <sub>4</sub> (CH <sub>2</sub> ) <sub>3</sub> COPh <b>8</b> 39 (50) + <b>9<sup>b</sup></b> 19.5 (28) + PhCOMe (22) <i>p</i> -MeO-C <sub>6</sub> H <sub>4</sub> CH=CH <sub>2</sub> (24)
4		<i>p</i> -MeO-C <sub>6</sub> H <sub>4</sub> (CH <sub>2</sub> ) <sub>3</sub> COC <sub>6</sub> H <sub>4</sub> - <i>p</i> -F <b>11</b> 38 (54) + <b>12<sup>c</sup></b> 19 (22) + <i>p</i> -F-C <sub>6</sub> H <sub>4</sub> COMe (23) <i>p</i> -MeO-C <sub>6</sub> H <sub>4</sub> CH=CH <sub>2</sub> (13)
5		<b>14</b> 9 (15) + <b>15</b> (85)
6		PhCH=CH <sub>2</sub> (>95)
7		<b>18</b> (>95)

<sup>a</sup> Yields refer to isolated products wherever possible. <sup>1</sup>H NMR yields determined on the crude reaction mixtures after removal of volatiles under vacuum, by comparison with authentic samples, are given in parentheses. <sup>b</sup> *cis/trans* = 1.7/1. <sup>c</sup> *cis/trans* = 2.0/1. *Z/E* = 3.5/1.

tributyltin hydride (TBTH) and azoisobutyronitrile (AIBN) over 18 h resulted in the formation of the migration product **2** together with the direct reduction product **3** (Table, entry 1). A number of other examples, prepared similarly by application of the Tebbe or Oshima-Takai<sup>9</sup> protocols to the corresponding esters are presented in Table 1 and serve to define the present scope of the rearrangement. The major byproducts are either the straight reduction products, as in entries 1 and 2, or in the case of the 1-aryl-1-alkoxyethenes **7** and **10** the corresponding substituted acetophenones and tetrahydrofurans (Table 1, entries 3 and 4). Substitution at either end of the purported new C-C bond (Table 1, entries 5 and 6) results in drastically reduced yields and the isolation of alkenes. Finally, migration was not observed for the enol ether derivative **17** of a simple aliphatic bromohydrin derived from camphor (Table 1, entry 7).

On the basis of the above observations we feel justified in considering a mechanism involving radical elimination followed by cage recombination (Scheme 2).<sup>†</sup> The elimination is



accelerated by formation of a conjugated alkene, and hence the minimization of the reduction product in all cases but one (Table 1, entry 7). Readdition is retarded by substitution at the addition site, a hallmark of radical addition reactions.<sup>10</sup>

However, an alternative pathway involving ring closure with formation of an  $\alpha$ -tetrahydrofuranyl radical followed by ring opening cannot be ruled out although it is disfavoured by Baldwin's rules,<sup>11</sup> and is somewhat unlikely in view of the known reluctance of such radicals to suffer ring opening<sup>12</sup> except under drastic conditions<sup>13</sup> as well as of their ready participation in preparatively useful chemistry.<sup>14</sup> The formation of tetrahydrofurans **9** and **12**<sup>15</sup> as byproducts from **7** and **10**, respectively, is noteworthy and indicates that 5-*endo-trig* cyclization at least occurs as a side reaction when benzylic stabilization is available to the ring closed radical.<sup>16</sup> Efforts are currently underway to extend the scope of this new C-C

<sup>†</sup> A crossover experiment involving heating **7** and TBTH in the presence of styrene gave no indication of the formation of the crossover product pointing to an intramolecular mechanism.

bond forming rearrangement and will be reported in due course.‡

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## References

- 1 J.-M. Surzur and P. Teissier, *Compt. Rend. Acad. Sci. Fr., Ser. C*, 1967, **264**, 1981; J.-M. Surzur and P. Teissier, *Bull. Soc. Chim. Fr.*, 1970, 3060; D. D. Tanner and F. C. P. Law, *J. Am. Chem. Soc.*, 1969, **91**, 7537.
- 2 G. O. Schenck, O. A. Neumuller and W. Eisfeld, *Liebigs Ann. Chem.*, 1958, **618**, 202.
- 3 D. Crich and Q. Yao, *J. Am. Chem. Soc.*, 1993, **115**, 1165; A. Koch, C. Lamberth, F. Wetterich and B. Giese, *J. Org. Chem.*, 1993, **58**, 1083.
- 4 D. Crich and G. Filzen, *Tetrahedron Lett.*, 1993, **34**, 3225 and references therein.
- 5 A review on radical rearrangements: A. L. J. Beckwith and K. U. Ingold, in *Rearrangements in Ground and Excited States*, ed. P. de Mayo, Academic, New York, 1980, vol. 1, 162; Latest collation of rates of radical rearrangements: M. Newcomb *Tetrahedron*, 1993, **49**, 1151.
- 6 Acetoxy migration most recent study: A. L. J. Beckwith and P. J. Duggan, *J. Chem. Soc., Perkin Trans. 2*, 1992, 1777.
- 7 Allylperoxy migration most recent study: S. L. Boyd, R. J. Boyd, Z. Shi, L. R. C. Barclay and N. A. Porter, *J. Am. Chem. Soc.*, 1993, **115**, 687.
- 8 F. N. Tebbe, G. W. Parshall, and G. S. Reddy, *J. Am. Chem. Soc.*, 1978, **100**, 3611; S. H. Pine, R. Zahler, D. A. Evans and R. H. Grubbs, *J. Am. Chem. Soc.*, 1980, **102**, 3270.
- 9 T. Okazoe, K. Takai, K. Oshima and K. Utimoto, *J. Org. Chem.*, 1987, **52**, 4410.
- 10 W. B. Motherwell and D. Crich, *Free Radical Chain Reactions in Organic Synthesis*, Academic, London, 1992; D. P. Curran, in *Comprehensive Organic Synthesis*, ed. B. M. Trost and I. Fleming, Pergamon, 1991, **4**, 715.
- 11 J. E. Baldwin, *J. Chem. Soc., Chem. Commun.*, 1976, 734.
- 12 Observations of ESR spectra without ring opening: A. L. J. Beckwith and P. Tindall, *Aust. J. Chem.*, 1971, **24**, 2099; B. C. Gilbert and M. Trenwith, *J. Chem. Soc., Perkin Trans. 2*, 1975, 1083; A. J. Dobbs, B. C. Gilbert and R. O. C. Norman, *J. Chem. Soc., Perkin Trans. 2*, 1972, 787; A. J. Dobbs, B. C. Gilbert and R. O. C. Norman, *J. Chem. Soc., A*, 1971, 124.
- 13 T. J. Wallace and R. J. Gritter, *J. Org. Chem.*, 1961, **26**, 5256.
- 14 B. Maillard, A. Kharrat, F. Rakotomanana, E. Montaudon and C. Gardrat, *Tetrahedron*, 1985, **41**, 4047; J. Boivin, E. Crépon and S. Z. Zard, *Tetrahedron Lett.*, 1990, **31**, 6869.
- 15 *Cis-* and *trans-*isomers assigned by comparison with the spectra of authentic 2,5-diphenyltetrahydrofuran: H. Neudeck and K. Schlögl, *Monatsch.*, 1975, **106**, 229.
- 16 *5-endo-trig* Cyclizations: M. Julia and F. Le Goffic, *Bull. Soc. Chim. Fr.*, 1965, 1550, 1555; M. A. M. Bradney, A. D. Forbes and J. Wood, *J. Chem. Soc., Perkin Trans. 2*, 1973, 1655; H. Pines, N. C. Sih and D. B. Rosenfeld, *J. Org. Chem.*, 1966, **31**, 2255; J. W. Wilt, L. L. Maravetz and J. F. Zawadzki, *J. Org. Chem.*, 1966, **31**, 3018; L. W. Menapace and H. G. Kuivila, *J. Am. Chem. Soc.*, 1964, **86**, 3047; T. Sato, N. Nakamura, K. Ikeda, M. Okada, H. Ishibashi and M. Ikeda, *J. Chem. Soc., Perkin Trans. 1*, 1992, 2399.
- 17 M. Tiffeneau and Y. Deux, *Compt. Rend. Acad. Sci. Fr.*, 1942, 892.

‡ All new compounds gave spectral data and, with the exception of enol ethers **3** and **6** which could not be isolated without decomposition, HRMS/microanalytical data in accordance with the assigned structures.