# Rearrangement Reactions of Deprotonated α-Substituted Ketones in the Gas Phase

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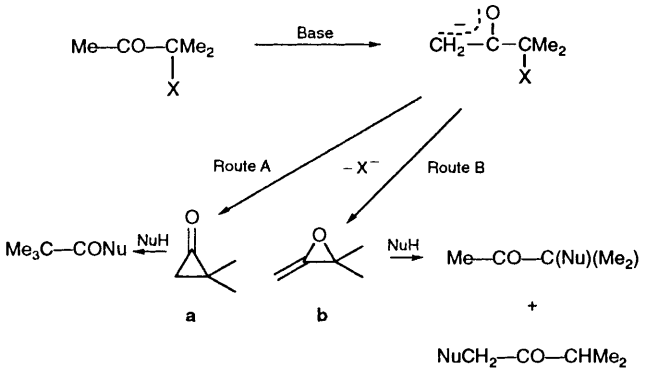
Ambident anions $[CH_2COC(X)Me_2]^-$, on collisional activation in the gas phase, could, in principle, undergo cyclisations through (i) $C^-$ to form a Favorskii cyclopropanone ion complex, or (ii) $O^-$ to form an allene oxide ion complex. No Favorskii intermediates are detected, but allene oxide ion complexes are formed when X = OMe or SMe. These cyclisation reactions are endothermic and would not be expected to occur should lower energy reaction channels be available. Such a scenario pertains when X = OH, *i.e.* no internal cyclisation occurs for ambident enolate $[CH_2COC(OH)Me_2]^-$ following collisional activation. Instead, proton transfer produces the alkoxide $[MeCOC(O^-)Me_2]$ which undergoes the acyloin rearrangement (to equilibrate the three methyl groups by 1,2-methyl anion migration) prior to decomposition.

The ambident behaviour of enolate anions in bimolecular gas phase reactions is well known.[1,2] Reactions through both the carbon and oxygen ends of an enolate anion are possible: this behaviour has been explained in particular systems in terms of the relative HOMO and LUMO energies of nucleophilic and electrophilic sites.[1,2] In contrast, little is known of the intramolecular behaviour of ambident enolate anions in the gas phase.

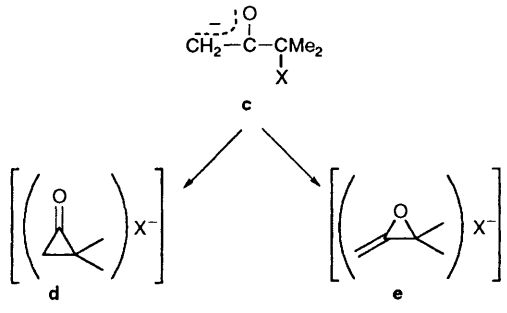
The base catalysed reactions of α-haloketones constitute the classical example of intramolecular cyclisations of ambident enolate anions in solution. Reaction through the carbanion centre [route A (Scheme 1), X = Cl, Br or I] to ultimately form




**Scheme 1**

a carboxylic acid (or derivative thereof) is called the Favorskii rearrangement,[3] a reaction which is known to proceed *via* cyclopropanone **a**.[4,5] The competing reaction occurs by cyclisation of $O^-$ to produce the allene oxide **b**, which reacts further (see Scheme 1) to form substitution products.[6,7] The relative distribution of products depends in a complex way on the nature of the nucleophile, the structure of the substrate, the polarity of the solvent and the nature of the leaving group.[8] In principle, the use of a protic solvent and a chloro leaving group kinetically favours the Favorskii rearrangement, since the protic solvent should preferentially solvate $O^-$, thus enabling attack of the 'softer'[9] carbanion site at the 'soft' electrophilic centre.

This paper investigates the gas-phase reactivity of such ambident enolate anions upon collisional activation in the gas phase, *i.e.* where there is no solvent or counter ion present to modify the reactivity of the system. However there are two fundamental differences between condensed phase and gas phase studies of this rearrangement. First, for an intramolecular




**Scheme 2**

gas phase study, the α substituent must be both the leaving group, and the attacking nucleophile, *i.e.* X = Nu in Scheme 1. Secondly, as a consequence of the above prerequisite, the gas phase reactions (see below) will be endothermic, whereas the reactions outlined in Scheme 1 are exothermic.

## Results and Discussion

In the current intramolecular study, we wish to determine whether enolate **c** (Scheme 2) can react through the carbanion site to form the Favorskii intermediate **d**, or through $O^-$ to yield the allene oxide ion complex **e**. In principle, it should be possible to differentiate between these possibilities if (i) ion complexes **d** and **e** undergo further characteristic reactions (*e.g.* deprotonation of the neutral portion of the complex by $X^-$) and (ii) if the product ions of these reactions can be identified unequivocally. The formation of these two complexes will be endothermic, as may their subsequent reactions. However, the decomposing parent anions are collisionally activated, so endothermicity will only be a problem if the parent anion has a more facile reaction channel available than those which might proceed through **d** and/or **e**.

*α-Haloketones.*—The prototypical species for the gas phase study is of course **c** (X = halogen, in particular Cl). Unfortunately, an α-halo group is not appropriate for this investigation since the only product anion observed in the negative ion spectra of $[MeCOC(X)Me_2 - H]^-$ (X = Cl and Br) is $X^-$. This is not unexpected since the electron affinity of a halo radical is very high: thus any initial deprotonated species will decompose to a halide anion to the virtual exclusion of any other ionic product. In addition, the reactivity of $Cl^-$ and $Br^-$ as bases and

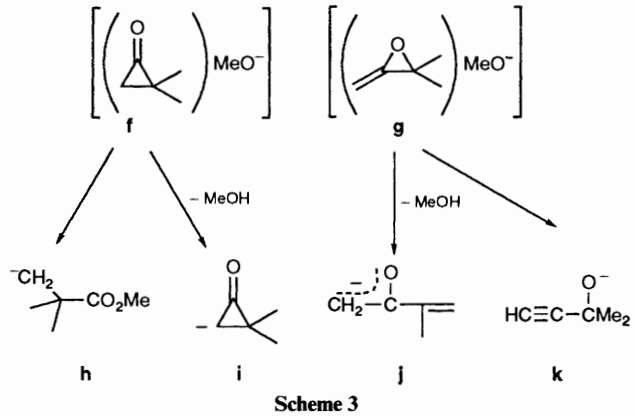
**Table 1** Collisional activation mass spectra of deprotonated α-methoxyketones

| Parent ion (*m/z*) | *m/z* (loss or formation) (%) |
|---|---|
| $[CD_3COC(OMe)(Me)_2 - D]^-$ (117) | 85 (MeOH) 100, 42 ($DC_2O^-$) 3, 31 ($MeO^-$) 3 |
| $[MeCOC(OMe)(Me)(CD_3) - H]^-$ (118) | 86 (MeOH) 100, 85 (MeOD) 86, 41 ($HC_2O^-$) 8, 31 ($MeO^-$) 9 |
| $[MeCOCH(OMe)(Me) - H]^-$ (101) | 86 (Me$^\bullet$) 54, 69 (MeOH) 100, 57 ($MeCOCH_2^-$) 14, 42 ($MeCO^-$ and/or $^-CH_2CHO$) 6, 41 ($HC_2O^-$) 12, 31 ($MeO^-$) 12 |
| $[MeCOCH_2OMe - H]^-$ (87) | 86 (H$^\bullet$) 4, 85 ($H_2$) 2, 72 (Me$^\bullet$) 100, 71 ($CH_4$) 2, 56/57[a] (MeO$^\bullet$, $CH_2O$) 4, 55 (MeOH) 6, 43 ($MeCO^-$ and/or $^-CH_2CHO$) 4, 41 ($HC_2O^-$) 2, 31 ($MeO^-$) 1 |

[a] These peaks are not fully resolved.

nucleophiles will be low [$\Delta G°_{acid}$ for HCl and HBr are 1372 and 1330 kJ mol$^{-1}$ respectively,[10] thus ion molecule complexes **d** or **e** (Scheme 2; X = Cl or Br), if formed, will only decompose to yield $X^-$]. As a consequence, we have no probe to investigate the possibility of the formation of **d** or **e** (X = Cl or Br) from deprotonated α-haloketones in the gas phase.

*Rearrangements of Deprotonated α-Methoxyketones.*—Let us now consider the situation where the α-substituent is MeO (*i.e.* Scheme 2, X = MeO). Reaction through carbon could, in principle, yield the Favorskii intermediate **f**, (Scheme 3) while




**Scheme 3**

the alternative reaction through oxygen could form **g**. The methoxide anion can react as a nucleophile or base within these complexes. Thus ion **f** could undergo two reactions *viz.* (i) the normal Favorskii rearrangement to form **h**, which will be unstable with respect to electron loss and will not be observed,[11] and (ii) deprotonation to form **i** or some rearrangement product of **i** (deprotonation of a methyl group will be unfavourable in comparison by at least 100 kJ mol$^{-1}$). Ion **g** could undergo (i) internal nucleophilic addition to form the starting material $[CH_2COC(OMe)(Me)_2]^-$ [the other possible product, $MeO\text{-}CH_2COC^-(Me)_2$ will be minor in comparison], or (ii) deprotonation to form **j** and/or **k**.

Let us assume that loss of methanol does occur for this system: what product ion(s) would we expect to form? Of the two intermediates **f** and **g**, **g** should be the kinetically favoured species, since the harder nucleophile ($O^-$) would be expected to react at the now hard electrophilic centre (a consequence of the α-substituent being MeO). We calculate (using Benson's rules[12]) that reaction $[CH_2COC(OMe)(Me)_2]^- \rightarrow$ **i** + MeOH is endothermic by some 110 kJ mol$^{-1}$, whereas the competing processes to form **j** + MeOH and **k** + MeOH are endothermic by 75 and 150 kJ mol$^{-1}$ respectively. Therefore, of the two complexes, the formation of the **g** is favoured kinetically, while decomposition of **g** to **j** is favoured thermodynamically.

The collisional activation (CA) mass spectra of some deprotonated α-methoxyketones and some deuterium labelled derivatives are recorded in Table 1, while that of [MeCOC-

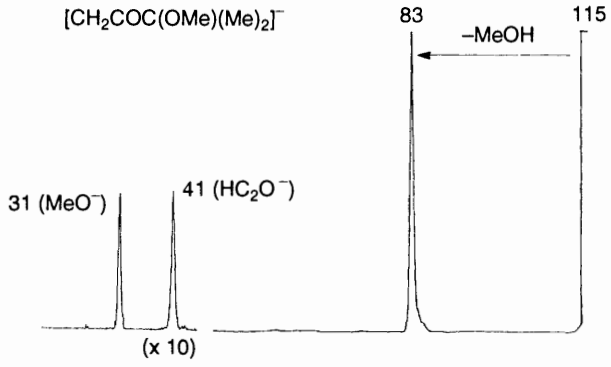
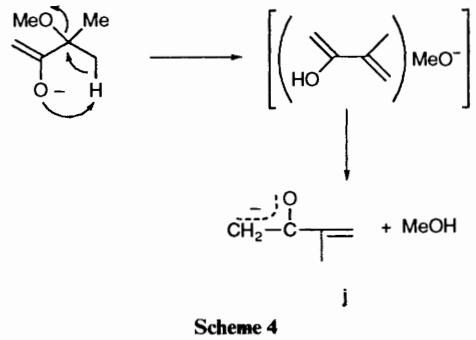



**Fig. 1** Collisional activation mass spectrum of $[CH_2COC(OMe)\text{-}(Me)_2]^-$

$(OMe)(Me)_2 - H]^-$ is illustrated in Fig. 1. The collisional activation and charge reversal (positive ion) (CR)[13] mass spectra of particular product ions are listed in Table 2. The spectrum shown in Fig. 1 is dominated by loss of methanol to form *m/z* 83, and this ion is formed without equilibration of the methoxy methyl group between the two oxygens (*cf.* the spectrum of the $D_2$ ion shown in Table 1). The CA and CR mass spectra of *m/z* 83 are identical with those of authentic deprotonated 2-methylbut-1-ene-3-one (see Table 2). Thus *m/z* 83 in Fig. 1 corresponds specifically to ion **j** (*cf.* Scheme 3).

This is the predicted result, but we must be careful to exclude the possibility that **j** may arise by a different pathway from that shown in Scheme 3. The only reasonable alternative to the mechanism in Scheme 3 is a proton transfer/elimination process of the type shown in Scheme 4.* How could the mechanisms




**Scheme 4**

shown in Schemes 3 and 4 be distinguished? In principle, the

* The reaction is shown as synchronous to the ion complex. The stepwise process proceeding through a discrete $E1_{cb}$ intermediate is also possible and will not alter the above argument. A concerted, and 'charge remote' (*cf.* refs. 14 and 15) elimination of methanol through a four centre transition state is not considered a viable alternative, in view of the considerable activation energy for such a process.

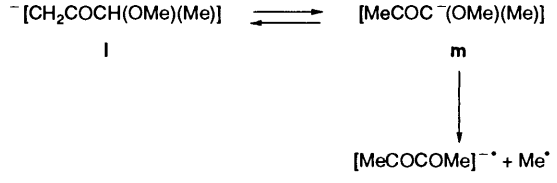
**Table 2** Collisional activation and charge reversal (positive ion) mass spectra (MS/MS) of product ions from deprotonated α-methoxyketones

| Parent ion (*m/z*) | Product ion (*m/z*) | Spectrum type | CA [*m/z* (loss or formation) (%)] CR [*m/z* (%)] |
|---|---|---|---|
| $[CH_2COCH(OMe)(Me)]^-$ (101) | ($-H_2O$) (69) | CA | 68 ($H^•$) 100, 67 ($H_2$) 10, 41 ($C_2H_4$) 35,[ai] 27 ($C_2H_3^-$) 7[aii] |
| | | CR | 68 (3), 55 (11), 54 (4), 53 (7), 52 (6), 51 (9), 50 (14), 49 (4), 42 (100), 41 (32), 39 (59), 38 (26), 37 (12), 29 (16), 27 (78), 26 (60), 25 (18), 15 (2), 14 (12), 13 (3), 12 (1) |
| $(CH_2COCH{=}CH_2)^-$ (69) | | CA | 68 ($H^•$) 100, 67 ($H_2$) 12, 41 ($C_2H_4$) 32,[aiii] 27($C_2H_3^-$) 6[aiv] |
| | | CR | 68 (3), 55 (14), 54 (2), 53 (7), 52 (6), 51 (9), 50 (13), 49 (5), 42 (100), 41 (28), 39 (49), 38 (22), 37 (12), 29 (10), 27 (78) 26 (67), 25 (18), 15 (2), 14 (15), 13 (4), 12 (1) |
| $[CH_2COC(OMe)(Me)_2]^-$ (115) | ($-$MeOH) (83) | CA | 82 ($H^•$) 50, 81 ($H_2$) 22, 55 (28) 5, 41 ($CH_2CO$, $C_3H_6$) 100[av] |
| | | CR | 82 (1), 81 (1), 55 (7), 54 (9), 53 (16), 51 (12), 42 (80), 41 (42), 39 (100), 29 (13), 27 (14), 26 (10), 15 (3), 14 (6) |
| $[CH_2COC(Me){=}CH_2]^-$ (83) | | CA | 82 ($H^•$) 38, 81 ($H_2$) 18, 55 (28) 5, 41 ($CH_2CO$, $C_3H_6$) 100[avi] |
| | | CR | 82 (1), 81 (1), 55 (6), 54 (7), 53 (13), 51 (11), 50 (12) 42 (82), 41 (40), 39 (100), 29 (11), 27 (14), 26 (11), 15 (3), 14 (5) |

[a] Peak widths at half height (V ± 0.3, an average of 10 measurements) [*m/z* (peak width)]. (i) 41 (67.9); (ii) 27 (33.3); (iii) 41 (67.5); (iv) 27 (32.9); (v) 41 (39.8); and (vi) 41 (40.3). [b] The species formed by loss of MeOH from $[CD_2COC(OMe)(Me)_2]^-$, *viz.* *m/z* 85, loses $CD_2CO$ and $C_3H_5D$ in the ratio 100:8. [c] $[CD_2COC(Me){=}CH_2]^-$ (*m/z* 85) loses $CD_2CO$ and $C_3H_5D$ in the ratio 100:9.

proton transfer shown in Scheme 4 could exhibit a pronounced kinetic deuterium isotope effect. In contrast, the kinetic deuterium isotope effect for reaction **g** to **j** might be absent or small, since we would expect the formation of **g** to be the rate determining step. We have synthesised MeCOC(OMe)(Me)-($CD_3$) and the spectrum (Table 1) of its deprotonated form shows losses of MeOH and MeOD in the ratio 1.00:0.86 (an average of ten measurements, accuracy ±2%), indicating an isotope effect H/D of 1.15. We believe this small value to be inconsistent with the mechanism shown in Scheme 4.

The CA mass spectrum of $[MeCOCH(OMe)(Me) - H]^-$ (Table 1) is more complex than that shown in Fig. 1 since two enolate ions **l** and **m** (Scheme 5) will be formed by de-



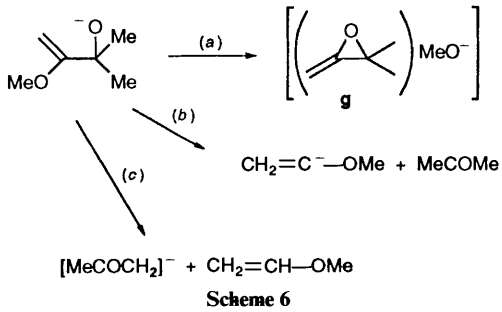

**Scheme 5**

protonation of the neutral. In addition, **l** and **m** will equilibrate under conditions of collisional activation.[16] Both enolate ions will undergo characteristic fragmentation: **m** fragments by loss of a methyl radical as shown in Scheme 5 while **l** could, in principle, undergo analogous fragmentations to those shown in Scheme 3. The spectrum is again dominated by loss of methanol. This is a fragmentation of **l**, and the product ion, *m/z* 69, is identified as $[MeCOCH{=}CH_2 - H]^-$ (*cf.* **j**, Scheme 3) by comparison of its mass spectra with those of the ion formed by deprotonation of methyl vinyl ketone (Table 2). The mass spectrum of the corresponding species $[MeCOCH_2OMe - H]^-$ also shows product ions resulting from decomposition of two enolate ions. The process corresponding to that shown in Scheme 5 dominates the spectrum, while the loss of methanol is now insignificant (Table 1). Thus in these systems, fragmentation through enolate ions analogous to **m** is more pronounced as the number of alkyl groups attached to the carbon atom bearing the MeO substituent is decreased.

*Rearrangements of Deprotonated α-Thiomethoxyketones.*— We next wished to investigate an enolate system in which the leaving group X is intermediate in reactivity between Cl and OMe. Would such a system form allene oxide intermediate **e** (Scheme 2), or might it react *via* the Favorskii intermediate **d**? The substituent chosen was the α-methylthio moiety. Thus we have studied the spectra (Table 3) of $[MeCOC(SR)(Me)_2 - H]^-$ (R = Me and $CD_3$). The spectra are dominated by loss of R• and (RS − H) [or (RS − D)], while processes involving loss of RSH are minor in comparison. The latter observation is to be expected since the basicity of $RS^-$ is only moderate [$\Delta G°_{acid}$ (MeSH) = 1467 kJ $mol^{-1}$],[18] which means that the species undergoing deprotonation will require at least 60 kJ $mol^{-1}$ of excess energy. We have examined the spectra of the ion formed by loss of MeSH from $^-[CH_2COC(SMe)(Me)_2]$: they are identical with those of ion **j** (Scheme 3). We propose that this ion is formed from allene oxide intermediate **e** (X = SMe).

The above data suggest that when the α-substituent is either MeO or MeS, the initial enolate ion reacts specifically through oxygen to form intermediates corresponding to **e** (Scheme 2). Such intermediates may then undergo specific deprotonation at the *gem*-dimethyl position to form **j**. Although isotope effect data (see above) are consistent with this scenario, we need further evidence to establish the mechanism without doubt. Normally this would be no problem: we need to synthesise the substituted cyclopropane and allene oxide neutrals **a** and **b** (Scheme 1), to deprotonate them, and to compare their mass spectra with those of the key product ion **j** (*m/z* 83). Unfortunately this cannot be done, since both neutrals are known to be unstable.[19,20]

The dimethylallene oxide intermediate **g** (Scheme 3) is really the key to this study, and we have attempted to make it by an independent route. Deprotonated 2-methoxy-3-methylbut-1-en-3-ol, upon collisional activation, might cyclise to **g** as shown in [Scheme 6(*a*)]: if the intermediate is formed, then it should




**Scheme 6**

**Table 3** Collisional activation mass spectra of deprotonated 3-methyl-3-methylthiobutan-2-one and a labelled analogue

| Parent ion | *m/z* (loss or formation) (%) |
|---|---|
| $[MeCOC(SMe)(Me)_2 - H]^-$ (131) | 130 ($H^•$) 5, 116 ($Me^•$) 33, 85 ($CH_2S$) 100,[a] 83 (MeSH) 10, 47 ($MeS^-$) 11 |
| $[MeCOC(SCD_3)(Me)_2 - H]^-$ (134) | 133 ($H^•$) 5, 116 ($CD_3^•$) 100, 86 ($CD_2S$) 43, 43 ($CD_3SH$) 5, 50 ($CD_3S^-$) 2, 49 ($CHD_2S^-$) 2 |

[a] Loss of $CH_2S$: (i) yields an ion whose CA spectrum is identical with that of $(MeCOPr^i - H)^-$,[17] and (ii) shows a pronounced deuterium isotope effect (see spectra above). The proton transfer could proceed to either $O^-$ or $C^-$. The latter possibility is shown below, but irrespective of the mode of the initial proton transfer, subsequent proton transfers will effect equilibration of the enolate anions.[16]

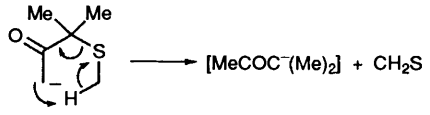
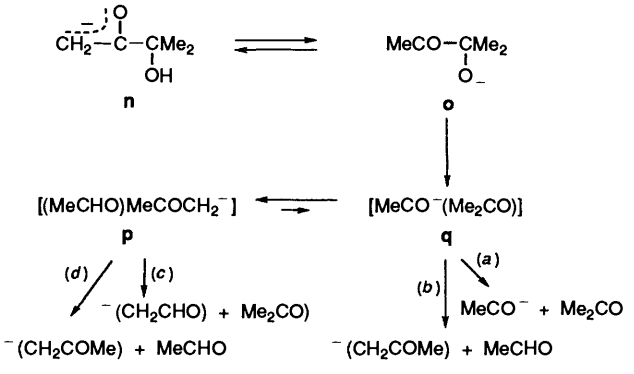



**Table 4** Collisional activation mass spectra of deprotonated 2-methoxy-3-methylbut-1-en-3-ol and a deuteriated analogue

| Parent ion | *m/z* (formation) (%) |
|---|---|
| $[CH_2{=}C(OMe)C(O^-)(Me)_2]$ (115) | 57 ($MeCOCH_2^-$ and $CH_2{=}C^-{-}OMe$) 100, 41 ($HC_2O^-$) 2 |
| $[CH_2{=}C(OMe)C(O^-)(CD_3)_2]$ (121) | 62 ($CD_3COCD_2^-$) 100, 57 ($CH_2{=}C^-{-}OMe$) 48, 42 ($DC_2O^-$) 1 |

decompose to eliminate methanol and form **j**. The mass spectra of deprotonated 2-methoxy-3-methylbut-1-en-3-ol and its (gem-dimethyl) $D_6$ analogue are listed in Table 4. Unfortunately, no loss of methanol is observed. Instead, the ion undergoes direct cleavage [Scheme 6(*b*)], together with cleavage accompanied by deprotonation (*c*).

*Deprotonated α-Hydroxyketones.*—The rearrangement reactions that we have considered above are endothermic and only occur because they must compete favourably with any other possible collision-induced decomposition modes of these systems. We next chose to study deprotonated α-hydroxyketones because this system suggests a further interesting possibility. Deprotonation of *e.g.* $MeCOC(OH)Me_2$ will occur preferentially to form the enolate anion **n** (Scheme 7) [$\Delta G°_{acid}$




**Scheme 7**

$MeCOC(OH)(Me)_2$[21] and $CH_3COC(OH)(Me)_2$[22] should be *ca.* 1548 and 1506 kJ $mol^{-1}$ respectively].* The evidence from the cognate systems (outlined above) suggests that enolate ion **n** should not form Favorskii intermediate **d** (X = OH), but that the allene oxide species **e** (X = OH) might be formed. However, there is another scenario which might pertain in this case. The first formed enolate anion needs a minimum of 58 kJ $mol^{-1}$ (see above) in order to effect an internal proton transfer to produce alkoxide $MeCOC(O^-)Me_2$ (see Scheme 7), and if this anion is formed it should undergo facile and characteristic cleavage reactions. Thus in such a case, it is possible that any enolate rearrangements will be suppressed with respect to fragmentation of the alternative alkoxide anion.

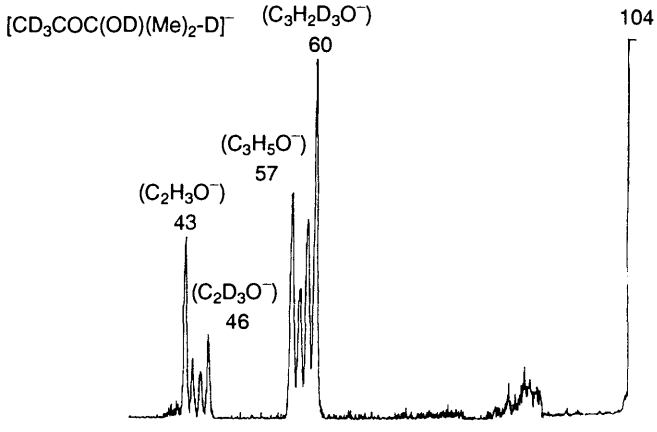



**Fig. 2** Collisional activation mass spectrum of $[CD_3COC(OD)(Me)_2 - D]^-$

The collisional activation mass spectra (MS/MS) of deprotonated 3-hydroxy-3-methylbutan-2-one is recorded in Table 5. The expectation outlined above is realised. The major fragmentations of this system are those of the alkoxide species **o** (Scheme 7). The fragmentations of **o** look deceptively simple, with *m/z* 57 and 43 forming major peaks. The collisional activation and charge reversal (positive ion) mass spectra of *m/z* 57 formed in the source identify it as $^-(CH_2COMe)$ (Table 6).[23] However, *m/z* 43 decomposes to both $Me^-$ and $C_2H^-$ (Table 6); it is therefore a mixture of $MeCO^-$ and $(CH_2CHO)^-$.[24] Thus **o** fragments through ion complex **q** which may (i) decompose as shown in Scheme 7(*a*) and (*b*), or (ii) proton transfer to form **p** [$\Delta G°_{acid}$ $MeCHO$[25] and $(CH_3)_2CO$[22] are 1602 and 1515 kJ $mol^{-1}$ respectively], which should, in turn, yield the products shown in Scheme 7 (*c*) and (*d*). Fig. 2 shows the situation to be more complex however: not only have the three methyl groups equilibrated prior to or during decomposition, but partial H/D scrambling also precedes fragmentation. Proton transfer reactions are quite common for negative ion species[16] but the methyl equilibration is interesting and must involve methyl

* The reactions between $MeCOC(OH)(Me)_2$ and $NH_2^-$, $HO^-$, $MeO^-$ and $Bu^tO^-$ yield deprotonated species which give identical spectra. Since $Bu^tO^-$ [$\Delta G°_{acid}$ ($Bu^tOH$) = 1540 kJ $mol^{-1}$][22] should not readily deprotonate the HO group, proton transfer **n** to **o** (Scheme 7) precedes fragmentation in this case.

**Table 5** Collisional activation mass spectra of deprotonated α-hydroxyketones

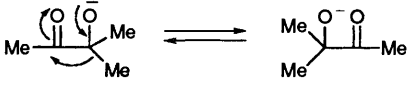
| Parent ion | *m/z* (loss or formation) (%) |
|---|---|
| $[MeCOC(OH)(Me)_2 - H]^-$ | 100 ($H^•$)8, 86 ($Me^•$) 4, 85 ($CH_4$) 6, 83 ($H_2O$) 2, 57 (MeCHO) 100, 43 ($Me_2CO$) 48 |
| $PhCOC(O^-)(Me)_2$ | 162($H^•$) 60, 148 ($Me^•$) 28, 119 (MeCHO) 71, 105 ($Me_2CO$) 100, 85 (PhH) 11, 77 ($Ph^-$) 54, 57 (PhCHO) 52, 43 (PhCOMe) 4, 41 ($HC_2O^-$) 5 |
| $[MeCOC(OH)(Me)(Ph) - H]^-$ | 162 ($H^•$) 59, 148 ($Me^•$) 26, 119 (MeCHO) 69, 105 ($Me_2CO$) 100, 85 (PhH) 10, 77 ($Ph^-$) 52, 57 (PhCHO) 49, 43(PhCOMe) 3, 41 ($HC_2O^-$) 5 |
| $[PhCOC(O^-)(Ph)(C_6D_5)]$ | 290/289[a] ($H_2$, HD) 100, 274 ($H_2O$) 10, 273 (19) 62, 272 (20) 25, 215 ($Ph^•$) 10, 210 ($C_6D_5^•$) 4, 185/186[a] (PhCDO, PhCHO) 6, 181 ($C_6D_5CHO$) 3, 170 ($PhCO_2H$) 8, 169 ($PhCO_2D$) 3, 121 ($PhCO_2^-$) 8, 110 ($C_6D_5CO^-$) 0.3, 105 ($PhCO^-$) 0.8, 82 ($C_6D_5^-$) 1.6, 77 ($Ph^-$) 4 |

[a] These peaks are unresolved.

**Table 6** Collisional activation (CA) and charge reversal (positive ion) (CR)[13] mass spectra of product ions from $[MeCOC(OH)Me_2 - H]^-$

| Product ion (*m/z*) | Spectrum type | *m/z*(%) |
|---|---|---|
| 57 | CA | 56 (100), 41 (40), 39 (3) |
| | CR | 56 (2), 55 (10), 54 (1), 53 (4), 43 (67), 42 (100), 41 (21), 40 (8), 39 (57), 38 (10), 37 (5), 29 (42), 28 (10), 27 (48), 26 (20), 25 (3), 15 (9), 14 (8), 13 (1), 12 (0.5) |
| $(MeCOCH_2)^-$ | CA and CR | see ref. 23 |
| 43 | CA | 42 (82), 41 (100), 25 (1), 15 (5) |
| | CR | 43 (65), 42 (100), 41 (38), 29 (48), 28 (26), 27 (13), 26 (12), 25 (8), 15 (26), 14 (18), 13 (6) |
| $MeCO^-$ and $^-(CH_2CHO)$ | CA and CR | see ref. 24 |

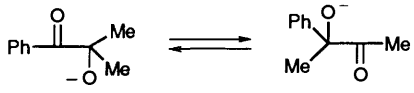
migration. The reaction may be a concerted 1,2-anion rearrangement as shown in Scheme 8, or it may be stepwise.



**Scheme 8**

Similar 1,2-anionic rearrangements have been reported in gas phase studies (see ref. 26 for a review), and this particular process is directly analogous to the condensed-phase acyloin rearrangement.[27] Thus not only is fragmentation of the enolate ion repressed in this system, but the alkoxide ion (formed following proton transfer) itself undergoes rearrangement prior to fragmentation.

Similar migration reactions also occur when the α-hydroxyketone system contains phenyl substituents. For example the collisional activation mass spectra of the isomeric ions $[PhCOC(OH)(Me)_2 - H]^-$ and $[MeCOC(OH)(Me)(Ph) - H]^-$ (Table 5) are identical within experimental error. The two ions shown in Scheme 9 have equilibrated prior to



**Scheme 9**

fragmentation,* the former yields $PhCO^-$ and $(CH_2COMe)^-$ while the latter forms $Ph^-$ and eliminates PhH and MeCHO by reactions similar to those outlined in Scheme 7. The spectrum of $PhCOC(O^-)Ph_2$ is shown in Fig. 3 while that of $PhCOC(O^-)(Ph)(C_6D_5)$ is listed in Table 5. The data in Table 5 shows that the phenyl groups have equilibrated† prior to the losses of $Ph^•$ [Scheme 10(*a*)] and PhCHO, and the formation of $Ph^-$ and

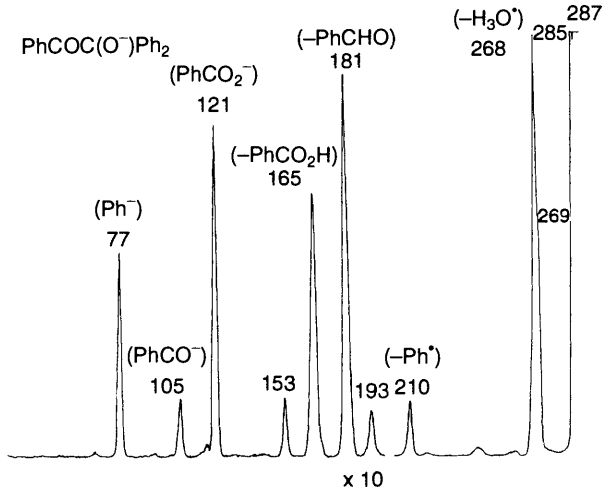
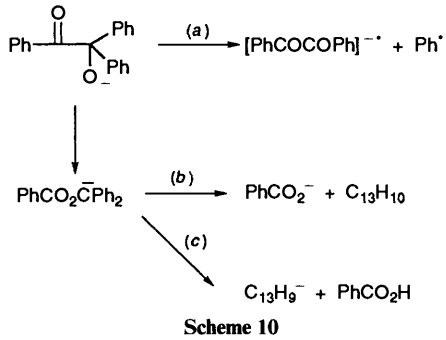



**Fig. 3** Collisional activation mass spectrum of $PhCOC(O^-)Ph_2$




**Scheme 10**

$PhCO^-$. However the formation of $PhCO_2^-$ and the elimination of $PhCO_2H$ do not involve phenyl equilibration

* The two neutral precursors are known to equilibrate when heated to 250 °C for 7.5 h. Phenyl migration is faster than methyl migration and kinetic data suggest the reaction to be concerted.[28] In order to eliminate the possibility of isomerism of the neutrals at high temperature, the mass spectra of their $(M - H)^-$ ions were determined using an ion source temperature of 50 °C, and the compounds were introduced through the direct probe with no heating.

† It is reported that some aryl rearrangement occurs during the reaction between Grignard reagents ArMgX and benzil.[29] Rearrangement has not occurred during the analogous formation of $PhCOC(OH)(Ph)(C_6D_5)$ since the positive ion mass spectrum exhibits only loss of $PhCO^•$: no loss of $C_6D_5CO^•$ is observed.

(Table 5), these processes involve cyclisation [Scheme 10(*b*) and (*c*)] which must occur before phenyl migration. The losses of $H_2O$ and ($H_2O + H^•$) shown in Fig. 3 are also due to cyclisation processes, but the structures of the resulting product ions are not known.

## Conclusions

(i) Cyclisation reactions of ambident enolate ions $[CH_2COC(X)(Me)_2]^-$ to form ion complexes are endothermic processes. Favorskii intermediates **d** (X = Cl, Br, OH, OMe or SMe) have not been detected in this study. However, products resulting from allene oxide complexes **e** are formed when X = OMe and SMe.

(ii) Unlike the previous examples, enolate anion $[CH_2COC(OH)(Me_2]^-$ does not undergo internal cyclisation upon collisional activation, instead, proton transfer forms the alkoxide anion $[MeCOC(O^-)(Me)_2]$ in which the methyl groups equilibrate by an acyloin rearrangement prior to or during fragmentation.

## Experimental

Collisional activation (CA) and charge reversal (CR, positive ion)[13] mass spectra (MS/MS) were determined with a VG ZAB 2HF instrument. Full experimental details have been reported previously.[30] Specific details were as follows: a chemical ionization slit was used in the ion source, the ionizing energy was 70 eV, the ion source temperature was 150 °C (unless indicated to the contrary), and the accelerating voltage was 7 kV. Liquids were introduced through the septum inlet at 100 °C; solids *via* the direct probe using no heating (source pressure of sample $5 \times 10^{-7}$ Torr). Deprotonation was effected using $NH_2^-$ (from $NH_3$; source pressure $1 \times 10^{-5}$ Torr), unless indicated to the contrary. The estimated source pressure was $10^{-1}$ Torr.* Argon was used in the second collision cell (measured pressure, outside the cell, $2 \times 10^{-7}$ Torr), giving a 10% reduction in the main beam, equivalent to single collision conditions.

The following compounds were prepared by reported procedures: 3-chloro-3-methylbutan-2-one,[31] 3-bromo-3-methylbutan-2-one,[32] 3-hydroxy-3-methylbutan-2-one,[33] α-hydroxyisobutyrophenone,[34] 3-hydroxy-3-phenylbutan-2-one,[35] α-phenylbenzoin,[36] methoxypropan-2-one,[37] 3-methoxybutan-2-one,[38] 3-methoxy-3-methylbutan-2-one,[39] 3-methyl-3-thiomethoxybutan-2-one,[40] 2-methylbut-1-en-2-one,[41] and 3-methoxy-2-methylbut-1-en-3-ol.[42]

The $(M - D)^-$ ions of $CD_3COC(OD)(Me)_2$ and $CD_3CO(OMe)(Me)_2$ were formed following equilibration[43] of the appropriate neutrals with $D_2O$ in the septum inlet system [the reactant ion $DO^-$ was used to form the parent $(M - D)^-$ species]. The neutral $(CD_3)_2(OH)CC(OMe)=CH_2$ was made by a standard procedure using $[^2H_6]$acetone.[42] α-($[^2H_5]$Phenyl)-benzoin was prepared by the standard Grignard route[36] from $[^2H_5]$phenylmagnesium bromide and benzil in 63% yield.

*3-Methoxy-3-*$[^2H_3]$*methylbutan-2-one.* A solution of $[^2H_3]$-methyllithium (0.2 mol) in dry diethyl ether (5 $cm^3$), was added dropwise, at 0 °C, to a solution of but-3-yn-2-one[44] (0.75 g) in anhyd. diethyl ether (25 $cm^3$). The mixture was allowed to stir at 0 °C for 30 min, and then at 25 °C for 15 h. Water (2 $cm^3$) was added, the mixture extracted with diethyl ether ($2 \times 25$ $cm^3$), the ethereal extract washed with water ($2 \times 10$ $cm^3$), and dried ($Na_2SO_4$). Removal of the solvent gave 2-$[^2H_3]$methylbut-3-yn-2-ol (0.5 g, 52% yield), which was O-methylated[45] with dimethyl sulfate to give 3-methoxy-3-$[^2H_3]$methylbutyne (0.45 g, 42% yield), which was then hydrolysed[39] to give 3-methoxy-3-$[^2H_3]$methylbutan-2-one (0.25 g, 47% yield, $^2H_3$ = 99%).

*3-Methyl-3-*$[^2H_3]$*methylthiobutan-2-one.* To a solution of 3-bromo-3-methylbutan-2-one (1.5 g) in anhyd. methanol (30 $cm^3$) under nitrogen and at 0 °C, was added $[^2H_3]$methylthiolithium[46] (0.8 g). The mixture was allowed to stir at 0 °C for 1 h, and at 25 °C for 46 h. The methanol was removed *in vacuo*, a mixture of water–diethyl ether (1 : 1; 50 $cm^3$) was added, the ethereal layer separated, washed with water (25 $cm^3$), and dried ($Na_2SO_4$). Removal of the solvent gave 3-methyl-3-$[^2H_3]$methylthiobutan-2-one (0.9 g, 73% yield, $^2H_3$ = 99%).

* 1 Torr ≈ 133 Pa.

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