Pergamon

*Tetrahedron*, Vol. 52, No. 11, pp. 3973-3982, 1996

0040-4020/96 $15.00 + 0.00

S0040-4020(96)00051-8

# Studies on Dioxirane Chemoselectivity: the Oxidation of an Enamino Moiety Present in a Fischer Carbene Complex

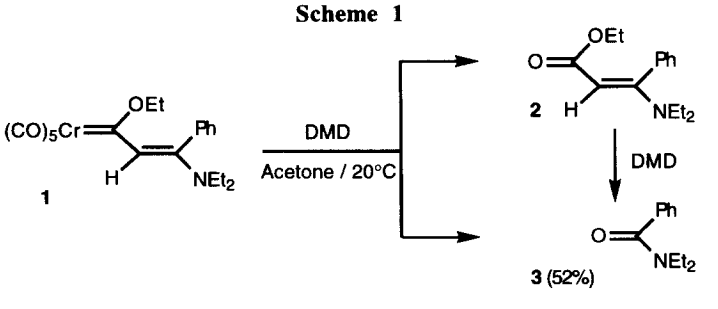
**Anna-Maria Lluch, Mariona Gibert, Francisco Sánchez-Baeza and Angel Messeguer ***

Dpt. of Biological Organic Chemistry, CID (CSIC). J. Girona, 18. 08034 Barcelona, Spain.

**Abstract**: The dimethyldioxirane (DMD) promoted oxidative decomplexation of Fischer carbene complex **1**, which contains a conjugated enamino moiety, was investigated. Thus, treatment of **1** with 3 molecular equivalents of DMD afforded a 52% yield of amide **3** as unique isolable organic product. When the reaction was performed with 1 molecular equivalent of DMD the formation of the enol intermediate **15** was evidenced by its capture as the tetrafluoroboric acid salt **16**. This salt was unstable and when it was exposed to air gave rise to amide **3** and to low amounts of ethyl benzoate and acetophenone. These results indicate that the presence of an enamino group conjugated to the Fischer carbene moiety inverts the chemoselectivity previously observed in the DMD promoted decomplexation of these compounds. Thus, the major pathway involves the oxidation of the enamino double bond through the formation of an enol intermediate which reacts with oxygen to give products resulting from the breakdown of the molecule.

Recently we reported that dimethyldioxirane (DMD) is a valuable reagent for the oxidative decomplexation of Fischer carbene complexes.[1] In some cases, the more powerful reagent methyl(trifluoromethyl)dioxirane (TFMD) was required for accomplishing the decomplexation reaction in satisfactory preparative yields.[2] From the different compounds examined it was apparent that the oxidation of the metal carbonyl moiety was preferred to that of the organic ligand. However, when this decomplexation reaction was assayed on a Fischer carbene molecule bearing a conjugated enamine moiety, *i.e.*, compound **1**, the expected enaminoester **2** was not obtained. Instead, *N,N*-diethylbenzamide (**3**), was isolated in 52% yield (Scheme 1).

**Scheme 1**




According to dioxirane reactivity,[3] carbene complex **1** presents three sites susceptible of attack by DMD, *i.e.*, the carbene moiety, the nitrogen atom and the enamine double bond. The above result could be explained assuming the initial formation of enaminoester **2**, the expected compound resulting from the decomplexation, which could then react with excess DMD to give **3**. Alternatively, the enamine moiety present in **1** might undergo a direct oxidative cleavage to render **3** as the unique isolable organic compound. In this latter case, the

enamine moiety would had been the most reactive center of the carbene complex towards DMD. The present paper reports the results obtained for elucidating the pathway operating in this oxidation reaction. This study might contribute to shed additional light to the problem of chemoselectivity in dioxirane reactivity, particularly in molecules containing heteroatoms and unsaturated moieties.[4]

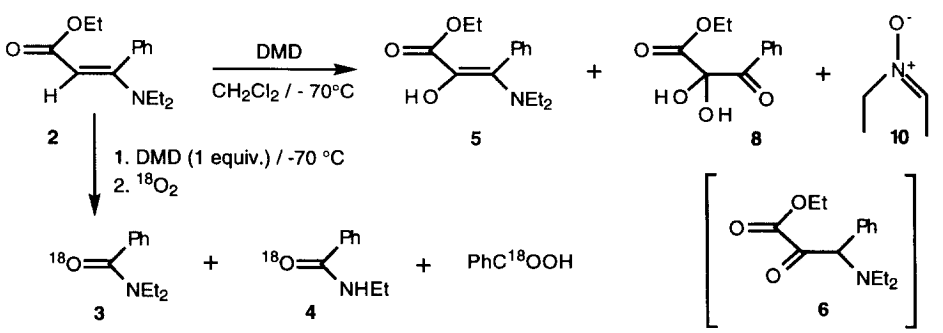
## Results and Discussion

**Reaction with model enamines**. After the preliminary results obtained from the reaction of **1** with DMD, we focused our attention on the oxidation of enamine **2**, which can be considered as a model of that one present in carbene complex **1**. Enamines are highly oxidizable molecules and their reaction with peroxyacids [5,6] or *N*-sulfonyloxaziridines [7] affords products that could be rationalized by the initial formation of a hypothetical epoxy intermediate, although the enamine substitution pattern would also condition the reaction course.[8]

Concerning the reaction of enamines with DMD, Adam et al. described the oxidation of enamines derived from aldehydes to give 1,4-dioxane derivatives. These compounds would had been originated from a formal dimerization of the corresponding epoxy intermediates.[9] Subsequently, this same group reported the reaction of DMD with ketone derived enamines bearing silyl substituted nitrogen atoms, which enabled the NMR detection of the corresponding epoxy intermediates at low temperature, although the rearranged α-aminoketones were the compounds finally isolated.[10]

In our case, reactions of enamine **2** with DMD were conducted in anhydrous dichloromethane in an inert atmosphere, observing after 30 min at -70 °C the total conversion of the substrate using 3 molar equivalents of the oxidation reagent. The analysis of the crude reaction mixture by GC showed the presence of two peaks, which were distinct from that corresponding to amide **3**. However, the GC analysis of the residue obtained after solvent elimination showed the absence of one of the these peaks and the concomitant presence of that corresponding to amide **3**. Moreover, when the elimination of solvent was carried out in the absence of oxygen, the original GC profile was maintained. Finally, an experiment carried out with 1 molar equivalent of DMD at -70 °C, followed by elimination of solvent in a $^{18}O_2$ atmosphere, showed the conversion of the above initial intermediate into $^{18}O$ labeled amide **3** as major compound (GC/MS analysis). Labeled *N*-ethyl benzamide (**4**) and benzoic acid were also detected, although in very low amounts, in the crude reaction mixture. (Scheme 2).

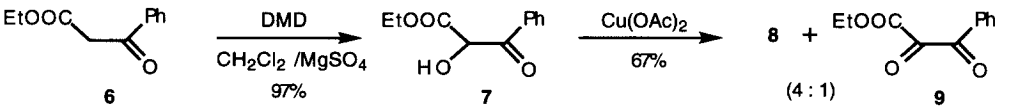
**Scheme 2**



The above unstable intermediate was identified as enol **5**. The presence of a quadruplet at 3.07 ppm and a triplet at 1.05 ppm (J = 7 Hz) in the $^1$H NMR spectrum indicated that the $NEt_2$ group was still linked to the C=C moiety. Likewise, the absorptions corresponding to the aromatic hydrogen atoms and to the ethoxy moiety were not different from those of enaminoester **2**, and no peaks that could be attributed to hydrogen atoms of an epoxide ring or α to a carbonyl group were observed. Instead, a broad singlet at 5.3 ppm which was assigned to the enol hydroxy group was detected. With respect to the $^{13}$C NMR data, significant shifts in comparison with those of **2** were observed for C-3 (from 161.9 (**2**) to 139.0 (**5**) ppm) and C-2 (from 85.4 (**2**) to 124.2 (**5**) ppm), which were in agreement with the effects reported for the presence of an oxygen atom linked to a C=C bond.[11] These data were more consistent with the structure of enol **5** in front of its putative rearranged product, ketone **6** (Scheme 2). Finally, the formation of amide **3** by reaction of this intermediate with oxygen supported its identification as enol **5**. Actually, the oxidative cleavage of 1,2-diarylethenols to give carbonyl and carboxyl derivatives has been described.[12]

The second product formed in the reaction of enamine **2** with DMD was identified as hydrate **8** by comparison with an authentic sample independently prepared. Thus, treatment of ethyl benzoylacetate with DMD afforded the corresponding acyloin **7** [13] which was further oxidized by $Cu(OAc)_2$ to give a 4:1 mixture of **8** and the structurally related α-dicarbonyl derivative **9** (Scheme 3). In this context, previous work by Curci et al.[14] and Bovicelli et al.[15] on the oxidation of 1,2-diols with dioxiranes supported the reluctance observed for the DMD mediated oxidation of the above acyloin to give **9**. The fact that acyloin **7** did not afford **8** or **9** upon treatment with DMD indicated that it was not an intermediate in the formation of **8** from the oxidation of enamine **2**.

**Scheme 3**



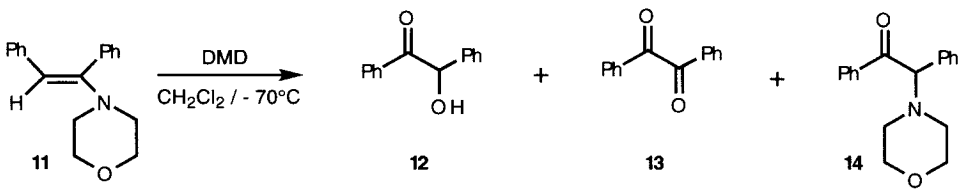

Reaction of **2** with 3 molar equivalents of DMD gave a 23:77 mixture of enol **5** and hydrate **8**, and this ratio was not substantially modified by performing the oxidation at 0 or 20 °C. Use of lower amounts of DMD led to the partial recovery of unreacted enamine. For instance, reaction with 2 molar equivalents of DMD at 0 °C afforded a 38:25:34 **2**:**5**:**8** mixture of products (GC), and use of more than 3 DMD molar equivalents gave a lower amount of enol **5** with the concomitant increase in hydrate **8**. These results suggested that further oxidation of enol **5** might give rise to diketone **9**, which would be easily hydrated in DMD solutions to render **8**.

With respect to the diethylamino moiety present in enamine **2**, analysis of the crude reaction mixture after the elimination of solvents revealed the presence of nitrone **10** (Scheme 2) The formation of this compound could be rationalized assuming the release of diethyl amine during the conversion of **5** into **9**, and its further oxidation by DMD.[16]

The results obtained from the oxidation of enamine **2** prompted us to assay the reaction with another model enamine, *i.e*, compound **11**, where the polarization induced by the ester moiety in **2** was absent (Scheme 4). Reaction of **11** with 3 DMD molar equivalents at -70 °C afforded a mixture of benzoin (**12**), benzil (**13**) and ketone **14** in a 15:37:26 ratio, respectively ($^1$H NMR). When 1.5 molecular equivalents of DMD were used, a 21:27:52 **12**:**13**:**14** ratio, respectively, was obtained. As occurred above, acyloin **12** did not yield benzil upon

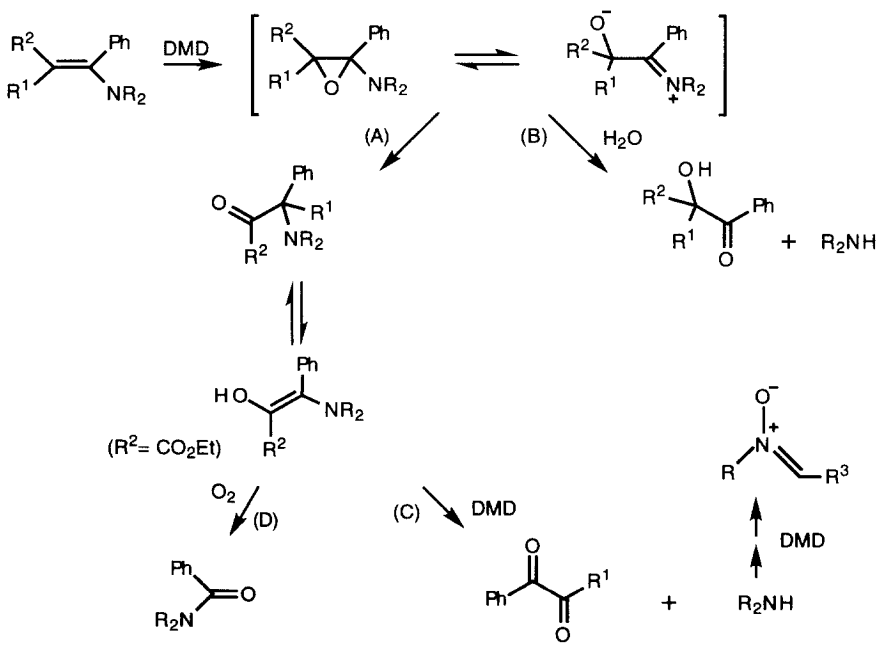
treatment with DMD. Likewise, it was observed that ketone **14** was slowly converted by DMD into **13**. Finally, the presence of water led to a slow hydrolysis of enamine **11** (30% after 5 days at 20 °C), and in contrast to what happened with enamine **2**, the ketone generated (which was not enolized in $CDCl_3$ solution), did not give acyloin **12** by treatment with DMD. These results suggested that benzil was probably originated from the oxidation of the rearranged ketone **14**, and that benzoin did not arise from **14** or from the oxidation of the enamine hydrolysis product.

**Scheme 4**




In summary, it appears that DMD performs a rapid reaction on the enamine double bond to form an epoxy intermediate which can give rise to different products (Scheme 5).

**Scheme 5**



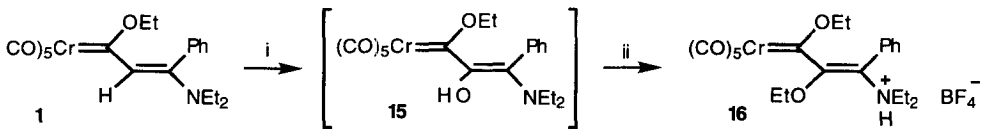

It is worth of noting that no product originated from a preferential attack on the nitrogen atom was detected, in agreement to that previously reported by using either DMD or other electrophilic oxidation reagents.[7,9,10] This

epoxy intermediate or its zwitterionic tautomer, if contains a ß hydrogen atom, would rearrange to give the corresponding ketone as major product (pathway A). On the other hand, it can react with nucleophiles present in the reaction medium. In the case of water, this reaction would originate the acyloin (pathway B), and the relative rates of both processes would determine the ratio of products obtained. In addition, the rearranged carbonyl intermediate might be in equilibrium with its enol form, and this species could then react with excess DMD to give diketone derivatives and compounds arising from the oxidation of the released secondary amine (pathway C), or with oxygen leading to breakdown products such as the corresponding amide (pathway D).

According to these proposed pathways, rearrangement of the hypothetical initial epoxy intermediate to the corresponding ketone would be the preferential reaction for the case of enamine **2**. This ketone intermediate would be converted into its enol tautomer **5**, a highly unstable compound susceptible of further oxidation by DMD and/or $O_2$ to give the reaction products shown in Scheme 2. In this context, the presence of labeled amide **4** and benzoic acid in addition to amide **3** in the experiments carried out in $^{18}O_2$ atmosphere indicates that breakdown of enol **5** is a complex process in which radical intermediates are probably involved. This fact could explain the moderate yields systematically obtained in amide **3**.

**Reaction of DMD with carbene complex 1**. With these antecedents, the reaction of carbene complex **1** with DMD was investigated to elucidate whether the carbene or the enamine moiety was the initial target of the oxidation reagent. As indicated above, treatment of **1** with 3 molar equivalents of DMD afforded a 52% yield of amide **3** as sole organic isolable product. Therefore, assuming that in parallel to what occurred with model enamine **2**, the enamine double bond could be the more reactive species in **1**, the detection of the putative enol intermediate **15** was attempted (Scheme 6). For this purpose, the oxidation of **1** with 1 molecular equivalent of DMD was assayed. However, the formation of enol **15** was not detected by NMR, even working at low temperatures. Consequently, its indirect detection by formation of an enol ether was contemplated.

**Scheme 6**




i: DMD (1 equiv.), $CH_2Cl_2$/acetone, -30 °C
ii: $Et_3OBF_4$, $CH_2Cl_2$/acetone, -70° C

When the orange-brown precipitate formed in the reaction of **1** with DMD at -30 °C in $CH_2Cl_2$ was treated with $Et_3OBF_4$, an intense red colour was developed. The residue obtained after elimination of solvent at -70 °C was partially soluble in $CDCl_3$. The oil separated from this organic solution was dissolved in $CD_3COCD_3$. The $^1H$ and $^{13}C$ NMR spectra of the $CDCl_3$ solution showed the presence of a complex mixture of compounds in which unreacted **1** was the only product identified. Conversely, the spectral data obtained from the $CD_3COCD_3$ fraction indicated the presence of a major compound which was identified as the tetrafluoroboric salt of the enol intermediate **16**. Thus, absorptions at 344, 223 and 215 ppm in the $^{13}C$ NMR spectrum showed that the pentacarbonylcarbenechromium structure was maintained. It is remarkable that the carbon atom absorption in **1** (292 ppm) was shifted downfield to 344 ppm in **16**. This difference suggested that intermediate **16** lacks of the

stabilization due to conjugation present in **1**. On the other hand, the $^1H$ NMR spectrum showed the resonances from four ethyl groups (5.28, 4.61, 4.26 and 3.97 ppm for the $CH_2$ quadruplets). In this context, the absorptions centered at 4.26 and 3.97 indicated that the nitrogen atom was quaternized. Finally, the absence of resonance attributable to the vinyl hydrogen atom and the presence of two quaternary carbon atom peaks in the $^{13}C$ NMR spectrum (212 and 167 ppm), supported the existence of an enol ether moiety bearing a quaternized nitrogen atom at β-position.

Unfortunately, this salt was too unstable to be isolated. Actually, when exposed to air, this $CD_3COCD_3$ solution gave rise to a mixture of compounds from which amide **3** was the major product (GC/MS analysis). Other minor products identified in this mixture were ethyl benzoate and acetophenone. Formation of these products indicate that radical intermediates are involved in the decomposition process suffered by **16**. It is worth of noting that no evidence of the formation of hydrate **8** or ketone **9** was obtained in these experiments, which rules out the possibility that a direct attack of DMD on the carbene moiety with concomitant release of enamine **2** had occurred.

In conclusion, the above results indicate that the presence of an enamino group conjugated to the Fischer carbene moiety inverts the chemoselectivity previously observed in the DMD promoted oxidative decomplexation of these compounds. Although a partial attack on the carbene moiety cannot be completely discarded, the major pathway involves the oxidation of the enamino double bond. This oxidation follows a similar pattern to that observed for more simple enamines conjugated to carbonyl groups. Crucial steps of this reaction pattern are the formation of an enol intermediate and its further reaction with oxygen to give products resulting from the breakdown of the molecule.

## Experimental Section

Melting points were obtained with a Koffler apparatus and are uncorrected. The IR spectra were recorded in film layer with a Bomen model MB120 apparatus and absorptions are given in $cm^{-1}$. The NMR spectra ($^1H$, 300 MHz; $^{13}C$ NMR, 75 MHz) were recorded with a Varian Unity 300 spectrometer. Unless otherwise indicated NMR spectra were performed in neutralized $CDCl_3$ solutions and chemical shifts are given in ppm downfield from tetramethylsilane for $^1H$ and deuterochloroform for $^{13}C$. The GC-MS-EI spectra (70 eV) were obtained using a Fisons model MD 800 mass spectrometer coupled to a Fisons GC 8000 apparatus, which was equipped with a 25 m HP-5 capillary column.

Benzoin (**12**) and benzyl (**13**) were commercially available. Unless otherwise stated, organic extracts coming from crude reaction mixtures were routinely washed with water, brine and dried over $MgSO_4$, and silica gel was used for the chromatography purifications. Solutions of dimethyldioxirane (70-90 mM) in acetone were obtained as described previously.[17] All experiments carried out under inert atmosphere were conducted in a vacuum line using Ar as inert gas.

**Ethyl (2*E*)-3-diethylamino-3-phenylprop-2-enoate (2).**[18] A mixture of ethyl phenylpropiolate (0.99 g, 5.8 mmol) and diethyl amine (0.46 g, 6.3 mmol) was heated for 7 h at 100 °C under $N_2$ atmosphere. Purification of the crude reaction mixture by bulb-to-bulb distillation afforded pure enamine **2** (175 °C, 1 Torr) (1.3 g, 96% yield). **2**: $^1H$ NMR: 7.44-7.34 (3 H, $H_{Ar}$), 7.23-7.15 (2 H, $H_{Ar}$), 4.81 (s, 1 H, H-2), 3.87 (q, J = 7 Hz, 2 H, $OCH_2$), 3.13 (q, J = 7.0 Hz, 4 H, $CH_2NCH_2$), 1.09 (t, J = 7 Hz, 6 H, 2 x $CH_3$), 1.05 (t, J = 7 Hz, 3 H, $CH_3$ ester); $^{13}C$ NMR: 168.0 (C-1), 161.9 (C-3), 136.9 ($C_{Ar}$), 128.0 and 127.9 ($C_{Ar}H$), 85.4 (C-2),

58.1 ($OCH_2$), 43.7 ($CH_2NCH_2$), 14.3 ($CH_3$ ester), 12.8 ($CH_3$ $NEt_2$); MS 248 ($M^+$+1, 5), 247 ($M^+$, 45), 246 ($M^+$-1, 100), 218 ($M^+$-29, 37), 202 ($M^+$-45, 31).

**(1*Z*)-1-Morpholino-1-phenyl-1-propene (11).**[19] A solution of $TiCl_4$ (1.15 g, 6 mmol) in benzene (10 mL) was added dropwise to a solution of deoxybenzoin (2.0 g, 10.2 mmol) and morpholine (2.7 g, 31 mmol) in benzene (60 mL), maintained at 5 °C under $N_2$ atmosphere. The mixture was stirred for 24 h at 25 °C, filtered and solvent was eliminated under vacuum. Purification of the residue by bulb-to-bulb distillation afforded pure enamine **11** (140 °C, 0.4 Torr) (1.6 g, 60% yield). **11**: $^1H$ NMR: 7.34-7.27 (5 H, $H_{Ar}$), 7.06-6.90 (3 H, $H_{Ar}$), 6.78 (d, J = 7 Hz, 2 H, $H_{Ar}$), 5.62 (s, 1 H, H-2), 3.75 (m, 4 H, $CH_2OCH_2$), 2.90 (m, 4 H, $CH_2NCH_2$); $^{13}C$ NMR: 151.0 (C-1), 138.5 and 136.9 ($C_{Ar}$), 130.4, 128.5, 128.4 ($C_{Ar}H$), 128.2 ($C_{Ar}H$), 127.7 ($C_{Ar}H$), 124.3 ($C_{Ar}H$), 105.9 (C-2), 67.1 ($CH_2NCH_2$), 49.4 ($CH_2OCH_2$); MS: 266 ($M^+$+1, 25), 265 ($M^+$, 88), 264 ($M^+$-1, 100), 206 ($M^+$-59, 66).

**Preparation of acyloin 7**. A solution of DMD (0.7 mmol) was added to a suspension of ketoester **6** (0.12 g, 0.6 mmol) and $MgSO_4$ in $CH_2Cl_2$ (8 ml), and the mixture was stirred at 20 °C until reaction was complete (2 h, HPLC monitoring). The crude reaction mixture was filtered off and the solvent was eliminated to render acyloin **7** (0.13 g, 97% yield), which showed by $^1H$ NMR to be a 84:16 keto:enol mixture. **Ethyl 2-hydroxy-3-phenyl-3-oxopropanoate (7)**[20]: $^1H$ NMR: 8.08 (2 H, $H_{Ar}$ keto form), 7.82 (2 H, $H_{Ar}$ enol form), 7.65 (m, 1 H, $H_{Ar}$), 7.51 (m, 2 H, $H_{Ar}$), 5.60 (s, 1 H, H-2), 4.17 (q, J = 7 Hz, 2 H, $OCH_2$), 1.16 (t, J = 7 Hz, $CH_3$); $^{13}C$ NMR: 193.9 (C-3), 168.6 (C-1), 134.6 ($C_{Ar}$), 129.4 i 128.8 ($C_{Ar}H$), 74.6 (C-2), 62.3 ($OCH_2$), 13.8 ($CH_3$).

**Preparation of diketone 8 and hydrate 9**. A mixture of an aqueous saturated solution of $Cu(OAc)_2$-$H_2O$ (0.73 g, 3.7 mmol) and acyloin **7** (0.13 g, 0.6 mmol) was stirred at 20 °C until reaction was completed (1 h, HPLC monitoring). The precipitate was filtered and the filtrate was diluted with water and extracted with $Et_2O$. Purification of the crude reaction mixture by chromatography afforded a mixture of **8** and its hydrate form **9** in a 35:65 ratio ($^1H$ NMR) (0.08 g, 60% yield). An aliquote of this sample was further distilled bulb-to-bulb to give a **8**:**9** mixture in a 4:1 ratio ($^1H$ NMR).[20] IR: 3450, 1751, 1731, 1689, 1685, 1675, 1596, 1238; $^1H$ NMR: 8.08 (m, 2 H, $H_{Ar}$ hydrate), 8.00 (m, 2 H, $H_{Ar}$ diketone), 7.71 (m, 1 H, $H_{Ar}$ diketone), 7.63 (m, 1 H, $H_{Ar}$ hydrate), 7.55 (m, 2 H, $H_{Ar}$ diketone), 7.47 (m, 2 H, $H_{Ar}$ hydrate), 5.39 (br. s, 1 H, OH), 4.43 (q, J = 7 Hz, 2 H, $OCH_2$, diketone), 4.21 (q, J = 7 Hz, 2 H, $OCH_2$, hydrate), 1.39 (t, J = 7 Hz, $CH_3$, diketone), 1.08 (t, J = 7 Hz, $CH_3$, hydrate); $^{13}C$ NMR: 191.6, 169.8 (CO hydrate), 190.1, 183.8 i 160.5 (CO diketone), 135.4 ($C_{Ar}H$ diketone), 134.5 ($C_{Ar}H$ hydrate), 131.6 ($C_{Ar}$, diketone), 131.5 ($C_{Ar}$, hydrate), 130.1 ($C_{Ar}H$, hydrate), 130.0, 129.1 ($C_{Ar}H$, diketone), 128.7 ($C_{Ar}H$, hydrate), 91.7 (C hydrate), 63.2 ($OCH_2$, diketone), 63.1 ($OCH_2$, hydrate), 13.9 ($CH_3$, diketone), 13.6 ($CH_3$, hydrate); MS: 206 ($M^+$, 0.5), 178 ($M^+$-28, 1), 106 (20), 105 (100), 77 (81).

**Preparation of nitrone 10**. A solution of *N*,*N*-diethyl amine (0.05 g, 0.7 mmol) in acetone (5 mL) was treated with 2 molecular equivalents of DMD for 30 min at 0° C. Elimination of solvent under vacuum afforded compound **10** (0.03 g, 45 % yield), which was identified from its spectroscopic data. *N*-(α-Methylidene)ethyl amine N-oxide:[21] $^{13}C$ NMR: 133.1 (CH=N), 59.9 ($NCH_2$), 13.3 and 12.6 ( 2 x $CH_3$).

**Preparation of amide 3**. A solution of diethyl amine (0.16 g, 2 mmol) in $CH_2Cl_2$ (5 mL) was added dropwise to a solution of benzoyl chloride (0.14 g, 1 mmol) in the same solvent (5 mL) and the mixture was stirred for 30 minutes at 20 °C. The crude reaction mixture was washed with water, 0.5 M NaOH, 0.5 M HCl and dried. The residue obtained after elimination of solvent afforded pure amide **3** (0.16 g, 89% yield). *N*,*N*-

**Diethylbenzamide (3)**:[22] $^1$H NMR: 7.37 (m, 5 H, $H_{Ar}$), 3.53 and 3.26 (br. s, 4 H, $CH_2NCH_2$), 1.21 and1.13 (br. s, 6 H, 2 x $CH_3$); $^{13}$C NMR: 171.3 (CO), 137.2 ($C_{Ar}$), 129.0 ($C_{Ar}H$), 128.3 ($C_{Ar}H$), 126.2 ($C_{Ar}H$), 43.2 and 39.3 ($CH_2NCH_2$), 14.2 ($CH_3$), 12.9 ($CH_3$); MS: 177 ($M^+$+1, 10), 176 ($M^+$, 31), 106 (8), 105 (100), 77 (41).

**Preparation of ketone 14**. A mixture of 2-chloro-2-phenylacetophenone (0.5 g, 2.2 mmol) and morpholine (0.43 g, 4.9 mmol) in toluene (7 mL) was heated for 6 hours under reflux. The crude reaction mixture was cooled down, washed with 10% NaOH and the aqueous phase was extracted with toluene. The residue obtained after elimination of solvent from the joined organic fractions was redissolved in AcOEt and extracted with 1 N HCl. The acid fraction was basified to pH 8 with NaOH and extracted with $CH_2Cl_2$ and dried. The residue obtained after elimination of solvent afforded the expected ketone (0.37 g, 60% yield). **2-Morpholino-2-phenylacetphenone (14)**:[23] IR: 1687; $^1$H NMR: 8.02 (m, 2 H, $H_{Ar}$ PhCO), 7.54-7.24 (8 H, $H_{Ar}$), 4.93 (s, 1 H, H-2), 3.76 (4 H, $CH_2OCH_2$), 2.51 (4 H, $CH_2NCH_2$); $^{13}$C NMR: 197.3 (CO), 136.4 ($C_{Ar}$ PhCH), 134.7 ($C_{Ar}$ PhCO), 133.1 ($C_{Ar}H$ PhCO), 129.7 ($C_{Ar}H$ PhCO), 128.9 ($C_{Ar}H$ PhCO), 128.7, ($C_{Ar}H$ PhCH), 128.5 ($C_{Ar}H$ PhCH), 128.4 ($C_{Ar}H$ PhCO), 76.5 (C-2), 66.9 ($CH_2OCH_2$), 52.2 ($CH_2OCH_2$) ; MS: 281 ($M^+$, 2), 177 ($M^+$-104, 68), 176 ($M^+$-105, 100), 117 (58), 105 (87), 91 (82), 77 (82).

**Reaction of enamine 2 with DMD**. A solution of **2** (0.20 g, 0.8 mmol) in anhydrous $CH_2Cl_2$ (2 mL) was allowed to react with DMD (1.5 mmol) under Ar atmosphere at -70 °C. After reaction was completed (GC monitoring), solvents were eliminated under vacuum in an inert atmosphere at -20 °C, and the residue was dissolved in degassed $CDCl_3$ and transferred into the NMR tube. The NMR analysis showed the presence of a mixture of enol **7**, hydrate **8** and nitrone **10** in a 27:49:24 ratio, respectively. An aliquote from this solution was analyzed by GC/MS. Finally, the residue obtained from the elimination of solvent was purified by chromatography to give hydrate **8** and nitrone **10**, which were identified by comparison with standard samples independently prepared. **Ethyl 3-diethylamino-2-hydroxy-3-phenylprop-2-enoate (5)**: $^1$H NMR: 7.50-7.18 (5 H, $H_{Ar}$), 3.82 (q, J = 7 Hz, 2 H, $OCH_2$), 3.08 (q, J = 7 Hz, 4 H, $CH_2NCH_2$), 1.05 (t, J = 7 Hz, 6 H, $CH_3$ from $NEt_2$), 0.72 (t, J = 7 Hz, 3 H, $CH_3$ ester) ; $^{13}$C NMR: 166.7 (CO), 139.0 (C-3), 136.8 ($C_{Ar}$), 129.9 ($C_{Ar}H$), 128.1 ($C_{Ar}H$), 127.4 ($C_{Ar}H$), 124.2 (C-2), 60.1 ($OCH_2$), 45.1 ($CH_2NCH_2$), 14.1 ($CH_3$ ester), 13.2 (2 x $CH_3$ $NEt_2$); MS: 263 ($M^+$, 18), 234 ($M^+$-29, 3), 190 (6), 189 (14), 162 (29), 161 (46), 160 (40), 133 (14), 132 (100).

A solution of **2** (16 mg, 70 µmol) in $CH_2Cl_2$ (1 mL) was allowed to react with DMD (1.2 mL, 96 µmol) for 30 min at -20 °C under the above inert conditions. The GC analysis of the crude reaction mixture revealed the presence of a 23:23:47 mixture of **2**:**7**:**8**, respectively. Then solvents were eliminated in the vacuum line at -20 °C, the temperature was allowed to reach 20 °C under vacuum, $^{18}O_2$ and degassed acetone (5 mL) were introduced into the system and the mixture was stirred for 3h. The GC/MS analysis of an aliquote of this mixture revealed the absence of enol **7** and the presence of labeled amide **3** as major compound, and traces of labeled *N*-ethyl benzamide (**4**) and benzoic acid. **[$^{18}$O]-3**: MS: 179 ($M^+$+1, 8), 178 ($M^+$, 25), 177 ($M^+$-1, 2), 176 ($M^+$-2, 6), 108 (8), 107 (PhC$^{18}$O, 100), 106 (4), 105 (PhCO, 25), 77 (38).

A solution of **2** (0.11 g, 0.4 mmol) in $CH_2Cl_2$ (5 mL) was allowed to react with DMD (1.3 mmol) for 1h at 0 °C. After evaporation of solvents in the vacuum line at -20 °C, the residue was purified by chromatography to give hydrate **8** (0.05 g, 57% yield) and amide **3** (0.01 g, 13% yield). This latter compound was identified by comparison with a standard independently prepared.

**Reaction of enamine 11 with DMD**. A solution of enamine **11** (0.13 g, 0.5 mmol) in $CH_2Cl_2$ (6 mL) was allowed to react with DMD (0.8 mmol) for 1 hour at -70 °C. The crude reaction mixture was treated as indicated above to give a residue which showed the presence of a mixture of **12**:**13**:**14** in a 21:27:52 ratio ($^1H$ NMR). Purification of this residue by chromatography afforded benzoin (**12**, 0.015 g, 15% yield), benzil (**13**, 0.037 g, 37% yield) and ketone **14** (0.034 g, 26% yield). This latter compound was identified by comparison with a sample independently prepared.

**Preparation of carbene complex 1.** Diethyl amine (0.9 mL, 8.7 mmol) was added to a solution of pentacarbonyl[(ethoxy)phenylethynylcarbene]chromium (0) (3.0 g, 8.6 mmol, prepared according to Fischer and Kreissl [24]) in anh. $Et_2O$ (150 mL) and the mixture was stirred at 20 °C for 15 min. The residue obtained from the elimination of solvent was purified by chromatography to give pure carbene **1** (1.9 g, 63% yield). **Pentacarbonyl[(ethoxy)(*E*)-2-diethylamino-2-phenylvinylcarbene]chromium(0) (1)**:[25] $^1H$ NMR: 7.35-7.41 (3 H, $H_{Ar}$), 7.08-7.15 (2 H, $H_{Ar}$), 6.62 (s, 1 H, =CRH) , 4.14 (q, J = 7.0 Hz, 2 H, $OCH_2$), 3.57 (br. s, 2 H, $NCH_2$), 2.98 (br. s, 2 H, $NCH_2$), 1.42 (br. s, 3 H, $NCH_2CH_3$), 1.02 (br. s, 3 H, $NCH_2CH_3$), 0.56 (t, J = 7.0 Hz, 3 H, $OCH_2CH_3$); $^{13}C$ NMR: 292.0, (C=Cr), 224.4 (CO trans), 219.2 (CO cis), 153.8 (=C), 137.6 ($C_{Ar}$), 128.42 ($C_{Ar}H$), 127.32 ($C_{Ar}H$), 128.3 ($C_{Ar}H$), 117.6 (=C), 73.0 ($OCH_2$), 45.4 ($NCH_2$), 44.6 ($NCH_2$), 14.1 ($OCH_2CH_3$), 11.7 ($NCH_2CH_3$).

**Reaction of carbene complex 1 with DMD**. A soln. of **1** (0.16 g, 0.4 mmol) in acetone (16 mL) was allowed to react with 80 mM DMD, added in 1 equiv. portions during 24 h at -20 °C. After the addition of 4.5 molar equivalents of DMD, reaction was completed. The residue obtained after filtration and elimination of solvents was purified by chromatography on silica gel eluting with 4:1 hexane EtOAc, to give 35 mg (52% yield) of *N,N*-diethyl benzamide.[22]

In another experiment, where all solvents used were previously degassed, a solution of DMD (0.24 mmol) in acetone was added to a solution of complex **1** (0.10 g, 0.24 mmol) in $CH_2Cl_2$ (8 mL) maintained at -30 °C. The mixture was stirred for 15 min and the formation of brownish precipitate was observed. Then a solution of $Et_3OBF_4$ (0.96 mmol) in $CH_2Cl_2$ (1 mL) was added to the reaction mixture and stirring was prolonged for 1 h. A deep red color was developed during this period. After the elimination of solvents at -70 °C, the residue was resuspended in neutralized $CDCl_3$ (2 mL). An oil was separated from this solution, which was redissolved in $CD_3COCD_3$. The analysis of both fractions by $^1H$ and $^{13}C$ NMR revealed, for the $CDCl_3$ fraction, the presence of a complex mixture of compounds from only which the starting complex **1** could be identified. The deuterated acetone fraction contained as major component compound **16**. **16**: $^1H$ NMR: 7.60 (br. s, 5 H, $H_{Ar}$), 5.28 (q, 2 H, J = 6.5, $CH_2O$), 4.61 (br. s, 2 H, $CH_2O$), 4.26 (q, 2 H, J = 6, $CH_2N$), 3.97 (q, 2 H, J = 6, $CH_2N$), 1.72 (t, 3 H, J = 6.5, $CH_3CH_2O$), 1.55 (br. 3 H, $CH_3CH_2N$), 1.37 (br. s, 3 H, $CH_3CH_2N$), 1.27 (br., 3 H, $CH_3CH_2O$); $^{13}C$ NMR: 344.5 (C-1), 223.5 (CO), 215.5 (4 x CO), 212.3 (CN), 167.6 (CO), 133.8 ($C_{Ar}$), 132.7 ($C_{Ar}H$), 130.2 ($C_{Ar}H$), 126.6 ($C_{Ar}H$), 80.7 ($CH_2O$), 56.4 ($CH_2O$), 52.4 ($CH_2N$), 51.0 ($CH_2N$), 15.2 ($CH_3CH_2O$), 14.9 ($CH_3CH_2O$), 13.6 ($CH_3CH_2N$), 13.3 ($CH_3CH_2N$).

**Acknowledgement.** Financial support from CICYT (Grant AGR 178/92), CICYT-Generalitat de Catalunya (Grant QFN 92-4304) and CIRIT (GRQ-93-8016) is acknowledged. Fellowship from the Ministerio de Educación y Ciencia to A-M. L. and from the Generalitat de Catalunya to M.G. are also acknowledged. We also thank Dr. S. Ricart for her advice on the preparation of carbene complexes.

## Notes and References


1. Lluch, A. M.; Jordi, L.; Sanchez, B. F.; Ricart, S.; Camps, F.; Messeguer, A.; Moreto, J. M. *Tetrahedron Lett.* **1992**, *33*, 3021-3022.
2. Barluenga, J.; Canteli, R.-M.; Florez, J.; Garcia-Granda, S.; Gutierrez-Rodriguez, A. *J. Am. Chem. Soc.* **1994**, *116*, 6949-6950.
3. For reviews on dioxiranes see: a) Adam, W., Hadjiarapoglou, L. P., Curci, R., Mello, R., in *Organic Peroxides* W. Ando, Ed. (John Wiley, Chichester, 1992) pp. 195-219. b) Murray, R. W., *Chem. Rev.* **1989**, *89*, 1187-1201.
4. Ferrer, M.; Sánchez-Baeza, F.; Messeguer, A.; Diez, A.; Rubiralta, M. *J. Chem. Soc., Chem. Commun.* **1995**, 293-294.
5. Bernhard, H. O.; Reed, J. N.; Snieckus, V. J. *J. Org. Chem.* **1977**, *42*, 1093-1095.
6. Back, T. G.; Edwards, O. E.; Macalpine, G. A. *Tetrahedron Lett.* **1977**, 2651-2654.
7. Davis, F. A.; Sheppard, A. C. *Tetrahedron Lett.* **1988**, 4365-4368.
8. In this context, it has been reported the first isolation of an α-aminoepoxide from the reaction of singlet oxygen with a pyrrole derivative: Wasseman, H. H.; Frechette, R.; Rotello, V. M.; Schulte, G. *Tetrahedron Lett* **1991**, *32*, 7571-.
9. Adam, W.; Peters, E. M.; Peters, K.; Von, S. H. G.; Voerckel, V. *Chem. Ber.* **1992**, *125*, 1263-1266.
10. Adam, W.; Ahrweiler, M.; Paulini, K.; Reissig, H. U.; Voerckel, V. *Chem. Ber.* **1992**, *125*, 2719-2721.
11. Breitmaier, E.; Voelter, W. *Carbon 13-NMR Spectroscopy: High resolution methods and Applications in Organic Chemistry and Biochemistry", 3rd. Ed.*; VCH Verlagsgesellschaft: Weinheim, 1987.
12. Hart, H.; Rappoport, Z.; Biali, S. E. In *The Chemistry of Enols*; Z. Rappoport, Ed.; John Wiley & Sons: New York, 1990; pp 516-583.
13. Adam, W.; Prechtl, F. *Chem. Ber.* **1991**, *124*, 2369-2372.
14. Curci, R.; D'Accolti, L.; Detomaso, A.; Fusco, C.; Takeuchi, K.; Ohga, Y.; Eaton, P. E.; Yip, Y. C. *Tetrahedron Lett.* **1993**, *34*, 4559-4562.
15. Bovicelli, P.; Lupattelli, P.; Sanetti, A.; Mincione, E. *Tetrahedron Lett.* **1995**, *36*, 3031-3034.
16. Murray, R. W.; Singh, M. *J. Org. Chem.* **1990**, *55*, 2954-2957.
17. Adam, W.; Bialas, J.; Hadjiarapoglou, L. *Chem. Ber.* **1991**, *124*, 2377.
18. *Beilstein* **1906**, *Band XIV*, 524.
19. White, W. A.; Weingarten, H. *J. Org. Chem.* **1967**, *32*, 213-214.
20. Karrer, P.; Kebrle, J.; Thakkar, R. M. *Helv. Chim. Acta* **1950**, *33*, 1711-1724.
21. Dicken, C. M.; DeShong, P. *J. Org. Chem.* **1982**, *47*, 2047-2051.
22. Hauser, C. R.; Walker, H. G. *J. Am. Chem. Soc.* **1947**, *69*, 295-297.
23. Sasaki, T.; Kanematsu, K.; Minamoto, K.; Fujimua, H. *Chem. Pharm. Bull.* **1964**, *12*, 191-195.
24. Fischer, E. O.; Kreissl, F. R. *J. Organomet. Chem.* **1972**, *35*, C47-C51.
25. Aumann, R.; Heinen, H.; Hinterding, P.; Sträter, N.; Krebs, B. *Chem. Ber.* **1991**, *124*, 1229-1236.


(*Received in UK* 18 *December* 1995; *accepted* 11 *January* 1996)