PERKIN 1

Effects of catalysts on the cyclization of 2-diazo-2-methoxycarbonyl-*N*-aryl-*N*-alkylethanamides

Keith Smith * and Dawoud Bahzad

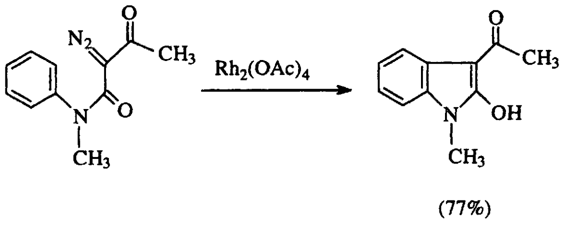
Department of Chemistry, University of Wales, Swansea,† Swansea SA2 8PP, UK

Inorganic solids have pronounced effects on the product distribution from decomposition of the title compounds; zeolite Kβ is particularly useful for directing the synthesis of indolinones such as 5-methoxy-*N*-methylindolin-2-one, which is formed in 89% yield from 2-diazo-2-methoxycarbonyl-*N*-(4-methoxyphenyl)-*N*-methylethanamide; speculation is made about a possible mechanism.

Introduction

Catalysed decomposition of α-diazocarbonyl compounds[1-4] can be a useful synthetic method. In particular, intramolecular cyclization reactions of diazoamides and diazoesters can provide a valuable route to heterocyclic compounds.[4-12] Unfortunately, the reactions can often lead to a variety of products and the selectivity is strongly influenced by the nature of any α-substituents and by electronic, steric and conformational factors in the rest of the molecule.[8] Therefore, it is not always easy to predict the outcome of any particular reaction which has not been previously studied.

The role played by the catalyst in such reactions has not been extensively investigated. Dirhodium tetraacetate has been widely used and is believed to generate intermediate rhodium carbenoid species.[5-9] These intermediates provide selective reactions in favourable cases such as the cyclization of *N*-aryldiazoacetoacetamides [*e.g.* eqn. (1)].[7]



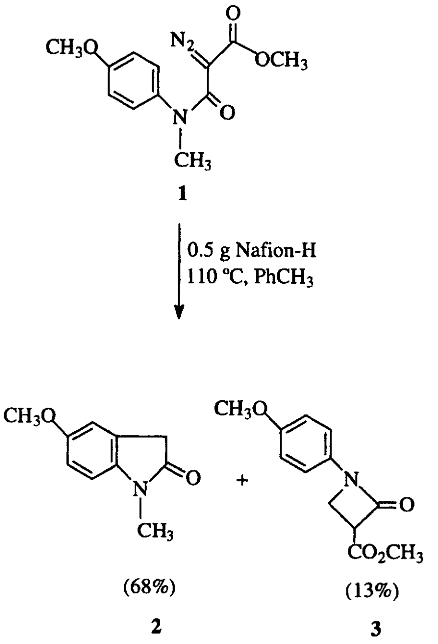
(1)

Acid-catalysed reactions are favoured in other cases.[9-12] For example, Nafion-H has been recommended for the cyclization of *N*-aryl-2-methoxycarbonyldiazoacetamides.[10,11] Even so, two products are generally obtained in significant quantities [*e.g.* eqn. (2)].[10]

In view of our interests in the use of solids for catalysis and control of organic reactions[13-20] and in the synthesis of heterocyclic compounds[21-25] we undertook to investigate the effectiveness of different catalysts for the reaction depicted in eqn. (2), in the hope of finding procedures which would render such reactions of even greater value for organic synthesis. We now report that the nature of the additive can indeed influence the reaction product mixture and recommend a superior procedure for synthesis of compound **2** and its analogues.

Results and discussion

Compound **1** was prepared according to the literature procedure (Scheme 1).[10] We then subjected it to decomposition under a standard set of conditions (toluene solution, reflux, 20 h) in the presence of a variety of potential catalysts.



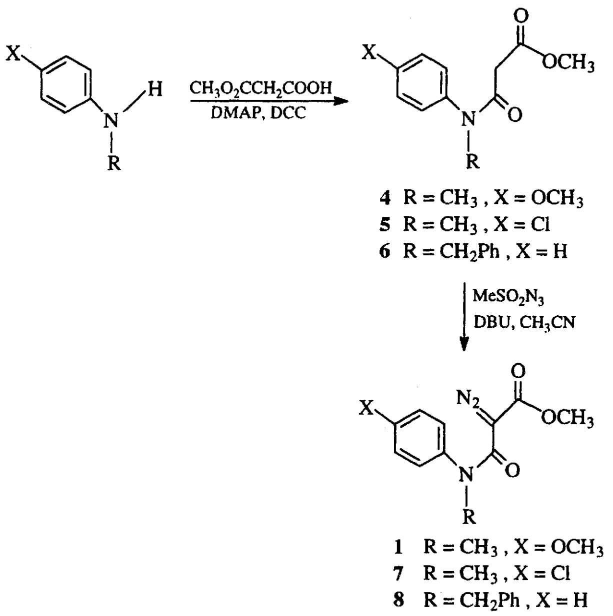
(2)

Initial experiments were carried out without an added catalyst, and in the presence of Nafion-H, dirhodium tetraacetate or a solution phase acid (methanesulfonic acid) as catalyst, in order to provide a baseline against which to compare other potential catalysts. A range of different acidic solids, including an ion-exchange resin (Amberlyst XN1010), several amorphous inorganic solids (silica, alumina, Synclyst-25 silica–alumina), an acid-treated clay (K10) and a variety of different acidic zeolites (HX, HY, Hβ, H-mordenite, H-ZSM5, HA), was then tested under the same conditions. After the reaction period the catalyst was removed and the reaction mixture was analysed by GC. This revealed that five different compounds were formed in significant quantities in one or other of the reactions. The five compounds were isolated and purified using column chromatography of appropriate reaction mixtures and were identified as compounds **2**, **3**, **9**, **10** and **11** by mass spectrometry and NMR spectroscopy. Compound **11** was produced only when methanesulfonic acid was used as catalyst.

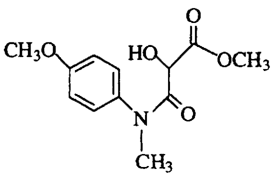
GC Response factors with respect to an added standard (hexadecane) were determined for compounds **2**, **3**, **9**, **10** and **11**, which then enabled calculation of the absolute amounts of each component formed in the reactions described above. A complication arose if there was any residual **1** in the mixture

---

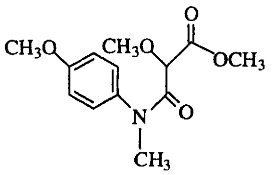
† Formerly known as the University College of Swansea.



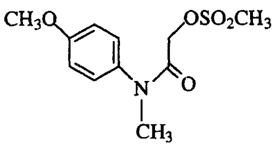
Scheme 1



9



10

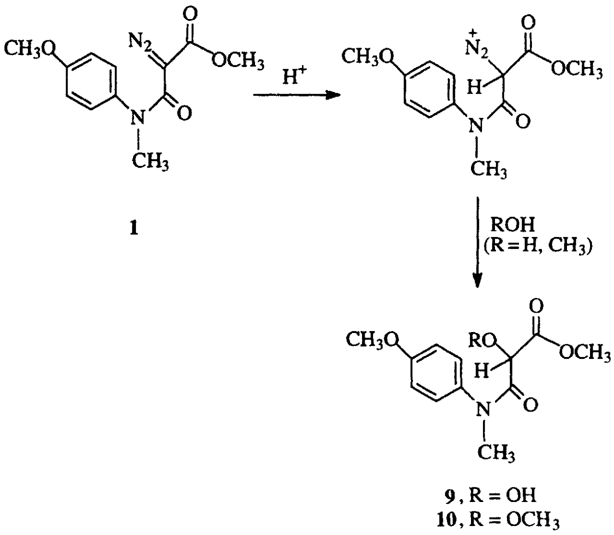


11

because this compound would decompose to give a mixture of **2** and **3** in the injection block of the gas chromatograph. Fortunately, the methoxy groups on the aromatic rings of the various compounds could be clearly distinguished in the proton NMR spectra of the mixtures, which allowed estimation of the amount of residual **1**. A correction could then be made for the sizes of the peaks due to **2** and **3** in the GC, and since there was only ever a small quantity of **1** present, the total values for all compounds could be calculated. The results obtained are recorded in Table 1. It can be seen that residual **1** was present only for reactions with silica gel or zeolite HX as catalyst; in the presence of other catalysts **1** was completely consumed.

Several features emerge from the results in Table 1. Obviously, formation of compound **11** is possible only in the case when methanesulfonic acid is the catalyst. However, if a similar process were to occur with sulfonic acid resins the product would be covalently bound to the resin. This could explain the relatively low material balance observed with Amberlyst XN1010 and could also have influenced the **2**:**3** ratio observed with Nafion-H. The relatively low material balances observed with rhodium acetate, alumina, Synclyst 25, K10 and HX must be due to different phenomena, and it would be wise to place little weight on the **2**:**3** ratios achieved in such cases unless more is known about the means of loss of product from the system.

In cases where significant amounts of compounds **9** and/or **10** are obtained the ratio **2**:**3** increases substantially, while the ratio **2**:(**3** + **9** + **10**) remains within a narrow range (1.8–3.6, except for the case of dirhodium tetraacetate where the material balance is so low as to make comparison meaningless). This suggests that **9** and **10** may result from trapping by water or methanol of an intermediate which is involved in the formation of **3**. It is also interesting that the appearance of compounds **9** and **10** generally coincides with the use of a strongly acidic solid. This suggests that **9** and **10** arise *via* protonation of the initial diazo compound (Scheme 2).



Scheme 2

In accordance with this suggestion, the ratio of **2**:(**3** + **9** + **10**) is higher for weakly acidic solids than for strongly acidic solids. This suggested that even higher yields of **2** might be achieved by use of inorganic solids which are more basic and less acidic than those recorded in Table 1. Therefore, a range of ion-exchanged zeolites was tested (Table 2).

As can be seen from Table 2, different cation-exchanged forms of the same zeolite can produce significantly different product mixtures. Within the series of cation-exchanged β-zeolites, for example, the ratio of **2**:(**3** + **9** + **10**) varies from 1.9 to 10 with material balances all close to 100%. The alkali metal-exchanged examples almost invariably give a higher proportion of **2** than the proton form, clearly demonstrating that acidity is not the primary factor promoting formation of **2**. It is possible that the zeolite acts as a base to mop up any acid and inhibit the reaction depicted in Scheme 1 or that the determining feature is the surface and pore structure of the solid. Whatever the precise reason, it is clear that the potassium forms of mordenite, ZSM-5 and particularly zeolite β can give excellent yields of **2**, the latter giving the highest yield ever recorded for this reaction (89%). Potassium carbonate was also examined as a catalyst to see if a simple base would give comparable results, but the reaction gave a mixture of **2** (16%), **3** (25%) and residual **1** (5%).

Having shown that Kβ and K-mordenite give an excellent yield of **2**, it was of interest to investigate the effects of these catalysts with different examples. Compounds **7** and **8** were therefore prepared according to literature procedures (Scheme 1).[10] Each compound was then reacted with Kβ and K-mordenite as catalyst under the standard set of conditions (toluene solution, reflux, 20 h) according to eqn. (3). The results are presented in Tables 3 (for **7**) and 4 (for **8**).

The results in Tables 3 and 4 show that Kβ and K-mordenite as catalysts give better yields of **12** and **13** than in the absence of a catalyst. They also reduce the amounts of **14** and **15**, thereby producing better ratios of **12**:**14** and **13**:**15**. K-Mordenite is

Table 1 Effect of different catalaysts on the decomposition of compound **1**

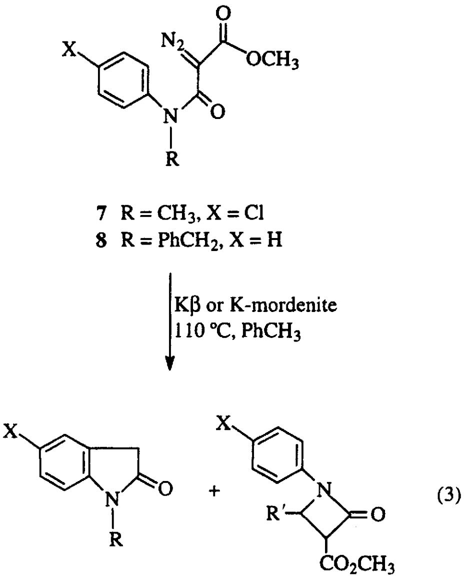
	Yields of compounds **1**–**3**, **6** and **7** in the product (%)[b]						Ratio	Ratio
Catalyst[a]	**1**	**2**	**3**	**9**	**10**	Total	**2**:**3**	**2**:(**3** + **9** + **10**)
None	—	70	20	—	—	90	3.5	3.5
$Rh_2(OAc)_4$	—	19	16	14	—	49	1.2	0.63
Nafion-H	—	61	16	1	13	88	3.8	2.3
$MeSO_3H$	—	23	—	—	—	51[c]	—	—
Amb-XN1010	—	46	1	11	1	59	46	3.5
Silica gel 60	3	72	20	—	—	95	3.6	3.6
Alumina	—	63	18	—	—	81	3.5	3.5
Synclyst 25	—	45	18	—	—	63	2.5	2.8
K10	—	56	21	—	—	77	2.7	2.7
HX	3	59	23	—	—	85	2.6	2.6
HY	—	62	—	31	4	97	—	1.8
Hβ	—	64	2	28	3	97	32	1.9
H-mordenite	—	72	18	7	—	97	4.0	2.9
H-ZSM5	—	70	23	—	—	93	3.0	3.0
HA	—	70	30	—	—	100	2.3	2.3

[a] 0.5 g Catalyst for 1 mmol **1** in 15 ml toluene at reflux for 20 h. [b] Estimated by GC (NMR in the case of compound **1**); inorganic solid catalysts were decomposed with hydrofluoric acid to ensure complete recovery of material. [c] Includes 28% of **11**.

Table 2 Effect of ion-exchanged zeolites on the decomposition of compound **1**[a]

	Yields of compounds **1**–**3**, **9** and **10** in the product (%)[b]						Ratio	Ratio
Catalyst[c]	**1**	**2**	**3**	**9**	**10**	Total	**2**:**3**	**2**:(**3** + **9** + **10**)
Naβ	—	70	19	7	—	96	3.7	2.7
Kβ	—	89	7	1	<1	98	12.7	10
Csβ	—	77	20	1	—	98	3.9	3.7
Caβ	—	64	18	14	—	96	3.6	2.0
NaX	3	53	12	—	—	68	4.4	4.4
KX	—	67	11	—	—	78	6.1	6.1
NaY	2	60	30	—	—	92	2.0	2.0
KY	3	62	23	3	2	93	2.7	2.2
Na-mordenite	2	66	31	—	—	99	2.1	2.1
K-mordenite	—	81	15	—	—	96	5.4	5.4
Na-ZSM5	—	71	22	—	—	93	3.2	3.2
K-ZSM5	—	81	17	—	—	98	4.7	4.7
NaA	—	72	21	—	—	93	3.4	3.4
KA	—	77	17	—	—	94	4.5	4.5
CaA	2	66	31	—	—	99	2.1	2.1

[a] 0.5 g Catalyst per 1 mmol of **1** in 15 ml of toluene, 110 °C, 20 h. [b] Estimated by GC (NMR in the case of compound **1**). [c] For results with proton-form catalysts, see Table 1.



7 R = CH_3, X = Cl
8 R = $PhCH_2$, X = H

(3)

12 R = CH_3, X = Cl
13 R = $PhCH_2$, X = H

14 R′ = H, X = Cl
15 R′ = Ph, X = H

not as good as Kβ. Indeed, Kβ is an excellent catalyst for cyclization of **8**, producing a good yield of **13** (83%) with a high selectivity ratio of **13**:**15** (13.8). The cyclization of **7** is less selective, but the yield of **12** over Kβ is respectable (56%) and significantly higher than in the absence of a catalyst. Since Kβ is the best catalyst for synthesis in all three cases tried, we recommend this catalyst in general for similar cyclizations.

Although not all catalysts produce **9** and **10**, it can be seen that both Hβ and HY have the ability to form relatively high yields of these products. This suggested that it might be possible to increase either **9** or **10** by addition of water or methanol to the reaction, as shown in Table 5. Indeed, on addition of water in the presence of HY, the yield of product **9** was increased to 42%, a higher absolute yield than the total of **3**, **9** and **10** in the absence of water. When methanol was added the yield of product **10** was increased to 29%. We have not attempted to gain further improvements in the yields of **9** and **10**, which are normally undesirable products from the reaction, but these results can help in understanding the reaction.

Conclusion

The results obtained in this study require some reassessment of the mechanisms of the reactions leading to **2** and **3**. It seems likely that the two arise *via* different intermediates and we

Table 3 Effect of potassium zeolites on the decomposition of **7** according to eqn. (3)

Catalyst	Yield (%)[b] **7**	**12**	**14**	Total	Ratio **12**:**14**
None	6	40	52	98	0.8
Kβ[a]	2	56	39	97	1.4
K-mordenite[a]	2	52	43	97	1.2

[a] 0.5 g Catalyst per 1 mmol of **7** in 15 ml of toluene, 110 °C, 20 h. [b] Estimated by GC (NMR in the case of compound **7**).

Table 4 Effect of potassium zeolites on the decomposition of **8** according to eqn. (3)

Catalyst	Yield (%)[b] **8**	**13**	**15**	Total	Ratio **13**:**15**
None	13	69	12	94	5.8
Kβ[a]	7	83	6	96	13.8
K-mordenite[a]	9	74	12	95	6.2

[a] 0.5 g Catalyst per 1 mmol of **8** in 15 ml of toluene, 110 °C, 20 h. [b] Estimated by GC (NMR in the case of compound **8**).

Table 5 Effect of water and methanol on HY zeolite catalysed decomposition of **1**[a]

Additive	Yield (%)[b] **1**	**2**	**3**	**9**	**10**	Total	Ratio **2**:(**3** + **9** + **10**)
H_2O, 0.025 ml	—	42	—	42	>1	84	1.0
H_2O, 0.075 ml	—	35	—	42	>1	77	0.81
MeOH, 0.025 ml	—	54	—	12	29	95	1.3
MeOH, 1.05 ml	—	67	—	6	24	97	2.2

[a] 0.5 g HY per 1 mmol of **1** in 15 ml of toluene, 110 °C, 20 h. [b] Estimated by GC (NMR in the case of compound **1**).

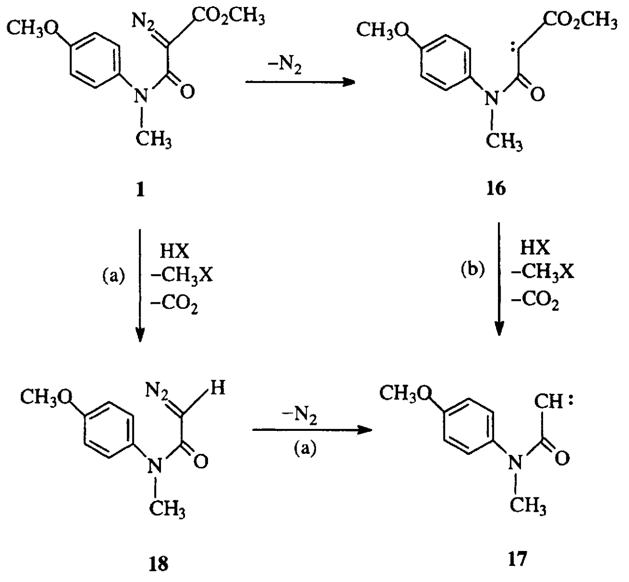
speculate that these might be the two carbenes **16** and **17** (Scheme 3), with **17** being formed *via* demethoxycarbonylation at some stage [pathway (a) or (b)].

According to this speculation, compound **2** would be formed from **17** and **3** from **16**. The fact that strongly acidic solids reduce the amount of **3** (to favour **9** and **10**) more than they reduce **2** favours pathway (a) (*via* **18**) for formation of **17**. If **2** is formed from **17** rather than *via* **16** it would also explain why we never see any trace of the 3-methoxycarbonyl derivative of **2** in any reactions. Precursor **18** could also be an intermediate leading to **11**. Alkali cation forms of zeolites might be able to encourage demethoxycarbonylation by acting as nucleophiles without simultaneously catalysing formation of **9** and **10** according to Scheme 1. Much more work would be required in order to test these mechanistic speculations, but they are consistent with all the observations to date, whereas previous speculations are not consistent with some of the new results reported herein.

Probably the most significant finding, however, is that zeolite Kβ is an excellent catalyst for encouraging the selective formation of **2** from **1** in very high yield and similarly giving higher yields of **12** and **13** from **7** and **8**, respectively. This catalyst is therefore recommended for such cyclization reactions.

Experimental

NMR Spectra were recorded in deuteriochloroform solutions using a Bruker AC 400 spectrometer at 400 MHz for ^1H and 100 MHz for ^{13}C spectra. Chemical shifts (δ) are reported in parts per million (ppm) relative to tetramethylsilane; *J* values are given in Hz. Mass spectra (MS) were recorded using a VG 12-250 for low resolution spectra and VG ZAB-E for high resolution spectra at 70 eV for EI or with ammonia as ionising gas for CI. GC Analyses of reaction products employed a Philips PU 4400 gas chromatograph fitted with a capillary RTX-1 (100% dimethyl polysiloxane) column, operated isothermally at 240 °C. Preparative reactions were monitored by TLC on Merck silica gel 60_{F254} pre-coated on aluminium sheet,[26] and then chromatographed over silica gel.[8,10]



Scheme 3

Standard reagents were used as purchased. Solvents were used as purchased and were of Analar types. Methanesulfonyl azide was prepared according to the procedure of Boyer.[27,28] (**CAUTION**! This reagent is potentially explosive[28,29] and should be handled with care, especially during distillation.)

Preparation of anilides[10]

The appropriate aniline derivative (1.0 mmol) and methyl hydrogen malonate[30] (0.13 g, 1.1 mmol) were dissolved in dry dichloromethane (5 ml) under nitrogen. DMAP (4-Dimethylaminoplyridine) (0.012 g, 0.1 mmol) was added, the solution was cooled to 0 °C, then DCC (1,3-dicyclohexylcarbodiimide)[31] (0.221 g, 1.07 mmol) was added portionwise. The mixture was stirred for 15 min at 0 °C then at room temperature for 5 h. 1 M HCl (1 ml) was added, the mixture was stirred for 20 min and the precipitated urea was filtered off. The filtrate was washed with 1 M HCl (2 × 5 ml), and sat. aq. $NaHCO_3$ (2 × 5 ml) and then dried (Na_2SO_4). The filtered solution was chromatographed using ethyl acetate as eluent, to give the anilide. Mass and NMR (^1H and ^{13}C) spectroscopy were used to identify the product. (See refs. 8 and 10 for further information.)

***N*-Methyl-*N*-(4-methoxyphenyl)-2-methoxycarbonylethanamide 4.**[10] *N*-Methyl-*p*-anisidine was used as starting material; yield 0.20 g (41%); δ_H 3.21 (2 H, s, CH_2), 3.27 (3 H, s, NCH_3), 3.67 (3 H, s, OCH_3), 3.83 (3 H, s, OCH_3), 6.92 (2 H, dd, *J* 6.7, 2.2, ArH), 7.14 (2 H, dd, *J* 6.7, 2.2, ArH); δ_C 37.6, 41.2, 52.2, 55.5, 115.0, 128.3, 136.2, 159.2, 166.3, 168.2.

***N*-Methyl-*N*-(4-chlorophenyl)-2-methoxycarbonylethanamide 5.** 4-Chloro-*N*-methylaniline was the starting material; yield 1.49 g (84%) (Found: C, 54.72; H, 5.09; N, 5.74. $C_{11}H_{12}NO_3Cl$ requires C, 54.76; H, 5.02; N, 5.81%); δ_H 3.21 (2 H, s, CH_2), 3.28 (3 H, s, NCH_3), 3.67 (3 H, s, OCH_3), 7.19 (2 H, dd, *J* 6.6, 2.1, ArH), 7.40 (2 H, dd, *J* 6.6, 2.2, ArH); δ_C 37.5, 41.2, 52.4, 128.6, 130.2, 134.2, 141.9, 165.7, 168.0; *m/z* (CI) (Found: MH^+, 242.0584. $C_{11}H_{13}NO_3{}^{35}Cl$ requires *M*H, 242.0584), 243 (M^+ for ^{37}Cl, 5%), 241 (M^+ for ^{35}Cl, 15), 168 (23), 141 (100), 127 (8), 101 (8), 77 (5), 59 (25).

***N*-Benzyl-*N*-phenyl-2-methoxycarbonylethanamide 6.** *N*-Phenylbenzylamine was the starting material; yield 1.13 g

(57%); mp 76–77.5 °C (Found: C, 71.95; H, 6.28; N, 4.77. $C_{17}H_{17}NO_3$ requires C, 72.05; H, 6.05; N, 4.95%); δ_H 3.23 (2 H, s, CH_2), 3.68 (3 H, s, OCH_3), 4.92 (2 H, s, $PhCH_2$), 7.00–7.02 (2 H, m, ArH), 7.20–7.34 (8 H, m, ArH); δ_C 41.6, 52.3, 53.1, 127.5, 128.3, 128.4, 128.5, 128.8, 129.7, 136.9, 141.6, 165.9, 168.2; *m/z* (CI) (Found: MH^+, 284.1287. $C_{17}H_{18}NO_3$ requires *M*H, 284.1287), 283 (M^+, 8%), 210 (3), 182 (100), 104 (13), 91 (100), 77 (22), 65 (24).

Diazotization of anilides to produce diazoanilides

The anilide (1.0 mmol) was dissolved in dry CH_3CN (2 ml) under N_2 and cooled to 0 °C. Methanesulfonyl azide ($MeSO_2N_3$)[27,28] (0.242 g, 2.0 mmol) was added followed by dropwise addition of DBU (1,8-diazabicyclo[5.4.0]undec-7-ene) (0.30 ml, 2.0 mmol). The mixture was stirred at 0 °C for 30 min then at room temperature for 6 h, diluted with CH_2Cl_2 (8 ml) and washed with aq. NaOH (3 × 5 ml). The aqueous phase was re-extracted once with CH_2Cl_2 (5 ml). The combined organic extracts were washed with water (10 ml), dried (Na_2SO_4 or $MgSO_4$), filtered and evaporated. The crude product was monitored by TLC, and then chromatographed using ethyl acetate as eluent. Mass and NMR (^1H and ^{13}C) spectra were used to identify the product.

2-Diazo-2-methoxycarbonyl-*N*-(4-methoxyphenyl)-*N*-methylethanamide 1.[10] Compound **4** was used as the starting material; yield 0.10 g (53%); δ_H 3.33 (3 H, s, NCH_3), 3.63 (3 H, s, OCH_3), 3.82 (3 H, s, OCH_3), 6.90 (2 H, dd, *J* 6.7, 2.2, ArH), 7.13 (2 H, dd, *J* 6.7, 2.2, ArH); δ_C 38.8, 52.2, 55.5, 114.7, 127.2, 136.4, 158.4, 160.6, 162.8.

2-Diazo-*N*-(4-chlorophenyl)-2-methoxycarbonyl-*N*-methylethanamide 7. Compound **5** was the starting material; yield 0.63 g (43%) (Found: C, 49.36; H, 4.16; N, 14.57. $C_{11}H_{10}N_3O_3Cl$ requires C, 49.43; H, 3.77; N, 15.73%) (the observed figure for N may be low because of some loss of N_2 by decomposition during the analysis); δ_H 3.35 (3 H, s, NCH_3), 3.58 (3 H, s, OCH_3), 7.15 (2 H, dd, *J* 6.6, 2.1, ArH), 7.33 (2 H, dd, *J* 6.6, 2.1, ArH); δ_C 38.7, 52.2, 127.0, 128.6, 129.5, 132.5, 142.5, 161.0, 161.9; *m/z* (CI) (Found: MH^+, 268.0489. $C_{11}H_{11}N_3O_3{}^{35}Cl$ requires *M*H, 268.0489), 267 (M^+), 239 (15%), 207 (45), 180 (100), 152 (56), 140 (39), 111 (100), 99 (17), 75 (69).

2-Diazo-*N*-benzyl-2-methoxycarbonyl-*N*-phenylethanamide 8. Compound **6** was the starting material; yield 0.82 g (68%) (Found: C, 65.93; H, 5.01; N, 13.42. $C_{17}H_{15}N_3O_3$ requires C, 66.00; H, 4.89; N, 13.59%); δ_H 3.57 (3 H, s, OCH_3), 4.99 (2 H, s, CH_2Ph), 7.09–7.11 (2 H, m, ArH), 7.20–7.33 (8 H, m, ArH); δ_C 52.2, 53.1, 126.5, 127.1, 127.5, 128.4, 128.4, 128.8, 129.4, 136.8, 142.4, 160.8, 162.5; *m/z* (CI) (Found: MH^+, 310.1192. $C_{17}H_{16}N_3O_3$ requires *M*H, 310.1192), 309 (M^+), 281 (2%), 249 (12), 222 (8), 194 (10), 182 (9), 104 (7), 91 (100), 77 (36), 65 (21).

Cyclization reactions of diazo compounds with catalyst—analytical reactions

The diazo anilide (1.0 mmol) was dissolved in dry toluene (15 ml) and the catalyst (0.50 g) was added. The mixture was refluxed, under argon, for 20 h, then cooled to room temperature, filtered and evaporated to remove solvents. The catalyst remaining after filtration was broken down by addition of hydrofluoric acid (40%, 10 ml) and the solution was extracted with dichloromethane (3 × 90 ml). The extract was dried ($MgSO_4$), filtered and evaporated to give a second fraction of product. The two organic fractions were combined and monitored by GC.

Isolation and identification of products

Reactions were performed as described for the analytical procedure. Isolation of a particular product was achieved by column chromatography of a suitable product mixture rich in the component using 40% ethyl acetate–petroleum spirit (bp 60–80 °C) or 20% ethyl acetate–chloroform as eluent. Mass and NMR (^1H and ^{13}C) spectra and GC were used to identify the products.

1-Methyl-5-methoxyindolin-2-one 2.[10] From compound **1** in the presence of silica gel 60 as a catalyst; yield 0.030 g (33%); mp 91–92.5 °C (lit.,[10] 97–98.5 °C); δ_H 3.18 (3 H, s, NCH_3), 3.49 (2 H, s, CH_2), 3.78 (3 H, s, OCH_3), 6.70 (1 H, d, *J* 8.5, ArH), 6.79 (1 H, dd, *J* 8.5, 2.6, ArH), 6.87 (1 H, br s, ArH); δ_C 26.2, 36.1, 55.8, 108.2, 111.9, 112.1, 125.8, 138.8, 155.8, 174.7.

3-Methoxycarbony-1-(4-methoxyphenyl)azetidin-2-one 3.[10] From compound **1** in the presence of silica gel 60 as catalyst; yield 0.025 g (21%); δ_H 3.76 (1 H, t, *J* 5.7, H-4), 3.79 (3 H, s, OCH_3), 3.82 (3 H, s, OCH_3), 3.93 (1 H, dd, *J* 5.7, 2.8, H-3), 4.18 (1 H, dd, *J* 5.7, 2.8, H-4′), 6.88 (2 H, dd, *J* 6.8, 2.2, ArH), 7.29 (2 H, dd, *J* 6.8, 2.2, ArH); δ_C 41.5, 52.8, 53.0, 55.5, 114.4, 117.8, 131.4, 156.5, 158.2, 167.4.

2-Hydroxy-2-methoxycarbonyl-*N*-4-methoxyphenyl-*N*-methylethanamide 9. From compound **1** in the presence of zeolite HY (0.5 g); yield 0.012 g (14%) of a sticky gum which was one peak by GC; δ_H 3.32 (3 H, s, NCH_3), 3.65 (3 H, s, OCH_3), 3.84 (3 H, s, OCH_3), 4.02 (1 H, d, *J* 8.6, CHO*H*), 4.62 (1 H, d, *J* 8.6, C*H*OH), 6.86 (2 H, dd, *J* 6.7, 2.2, ArH), 7.10 (2 H, dd, *J* 6.7, 2.2, ArH); δ_C 38.3, 52.7, 55.5, 69.1, 115.0, 128.9, 134.0, 159.6, 168.3, 169.5; *m/z* (Found: M^+, 253.0950. $C_{12}H_{15}NO_5$ requires *M*, 253.0950), 253 (M^+, 73%), 194 (35), 176 (20), 164 (80), 136 (100), 122 (65).

2-Methoxy-2-methoxycarbonyl-*N*-(4-methoxyphenyl)-*N*-methylethanamide 10. From compound **1** in the presence of zeolite HY (0.5 g); yield 0.006 g (11%) of a sticky gum which was one peak by GC; δ_H 3.27 (3 H, s, NCH_3), 3.29 (3 H, s, OCH_3), 3.76 (3 H, s, OCH_3), 3.84 (3 H, s, OCH_3), 4.35 (1 H, s, C*H*OCH_3), 6.94 (2 H, dd, *J* 6.7, 2.2, ArH), 7.21 (2 H, dd, *J* 6.7, 2.2, ArH); δ_C 38.0, 52.5, 55.5, 58.2, 78.1, 114.8, 128.8, 135.3, 159.4, 166.1, 168.0; *m/z* (Found: M^+, 267.1107. $C_{13}H_{17}NO_5$ requires *M*, 267.1107), 267 (M^+, 35%), 208 (5), 176 (21), 164 (61), 136 (100), 108 (15).

2-Methylsulfonyloxy-*N*-(4-methoxyphenyl)-*N*-methylethanamide 11. From compound **1** in the presence of $MeSO_3H$ as catalyst; yield 0.016 g (25%) of an oil which was one peak by GC; δ_H 3.19 (6 H, s, 2 CH_3), 3.77 (3 H, s, OCH_3), 4.49 (2 H, s, CH_2), 6.88 (2 H, dd, *J* 6.7, 2.2, ArH), 7.06 (2 H, dd, *J* 6.7, 2.2, ArH); δ_C 37.7, 39.4, 55.6, 66.2, 115.4, 128.2, 133.7, 159.7, 165.7; *m/z* (Found: M^+, 273.0671. $C_{11}H_{15}NO_5S$ requires *M*, 273.0671), 273 (M^+, 34%), 164 (14), 150 (60), 136 (100), 122 (50), 79 (45).

1-Methyl-5-chloroindolin-2-one 12. From compound **7** in the absence of a catalyst; yield 0.016 g (25%); mp 114–116 °C (Found: C, 59.68; H, 4.51; N, 7.51. C_9H_8NOCl requires C, 59.66; H, 4.45; N, 7.74%); δ_H 3.19 (3 H, s, NCH_3), 3.51 (2 H, s, CH_2), 6.73 (1 H, d, *J* 8.2, ArH), 7.22–7.27 (2 H, m, ArH); δ_C 26.3, 35.6, 108.9, 124.8, 126.0, 127.6, 127.8, 143.7, 174.4; *m/z* (CI) (Found: MH^+, 182.0373. $C_9H_9NO^{35}Cl$ requires *M*H, 182.0373), 183 (M^+ for ^{37}Cl, 30%), 181 (M^+ for ^{35}Cl, 100), 166 (10), 152 (65), 117 (42), 112 (5), 89 (14), 77 (10) and 63 (6).

3-Methoxycarbonyl-1-(4-chlorophenyl)azetidin-2-one 14. From compound **7** in the absence of a catalyst; yield 0.020 g (24%); mp 86–88 °C (Found: C, 55.22; H, 4.38; N, 5.92. $C_{11}H_{10}NO_3Cl$ requires C, 55.22; H, 4.22; N, 5.86%); δ_H 3.79 (1 H, t, *J* 5.7, H-4), 3.83 (3 H, s, OCH_3), 3.97 (1 H, dd, *J* 5.7, 2.8, H-3), 4.23 (1 H, dd, *J* 5.7, 2.8, H-4′), 7.27–7.33 (4 H, m, ArH); δ_C 41.5, 53.0, 53.2, 117.7, 129.3, 129.5, 136.3, 158.7, 167.1; *m/z* (CI) (Found: MH^+, 240.0427. $C_{11}H_{11}NO_3{}^{35}Cl$ requires *M*H, 240.0427), 241 (M^+ for ^{37}Cl, 9%), 239 (M^+ for ^{35}Cl, 30), 153 (73), 139 (100), 125 (45), 111 (23), 75 (22), 63 (12), 55 (38).

1-Benzylindolin-2-one 13. From compound **8** in the absence of a catalyst; yield 0.013 g (12%) (Found: C, 78.47; H, 5.88; N, 5.83. $C_{15}H_{13}NO{\cdot}0.06\ CHCl_3$ requires C, 78.42; H, 5.67; N, 6.08%) (the compound evaporated on attempted prolonged drying under reduced pressure); δ_H 3.63 (2 H, s, CH_2CO), 4.92 (2 H, s, CH_2Ph), 6.72 (1 H, d, *J* 7.7, ArH), 7.00 (1 H, t, *J* 7.7, ArH), 7.15 (1 H, t, *J* 7.7, ArH), 7.24–7.32 (6 H, m, ArH); δ_C 35.8, 43.7, 109.1, 122.4, 124.4, 124.5, 127.4, 127.6, 127.8, 128.8, 135.8, 144.3, 175.2; *m/z* (CI) (Found: MH$^+$, 224.1075. $C_{15}H_{14}NO$ requires *M*H, 224.1075), 223 (M$^+$, 30%), 194 (5), 180 (3), 104 (4), 91 (100), 77 (12), 65 (26).

3-Methoxycarbonyl-1,4-diphenylazetidin-2-one 15. From compound **8** in the absence of a catalyst; yield 0.009 g (9%) as a gum which was one peak by GC; δ_H 3.84 (3 H, s, OCH_3), 3.99 (1 H, d, *J* 2.6, H-3), 5.34 (1 H, d, *J* 2.6, H-4), 7.05–7.40 (10 H, m, 2 Ph); δ_C 53.0, 57.5, 63.3, 117.2, 124.5, 126.1, 129.07, 129.12, 129.3, 136.2, 137.1, 159.1, 166.7; *m/z* (CI) (Found: MH$^+$, 282.1130. $C_{17}H_{16}NO_3$ requires *M*H, 282.1130), 281 (M$^+$, 7%), 180 (15), 163 (100), 131 (63), 119 (22), 103 (33), 91 (25), 77 (44).

Acknowledgements

We thank the Kuwait Institute for Scientific Research (KISR) for a grant to D. B., the EPSRC for a grant which enabled the purchase of the NMR equipment used in this study and the EPSRC mass spectrometry centre in Swansea for mass spectra. We also thank PQ Zeolites for gifts of zeolite samples.

References

1 M. P. Doyle, *Acc. Chem. Res.*, 1986, **19**, 348; *Chem. Rev.*, 1986, **86**, 919.
2 S. D. Burke and P. A. Grieco, *Org. React.*, 1979, **26**, 61; J. Adams and D. M. Spero, *Tetrahedron*, 1991, **47**, 1765.
3 G. Maas, *Top. Curr. Chem.*, 1987, **137**, 75.
4 A. Padwa and K. E. Krumpe, *Tetrahedron*, 1992, **48**, 5385; A. Padwa and S. F. Horubudde, *Chem. Rev.*, 1991, **91**, 263.
5 M. Hrytsak and T. Durst, *J. Chem. Soc., Chem. Commun.*, 1987, 1150.
6 M. P. Doyle, M. S. Shanklin, S. M. Oon, H. Q. Pho, F. R. Van der Heide and W. R. Veal, *J. Org. Chem.*, 1988, **53**, 3384.
7 N. Etkin, S. D. Babu, C. J. Fooks and T. Durst, *J. Org. Chem.*, 1990, **55**, 1093.
8 A. G. H. Wee, B. Liu and L. Zhang, *J. Org. Chem.*, 1992, **57**, 4404.
9 M. P. Doyle, M. S. Shanklin, H. Q. Pho and S. N. Mahapatro, *J. Org. Chem.*, 1988, **53**, 1017.
10 A. G. Wee and B. Liu, *Tetrahedron*, 1994, **50**, 609.
11 B. Liu and A. G. Wee, *Heterocycles*, 1993, **36**, 445.
12 G. M. Rishton and M. A. Schwartz, *Tetrahedron Lett.*, 1988, **29**, 2643.
13 *Solid Supports and Catalysts in Organic Synthesis*, ed. K. Smith, Ellis Horwood, Chichester, 1992; *Stud. Surf. Sci. Catal.*, 1991, **59**, 55; *Bull. Soc. Chim. Fr.*, 1989, 272.
14 L. Delaude, P. Laszlo and K. Smith, *Acc. Chem. Res.*, 1993, **26**, 607.
15 K. Smith, D. M. James, I. Matthews and M. R. Bye, *J. Chem. Soc., Perkin Trans. 1*, 1992, 1877; K. Smith, D. M. James, A. G. Mistry, M. R. Bye and D. J. Faulkner, *Tetrahedron*, 1992, **48**, 7479.
16 K. Smith and G. Pollaud, *J. Chem. Soc., Perkin Trans. 1*, 1994, 3519.
17 K. Smith and K. B. Fry, *J. Chem. Soc., Chem. Commun.*, 1992, 187.
18 K. Smith and D. Jones, *J. Chem. Soc., Perkin Trans. 1*, 1992, 407.
19 K. Smith, M. Butters, W. E. Paget and B. Nay, *Synthesis*, 1985, 1155; K. Smith, M. Butters and B. Nay, *Synthesis*, 1985, 1157.
20 K. Smith, K. Fry, M. Butters and B. Nay, *Tetrahedon Lett.*, 1989, **30**, 5333; K. Smith, M. Butters and B. Nay, *Tetrahedron Lett.*, 1988, **29**, 1319; A. G. Mistry, K. Smith and M. R. Bye, *Tetrahedron Lett.*, 1986, **27**, 1051.
21 K. Smith, D. Anderson and I. Matthews, *Sulfur Lett.*, 1995, **18**, 79; K. Smith, C. M. Lindsay, I. K. Morris, I. Matthews and G. J. Pritchard, *Sulfur Lett.*, 1994, **17**, 197.
22 K. Smith, A. Small and M. G. Hutchings, *Synlett*, 1991, 485; *Chem. Lett.*, 1990, 347.
23 K. Smith, M. E. W. Hammond, D. M. James, I. J. Ellison and M. G. Hutchings, *Chem. Lett.*, 1990, 351.
24 K. Smith and G. J. Pritchard, *Angew. Chem.*, 1990, **102**, 298; *Angew. Chem., Int. Ed. Engl.*, 1990, **29**, 282.
25 C. M. Lindsay, K. Smith, I. Matthews, W. W. Lam, M. J. Musmar, G. E. Martin, A. F. Hoffschwelle, V. M. Lynch and S. H. Simonsen, *Sulfur Lett.*, 1992, **15**, 68.
26 W. C. Still, M. Kahn and A. Mitra, *J. Org. Chem.*, 1978, **43**, 2923.
27 D. F. Taber, R. E. Ruckle and M. Hennessy, *J. Org. Chem.*, 1986, **51**, 4077.
28 J. H. Boyer, C. H. Mack, N. Goebel and L. R. Morgan, *J. Org. Chem.*, 1958, **23**, 1051.
29 R. L. Danheiser, R. F. Miller, R. G. Brisbois and S. Z. Park, *J. Org. Chem.*, 1990, **55**, 1959.
30 R. E. Strube, *Org. Synth.*, 1963, Coll. Vol. **IV**, 417.
31 B. Neises and W. Steglich, *Angew. Chem., Int. Ed. Engl.*, 1978, **17**, 522.

Paper 6/04821H
Received 9*th July* 1996
Accepted 16*th August* 1996