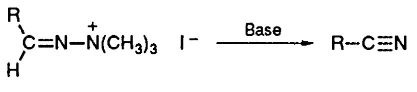
Photoisomerisation of (*E*)- to (*Z*)-*N*,*N*-Dimethylhydrazones and Thermal Reversion

Leo F. Clarke, Fiona O'Sullivan and Anthony F. Hegarty *
Chemistry Department, University College Dublin, Dublin 4, Ireland

The *E*-isomers of aliphatic aldehyde *N*,*N*-dimethylhydrazones undergo competing *E* to *Z* isomerisation and photolysis to nitriles under UV (254 nm) irradiation. The *Z*–*E* isomer mixture which results thermally reverts to the more stable *E*-isomer and under short irradiation times the photoisomerisation/thermal reversion cycle can be reversible. Trimethylacetaldehyde *N*,*N*-dimethylhydrazone undergoes similar reactions (ruling out the intervention of other types of hydrazone isomerisation) and the rates of the thermal *Z*→*E* reactions for RCH=N–NMe$_2$ are in the order R = Bu^t > Et > Me. The results are considered in terms of conformations of the hydrazones and the mechanism of *E*–*Z* isomerisation.

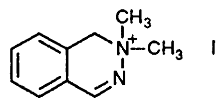
Hydrazonium salts **1** are, in principle, capable of existing as geometrical isomers about the C=N double bond but such isomers have not to date been reported. The individual *E* and *Z* isomers could show a stereochemical effect on the rate of the 1,2-elimination which **1** undergoes to afford the common nitrile **2**.[1] If this is as marked as that reported for the rate of Cl$^-$ loss from (*E*)- and (*Z*)-hydroximoyl chlorides[2] then the availability of *E* and *Z* isomers of **1** would be useful in determining the stereoelectronic factors which control such eliminations.



$$\mathrm{R(H)C{=}N{-}\overset{+}{N}(CH_3)_3\ I^-} \xrightarrow{\text{Base}} \mathrm{R{-}C{\equiv}N}$$

1 **2**

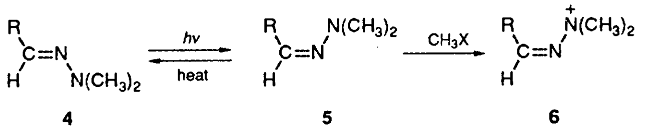
This objective, however, is limited by the fact that aldehydequaternary hydrazonium salts **1** (R = alkyl, aryl) appear to exist only in the *E*-configuration and do not isomerise, either in the presence of acid or by the application of heat.[1] We have examined the isomerisation of **1** (R = Ph) by photochemical means and only observed formation of the nitrile **2**. Direct *E* to *Z* photoisomerisation of **1** therefore appears to be ruled out.



3

Our initial solution to this configurational problem involved examining the phthalazinium iodide **3**, which was taken as a model for the acyclic (*Z*)-hydrazonium salt **1**. Its reactivity relative to acyclic (*E*)-hydrazonium salts enabled us to approximate the stereoelectronic effect as the ratio k_Z/k_E.[1]

We now wish to report on a study of the photoisomerisation of the parent aldehydedimethylhydrazones. Control of this reaction may then provide a viable synthetic route to (*Z*)-hydrazonium salts (Scheme 1); methylation essentially involves the trapping of the thermodynamically less stable *Z*-isomer.



4 **5** **6**

Scheme 1

Results and Discussion

Unlike *N*-monosubstituted hydrazones of aldehydes, *N*,*N*-disubstituted hydrazones (such as dimethyl- and methylphenylhydrazones) exist exclusively in the *E*-configuration not only in the solid but also in the liquid state and in solution.[3] Their isomerisation cannot be induced by heat or by acid treatment.[4]

The available literature[5–10] shows that photoisomerisation studies of hydrazones have primarily involved derivatives of *N*-monosubstituted phenylhydrazones, usually of aromatic aldehydes. The possibility of photoisomerising dimethylhydrazones has not yet been addressed. It has, however, been reported that these compounds are capable of undergoing photo-oxidative cleavage to afford the parent carbonyl compound in yields of 52–88% after irradiation in the presence of oxygen followed by reduction and hydrolysis of the reaction mixture.[11]

In our initial investigation the aliphatic aldehyde *N*,*N*-dimethylhydrazones were directly irradiated with 254 nm monochromatic light, as 10^{-4}–10^{-5} mol dm^{-3} solutions prepared in deoxygenated hydrocarbon solvents. Chemical changes following irradiation were monitored by UV spectroscopy. It was noted that (*E*)-acetaldehyde *N*,*N*-dimethylhydrazone **4** (R = Me) (λ_{max} 245 nm) displayed marked spectral changes after relatively short exposure times (< 5 min) [Fig. 1, spectrum (*b*)]. Prolonged irradiation for 30 min of 1 × 10^{-5} mol dm^{-3} hexane solutions resulted in decomposition of the substrate [Fig. 1, spectrum (*c*)] as confirmed by NMR analysis of the irradiated solution (Fig. 2).

Repetitive scanning of the UV spectrum of the reaction mixture after short irradiation indicated a 'dark' reaction which brought about partial restoration of the system to its initial state [Fig. 3, direction (*b*)]. The thermal relaxation reaction has a sharp isosbectic point at 272 nm. The observation that the final spectrum for thermal relaxation did not exactly superimpose on the UV spectrum of the initial, unirradiated solution (by a factor which depended on the irradiation time) indicates a concurrent (slower) photolytic reaction. The (limited) reversibility of the reaction that followed irradiation was confirmed by the observation that a solution which had already been irradiated and permitted subsequently to reach equilibrium was capable of undergoing the same photo/thermal cyclic phenomenon several times (Fig. 4).

Under optimum conditions (≤15 s irradiation time) quantitative reconversion was observed. The inhibition of photodecomposition by reducing the irradiation time, however, meant that the extent of the observed reaction was also reduced. It was estimated that (*E*)-acetaldehyde *N*,*N*-dimethylhydrazone (2.5 × 10^{-4} mol dm^{-3}) after a 15 s exposure at 254 nm in deoxygenated hexane was isomerised by *ca.* 25% to the (*Z*)-isomer.

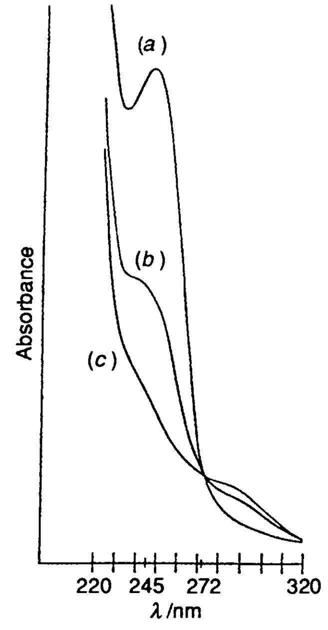


Fig. 1 $CH_3CH=N-N(CH_3)_2$ in pentane (1×10^{-4} mol dm^{-3}): (*a*) UV spectrum prior to irradiation; (*b*) after 15 min irradiation and (*c*) after 30 min irradiation

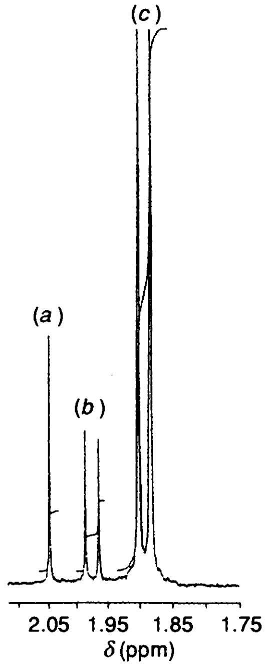


Fig. 2 Partial ^1H NMR spectrum of $CH_3CH=N-N(CH_3)_2$ in CD_3OD after irradiation: (*a*) $CH_3-C\equiv N$; (*b*) (*Z*)-$CH_3CH=NNMe_2$; (*c*) (*E*)-$CH_3CH=NNMe_2$

Table 1 Chemical shift values[a] for (*E*)- and (*Z*)-acetaldehyde *N*,*N*-dimethylhydrazones in CD_3OD

Group (multiplicity)	δ(*E*-isomer)	δ (*Z*-isomer)
CH_3 (d)	1.88, 1.90	1.96, 1.98
H_a (q)	6.6	—
$N(CH_3)_2$ (s)	2.67	2.48

[a] δ Values relative to tetramethylsilane.

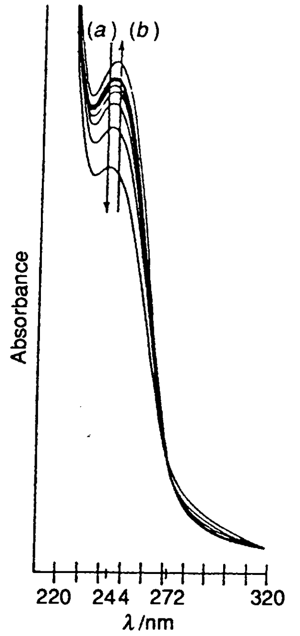


Fig. 3 UV spectra of $CH_3CH=N-N(CH_3)_2$ in hexane (2.5×10^{-4} mol dm^{-3}). *E–Z* photoisomerisation, followed by thermal *Z–E* isomerisation. (*a*) irradiation time: 15 s; cycle time: 10 min; (*b*) $t_{\frac{1}{2}}$ = 12 min (40 °C).

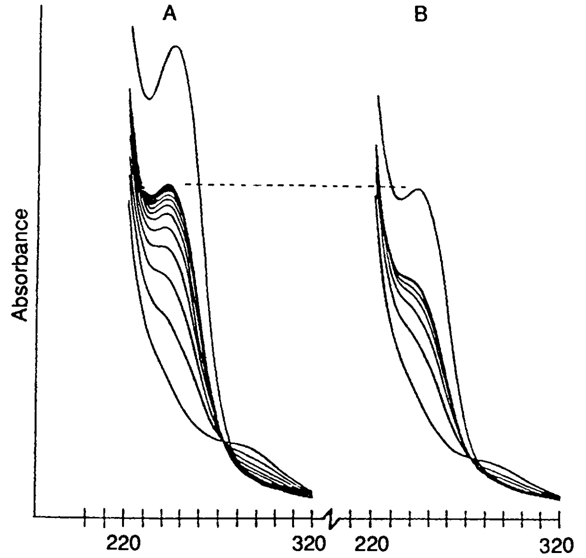


Fig. 4 UV spectra for the double irradiation of $CH_3CH=N-N(CH_3)_2$ in hexane (1×10^{-4} mol dm^{-3}). Irradiation time: 5 min; cycle time: 10 min (in both cases). Second irradiation B was taken several hours after the first irradiation, A.

Support for the conclusion that the photo-reaction was *E–Z* isomerisation was provided by NMR analysis of an irradiated solution in [$^2H_4$]methanol (Table 1). There was no indication of hydrazone–enehydrazine tautomeric species (**7**) being present. Thus it was only possible to detect signals which could be attributed to *E*- and *Z*-isomers of acetaldehyde *N*,*N*-dimethylhydrazone (and to acetonitrile at longer reaction times). The different relative concentrations of the isomers (depending on the extent of irradiation) could be calculated from the downfield shift of 0.08 ppm for the methyl group (doublet) of the acetaldehyde moiety (see Fig. 2) or from integration of the dimethyl amino group (singlet) which interestingly exhibits an upfield shift of 0.19 ppm on *E–Z* isomerisation.

$CH_2=CHNHNMe_2$
7

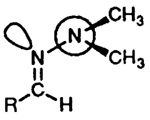
Concomitant changes in the concentrations of the *E*- and *Z*-

isomers after irradiation identified the 'dark' reaction as thermal *Z–E* isomerisation. NMR analysis, furthermore, confirmed that the photodecomposition reaction led to acetonitrile (δ 2.03) as a by-product (Fig. 2). The quantity of acetonitrile formed was related to the UV exposure time but further formation of the nitrile did not occur subsequent to irradiation.

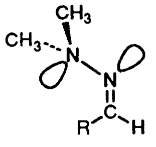
Photolytic reactions are also known in the photochemistry of *N*-monosubstituted hydrazones.[12,13] Decomposition products primarily indicate N–N bond cleavage, although reduction of the hydrazone to a hydrocarbon (applicable only when there is at least one hydrogen atom on the terminal nitrogen of the hydrazone) is also known to occur.

The lithio anions of aldehyde dimethylhydrazones exist predominantly in the *Z*-configuration[14] and unstable *Z*-hydrazones can be obtained on rapid neutralisation with electrophiles. The reported upfield shift ($\Delta\delta$ 0.20) for the dimethylamino singlet for the *Z*-isomer, relative to the *E*-isomer, is similar to that reported here (Table 1).

Unequivocal evidence for *E–Z* photoisomerisation came from an examination of (*E*)-trimethylacetaldehyde *N*,*N*-dimethylhydrazone (**8**, R = Bu^t). This hydrazone, which does not possess α-hydrogens and is thus incapable of hydrazone–enehydrazine tautomerism, was found to display the same behaviour on exposure to UV light as acetaldehyde *N*,*N*-dimethylhydrazone. The resulting thermal relaxation reaction, however, was considerably faster (*ca.* 70 fold) under similar experimental conditions. Thus, under conditions where photodecomposition of the substrate was minimal (254 nm/20 s; cyclohexane/1 × 10^{-4} mol dm^{-3}) the half-life for thermal relaxation was 1.3 min (25 °C). Clearly the greater steric hindrance present in the *Z*-configuration has contributed to this rate increase. In line with this trend, (*E*)-propionaldehyde *N*,*N*-dimethylhydrazone was found to thermally relax *ca.* four times as rapidly as the acetaldehyde analogue.



8, *E*



9, *Z*

The absence of stable *Z*-isomers in aldehyde dimethylhydrazones has been rationalised in terms of conformational isomerism (rotational isomerism) about their N–N single bond.[3d] Thus an aldehyde dimethylhydrazone in the configuration **8** has its lone pair on the amino nitrogen parallel to, and overlapping with, the π-orbitals of its carbon–nitrogen double bond. Its *Z* isomer **9**, on the other hand, is thermodynamically less favourable since the dimethylamino group must rotate out of the plane of the molecule by 90°, with accompanying loss of resonance stabilisation, in order to minimise non-bonding repulsions between R and N(CH$_3$)$_2$. This is consistent with the decrease in UV absorption observed on photoisomerisation. This interpretation is supported by the small extinction coefficient (ε 600) for acetone *N*,*N*-dimethylhydrazone which can be taken as a model for the *Z*-isomer of acetaldehyde *N*,*N*-dimethylhydrazone (**9**; R = CH$_3$), relative to the much larger value (ε 6800) for (*E*)-acetaldehyde *N*,*N*-dimethylhydrazone (**8**; R = CH$_3$)[15] (see also Fig. 1). The stereospecificity of long range spin–spin coupling[4b] and solvent effects[4a] on chemical shifts for dimethylhydrazones also demonstrates the importance of conformational isomerism in these molecules.

The photoisomerisation of (*E*)-2-naphthaldehyde phenylhydrazone[15] showed that when the photostationary state was asymptotically approached from both sides, quantum yields (φ) were found to be independent of the irradiation wavelength despite the substrate's different absorption bands.

The observation that φ does not depend on $\lambda_{\rm exc}$ supports the hypothesis that isomerisation proceeds *via* a common intermediate state, probably a triplet state, populated by an S–T transition from the S$_1$ state only. Homolytic splitting of the C=N bond *via* a triplet transition state would aid torsional motion and thus the likelihood of an internal rotational mechanism. The same conclusion was reached for substituted benzaldehyde phenylhydrazones which were found to undergo a photochemically reversible *E–Z* isomerisation about the C–N bond in cyclohexane solution and in light petroleum.[16]

We have also examined the photochemical behaviour of dimethylhydrazones of a benzaldehyde derivative using (*E*)-*p*-chlorobenzaldehyde *N*,*N*-dimethylhydrazone as a model. While the wavelength of irradiation was considerably displaced from the substrate's maximum absorption (298 nm), the system was also found to undergo photochemical isomerisation and thermal reversion. The latter reaction had a good isosbestic point at 260 nm and photolytic side reactions were minimised by short reaction times. Thermal reversion in this solvent was characterised by a half life of 30 min at 25 °C.

It has been reported[17] that for benzaldehyde methylphenylhydrazone in ethanol (60 °C) the rate constant for thermal relaxation is 3.21 × 10^{-5} s^{-1} and 2.37 × 10^{-5} s^{-1} for benzaldehyde diphenylhydrazone under the same conditions (E_a = 23 kcal mol^{-1}).* Thus the dimethylhydrazone systems which we have monitored in non-protic solvents maintained at 25 °C undergo considerably faster thermal *Z–E* isomerisation.

In conclusion, therefore, the observed photochemical behaviour of dimethylhydrazones of aliphatic and aromatic aldehydes is consistent with *E–Z* isomerisation. The resulting labile *Z*-isomer subsequently undergoes thermal relaxation to afford the thermodynamically more stable *E*-isomer. Concomitant decomposition of the substrate is facile but this can be minimised by careful control of irradiation time.

Experimental

Acetaldehyde N,N-*Dimethylhydrazone*.—*N*,*N*-Dimethylhydrazine (27.29 g, 0.454 mol) was added dropwise, over 2 h, to acetaldehyde (20 g, 0.454 mol) maintained at 0 °C. The reaction was stirred at room temperature for a further 3 h, and solid KOH was added. The organic layer was separated and distilled to yield the hydrazone (27.67 g, 71%), b.p. 93 °C (lit.,[18,19] b.p. 90–93 °C); $\delta_{\rm H}$(CDCl$_3$) 1.87 (3 H, d, *J* 5.13), 2.67 (6 H, s) and 6.66 (1 H, q, *J* 5.13).†

The following *N*,*N*-dimethylhydrazones were prepared similarly: propionaldehyde *N*,*N*-dimethylhydrazone, b.p. 116–118 °C (lit.,[20] b.p. 112–114 °C); $\delta_{\rm H}$(CDCl$_3$) 1.07 (3 H, t, *J* 7.51), 2.26 (2 H, m), 2.72 (6 H, s) and 6.67 (1 H, t, *J* 5.40). Trimethylacetaldehyde *N*,*N*-dimethylhydrazone, b.p. 132 °C, $\delta_{\rm H}$(CDCl$_3$) 1.06 (9 H, s), 2.69 (6 H, s) and 6.59 (1 H, s) (Found: C, 65.7; H, 12.9; N, 21.7. $\rm C_7H_{16}N_2$ requires: C, 65.68; H, 12.58; N, 21.84%). Phenylacetaldehyde *N*,*N*-dimethylhydrazone, b.p. 74 °C (1 mmHg); $\delta_{\rm H}$(CDCl$_3$) 2.76 (6 H, s), 3.57 (2 H, d, *J* 5.68), 6.68 (1 H, t, *J* 5.68) and 7.20–7.35 (5 H, m) (Found: C, 74.35; H, 9.35; N, 17.2. $\rm C_{10}H_{14}N_2$ requires: C, 74.03; H, 8.70; N, 17.27%). *p*-Nitrobenzaldehyde *N*,*N*-dimethylhydrazone, m.p. 113–114 °C (methanol) (lit.,[19,21] m.p. 112 °C, ethanol); $\delta_{\rm H}$(CDCl$_3$) 3.10 (6 H, s), 7.1 (1 H, s), 7.64 (2 H, d, *J* 9) and 8.16 (2 H, s, *J* 9). *p*-Chlorobenzaldehyde *N*,*N*-dimethylhydrazone, m.p. 65–66 °C (methanol) [lit.,[19,21] m.p. 72 °C (ethanol–water)]; $\delta_{\rm H}$(CDCl$_3$) 2.97 (6 H, s), 7.16 (1 H, s), 7.28 (2 H, *J* 8.7) and 7.49 (2 H, d, *J* 8.7) (Found: C, 59.1; H, 6.2; N, 15.4. $\rm C_9H_{11}N_2Cl$ requires: C, 59.18; H, 6.07; N, 15.34%).

---

* 1 cal = 4.184 J.

† Coupling constants are in Hz throughout.

Photochemical Experiments.—The solvents used in the photochemical experiments [pentane (Merck), cyclohexane (Labscan HPLC grade)], were stored in the presence of sodium wire under nitrogen. Photochemical irradiation was carried out using a 'Semi-Micro Photochemical Reactor' (Model RS-55, Applied Photophysics Ltd.) operating at either 254 or 350 nm. The lamp output was 2×10^{16} photons cm^{-3} s^{-1}. The housing was modified to allow watercooling of the reaction cell (which was a standard 10 mm quartz UV cell). Solutions for irradiation (*ca.* 1×10^{-4} mol dm^{-3}) were prepared by injecting 25 mm^3 of a 1×10^{-2} mol dm^{-3} stock solution (in the same solvent) into 2.5 cm^3 of the solvent in a quartz UV cell. When deoxygenated solutions were used a septum was fitted to the cell and the solutions were flushed for at least 30 min using oxygen-free nitrogen (obtained by passing the gas through Fieser's solution).[22] For solutions in the 20–25 cm^3 range the apparatus used (Pen-Ray RCQ9G-1 immersible double bore quartz lamp) consisted of a 10 inch pencil-thin lamp inserted in quartz glass that could be inserted into a test-tube with a side-arm. Cooling was by external water circulation (at 0 °C) and samples for spectroscopic analysis could be withdrawn by means of the side-arm (and subsequently deoxygenated).

Kinetic Measurements.—The kinetics of the thermal relaxation were followed spectrophotometrically using a Cary Model 210 UV spectrometer. First-order rate constants were determined from repetitive scans of the UV region and the experimentally determined infinity values.

References

1 M. T. Nguyen, L. F. Clarke and A. F. Hegarty, *J. Org. Chem.*, 1990, **55**, 6177.
2 A. F. Hegarty and M. Mullane, *J. Chem. Soc., Perkin Trans. 2*, 1986, 995.
3 (*a*) G. J. Karabatsos, B. Shapiro, F. M. Vane, J. Fleming and J. Ratka, *J. Am. Chem. Soc.*, 1963, **85**, 2784; (*b*) G. J. Karabatsos, F. M. Vane, R. A. Taller and N. Hsi, *J. Am. Chem. Soc.*, 1964, **86**, 3351; (*c*) G. J. Karabatsos and C. Osborne, *Tetrahedron*, 1968, **24**, 3361; (*d*) G. J. Karabatsos and R. A. Taller, *Tetrahedron*, 1968, **24**, 3357, 3923.
4 (*a*) G. J. Karabatsos and K. L. Krumel, *Tetrahedron*, 1967, **23**, 1097; (*b*) G. J. Karabatsos, R. A. Taller and F. M. Vane, *Tetrahedron Lett.*, 1964, 1081.
5 G. Wettermark, *The Chemistry of the Carbon–Nitrogen Double Bond*, ed. S. Patai, Interscience, New York, N.Y., 1968, 565.
6 P. Beak and W. R. Messer, *Organic Photochemistry*, ed. O. L. Chapman, Marcel Dekker, New York, 1960, vol. 2.
7 H. O. Kalinowski and H. Kessler, *Topics in Stereochemistry*, 1972, **7**, 255.
8 A. Padwa, *Chem. Rev.*, 1977, **77**, 37.
9 A. C. Pratt, *Chem. Soc. Rev.*, 1977, **6**, 63.
10 R. Paetzold, M. Reichenbacker and K. Appenroth, *Z. Chemie.*, 1981, **21**, 421.
11 E. Friedrich, W. Lutz, H. Eichenauer and D. Enders, *Synthesis*, 1977, 893.
12 (*a*) R. W. Binkley, *J. Org. Chem.*, 1970, **35**, 2796; (*b*) R. W. Binkley, *Tetrahedron Lett.*, 1969, **23**, 1893.
13 S. D. Carson, *J. Org. Chem.*, 1970, **35**, 2734.
14 K. G. Davenport, H. Eichenauer, D. Enders, M. Newcomb and D. E. Bergbreiter, *J. Am. Chem. Soc.*, 1979, **101**, 5654.
15 G. Condorelli, L. L. Costanzo, S. Pistara and S. Guiffrida, *Z. Phys. Chem.*, 1974, **90**, 58.
16 G. Condorelli and L. L. Costanzo, *Boll. Sedute Accad. Gioenia*, 1966, **8**, 753 (*Chem. Abstr.*, 1969, **70**, 3120).
17 G. Condorelli and L. L. Costanzo, *Boll. Sedute Accad. Gioenia*, 1966, **8**, 775 (*Chem. Abstr.*, 1969, **70**, 10815).
18 D. M. Lemal, F. Menger and E. Coats, *J. Am. Chem. Soc.*, 1964, **86**, 2395.
19 R. H. Wiley, S. C. Slaymaker and H. Kraus, *J. Org. Chem.*, 1957, **22**, 204.
20 E. J. Corey and E. Enders, *Chem. Ber.*, 1978, **111**, 1337.
21 R. F. Smith, J. A. Albright and A. M. Waring, *J. Org. Chem.*, 1966, **31**, 4100.
22 L. Fieser and M. Fieser, *Reagents for Organic Synthesis*, John Wiley and Sons, New York, 1967, 393.

Paper 1/02438H
Received 23*rd May* 1991
Accepted 25*th June* 1991