An Improved Method for the Preparation of Monoalkylketens

By Colin C. McCarney and Robert S. Ward,* Department of Chemistry, University College of Swansea, Singleton Park, Swansea SA2 8PP

Staudinger's keten synthesis has been modified to give monoalkylketens, free from starting materials and zinc salts, in 60—65% yield. The polymerisation of methyl- and ethyl-keten is discussed.

VARIOUS methods have been used to prepare ketens.[1-3] The oldest, due to Staudinger [equation (i)],[4] gives excellent yields of stable ketens, but is less satisfactory for the preparation of dialkyl-, monoaryl-, and monoalkyl-ketens (Table 1). Although several attempts have been made to improve the yield of this reaction, most have been unsuccessful.[5,6] However a modified procedure for the preparation of dimethylketen has been described in which 2-bromo-2-methylpropionyl bromide is treated with zinc granules in ethyl acetate at reduced pressure: dimethylketen codistils with the solvent in 46—54% yield.[7]

In recent years the most popular method for the preparation of monosubstituted ketenes has been by dehydrohalogenation of an acyl halide with triethylamine [equation (ii)].[8-11] The reaction is usually carried out *in situ* and therefore suffers from the disadvantage that the triethylamine or unchanged acyl halide may take part in, or alter the course of, any subsequent reactions.[12] Monosubstituted ketens have also been prepared by pyrolysis of ketones and esters [*e.g.* equation (iii)],[13] and methylketen has been obtained in high yield by pyrolysis of propionic anhydride [equation (iv)].[14]

The present paper describes a modification of Staudinger's procedure which enables methyl- and ethylketen to be prepared in solution free from starting materials and zinc salts, in 60—65% yield. Activated zinc dust[15] was suspended in dry tetrahydrofuran

$$RR'CX\cdot C(:O)X \xrightarrow{Zn} RR'C:C:O + ZnX_2 \quad (i)$$

$$RCH_2\cdot C(:O)X \xrightarrow{Et_3N} RCH:C:O + Et_3NHCl \quad (ii)$$

$$EtCOMe \xrightarrow{heat} MeCH:C:O + CH_4 \quad (iii)$$

$$(EtCO)_2O \xrightarrow{heat} MeCH:C:O + EtCO_2H \quad (iv)$$

TABLE 1

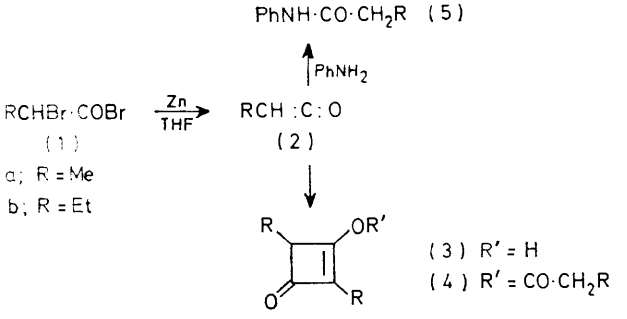
Yields of keten obtained by Staudinger's method

R	R′	Yield (%)	Ref.
Ph	Ph	95	*a*
Biphenylylene		90	*b*
Ph	Me	80—90	*c*
Me	Me	38	*d*
Et	CO_2Et	34	*e*
Ph	H	13	*a*
Me	H	6—8	*f*
Et	H	4—6	*f*
H	H	4—14	*g*

[a] Ref. 4. [b] H. Staudinger, *Ber.*, 1906, **39**, 3062. [c] H. Staudinger and L. Ruzicka, *Annalen*, 1911, **380**, 278. [d] H. Staudinger and H. W. Klever, *Ber.*, 1906, **39**, 968. [e] H. Staudinger and St. Bereza, *Ber.*, 1909, **42**, 4908. [f] H. Staudinger and H. W. Klever, *Ber.*, 1908, **41**, 906; H. Staudinger, *ibid.*, 1911, **44**, 533. [g] H. Staudinger and H. W. Klever, *Ber.*, 1908, **41**, 594; H. Staudinger and J. Kubinsky, *ibid.*, 1909, **42**, 4213.

[1] W. E. Hanford and J. C. Sauer, *Org. Reactions*, 1946, **3**, 108.
[2] R. N. Lacey, in 'Chemistry of Alkenes,' ed. S. Patai, Interscience, 1964, p. 1161.
[3] H. B. Kagan, *Ann. Chim.* (*France*), 1965, **10**, 203.
[4] H. Staudinger, *Ber.*, 1905, **38**, 1735.
[5] C. D. Hurd, F. W. Cashion, and P. Perletz, *J. Org. Chem.*, 1943, **8**, 367.
[6] E. B. Reid and S. J. Groszos, *J. Amer. Chem. Soc.*, 1953, **75**, 1655.
[7] C. W. Smith and D. G. Norton, *Org. Synth.*, Coll. Vol. IV, 1963, p. 348.
[8] W. T. Brady, E. F. Hoff, R. Roe, jun., and F. H. Parry, jun., *J. Amer. Chem. Soc.*, 1969, **91**, 5679; W. T. Brady and L. M. Smith, *Tetrahedron Letters*, 1970, 2963; W. T. Brady and E. F. Hoff, *J. Org. Chem.*, 1970, **35**, 3733; W. T. Brady, J. D. Stockton, and A. D. Patel, *ibid.*, 1974, **39**, 236.
[9] J. Jaz and E. Denis, *Bull. Soc. chim. belges*, 1965, **75**, 845.
[10] J. L. Luche and H. B. Kagan, *Bull. Soc. chim. France*, 1968, 2450.
[11] D. G. Farnham, M. A. T. Heybey, and B. Webster, *J. Amer. Chem. Soc.*, 1964, **86**, 673.
[12] W. T. Brady and O. H. Waters, *J. Org. Chem.*, 1967, **32**, 3703; W. T. Brady and L. Smith, *ibid.*, 1971, **36**, 1637.
[13] C. D. Hurd and C. Kocow, *J. Amer. Chem. Soc.*, 1923, **45**, 2167; C. D. Hurd, *ibid.*, p. 3095; C. D. Hurd, P. Perletz, and S. S. Drake, *J. Org. Chem.*, 1945, **10**, 62.
[14] A. D. Jenkins, *J. Chem. Soc.*, 1952, 2563.
[15] K. Tsuda, E. Ohki, and S. Nozoe, *J. Org. Chem.*, 1963, **28**, 783.

(THF) and the pressure in the apparatus was reduced to 100 mmHg. This allowed the THF to boil gently at room temperature. 2-Bromopropionyl bromide (1a) in tetrahydrofuran was then added dropwise. Methylketen (2a) was immediately formed and codistilled with the THF. The distillate was collected in a receiver cooled in liquid nitrogen. On warming to −78 °C the distillate was observed as a lime green solution whose i.r. spectrum contained a very intense keten band at 2 130 cm^{-1}. The intensity of this band diminished rapidly and on allowing the solution to warm to room temperature it became colourless in 30 min and afforded the dimer (3a) and trimer (4a). Similarly ethylketen (2b) was prepared from 2-bromobutyryl bromide (1b), and polymerised at room temperature to give (3b) and (4b).



The zinc dust was activated by treatment with hydrochloric acid and stored under vacuum.[15] In this form the zinc dust reacted immediately with the acid bromide. When unactivated zinc dust, or zinc dust activated by treatment with copper sulphate,[16] was used, long induction periods were observed.

The yield of the keten preparation was estimated by treating the keten with an excess of freshly distilled aniline at −60 °C. The anilide (5) was formed and unchanged aniline was determined by back titration with hydrochloric acid (Bromophenol Blue).[17] The yields of ketens (2a and b) estimated in this way are given in Table 2 along with the yields of the dimer (3), trimer (4), and anilide (5) actually isolated in each case.

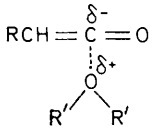
TABLE 2

Yields of products

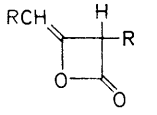
Starting material	% Yield (2) [a]	(3)	(4)	(5)
(1a)	59.5	41	16 [b]	55
(1b)	65.0	19	26 [c]	60

[a] Yield of ketene estimated titrimetrically as described in the text. [b] Polymerisation carried out at −30 °C. [c] Polymerisation carried out at −50 °C.

All attempts to isolate the ketens free from solvent were unsuccessful. A solution of methylketen in THF was slowly brought to 0 °C in the hope that the keten (b.p. −56°) [14] would distil into a receiver cooled in liquid nitrogen. However the green solution remained and no product collected in the receiver. The preparation of methylketen was also carried out in a higher boiling solvent (di-n-butyl ether), at 100 mmHg and room temperature as before. Di-n-butyl ether did not distil over, but neither did the keten. On completion of the reaction, the mixture was green but no product collected in the receiver. One must conclude that the keten is very soluble in polar solvents and can only be separated from the zinc salts and starting materials by codistillation. This may be due to the formation of a weak complex (6) between the keten and the solvent.



(6)



(7) a; R = Me
b; R = Et

Polymerisation of Methyl- and Ethyl-keten.—Staudinger observed that methyl-keten dimerised rapidly in ether to give two products, which have subsequently been shown to be the hydroxy-cyclobutenone (3a) [18,19] and the β-lactone (7a).[20,21] Enk and Spes later found that the trimer (4a) was also formed.[22] They found that the yield of each product varied with temperature and trimer formation did not occur when the reaction was carried out at −50 °C.

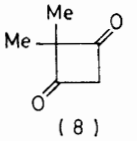
When a solution of methylketen in THF, prepared as described above, was kept at −30 °C overnight, two products, (3a) and (4a), were obtained. The only evidence for the presence of the β-lactone (7a) was a very weak i.r. absorption at 1 875 cm^{-1} in the spectrum of the trimer. Conducting the reaction at lower temperatures did not significantly alter the ratio of dimer to trimer but reduced the rate of polymerisation. Thus at −80 °C the solution was still lime green after 24 h but the trimer was still formed. Ethylketen (2b) likewise gave the dimer (3b) and the trimer (4b). Again little evidence was found for the existence of the β-lactone (7b).

The differences between these observations and those reported [22] may be due to differences in experimental procedure. Thus Enk and Spes prepared the keten in a continuous process by pyrolysis of propionic acid and absorbed the gas in a suitable solvent at a given temperature. This procedure would favour the formation of the dimer relative to the trimer since the keten is always present in low concentration.

The esters (4a and b) were extremely sensitive to moisture. Exposure to the atmosphere for more than

[16] W. T. Brady, H. G. Liddell, and W. L. Vaughan, *J. Org. Chem.*, 1966, **31**, 626.
[17] I. M. Kolthoff and V. A. Stenger, 'Volumetric Analysis: Vol. II—Titration Methods,' Interscience, New York, 1947, p. 126.
[18] R. B. Woodward and G. Small, *J. Amer. Chem. Soc.*, 1950, **72**, 1297.
[19] E. B. Reid, *J. Amer. Chem. Soc.*, 1950, **72**, 2853.
[20] J. R. Johnson and V. J. Shiner, jun., *J. Amer. Chem. Soc.*, 1953, **75**, 1350.
[21] J. Bregman and S. H. Bauer, *J. Amer. Chem. Soc.*, 1955, **77**, 1955.
[22] E. Enk and H. Spes, Ger. Pat., 1,081,455/1960; *Angew. Chem.*, 1961, **73**, 334.

2 min resulted in hydrolysis to the corresponding dimer (3a or b). Hydrolysis was best carried out, however, by treating the trimer with aqueous alcoholic sodium hydroxide: the dimer (3a) was formed in 88% yield. In deuteriochloroform solution (3a and b) exist only as their enol tautomers, as shown by n.m.r. spectroscopy. In contrast 2,2-dimethylcyclobutane-1,3-dione (8) exists entirely as the diketone.[23] As noted previously for (3a),[24] both the hydroxy- and methine protons of (3a and b) are exchanged on treatment with D_2O.



(8)

EXPERIMENTAL

I.r. and u.v. spectra were recorded on a Perkin-Elmer Infracord 257 and a Pye Unicam SP 800 spectrophotometer, respectively. N.m.r. spectra were obtained using a Varian HA-100 instrument (tetramethylsilane as internal reference) and mass spectra using an A.E.I. MS9 double-focussing instrument (electron-beam energy 70 eV; source temperature 250 °C). T.l.c. was performed on silica gel GF_{254} in benzene–methanol–acetic acid (10 : 2 : 1). THF was distilled from lithium aluminium hydride and stored under nitrogen.

2-Bromopropionyl bromide (1a) was prepared from propionic acid by the Hell–Volhard–Zelinsky procedure,[7] and stored under a tapped adaptor in the dark at 0 °C [yield 75%; b.p. 59° at 15 mmHg; $\nu_{max.}$ (film) 1 830, 1 780, and 685 cm^{-1}]. 2-Bromobutyryl bromide (1b) was prepared and stored in the same way (yield 72%; b.p. 78—81° at 30 mmHg).

Preparation of Methylketen (2a).—Activated zinc [15] (3.9 g) and THF (5 ml) were stirred in a flask which had been flushed with nitrogen. The pressure was reduced to 100 mmHg whereupon the THF boiled; the flask was then surrounded by a water bath to prevent cooling. A solution of 2-bromopropionyl bromide (4.3 g) in THF (30 ml) was then added dropwise over 10 min. The methylketen and THF were collected in a receiver cooled in liquid nitrogen. When the addition was complete distillation was continued for a further 5 min before the vacuum was released and nitrogen admitted. The distillate was allowed to warm to −78 °C, giving a lime green solution, whose i.r. spectrum showed a very intense absorption at 2 130 cm^{-1}.

Polymerisation of Methylketen.—When the solution of methylketen was kept at −30 °C for 24 h, t.l.c. showed two products (R_F 0.51 and 0.85). Evaporation left a white solid (0.80 g) which was suspended in light petroleum (b.p. 40—60°), filtered off, and recrystallised from benzene to give 3-hydroxy-2,4-dimethylcyclobut-2-enone (3a) (460 mg), m.p. 141—143° (lit.,[18] 138°; lit.,[19] 139°), R_F 0.51; $\nu_{max.}$ (KBr) 3 500—2 100, 1 950—1 800, and 1 738 cm^{-1}; $\lambda_{max.}$ (EtOH) 208sh (log ε 3.40) and 243 nm (4.07), $\lambda_{max.}$ (EtOH–NaOH) 224sh (3.52) and 256 nm (4.23); τ ($CDCl_3$) −2.41 (1 H, s), 7.6 (1 H, m), 8.49 (3 H, d, *J* 2 Hz), and 8.80 (3 H, d, *J* 7 Hz).

The filtrate remaining was evaporated, leaving a pale yellow oil, 2,4-dimethyl-3-oxocyclobut-1-enyl propionate (4a) (0.18 g), R_F 0.85; $\nu_{max.}$ (film) 1 790, 1 765, and 1 665 cm^{-1}; $\lambda_{max.}$ (EtOH) 206 (log ε 3.83) and 241 nm (4.12); $\lambda_{max.}$ (EtOH–NaOH) 224sh (3.57) and 256 nm (4.31); τ ($CDCl_3$) 6.38 (1 H, m), 7.41 (2 H, q, *J* 8 Hz), 8.40 (3 H, d, *J* 2 Hz), 8.78 (3 H, t, *J* 8 Hz), and 8.80 (3 H, d, *J* 7 Hz).

Hydrolysis of the Trimer (4a).—Sodium hydroxide solution (10%; 2 ml) was added to the ester (43 mg) in ethanol (5 ml) and the mixture was stirred for 2.5 h. The solution was acidified with dilute hydrochloric acid and extracted with ether (2 × 10 ml). The extract was dried ($MgSO_4$), filtered, and evaporated to give a white solid which was recrystallised from benzene to give 3-hydroxy-2,4-dimethylcyclobut-2-enone (3a) (25 mg), m.p. 141—143°.

Reaction of Methylketen with Aniline.—Methylketen was prepared as described above but collected in a flask containing aniline (3.141 g; redistilled from CaH_2). When the reaction was complete the receiver was warmed to −60 °C and the mixture stirred for 15 min; a colourless solution remained which was allowed to warm to room temperature. Aqueous ethanol (50% v/v) was added, followed by Bromophenol Blue, and the whole was titrated against 0.500M-hydrochloric acid (titre 44.0 ml; yield of methylketen 0.665 g).

The acidic solution from the titration was extracted with ether (2 × 50 ml), and extract dried ($MgSO_4$), filtered, and evaporated to leave an off-white solid (2.1 g). This was suspended in light petroleum (b.p. 60—80°), filtered off, and recrystallised from benzene to give *N*-propionylaniline (5a) (1.65 g), m.p. 104—106° (lit., 105—106°); $\nu_{max.}$ (KBr) 3 250, 1 670, 1 605, 1 550, 1 505, and 755 cm^{-1}.

Preparation of Ethylketen (2b).—Ethylketen was prepared by the same procedure as methylketen, from activated zinc (3.9 g) and 2-bromobutyryl bromide (4.6 g). The distillate was lime-green.

Polymerisation of Ethylketen.—When the solution of ethylketen was kept at −50 °C overnight, t.l.c. showed two products (R_F 0.41 and 0.79). Evaporation gave a sticky white solid which was suspended in cold light petroleum (b.p. 40—60°), filtered off, and recrystallised from light petroleum to give 2,4-diethyl-3-hydroxycyclobut-2-enone (3b) (0.26 g), m.p. 87—89° (lit.,[18] 87—88°), R_F 0.41; $\nu_{max.}$ (KBr) 2 400, 1 870, 1 725, 1 520, and 1 270 cm^{-1}; $\lambda_{max.}$ (EtOH) 210 (log ε 3.58) and 256 nm (4.05); $\lambda_{max.}$ (EtOH–NaOH) 225sh (3.23) and 257 nm (3.99); τ ($CDCl_3$) −1.46 (1 H, s), 6.62 (1 H, m), 7.99 (2 H, q, *J* 7 Hz), 8.32 (2 H, 2 quartets, *J* 7 and 6 Hz), 8.98 (3 H, t, *J* 7 Hz), and 9.08 (3 H, t, *J* 7 Hz).

The filtrate remaining from the isolation of (3b) was evaporated to leave an oil (4b) (0.37 g), R_F 0.79, $\nu_{max.}$ (film) 1 875, 1 850, 1 785, 1 755, 1 725, and 1 650 cm^{-1}.

Reaction of Ethylketen with Aniline.—Ethylketen was prepared as described above and treated with aniline (2.689 g) at −60 °C for 15 min. Titration of the solution with 0.500M-hydrochloric acid required 32.0 ml (yield of ethylketen 0.904 g). The *N*-butyrylaniline (5b) was isolated as an off-white solid (1.95 g) and recrystallised from benzene–light petroleum (b.p. 60—80°) to give white leaves (1.6 g), m.p. 93—96° (lit., 97°), $\nu_{max.}$ (KBr) 3 280, 3 250, 1 660, 1 605, 1 550, 1 505, 1 490, and 765 cm^{-1}.

Attempted Isolation of Methylketen.—Method 1. A solution of methylketen in THF was prepared as above. The flask containing the solution was connected by a large U-bend to a receiver which was cooled in liquid nitrogen.

[23] R. H. Hasek and J. C. Martin, *J. Org. Chem.*, 1962, **27**, 3743.
[24] J. S. Chickos, D. W. Larsen, and L. E. Legler, *J. Amer. Chem. Soc.*, 1972, **94**, 4266; J. S. Chickos and R. E. K. Winter, *ibid.*, 1973, **95**, 506.

The flask containing the methylketen solution was then allowed to warm to room temperature in the hope that the methylketen would selectively distil over. However when the solution reached 0 °C the receiver was still empty. After 30 min at room temperature the lime-green colour of the solution had completely disappeared and t.l.c. showed three compounds (R_F 0.76, 0.44, and 0.19). Evaporation left a white solid from which 2,4-dimethylcyclobutane-1,3-dione (320 mg) and the trimer (412 mg) were isolated.

Method 2. 2-Bromopropionyl bromide (2.1 ml) in di-n-butyl ether (10 ml) was added with stirring to activated zinc (3.9 g) and di-n-butyl ether over 10 min at room temperature and 100 mmHg. Under these conditions the di-n-butyl ether did not distil over and at the end of the reaction no product was observed in the receiver.

We thank the S.R.C. and Unilever Ltd. for a C.A.S.E. research studentship (to C. C. M.).

[5/330 *Received*, 17*th February*, 1975]