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A GENERAL METHOD FOR ALKYLATING 2(5H)-FURANONES; REDUCTION OF PRODUCTS TO 3-, 2,3-, AND 3,4-SUBSTITUTED FURANS

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Abstract—The cycloaddition of diazoalkanes, diazoesters and diazoketones to 2(5H)-furanones followed by thermal decomposition of the respective adducts is shown to provide a general method for the preparation of a variety of alkylated 2(5H)-furanones. Reduction of the latter compounds with diisobutylaluminum hydride affords the corresponding substituted furans in good yield.

Although abundant in nature,[1] the alkyl substituted 2(5H)-furanones ($\Delta^{\alpha,\beta}$-butenolides) are relatively inaccessible by synthesis. The previously reported cycloaddition of diazoalkanes to 2(5H)-furanones,[2,3] followed by thermal decomposition, suggested a promising general method of preparing alkyl 2(5H)-furanones. However, it was reported to suffer from certain disadvantages: (1) limitation in scope, notably diazomethane;[2] and (2) production of cyclopropyl derivatives as by-products.[3] The generality of this reaction for the alkylation of 2(5H)-furanones has not been explored in any systematic manner. This paper reports the application of this method to the synthesis of a variety of substituted 2(5H)-furanones and furans.[4]

We have established the usefulness of this reaction sequence by the addition of diazoalkanes, diazoesters and diazoketones to several inexpensive and readily available 2(5H)-furanones. The thermal decomposition of the resulting pyrazoline lactone adducts led in all cases to regeneration of the double bond and to the introduction of a side chain derived from the diazo compound. Because the preparation of diazoalkanes in good yields becomes increasingly more difficult as the carbon number increases, we developed a sequence utilizing a diazoketone which provides an efficient method of introducing a long alkyl chain on 2(5H)-furanones. For example, lauroyl diazomethane was prepared with ease and no difficulty was encountered in its addition to methyl aconate; pyrolysis of the adduct resulted in the introduction of its long carbon chain to methyl aconate.

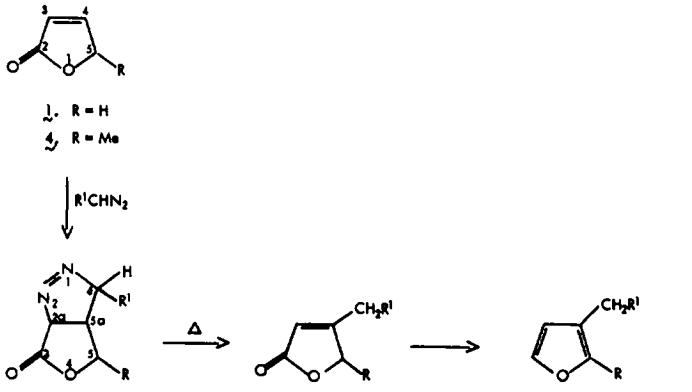
The adducts resulting from addition of diazoalkanes to 2(5H)-furanones bearing an unsubstituted 4 position are all 1-pyrazolines with an N, N double bond (Fig. 1). When either C-5 substituted 2(5H)-furanones (**4**) or monosubstituted diazomethanes are employed in 1-pyrazoline formation, epimeric mixtures are obtained involving C-5 and/or C-6 centers as indicated by NMR data. However, subsequent thermal decomposition of both epimeric adducts proceeds with loss of nitrogen and regeneration of the double bond to afford a single product. The formation of the intermediate epimeric adduct in no way interferes with the overall synthetic scheme. This point will be amplified in more detail.

Addition of diazomethane to γ-crotonolactone (**1**) led exclusively to crystalline pyrazoline **2**, which on pyrolysis afforded 4 - methyl - γ - crotonolactone (**3**). On the other hand, addition of diazomethane to β-angelica lactone* (**4**) gave a mixture of pyrazolines **5**, epimeric at C-5. Mixtures of pyrazolines **7**, **11**, **15** epimeric at C-6 were obtained by reaction of γ-crotonalactone with monosubstituted diazomethanes (R^1 = Me, Et, n-Pr). The stereochemistry is analogous to 1,3-dipolar addition of diazoethane to methyl aconate to be discussed later (Fig. 3). The addition products of monosubstituted diazoalkanes (R^1 = Me, Et, n-Pr) with β-angelica lactone (**4**) are C-5 and C-6 epimeric mixtures of pyrazolines **9**, **13**, **17**, respectively. The pyrazolines **7**, **9**, **11**, **13**, **15**, and **17** were obtained in essentially quantitative yield and were thermally decomposed to give exclusively 4-substituted 2(5H)furanones **8**, **10**, **12**, **14**, **16** and **18**.

When the C-4 position of the 2(5H)-furanone is substituted (Fig. 2), the addition of the diazo compound occurs in the opposite direction to also form a 1-pyrazoline. For example, the addition of diazomethane to methyl aconate (**19**) affords pyrazoline (**20**), which was converted to 3-methyl methaconate (**21**) upon pyrolysis.

Under the same experimental condition, when methyl aconate (**19**) was treated with diazoethane, a mixture of pyrazolines **22a** and **22b** was obtained, epimeric at C-3 (Fig. 3). The relative ratio of **22a** and **22b** (1:2) was obtained by NMR analysis of the cyclo-adducts mixture. The stereoisomeric pyrazolines were separated by fractional crystallization and their structures determined. The structure assignment of compounds **22a** and **22b** was based on NMR absorption of protons at C-3, C-3a and in the C-3–CH_3 group. Molecular models reveal that the dihedral angle between the C-3a and C-3 protons in compound **22a** is near zero degrees, while in compound **22b** the dihedral angle is about 120°. The NMR data agree with these findings. In compound **22a** the signal of the 3a proton is a doublet, J = 9 Hz, while in compound **22b** the corresponding signal is a doublet, J = 2 Hz. Additional confirmation of these structure assignments may be derived from the C-3 proton signal. In **22b** the C-3 proton is a doublet of doublet, at δ = 5·50, (J = 2, 8 Hz), which is shifted to δ 5·22 (J = 8, 2 Hz) in **22a**. This is consistent

*Structure **4** is designated as β-angelica lactone by most authorities, e.g.: Beilstein; Heilbron's *Dictionary of Organic Compounds* (1965); Y. S. Rao, *Chemistry of Butenolides*, in *Chem. Rev.* **64**, (4) 353 (1964). However, *Rodd's Chemistry of Carbon Compounds* (1973) designates structure **4** as α-angelica lactone.



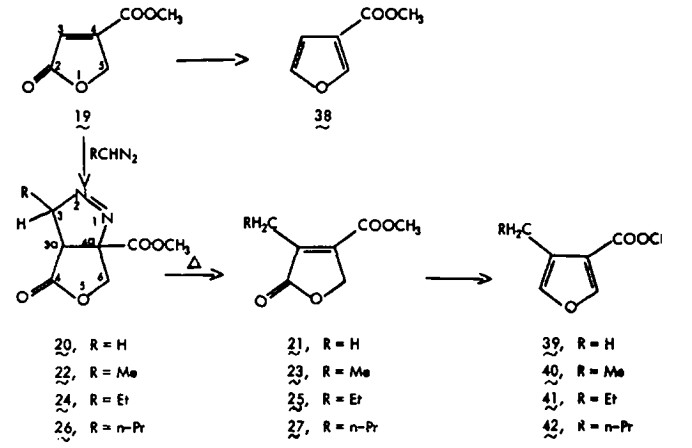
1, R = H
4, R = Me

2, R = R¹ = H
5, R = Me, R¹ = H
7, R = H, R¹ = Me
9, R = R¹ = Me
11, R = H, R¹ = Et
13, R = Me, R¹ = Et
15, R = H, R¹ = n-Pr
17, R = Me, R¹ = n-Pr

3, R = R¹ = H
6, R = Me, R¹ = H
8, R = H, R¹ = Me
10, R = R¹ = Me
12, R = H, R¹ = Et
14, R = Me, R¹ = Et
16, R = H, R¹ = n-Pr
18, R = Me, R¹ = n-Pr

34, R = H, R¹ = n-Pr
35, R = R¹ = Me
36, R = Me, R¹ = Et
37, R = Me, R¹ = n-Pr

Fig. 1.



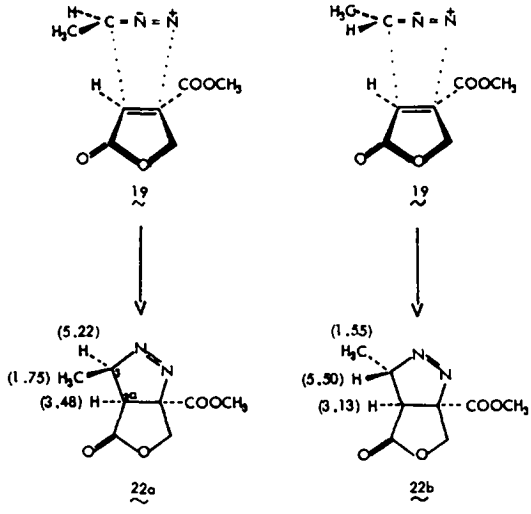
19
38

20, R = H
22, R = Me
24, R = Et
26, R = n-Pr

21, R = H
23, R = Me
25, R = Et
27, R = n-Pr

39, R = H
40, R = Me
41, R = Et
42, R = n-Pr

Fig. 2.



19
19
22a
22b

Fig. 3.

with the C-3 proton being closer to the CO group in **22b** than in **22a**. Also, the C-3–CH_3 group in **22a** is closer to the CO group ($\delta = 1{\cdot}75$) than in **22b** ($\delta = 1{\cdot}55$). Thermal decomposition of compounds **22a** and **22b** gave exclusively compound **23**.

The addition of diazo n-propane and diazo n-butane to methyl aconate afforded pyrazolines **24** and **26**, respectively. Again, each pyrazoline exists as a pair of epimers as indicated by the NMR data. Thermal decomposition of compounds **24** and **26** gave compounds **25** and **27**, respectively.

In contrast to diazoalkanes, which add to 2(5H)-furanones to afford 1-pyrazolines exclusively, ethyl diazoacetate reacts with γ-crotonolactone (**1**) to give the 2-pyrazoline (**28**),[5] with the ester CO group conjugated with the N = C (Fig. 4). Pyrolysis of compound **28** afforded the substituted 2(5H)-furanone (**29**).

Reaction of a diazoketone with a furanone provides an efficient method of introducing a long side chain (Fig. 4). Lauroyl and caproyl diazomethanes add with ease to methyl aconate. The stable conjugated 2-pyrazolines, **30**

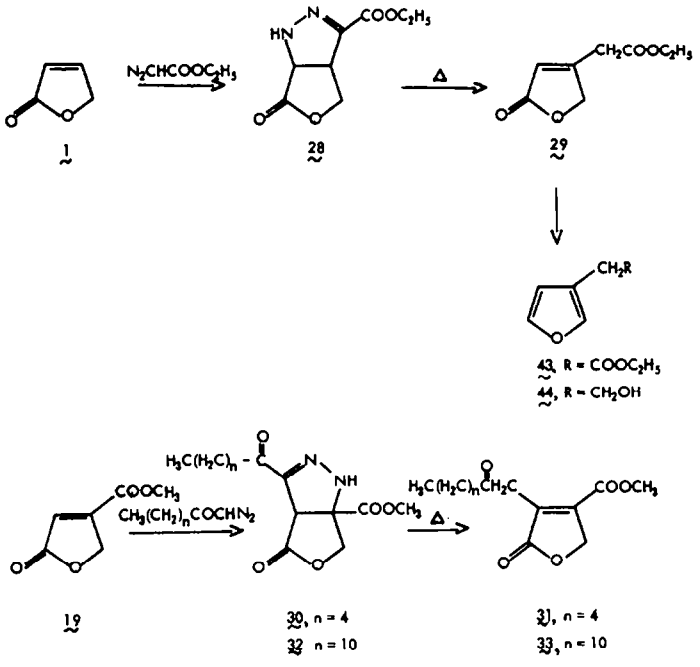


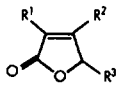
Fig. 4.

and **32**, required a considerably higher temperature (180°) to undergo thermal decomposition. In one attempt, compound **30** was distilled at 160°/1 mm Hg without any decomposition. When heated at 180° for 3 hr, compounds **30** and **32** decomposed with slow bubbling of nitrogen to afford the substituted methyl aconates **31** and **33**, respectively.

Recent reports[6] indicate that α,β-unsaturated γ-lactones attached to certain steroids or terpenes can be reduced with diisobutyl aluminum hydride (DIBALH) to the corresponding furans. No further reports have appeared which demonstrate the general applicability of this reaction, i.e. whether simple α,β-unsaturated γ-lactones can be converted into the corresponding β-substituted furans. Our studies have shown that such compounds may indeed be converted into the corresponding β-substituted furans.

Generally the reaction proceeds as shown in Fig. 5 even

Table 1. Substituted 2(5H)-furanones



Compound	R^1	R^2	R^3	mp or bp/mm Hg	%yield[c]	lit.
1	H	H	H	107-9°/24	*	8
3	H	Me	H	112-2°/14	70	9
4	H	H	Me	89°/15	*	10
6	H	Me	Me	80-2°/1	61	11
8	H	Et	H	65-7°/0.2	70	-
10	H	Et	Me	100-2°/0.9	55	-
12	H	n-Pr	H	103-5°/1	62	-
14	H	n-Pr	Me	107-9°/2	60	-
16	H	n-Bu	H	105-7°/0.6	46	-
18	H	n-Bu	Me	110-2°/0.7	51	-
19	H	CO_2Me	H	86°	*	2[b]
21	Me	CO_2Me	H	145-7°/25	70	2[b]
23	Et	CO_2Me	H	124-7°/3	54	-
25	n-Pr	CO_2Me	H	116-8°/1	59	-
27	n-Bu	CO_2Me	H	126-8°/2.5	51	-
29	H	CH_2CO_2Et	H	148-50°/0.8	80	-
31	CH_2-n-hexanoyl	CO_2Me	H	240°/1[a]	39	-
33	CH_2-n-lauroyl	CO_2Me	H	65-6°	49	-

[a] bath temperature

* used as starting material

[c] based on 2(5H)-furanones

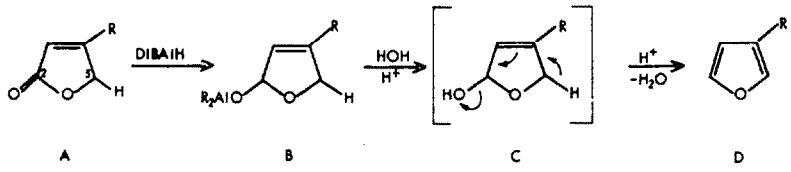


Fig. 5. Mechanism of diisobutylaluminum hydride reduction of α,β-unsaturated γ-lactones.

if very sensitive reducing groups are present (i.e. CO_2Me or CO_2Et, Fig. 2). A suggested mechanistic pathway is indicated. Reduction of the lactone CO ($A \rightarrow B$), followed by hydrolysis (C) and subsequent 2,5-elimination of water would yield furan D. Naturally, the presence of a 5-hydrogen is required for this step. Specifically, compounds **34**, **35**, **36**, and **37** (Fig. 1) have been synthesized in good yields. The selectivity of this procedure is obvious (Fig. 2). The reduction may be carried out so as to result only in the transformation of the α,β-unsaturated γ-lactone moiety to the corresponding β-substituted furans, and then may be followed by the reduction of other CO groups present in the molecule. We found that a 1·2:1 molar ratio of DIBALH to the lactone is the ratio of choice for the selective reduction of the lactone ring to the corresponding furans (i.e. compounds **38**, **39**, **40**, **41**, **42**, Fig. 2, and **43**, Fig. 4). If the ratio is increased, we found that other CO groups present in the molecule can be reduced (compound **44**, Fig. 4), e.g. an ester may be reduced via an intermediate aldehyde to an alcohol. The main problem is the recovery of the β-furyl alcohols from the aqueous reaction mixture. Even if the aqueous

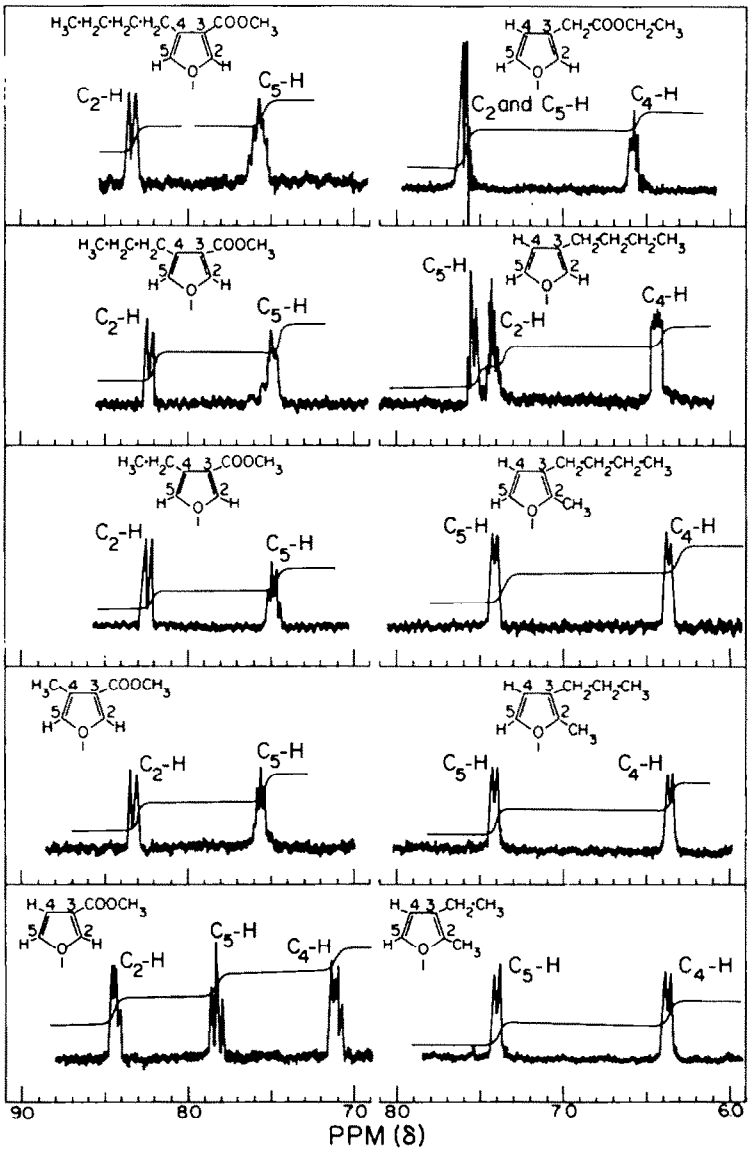
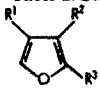


Fig. 6. NMR spectra of the furans in the region between 6 and 8 or 7 and 9 ($CDCl_3$, tetramethyl silane as internal standard, δ values in ppm).

Table 2. Substituted furans



Compound	R^1	R^2	R^3	bp/mm Hg	% yield	lit.
34	H	n-Bu	H	71-3°/58	74	-
35	H	Et	Me	55-6°/40	92	-
36	H	n-Pr	Me	62-4°/40	85	-
37	H	n-Bu	Me	81-3°/40	90	-
38	H	CO_2Me	H	50-1°/12	31	-
39	Me	CO_2Me	H	64-6°/12	59	-
40	Et	CO_2Me	H	72-5°/12	27	-
41	n-Pr	CO_2Me	H	viscous oil	20	-
42	n-Bu	CO_2Me	H	viscous oil	15	-
43	H	CH_2CO_2Et	H	83-5°/12	51	-
44	H	CH_2CH_2OH	H	89-90°/12	26	15

solution is saturated with NaCl during extraction with ether, some furyl alcohol can be detected in the aqueous solution by TLC. Water immiscible furan derivatives are easily extracted with ether, and the yields are higher.

EXPERIMENTAL

All m.ps were taken on a Büchi melting point apparatus and are uncorrected. IR spectra were determined in KBr or as film, unless otherwise stated, with a Perkin–Elmer Model 237B spectrometer. Mass spectra were taken with a Hitachi Perkin–Elmer RMU-6D2-s spectrometer operating with an ionization energy of 70 eV. The temp of the ion source was about 200°. NMR spectra were taken in deuterochloroform with a Varian A-60 or HA-100 spectrometer, using TMS as internal reference standard and are reported as δ values. Elementary analyses were carried out by Atlantic Microlab Inc., Atlanta, Georgia.

All the reactions were followed by TLC, silica gel (H:HF 1:1) Merck–Darmstadt. The developing solvent system was hexane-ether or hexane-acetone mixture. Visualization was effected with conc H_2SO_4 or anisaldehyde spray. Visualization of pyrazolines with Ehrlich reagent (*p*-dimethylaminobenzaldehyde) was successful showing yellow to orange color when heated on a hot plate at 300–350° for a few seconds. All the compounds are visible under short or long UV light.

Addition of diazoalkanes to furanones

General procedure. The ethereal soln of diazoalkane[7a] was added slowly to a stirred soln of the 2(5H)-furanone in THF at room temp for a period of 15–30 min, and stirred at the same temp for 1–8 hr. At the end of the reaction (followed by TLC) the small excess of diazoalkane was decomposed with ethereal benzoic acid (5%) and the solvent removed with a rotary evaporator. *Caution should be taken and the small excess of diazo compound removed to prevent the possibility of an explosion during the pyrolysis.* It should be noted that all diazo compounds are very strong poisons as well as explosives.

4 - *Methyl* - 2(5H) - *furanone* (3). A soln of 1[8] (18 g) in THF (100 ml) was treated with an ethereal soln of diazomethane by the general procedure. The crystalline adduct 2 was collected, yield 18·5 g, m.p. 109–110°, and the filtrate evaporated under reduced pressure. The residue (5·5 g) was a colorless oil that crystallized from ether to give 2·5 g, m.p. 107–109°. The total yield of pyrazoline 2 from 1 was 21·0 g (78%). After several recrystallizations from hot THF 2 had m.p. 110–110·5°. (Found: C, 47·82; H, 5·01; N, 22·51. Calc. for $C_5H_6N_2O_2$: C, 47·63; H, 4·79; N, 22·22%).

Compound 2 (5 g) in dioxane (50 ml) was heated in an oil bath at 120° with stirring for 48 hr. After removal of solvent with a rotary evaporator, the yellow oil remaining was distilled to yield 3·0 g (77·3%) of 3. In another experiment, pyrolysis of 15 g of 2 gave 10·5 g (90%) of 3. Compound 3, showed: b.p. 112–113°/14 mm Hg; IR (film) ν_{max}: 1785, 1750 and 1650 cm^{-1}; NMR ($CDCl_3$): δ 2·20 (3H, m, C-4-C$\underline{H}_3$), 4·90 (2H, m, C-5-$\underline{H}_2$) and 6·00 (1H, m, C-3-$\underline{H}$) ppm. Mass spectra: M^+ 98 *m/e*. Comparison of our 4 - methyl - 2(5H) - furanone (IR and NMR) with a sample, prepared by the procedure of Fleck and Schinc,[9] showed identity.

Thermolysis of the neat pyrazoline-lactone adduct 2 should be carried out at 20° or less above the m.p. in order to prevent too rapid liberation of N_2. *Thermolysis of the melt on a large scale is not recommended because the sudden liberation of N_2 may result in an explosion.* Thermolysis of the neat adduct is most useful for pyrolysis of 2–3 g quantities of pyrazolines.

4,5 - *Dimethyl* - 2(5H) - *furanone* (6). A soln of 4[10] (3·0 g) in THF (30 ml) was treated with an ethereal soln of diazomethane by the general procedure. After 8 hr of stirring at room temp, the solvent and excess diazomethane were removed. The pyrazoline 5 was obtained as an oily residue (4·0 g). Thermolysis of this compound at 120–130° over a $\frac{1}{2}$ hr gave 6[11] in a yield of 2·1 g (61·4%); b.p. 80–82°/1 mm Hg; IR (film)ν_{max}: 1750 and 1630 cm^{-1}; NMR ($CDCl_3$): δ 1·48 (3H, d, J = 7 Hz, C-5-C$\underline{H}_3$), 2·18 (3H, m, C-4-C$\underline{H}_3$), 5·15 (1H, m, C-5-$\underline{H}$) and 5·98 (1H, m, C-3-$\underline{H}$) ppm. Mass spectra: M^+ 112 *m/e*. (Found: C, 64·06; H, 7·18. Calc. for $C_6H_8O_2$: C, 64·27; H, 7·19%).

4 - *Ethyl* - 2(5H) - *furanone* (8), yield 70·0%: b.p. 65–67°/0·2 mm Hg; m.p. 36°; IR (film) ν_{max}: 1785, 1755 and 1640 cm^{-1}; NMR ($CDCl_3$): δ 1·25 (3H, t, J = 7 Hz, C-4-$CH_2C\underline{H}_3$), 2·55 (2H, m, C-4-$C\underline{H}_2CH_3$), 4·95 (2H, m, C-5-$\underline{H}_2$), and 6·00 (1H, m, C-3-$\underline{H}$) ppm. Mass spectra: M^+ 112 *m/e*. (Found: C, 64·45; H, 7·29. Calc. for $C_6H_8O_2$: C, 64·27; H, 7·19%).

4 - *Ethyl* - 5 - *methyl* - 2(5H) - *furanone* (10), yield 54·5%. b.p. 100–102°/0·9 mm Hg; IR (film) ν_{max}: 1770 and 1645 cm^{-1}; NMR ($CDCl_3$): δ 1·25 (3H, t, J = 7 Hz, C-4-$CH_2C\underline{H}_3$), 1·46 (3H, d, J = 7 Hz, C-5-C$\underline{H}_3$), 2·41 (2H, m, C-4-$C\underline{H}_2CH_3$), 5·20 (1H, m, C-5-$\underline{H}$) and 5·96 (1H, m, C-3-$\underline{H}$) ppm. Mass spectra: M^+ 126 *m/e*. (Found: C, 66·44; H, 7·99. Calc. for $C_7H_{10}O_2$: C, 66·64; H, 7·99%).

4 - *n* - *Propyl* - 2(5H) - *furanone* (12), yield 62·3%: b.p. 103–105°/1 mm Hg; IR (film) ν_{max}: 1775, 1750 and 1645 cm^{-1}; NMR ($CDCl_3$): δ 1·00 (3H, t, J = 7 Hz, C-4-$CH_2CH_2C\underline{H}_3$), 1·65 (2H, m, C-4-$CH_2C\underline{H}_2CH_3$), 2·50 (2H, m, C-4-$C\underline{H}_2CH_2CH_3$), 4·95 (2H, m, C-5-$\underline{H}_2$) and 6·00 (1H, m, C-3-$\underline{H}$) ppm. Mass spectra: M^+ 126 *m/e*. (Found: C, 66·57; H, 7·99. Calc. for $C_7H_{10}O_2$: C, 66·64; H, 7·99%).

4 - *n* - *Propyl* - 5 - *methyl* - 2(5H) - *furanone* (14), yield 60·0%,

*An ethereal soln of diazomethane was prepared from N - methyl - N - nitroso - p - toluenesulfonamide ("Diazald", product of Aldrich Chemical Company). [7a]Diazoethane, -n-propane, and n-butane were obtained from nitroso-β-ethyl (-n-propyl or - n - butyl) - amino - iso - butylmethyl ketone.

b.p. 107–109°/2 mm Hg; IR (film) ν_{max}: 1775 and 1655 cm^{-1}; NMR ($CDCl_3$): δ 1·02 (3H, t, J = 7 Hz, C-4-$CH_2CH_2CH_3$), 1·47 (3H, d, J = 7 Hz, C-5-CH_3), 1·65 (2H, m, C-4-$CH_2CH_2CH_3$), 2·45 (2H, m, C-4-$CH_2CH_2CH_3$), 5·20 (1H, m, C-5-H), and 5·95 (1H, m, C-3-H) ppm. Mass spectra: M^+ 140 *m/e*. (Found: C, 68·46; H, 8·64. Calc. for $C_8H_{12}O_2$: C, 68·55; H, 8·63%).

4 - *n* - *Butyl* - 2(5H) - *furanone* (**16**), yield 46·0%, b.p. 105–107°/0·6 mm Hg; IR (film) ν_{max}: 1780, 1745 and 1630 cm^{-1}; NMR ($CDCl_3$): δ 0·98 (3H, m, C-4-$(CH_2)_3CH_3$), 1·60 (4H, m, C-4-CH_2-$(CH_2)_2CH_3$), 2·56 (2H, m, C-4-$CH_2(CH_2)_2CH_3$), 4·95 (2H, m, C-5-H_2) and 6·00 (1H, m, C-3-H) ppm. Mass spectra: M^+ 140 *m/e*. (Found: C, 68·46; H, 8·67. Calc. for $C_8H_{12}O_2$: C, 68·55; H, 8·63%).

4 - *n* - *Butyl* - 5 - *methyl* - 2(5H) - *furanone* (**18**), yield 51%, b.p. 110–112°/0·7 mm Hg; IR (film) ν_{max}: 1760 and 1645 cm^{-1}; NMR ($CDCl_3$): δ 0·96 (3H, m, C-4-$(CH_2)_3CH_3$), 1·46 (3H, d, J = 7 Hz, C-5-CH_3), 1·57 (4H, m, C-4-$CH_2(CH_2)_2CH_3$), 2·45 (2H, m, C-4-$CH_2(CH_2)_2CH_3$), 5·15 (1H, m, C-5-H), and 5·93 (1H, m, C-3-H) ppm. Mass spectra: M^+ 154 *m/e*. (Found: C, 69·99; H, 9·14%. Calc. for $C_9H_{14}O_2$: C, 70·10; H, 9·15%).

α-Methyl methaconate (3 - *methyl* - 4 - *carbomethoxy* - 2(5H) - *furanone* (**21**). The pyrazoline lactone adduct **20** can be prepared directly from aconic acid[12] by introduction of excess diazomethane or from the corresponding methyl ester **19**. To a stirred soln of **19**[2] (5·0 g) in THF (50 ml) at room temp, an excess of ethereal diazomethane was added dropwise for a period of 15–20 min until the yellow color of diazomethane persisted, and then stirred at the same temp for 1 hr. After workup by the general procedure the adduct **20** was crystallized from either in a quantitative yield, m.p. 69–70°. (Found: C, 45·38; H, 4·35; N, 15·38. Calc. for $C_7H_8N_2O_4$: C, 45·65; H, 4·38; N, 15·21%).

The pyrazoline **20** was converted into **21** by thermal decomposition by stirring the melt at 130–140° in an oil bath for ½ hr. The yield of **21**, b.p. 145–147°/25 mm Hg, was 70·4%: IR (film) ν_{max}: 1780, 1760, 1745 and 1650 cm^{-1}; NMR ($CDCl_3$): δ 2·10 (3H, m, C-3-CH_3), 3·90 (3H, s, $COOCH_3$) and 4·95 (2H, m, C-5-H_2) ppm. Mass spectra: M^+ 156 *m/e*. (Found: C, 53·75; H, 5·18. Calc. for $C_7H_8O_4$: C, 53·84; H, 5·16%).

3 - *Ethyl* - 4 - *carbomethoxy* - 2(5H) - *furanone* (**23**). Methyl aconate (**19**) (5·00 g) was treated with an excess of diazoethane to give a mixture of **22a** and **22b** as an oil (6·2 g) which crystallized from THF, ether, or chloroform: hexane mixtures to afford 3·8 g of **22b** (54·5%): m.p. 78°; NMR ($CDCl_3$): δ 1·55 (3H, d, J = 8 Hz, 3α-CH_3), 3·13 (1H, d, J = 2 Hz, 3a-H), 3·95 (3H, s, $COOCH_3$), 4·95 (2H, d, J = 4 Hz, C-6-H_2) and 5·50 (1H, dd, J = 2, 8 Hz, C-3β-H) ppm. The **22a** was obtained as an oil, 1·8 g (25·8%); NMR ($CDCl_3$): δ 1·75 (3H, d, J = 8 Hz, 3β-CH_3), 3·48 (1H, d, J = 9 Hz, 3a-H), 3·93 (3H, s, $COOCH_3$), 4·98 (2H, d, J = 4 Hz, C-6-H_2) and 5·22 (1H, dd, J = 8, 9 Hz, C-3α-H) ppm.

22a and **22b** were converted into **23** by thermal decomposition by stirring the melt at 130–140° in an oil bath for 2·5 hr. The yield of **23**, b.p. 124–127°/3 mm Hg was 67·4%. IR (film) ν_{max}: 1760, 1735 and 1660 cm^{-1}; NMR ($CDCl_3$); δ 1·17 (3H, t, J = 8 Hz, C-3-CH_2CH_3), 2·75 (2H, q, J = 8 Hz, C-3-CH_2CH_3), 4·05 (3H, s, $COOCH_3$), and 5·10 (2H, m, C-5-H_2) ppm. Mass spectra: M^+ 170 *m/e*. (Found: C, 56·43; H, 5·93. Calc. for $C_8H_{10}O_4$: C, 56·47; H, 5·92%).

3 - *n* - *Propyl* - 4 - *carbomethoxy* - 2(5H) - *furanone* (**25**), yield 59·3%: b.p., 116–118°/1 mm Hg; IR (film) ν_{max}: 1775, 1745 and 1665 cm^{-1}; NMR ($CDCl_3$): δ 1·00 (3H, t, J = 7 Hz, C-3-$CH_2CH_2CH_3$), 1·55 (2H, m, C-3-$CH_2CH_2CH_3$), 2·75 (2H, m, C-3-$CH_2CH_2CH_3$), 4·05 (3H, s, -$COOCH_3$) and 5·15 (2H, m, C-5-H_2) ppm. Mass spectra: M^+ 184 *m/e*. (Found: C, 58·84; H, 6·59%. Calc. for $C_9H_{12}O_4$: C, 58·69; H, 6·57%).

3 - *n* - *Butyl* - 4 - *carbomethoxy* - 2(5H) - *furanone* (**27**), yield 51·0%: b.p. 126–128°/2·5 mm Hg; IR (film) ν_{max}: 1770, 1740 and 1640 cm^{-1}; NMR ($CDCl_3$): δ 0·95 (3H, m, C-3-$(CH_2)_3CH_3$), 1·52 (4H, m, C-3-$CH_2(CH_2)_2CH_3$), 2·77 (2H, m, C-3-$CH_2(CH_2)_2CH_3$), 4·01 (3H, s, $COOCH_3$) and 5·05 (2H, m, C-5-H_2) ppm. Mass spectra: M^+ 198 *m/e*. (Found: C, 60·43; H, 7·17. Calc. for $C_{10}H_{14}O_4$: C, 60·59; H, 7·12%).

3 - *Hydroxymethyl* - 4 - *carboethoxy* - *buten* - 2 - *enoic acid* - γ-*lactone* (**29**). To a stirred soln of γ-crotonolactone (8·40 g) in dry dioxane (50 ml) diazoethylacetate[13] (13·0 g) was added at room temp. The mixture was heated for 24 hr in an oil bath at 90–95°. Excess solvent was removed with a rotary evaporator and the crystalline material suspended in dry ether (50 ml), was collected and washed with ether to remove any excess of diazo compound. The yield of crude material was quantitative and after recrystallization from ether afforded 18·1 g (92·4%): **28**, m.p. 136–137°; IR (KBr) ν_{max}: 3310, 1810 and 1705 cm^{-1}: NMR ($CDCl_3$): δ 1·40 (3H, t, J = 7 Hz, CH_2-CH_3), 4·20–4·90 (4H, m), and 7·52 (1H, m, N-H) ppm. Compound **28** (10·0 g) was placed in dry dioxane (50 ml), and the mixture was refluxed for 48 hr. After the removal of solvent with a rotary evaporator, the yellow oil remaining was distilled to give 7·45 g (86·7%) of **29**; b.p. 148–150°/0·8 mm Hg; IR (film) ν_{max}: 1785, 1750, and 1650 cm^{-1}; NMR ($CDCl_3$): δ 1·33 (3H, t, J = 7 Hz, $COOCH_2CH_3$), 3·78 (2H, s, C-4-CH_2), 4·36 (2H, q, J = 7 Hz, $COOCH_2CH_3$), 5·13 (2H, m, C-5-H_2), and 6·28 (1H, m, C-3-H) ppm. (Found: C, 56·50; H, 5·97%. Calc. for $C_8H_{10}O_4$: C, 56·47; H, 5·92%).

3(2 - *Oxo* - *n* - *heptyl*) - 4 - *carbomethoxy* - 2(5H) - *furanone* (**31**). A soln of methyl aconate (4·0 g) and hexanoyl diazomethane [obtained in a similar manner as lauroyl diazomethane (see below), as an oily product and used directly without further purification] (3·95 g) in dry p-dioxane was heated at 85° for 24 hr. Excess solvent was removed and the residue crystallized from n-pentane. The yield of **30** was 5·5 g (70%); m.p. 83–84°. (Found: C, 55·25; H, 6·45; N, 9·98. Calc. for $C_{13}H_{18}N_2O_5$: C, 55·31; H, 6·43; N, 9·92%).

Pyrolytic decomposition of **30** (0·62 g) by heating at 180° for 3 hr, followed by distillation *in vacuo* gave 0·31 g (56%) of a light yellow oil; IR (film) ν_{max}: 1785, 1745 and 1650 cm^{-1}; NMR ($CDCl_3$): δ 0·90 (3H, m, C-3-$CH_2CO(CH_2)_4CH_3$), 1·00–1·60 (6H, m, C-3-$CH_2COCH_2(CH_2)_3CH_3$), 2·60 (2H, m, C-3-$CH_2COCH_2(CH_2)_3CH_3$), 2·55 and 3·05 (1H, d each, J = 4 Hz, C-3-$CH_2CO(CH_2)_4CH_3$), 3·90 (3H, s, $COOCH_3$) and 4·55 (2H, d, J = 4 Hz, C-5-H_2) ppm. (Found: C, 61·27; H, 7·19. Calc. for $C_{13}H_{18}O_5$: C, 61·40; H, 7·13%).

Lauroyl diazomethane.[14] To 250 ml of ethereal diazomethane (2·5 g of diazomethane as determined by titration with benzoic acid) previously chilled to 15°, was added dropwise 5·30 g of lauroyl chloride. The clear yellow soln was stirred overnight and was allowed to reach room temp gradually. Evaporation of the solvent, and crystallization of the residue from n-pentane afforded 4·74 g of light yellow plates, in 88% yield, m.p. 44–44·5°; IR (KBr) ν_{max}: 3080, 2130 and 1645; NMR ($CDCl_3$): δ 0·90 (3H, t, J = 5 Hz, CH_2-CH_3), 1·32 and 1·68 (18H, s, CO-$CH_2(CH_2)_9CH_3$), 2·40 (2H, t, J = 7 Hz, CO-CH_2-), and 5·45 (1H, s, CO-CH-N_2) ppm. (Found: C, 69·67; H, 10·80; N, 12·58. Calc. for $C_{13}H_{24}N_2O$: C, 69·60; H, 10·78; N, 12·49%).

3(2 - *Oxo* - *tridecanyl*) - 4 - *carbomethoxy* - 2(5H) - *furanone* (**33**). A soln of **19** (5·68 g) and lauroyl diazomethane (8·96 g) in dry p-dioxane was heated at 85° for 24 hr. Removal of p-dioxane in a rotary evaporator afforded a solid residue which was crystallized from 1:1 ether and p-dioxane solvent to give 11·34 g (80%) of white crystals of **32**, m.p. 93·5–94·5°. (Found: C, 62·16; H, 8·26; N, 7·72. Calc. for $C_{19}H_{30}N_2O_5$: C, 62·27; H, 8·25; N, 7·64%).

Pyrolytic decomposition was carried out by heating 1·5 g of **32** at 180° for 3 hr. Distillation of the residue at 250°/1 mm Hg, afforded 1·0 g of light yellow solid which was crystallized from ether-hexane mixture to give 0·85 g (61%) of white plates, m.p. 65–66°; IR (KBr) ν_{max}: 1785, 1745 and 1720 cm^{-1}; NMR ($CDCl_3$): δ 0·87 (3H, m, C-3-$CH_2CO(CH_2)_{10}CH_2)_{10}CH_3$), 1·27 (16H, s, C-3-$CH_2COCH_2CH_2(CH_2)_8(CH_3)$, 1·60 (2H, m, C-3-$CH_2COCH_2CH_2(CH_2)_8(CH_3)$, 2·50 and 3·09 (1H, d each, J = 2 Hz, C-3-$CH_2CO(CH_2)_{10}CH_3$), 2·61 (2H, t, J = 3 Hz, C-3-$CH_2COCH_2(CH_2)_9CH_3$), 3·70 (3H, s, $COOCH_3$) and 4·49 (2H, d, J = 4 Hz, C-5-H_2) ppm. (Found: C, 67·27; H, 8·99. Calc. for $C_{19}H_{30}O_5$: C, 67·43; H, 8·94%).

Reduction of butenolides

General procedure. A soln (10%) of diisobutylaluminum hydride (1·2 equiv) in dry hexane was added dropwise to a soln of the α,β-unsaturated γ-lactone (1 equiv) in dry THF with stirring at −25 to −35° in an atmosphere of argon. After addition stirring was continued for 0·5–1 hr. Sulfuric acid (20%) was added and the mixture extracted with ether. The extract was washed with $NaHCO_3$ aq. and water, dried over Na_2SO_4 and evaporated.

3 - *n* - *Butylfuran* (**34**) was obtained by distillation of the crude product in a yield of 74·4%: b.p. 71–73°/58 mm Hg; IR ($CHCl_3$)

ν_{max}: 1210, 1155, 1060, 1025 and 875 cm^{-1}; NMR ($CDCl_3$): δ 0·93 (3H, m, C-3-$(CH_2)_3CH_3$), 1·50 (4H, m, C-3-$CH_2(CH_2)_2CH_3$), 2·46 (2H, t, J = 8 Hz, C-3-$CH_2(CH_2)_2CH_3$), 6·41 (1H, m, C-4-H), 7·38 (1H, m, C-2-H) and 7·50 (1H, m, C-5-H) ppm. Mass spectra: 81 (100%), 82 (100%) and 124 (M^+ 20%) *m/e*. (Found: C, 77·19; H, 9·74. Calc. for $C_8H_{12}O$: C, 77·38; H, 9·74%).

2 - *Methyl* - 3 - *ethylfuran* (**35**) was obtained by distillation of crude product in a yield of 91·6%: b.p. 55–56°/40 mm Hg; IR ($CHCl_3$) ν_{max}: 1130, 930, and 859 cm^{-1}; NMR ($CDCl_3$): δ 1·15 (3H, t, J = 7, C-3-CH_2-CH_3), 2·23 (3H, s, C-2-CH_3), 2·60 (2H, q, J = 8 Hz, C-3-CH_2-CH_3), 6·37 (1H, d, J = 1·5 Hz, C-4-H) and 7·41 (1H, d, J = 1·5 Hz, C-5-H) ppm. Mass spectra: 95 (100%) and 110 (M^+ 30%) *m/e*. (Found: C, 76·39; H, 9·17. Calc. for $C_7H_{10}O$: C, 76·32; H, 9·15%).

2 - *Methyl* - 3 - *n* - *propylfuran* (**36**) was obtained by distillation of the crude product in a yield of 84·9%: b.p. 62–64°/40 mm Hg; IR ($CHCl_3$) ν_{max}: 1220, 1150, 1130, 940 and 895 cm^{-1}; NMR ($CDCl_3$): δ 0·93 (3H, t, J = 7 Hz, C-3-$(CH_2)_2CH_3$), 1·55 (2H, broad m, C-3-$CH_2CH_2CH_3$), 2·23 (3H, s, C-2-CH_3), 2·36 (2H, t, J = 8 Hz, C-3-$CH_2CH_2CH_3$), 6·33 (1H, d, J = 1·5 Hz, C-4-H) and 7·38 (1H, d, J = 1·5 Hz, C-5-H) ppm. Mass spectra: 95 (100%) and 124 (M^+ 32%) *m/e*. (Found: C, 77·40; H, 9·79. Calc. for $C_8H_{12}O$: C, 77·38; H, 9·74%).

2 - *Methyl* - 3 - *n* - *butylfuran* (**37**) was obtained by distillation of the crude product in a yield of 89·6%: b.p. 81°/40 mm Hg; IR ($CHCl_3$) ν_{max}: 1220, 1205, 1055 and 895 cm^{-1}; NMR ($CDCl_3$): δ 0·95 (3H, m, C-3-$(CH_2)_3CH_3$), 1·48 (4H, m, C-3-$CH_2(CH_2)_2CH_3$), 2·26 (3H, s, C-2-CH_3), 2·40 (2H, t, J = 8 Hz, C-3-$CH_2(CH_2)_2CH_3$), 6·36 (1H, d, J = 1·5 Hz, C-4-H), and 7·40 (1H, d, J = 1·5 Hz, C-5-H) Mass spectra: 81 (23%), 95 (100%), 96 (38%) and 138 (M^+ 23%) *m/e*. (Found: C, 78·08; H, 10·17. Calc. for $C_9H_{14}O$: C, 78·21; H, 10·21%).

3 - *Carbomethoxyfuran* (**38**) was obtained by distillation of the crude product in a yield of 30·9%. Compound **38** was established as 3-carbomethoxyfuran by comparison of IR and NMR spectra with a sample prepared independently from 3-furoic acid and diazomethane. The characteristics of **38** are as follows: b.p. 50°/12 mm Hg or 78°/21 mm Hg; IR (film) ν_{max}: 1725, 1240 and 1100 cm^{-1}; NMR ($CDCl_3$): δ 3·98 (3H, s, $COOCH_3$), 7·06 (1H, m, C-4-H), 7·80 (1H, m, C-5-H) and 8·41 (1H, m, C-2-H). (Found: C, 57·27; H, 4·78. Calc. for $C_6H_6O_3$: C, 57·15; H, 4·80%).

3 - *Carbomethoxy* - 4 - *methylfuran* (**39**) was obtained by distillation of the crude product in a yield of 59·1%: b.p. 64–66°/12 mm Hg; IR (film) ν_{max}: 1725, 1305, 1235 and 1095 cm^{-1}; NMR ($CDCl_3$): δ 1·46 (3H, d, J = 1·5 Hz, C-4-CH_3), 3·95 (3H, s, $COOCH_3$), 7·50 (1H, m, C-5-H), 8·24 (1H, d, J = 1·5 Hz, C-2-H) ppm. Mass spectra: 109 (100%), 125 (8·3%) and 140 (M^+ 50%). (Found: C, 59·91; H, 5·75. Calc. for $C_7H_8O_3$: C, 60·00; H, 5·75%).

3 - *Carbomethoxy* - 4 - *ethylfuran* (**40**) was purified on a 3 mm thick 200 × 400 mm silica gel plate. Development of the plate was carried out with hexane-ether 50:50. The least polar compound, the furan **40**, was obtained as an oil in a yield of 27%. The characteristics of **40** are as follows: b.p. 72–75°/12 mm Hg; IR(film) ν_{max}: 1730, 1320, 1230, 1160, 1100 and 880 cm^{-1}; NMR ($CDCl_3$): δ 1·23 (3H, t, J = 7 Hz, C-4-CH_2CH_3), 2·76 (2H, q, J = 8 Hz, C-4-CH_2CH_3), 3·93 (3H, s, $COOCH_3$), 7·50 (1H, m, C-5-H) and 8·30 (1H, d, J = 1·5 Hz, C-2-H) ppm. Mass spectra: 121 (85%), 122 (76%), 123 (100%), 139 (33%) and 154 (M^+ 76%). (Found: C, 62·48; H, 6·62. Calc. for $C_8H_{10}O_3$: C, 62·33; H, 6·54%).

3 - *Carbomethoxy* - 4 - *n* - *propylfuran* (**41**) was purified similar to furan **40** in a yield of 20·3%. The characteristics of **41** are as follows: viscous oil, IR (film) ν_{max}: 1730, 1315, 1230, 1150, 1100 and 1050 cm^{-1}; NMR ($CDCl_3$): δ 0·98 (3H, t, J = 6·5 Hz, C-4-$(CH_2)_2CH_3$), 1·60 (2H, m, C-4-$CH_2CH_2CH_3$), 2·73 (2H, t, J = 8 Hz, C-4-$CH_2CH_2CH_3$), 3·92 (3H, s, $COOCH_3$), 7·53 (1H, m, C-5-H) and 6·30 (1H, d, J = 1·5 Hz, C-2-H) ppm. Mass spectra: 109 (100%), 140 (90%) and 168 (M^+ 40%). (Found: C, 64·24; H, 7·22. Calc. for $C_9H_{12}O_3$: C, 64·27; H, 7·19%).

3 - *Carbomethoxy* - 4 - *n* - *butylfuran* (**42**) was purified similar to furan **40** in a yield of 15·1%. The characteristics of **42** are as follows: viscous oil, IR (film) ν_{max}: 1725, 1315, 1225, 1150, 1100 and 1050 cm^{-1}; NMR ($CDCl_3$): δ 0·96 (3H, m, C-4-$(CH_2)_3CH_3$), 1·50 (4H, m, C-4-$CH_2(CH_2)_2CH_3$), 2·75 (2H, t, J = 8 Hz, C-4-$CH_2(CH_2)_2CH_3$), 3·96 (3H, s, $COOCH_3$), 7·56 (1H, m, C-5-H) and 8·30 (1H, d, J = 1·5 Hz, C-3-H) ppm. Mass spectra: 109 (58%), 140 (100%) and 182 (M^+ 11%). (Found: C, 66·75;H, 8·07. Calc. for $C_{10}H_{14}O_3$: C, 65·92; H, 7·74%).

β - 3 - *Furylacetate* (**43**) was obtained by distillation of the crude mixture in a yield of 50·7%: b.p. 83–85°/12 mm Hg; IR (film) ν_{max}: 1740, 1270, 1170, 1025 and 875 cm^{-1}; NMR ($CDCl_3$): δ 1·26 (3H, t, J = 7 Hz, C-3-$COOCH_2CH_3$), 4·26 (2H, q, J = 7 Hz, C-3-$COOCH_2CH_3$), 6·60 (1H, m, C-4-H) and 7·61 (2H, m, C-5-H and C-2-H) ppm. Mass spectra: 81 (100%), 126 (12%) and 154 (M^+ 20%) *m/e*. (Found: C, 62·19; H, 6·56. Calc. for $C_8H_{10}O_3$: C, 62·33; H, 6·54%).

β - 3 - *Furylethanol* (**44**). Using 1:4 mol ratio of furanone: diisobutylaluminum hydride, reduction of furanone **29** afforded furan **44** in a yield of 26·6%. Compound **44** corresponds exactly to β-3-furylethanol previously synthesized.[15] B.p. 89–90°/12 mm Hg; IR (film) ν_{max}: 3400, 1035 and 875 cm^{-1}; NMR ($CDCl_3$): δ 2·70 (2H, t, J = 6·5 Hz, C-3-CH_2-CH_2OH), 2·73 (1H, s, C-3-CH_2-CH_2OH), 3·83 (2H, t, J = 6·5 Hz, C-3-CH_2-CH_2-OH), 6·50 (1H, m, C-4-H) and 7·56 (2H, m, C-2-H and C-5-H) ppm. Mass spectra: 81 (100%) and 112 (M^+ 33%) *m/e*.

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