The Alkylation and Ring-expansion of Chromones by Diazoalkanes; Reluctance of Oxygen to Engage in Sigmatropic Shifts

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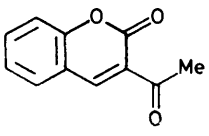
In general, chromones activated by electron-withdrawing groups at position 3 are alkylated (at position 2) by diazoalkanes in the same manner as the isomeric coumarins. For example, 6-methylchromone-3-carbonitrile (3a) is converted by diazoethane into 2-ethyl-6-methylchromone-3-carbonitrile (3c). 2-Diazopropane affords cyclopropane by-products as well, and a 3-formyl group usually suffers homologation to the appropriate ketone, as when 2-diazopropane converts 3-formyl-6-methylchromone into 2-isopropyl-6-methyl-3-(methylpropanoyl)chromone (8). In marked contrast to coumarin chemistry, there is no ring expansion into the 1-benzoxepin series.

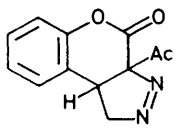
Chromones activated at position 2 show diverse reactions. Although nitriles are usually considered to be unreactive towards diazoalkanes, 6-methylchromone-2-carbonitrile slowly gives a triazole; subsequent protropy and further alkylation results in the isolation of what is provisionally considered to be the 2-(1,2,3-triazol-4-yl)chromone (12a). 2-Formylchromone (13a) is converted by diazomethane into a mixture of 2-acetylchromone and the 2-oxiranylchromone (14) but it does undergo ring expansion by diazoethane and 2-diazopropane giving derivatives of 1-benzoxepin, *e.g.* (15). Ethyl chromone-2-carboxylate (17a) reacts very slowly but affords 1-benzoxepin derivatives as well as 3-alkylated chromones.

The ring-expansions are considered to occur by way of sigmatropic shifts in unstable pyrazolines as in diagram (20) for a 2-acylchromone adduct. There is no corresponding shift (and therefore no ring-expansion) for any 3-acylchromone adduct [diagram (6a)] whence it appears that sigmatropic shifts of oxygen are unexpectedly difficult.

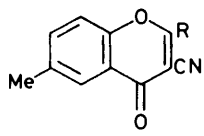
COUMARINS (1) bearing an acyl group at position 3 are known to be alkylated by diazomethane at position 4, or to undergo ring-expansion when attacked by higher diazoalkanes.[1,2] The result depends upon the conformation of the intermediate pyrazoline (2) since this determines whether electrocyclic elimination of nitrogen is concerted with hydrogen migration (giving a new alkyl group) or with aryl migration (resulting in ring-expansion), and it is the substituents on the diazoalkane that chiefly determine these conformations.[1-3] We have now studied a series of 3-substituted chromones such as (3a) analogous to coumarins such as (1) and found alkylation but not ring-expansion. If, however, the activating substituent is placed at the 2-position instead, then ring-expansion is again observed.



(1)



(2)

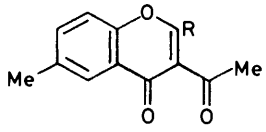


(3)
R
a; H
b; Me
c; Et
d; $CHMe_2$
e; CH_2CMe_3

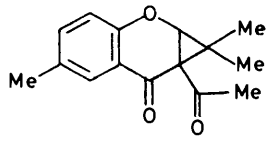
RESULTS AND DISCUSSION

6-Methylchromone-2-carbonitrile (3a) reacted smoothly with diazomethane, diazoethane, 2-diazopropane, and (though much more slowly) with t-butyldiazomethane to give the 2-alkyl derivatives (3b—e), respectively, in high yield (Table 1). This result exactly parallels that in the coumarin series.[2]

With 3-acetyl-6-methylchromone (4a), however, a major divergence from coumarins appeared. All three diazoalkanes, diazomethane, diazoethane, and 2-diazopropane, gave the appropriate alkylchromones (4b—d) (Table 2) and no other reaction was detected except for minor formation of a cyclopropane derivative (5) as is usual with 2-diazopropane. The ring-expansions characteristic of the coumarins with higher diazoalkanes [1] were therefore absent, yet not only is the appropriate conformation (6a) available to the intermediate pyrazoline, but also the alternative (6b), leading to the alkyl



(4)
R
a; H
b; Me
c; Et
d; $CHMe_2$



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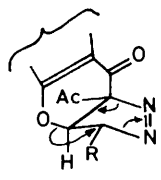
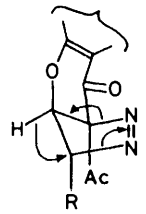


(6a)



(6b)

TABLE 1

Chromone-3-carbonitrile derivatives

Compound	R	Reaction time/h	Yield (%)	Crystal form (solvent)	M.p. (°C)	$M^{+\cdot}$
(3b)	Me	1.0	94	Plates (ethanol–hexane)	165—166	199.062 77
(3c)	Et	1.5	93	Needles (ethanol–hexane)	135	203.080 70
(3d)	$CHMe_2$	0.5	90	Prisms (ethanol)	144—145	227.094 40
(3e)	CH_2CMe_3	17.0	90	Plates (ethanol)	160—161	255.126 33

Spectroscopic properties

				^{1}H n.m.r. [δ ($CDCl_3$) at 100 MHz]					
Compound	$\lambda_{max.}$/nm [a]	log ε	ν_{max} (cm^{-1}) [b]	5-H [c]	7-H [d]	8-H [c]	6-Me	2-alkyl [f]	
(3b)	237	4.28	2 220 (CN)	7.87	7.50	7.27	2.42	2.65	
	305	3.60	1 665, 1 615, 1 567 (chromone)					(3 H)	
(3c)	237	4.16	2 218 (CN)	7.90	7.57	7.43	2.40	2.90	1.40
	304	3.79	1 644, 1 613, 1 560 (chromone)					(2 H)	(3 H)
(3d)	237	4.38	2 220 (CN)	7.84	7.57	7.43	2.45	3.46	1.45
	305	3.70	1 665, 1 618, 1 608, 1 568 (chromone)					(1 H)	(6 H)
(3e)	239	4.23	2 220 (CN)	7.94	7.55	7.36	2.42	2.82	1.12
	305	3.57	1 647, 1 618, 1 560 (chromone)					(2 H)	(9 H)

Elemental analysis

	Found (%)			Molecular formula	Required (%)		
	C	H	N		C	H	N
(3b)	72.1	4.5	6.95	$C_{12}H_9NO_2$	72.4	4.5	7.0
(3c)	73.4	5.1	6.5	$C_{13}H_{11}NO_2$	73.2	5.2	6.6
(3d)	74.1	5.7	6.2	$C_{14}H_{13}NO_2$	74.0	5.7	6.2
(3e)	75.5	6.6	5.6	$C_{16}H_{17}NO_2$	75.3	6.7	5.5

[a] In ethanol. [b] KBr disc; only cyano and characteristic chromone bands are given. [c] Broadened by *meta*-coupling. [d] All bands doublets of doublets, J 8 and 2 Hz. [e] Doublets, J 8 Hz. [f] All multiplicities were those required by the assigned structures, with J 7 Hz.

derivatives actually found, should be disfavoured by the pseudo-1,3-diaxial interaction between the substituents R and Ac. We conclude that the determining factor is a reluctance of oxygen to migrate in the preferred conformation (6a) (see below).

A formyl group at position 3 also strongly activates the chromone ring but it is itself too easily attacked by diazoalkanes for any simple result to emerge. With diazomethane, 3-formyl-6-methylchromone (7a) reacted vigorously even at −70 °C, and both the formyl group

TABLE 2

Derivatives of 3-acetylchromone

Compound	R	Reaction time/min	Yield (%)	Crystal form (solvent)	M.p. (°C)	$M^{+\cdot}$
(4b) [a]	Me	30	89	Needles (ethanol–hexane)	115	
(4c)	Et	5	84	Plates (pentane)	55	230.094 29
(4d)	$CHMe_2$	15	65 [b]	Prisms (pentane)	57	244.109 94

Spectroscopic properties

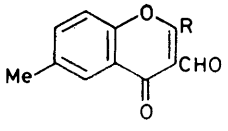
				^{1}H n.m.r. [δ ($CDCl_3$) at 100 MHz]					
Compound	$\lambda_{max.}$/nm [c]	log ε	$\nu_{max.}$ (cm^{-1}) [d]	5-H [e]	7-H [f]	8-H [g]	6-Me	2-alkyl [h]	Ac
(4b)			1 688 (Ac) 1 645, 1 616, 1 600, 1 560 (chromone)	7.90	7.43	7.26	2.45	2.40	2.58
(4c)	240	3.86	1 690 (Ac)	7.95	7.45	7.30	2.44	1.32	2.61
	305	3.33	1 640, 1 617, 1 608, 1 560 (chromone)					(3 H) 2.37 (2 H)	
(4d)	237	4.36	1 682 (Ac)	7.97	7.49	7.35	2.49	1.35	2.67
	303	3.87	1 645, 1 622, 1 550 (chromone)					(6 H) 3.10 (1 H)	

Elemental analysis

	Found (%)		Molecular formula	Required (%)	
	C	H		C	H
(4b)	73. 0	6.0	$C_{14}H_{14}O_3$	73.0	6.1
(4c)	73.7	6.5	$C_{15}H_{16}O_3$	73.8	6.6

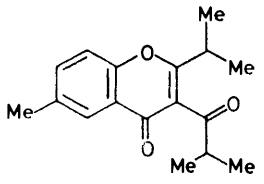
[a] G. Wittig, F. Bangert, and H. E. Richter, *Annalen*, 1925, **446**, 155. [b] A cyclopropane derivative is also formed (see text). [c] In ethanol. [d] KBr disc; only acetyl carbonyl and characteristic chromone bands are listed. [e] Broadened by *meta*-coupling. [f] All bands doublets of doublets, J 8 and 2 Hz. [g] Doublets, J 8 Hz. [h] Multiplicities agree with assignments, with J 7 Hz.

and the ring were attacked, giving 3-acetyl-2,6-dimethylchromone (4b). In the only previous relevant report,[4] 3-formylchromone was allowed a reaction time of 17 days to produce 3-formyl-2-methylchromone in very poor yield (no other product was characterised). We have indeed observed the survival of the formyl group, but only with diazoethane, which converted 3-formyl-6-methylchromone (7a) mainly into the 2-alkyl derivative (7b). On the other hand, 2-diazopropane effected dual alkylation, the main product being the doubly homologated chromone (8) along with a little of the cyclopropane derivative (9). This last compound was rather unstable. When kept or heated it underwent a sigmatropic shift as in (9) giving the enol (10) in a manner typical of cyclopropanes bearing *cis* methyl and acyl substituents.[5]



(7)

a; R=H
b; R=Me



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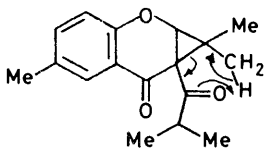

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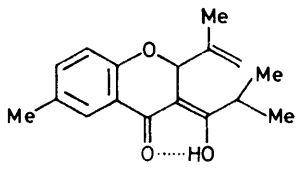
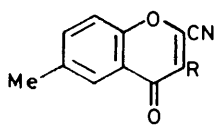


(10)

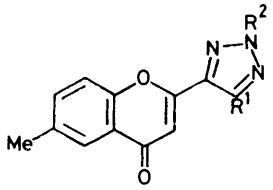
3-Acylchromones can be regarded as 1,1-diacylalkenes, so we next examined some 2-acylchromones since these correspond to 1,2-diacylalkenes with a rather different electronic character. The marked difference in susceptibility to 1,3-dipolar cycloaddition between 1,1-diacylalkenes and 1,2-diacylalkenes has already been thoroughly discussed.[6,7] In brief, bond formation to the nucleophilic carbon of (say) diazomethane is well developed early in the addition but with a 1,2-diacylalkene this must mean that the activating effect of one of the acyl groups is simultaneously destroyed. Consequently, 1,2-diacylalkanes add relatively slowly, and 2-substituted-chromones behave accordingly.

Moreover, a new feature emerged from the reaction between diazomethane and 6-methylchromone-2-carbonitrile (11a). The cyano-group reacts in preference to the chromone double bond to form a triazole which, after prototropy and methylation (by the excess of diazomethane), is isolated as the methyl derivative, possibly with the 2*H*-1,2,3-triazole structure (12a). Nitriles are usually considered to be inert towards diazomethane unless a catalyst is present, but exceptions have been recorded for nitriles bearing strongly electron-withdrawing or electron-releasing substituents.[8] In the present instance, the chromone system presumably activates the cyano-group by electron withdrawal, and it is this possibility that makes us dubious about the structure of the resulting triazole. Although simple nitriles would be expected to form 1,2,3-triazoles[9]



(11)

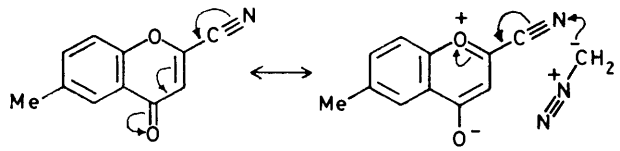
a; R = H
b; R = Et



(12)

a; R^1=H, R^2=Me
b; R^1=Me, R^2=Et

because only the *sp* carbon is electron-deficient, activated nitriles can be regarded as enones with nitrogen instead of carbon at the electron-deficient terminus, and should therefore be capable of directing the nucleophilic diazomethane carbon atom to produce a 1,2,4-triazole thus.

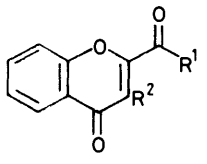


The point has occasionally been made before,[10] and gains weight from the fact that certain strongly activated nitriles do not give triazoles but suffer alkylation at *nitrogen* instead.[8] However, we have no direct evidence for the nature of our triazoles, so we formulate them as 1,2,3-triazoles for the time being. Diazoethane similarly affords mainly a triazole, tentatively assumed to have structure (12b), except that a small amount of the 3-ethylchromone (11b) is also produced, showing that the chromone ring is not entirely immune to attack.

Diazomethane slowly transformed 2-formylchromone (13a) into a mixture containing 2-acetylchromone[11] (13b) and the oxiran (14), but the yields were moderate and we may have overlooked nuclear reaction products, since certain other reactions gave them. Diazoethane supplied, in addition to the homologous ketone (13c), the 1-benzoxepin derivative (15), which could be expected to add diazoethane again since a new activated ene-grouping is present. The survival of this compound may owe something to steric hindrance, as well as to the fact that the interaction with diazoethane was intentionally restricted by terminating the reaction before all the starting material had been consumed. Such a precaution was not taken with the corresponding reaction with 2-diazopropane because the product, the 1-benzoxepin derivative (16a), is of a kind shown in the coumarin series to be resistant to further attack by the reagent.[2] Finally, the 2-propanoylchromone (13c) was found to react slowly but smoothly with diazomethane

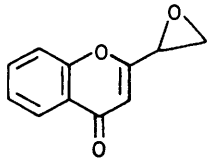
to yield the 3-methyl derivative (13d), and no ring-expansion was detected.

Much the same results attended experiments with ethyl 6-methylchromone-2-carboxylate (17a). The ester function is relatively weakly activating and the reaction with diazomethane, incomplete after a month, gave the 3-methyl derivative (17b). A similar reaction with



(13)

	R^1	R^2
a;	H	H
b;	Me	H
c;	Et	H
d;	Et	Me



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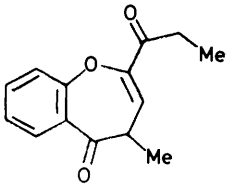

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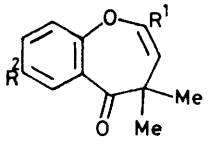
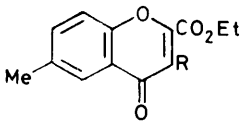
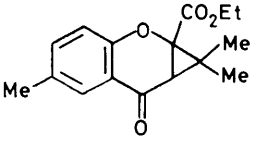


(16)

a; R^1=COCHMe$_2$, R^2=H
b; R^1=CO_2Et, R^2=Me





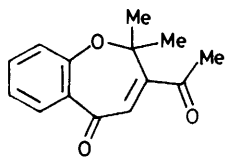
(17)

a; R = H
b; R = Me

(18)

diazoethane was continued for two months and gave a very complex product abandoned without regret. As usual 2-diazopropane reacted relatively quickly and supplied in fair yield the 1-benzoxepin derivative (16b), along with a little of the cyclopropane (18). This 1-benzoxepin and its relatives mentioned above were readily distinguished from their isomers of type (19) by means of the n.m.r. resonance of the proton at position 3 (or 4) which occurs around δ 6.3. Incremental shifts for acyclic enes suggest a value near δ 6.0 for the vinylic hydrogen in (16), and near 7.3 for that in (19). Mainly due to the electron release from the ring oxygen atom, this difference is so large that we have confidence in the assignment notwithstanding the fact that the calculation makes no allowance for any special features of the 1-benzoxepin ring.

It follows that the pyrazolines intermediate in reactions with 2-acylchromones had the orientation (20) and that ring enlargement is achieved by carbonyl group migration such as that already known in related adducts in the quinone series.[12] It could not have been predicted that the ester group and not the chromone carbonyl group would provide the main directive influence upon the diazoalkane addition. Since diazoalkane additions



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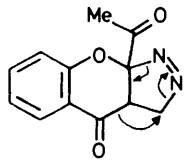
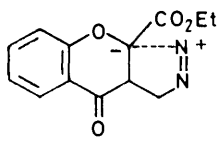


(20)



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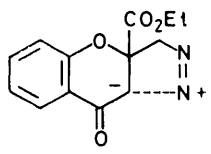

(22)

are not fully synchronous[6,7] at the two termini the transition states for the two modes of addition can be pictured as in diagrams (21) and (22), whence it appears that the latter should be favoured by ketonic, as opposed to ester carbonyl, stabilisation of negative charge. It appears that the determining factor might be provided not by the carbonyl group but by the ring oxygen atom, which will help stabilise only transition state (21) and so lead to the observed products. Apart from this consideration, however, the situation is like that amongst the 3-acylcoumarins, where diazomethane normally induced only methylation, whereas 2-diazopropane induced mainly ring-expansion, and diazoethane a mixture of alkylation and ring-expansion.[1,2]

In conclusion, we find that chromones undergo alkylation and ring-expansion reactions just as the isomeric coumarins do, but that ring expansions occur only through sigmatropic shifts of the carbonyl group. The ring oxygen atom shows no tendency to migrate as in (6a). In a review of [1, *j*] sigmatropic shifts, Spangler[13] could provide only one likely example of a rearrangement involving oxygen,[14] but he commented that sigmatropic shifts of oxygen might be rare simply because no specific search had been made for them. The present series of studies has shown that shifts of hydrogen, of alkyl, aryl and aralkyl groups, and of carbonyl groups are all readily observable at temperatures usually below 20 °C. This fact greatly increases the probability that the reluctance of oxygen to undergo sigmatropic shifts is a real phenomenon requiring explanation.

EXPERIMENTAL

U.v. spectra were obtained from solutions *ca.* 10^{-4}M in ethanol. N.m.r. spectra were recorded for $CDCl_3$ solutions at 100 or 220 MHz. Molecular weights were obtained mass spectroscopically.

Light petroleum usually refers to the fraction of b.p.

60—80 °C. Trichloromethane used for diazoalkane reactions was freed from ethanol by means of a column of alumina immediately before use. Tetrahydrofuran for diazoalkane experiments was purified immediately before use by refluxing over sodium and then distillation. Diazoalkane solutions were usually prepared by the standard alkylurea or alkylurethane methods, and dried by repeated distillation from potassium hydroxide pellets.

Reactions of 6-*Methylchromone*-3-*carbonitrile* [15] (3a).—To the nitrile (1.0 g) in tetrahydrofuran (20 ml) at 0 °C was added diazoethane (*ca.* 1.0 g) in ether (150 ml) also at 0 °C. After 1.5 h at this temperature the solution was concentrated by removal of volatile materials *in vacuo*, without application of heat, until a solid remained; this was recrystallised from ethanol–light petroleum giving 2-*ethyl*-6-*methylchromone*-3-*carbonitrile* (3b) as needles, m.p. 135 °C. Similar alkylations were effected with corresponding quantities of diazomethane, 2-diazopropane, and t-butyldiazomethane. Characteristic details and analytical results are collected into Table 1.

3-*Acetyl*-6-*methylchromone* (4a).—A mixture of freshly prepared acetic formic anhydride [16] (44 g) and sodium formate (34 g) was added to 2-hydroxy-5-methylbenzoylacetone (10 g) and stirred for 24 h. The mixture was then poured into water (500 ml) over trichloromethane (200 ml) and the organic phase was separated, washed with water (once) and saturated brine (twice), and dried (Na_2SO_4). Removal of solvent left the *chromone* which formed plates (8.5 g), m.p. 124—125 °C (from ethanol–light petroleum); $\lambda_{max.}$ 230 and 305 nm (log ε 4.16 and 3.75); $\nu_{max.}$ (KBr) 1 675 (acetyl CO), 1 645, 1 617, and 1 595 cm^{-1} (chromone pattern); δ 8.58 (1 H, s, 1-H), 8.07 (1 H, br, 5-H), 7.5 (1 H, dd, *J* 8, 2 Hz, 7-H), 7.41 (1 H, d, *J* 8 Hz, 8-H), 2.48 (3 H, Ar–*Me*), and 2.74 (3 H, COMe) (Found: C, 71.1; H, 4.9%; M^+, 202.060 56. $C_{12}H_{10}O_3$ requires C, 71.3; H, 5.0%; *M*, 202.062 99).

Reactions of 3-*Acetyl*-6-*methylchromone* (4a).—3-Acetyl-6-methylchromone (0.5 g) in pure trichloromethane (20 ml) was treated at 0 °C with diazoethane (*ca.* 0.2 g) in ether (200 ml). The rapid reaction evolved nitrogen and, after 5 min, the products were isolated by removing the solvents under reduced pressure (but without application of heat) and subjecting them to chromatographic separation from trichloromethane on a column of Kieselgel 60 (70 g). A forerun gave an oil (0.014 g) which was discarded. The main fraction gave 3-*acetyl*-2-*ethyl*-6-*methylchromone* (4c) as an oil which crystallised from cold pentane as plates (0.48 g), m.p. 55 °C. Corresponding alkylations were effected with diazomethane and 2-diazopropane used in the requisite proportions. Characteristic and analytical details are supplied in Table 2. The reaction mixture from 2-diazopropane contained a second product which left the column before the chromone (4d), and formed an oil that had to be purified further by chromatography. This was effected on Kieselgel 60 (35 g) from acetone–light petroleum which supplied two small fractions and then a large one that provided 7a-*acetyl*-1a,7a-*dihydro*-1,1,5-*trimethylcyclopropa*[b][1]*benzopyran*-7(1H)-*one* (5) as an oil (0.1 g); $\lambda_{max.}$ 221, 257, and 343 nm (log ε 4.42, 4.03, and 3.63); $\nu_{max.}$ (film) 1 694 (acetyl CO), 1 665 (ring CO), and 1 616 cm^{-1} (aromatic); δ 7.69 (1 H, br, 5-H), 7.28 (broadened d, *J* 8 Hz, 7-H), 6.82 (1 H, d, *J* 8 Hz, 8-H), 4.71 (1 H, 1a-H), 2.55 (3 H, Ar–*Me*), 2.27 (3 H, COMe), and 1.15 (6 H, *gem*-Me_2) (Found: M^+, 244.111 99. $C_{15}H_{16}O_3$ requires *M*, 244.109 94).

Reactions of 3-*Formyl*-6-*methylchromone*.—(i) *With diazomethane*. Tetrahydrofuran (100 ml) was cooled to −70 °C and to it was added, dropwise and simultaneously, 3-formyl-6-methylchromone (1.88 g) in pure trichloromethane (50 ml) and diazomethane (*ca.* 1 g) in ether (100 ml). Addition took *ca.* 0.25 h. After a further 0.25 h, volatile materials were removed *in vacuo* and at *ca.* −20 °C leaving an orange solid that was chromatographed on silica (200 g) from light petroleum (b.p. 40—60 °C) (5 : 1 v/v). Earlier eluates supplied 3-acetyl-2,6-dimethylchromone (4b) forming needles (0.14 g), and t.l.c. showed this compound to be by far the major component of the reaction product. However, further eluates contained other substances that could not be removed easily, so losses of the chief component were heavy.

(ii) *With diazoethane*. The reaction between 3-formyl-6-methylchromone (1.5 g) in tetrahydrofuran (30 ml) and diazoethane (*ca.* 1 g) in ether (250 ml) at 0 °C was immediate. Isolated in the usual way and purified on a column of silica (100 g) from acetone–light petroleum (b.p. 40—60 °C) (5 : 1 v/v), the product was an oil that crystallised from light petroleum giving 2-*ethyl*-3-*formyl*-6-*methylchromone* (7b) as plates (1.13 g), m.p. 113—114 °C; $\lambda_{max.}$ 235 and 300 nm (log ε 4.16 and 3.46); $\nu_{max.}$ (KBr) 1 698 (conj. CHO), 1 637, 1 615, 1 600, and 1 540 cm^{-1} (chromone); δ 10.55 (1 H, CHO), 7.97 (1 H, d, *J* 2 Hz, 5-H), 7.45 (1 H, dd, *J* 9, 2 Hz, 7-H), 7.26 (1 H, *J* 9 Hz, 8-H), 3.10 (2 H, q, *J* 7.5 Hz, C*H*$_2$Me), 2.42 (3 H, Ar–*Me*), and 1.32 (3 H, t, *J* 7.5 Hz, CH$_2$*Me*) (Found: C, 72.4; H, 5.4%; M^+, 216.078 61. $C_{13}H_{12}O_3$ requires C, 72.2; H, 5.6%; *M*, 216.078 4).

(iii) *With 2-diazopropane*. An experiment similar to the foregoing one was conducted with 3-formyl-6-methylchromone (1.0 g) in pure chloroform (30 ml) and 2-diazopropane (*ca.* 0.5 g) in ether (50 ml), initially at −78 °C but allowed to warm up towards room temperature. The products were isolated after 0.5 h and formed a red oil (1.9 g) which was chromatographed on silica (200 g), eluant trichloromethane, to give 1a,7a-*dihydro*-1,1,5-*trimethyl*-7a-(2-*methylpropanoyl*)*cyclopropa*[b][1]*benzopyran*-7(1H)-*one* (9) as an oil (0.26 g); $\lambda_{max.}$ 221, 258, and 340 nm (log ε 4.03, 3.67, and 3.21), $\nu_{max.}$ 1 690 (propanoyl CO), 1 667 (ring CO), 1 618 and 1 490 cm^{-1} (aromatic); δ 7.74 (1 H, br, 6-H), 7.28 (1 H, br d, *J* 9 Hz, 4-H), 6.82 (1 H, d, *J* 9 Hz, 3-H), 4.85 (1 H, OCH), 3.62 (1 H, sept, *J* 7.5 Hz, C*H*Me$_2$), 2.33 (3 H, Ar–*Me*), and 1.15 (6 H, *gem*-Me_2) (Found: M^+, 272.141 92. $C_{17}H_{20}O_3$ requires *M*, 272.141 24).

Further elution supplied 2-*isopropyl*-6-*methyl*-3-(2-*methylpropanoyl*)*chromone* (8) as a yellow oil, b.p. 130 °C (0.1 mmHg), which slowly crystallised from light petroleum as colourless prisms (0.73 g), m.p. 98—99 °C; $\lambda_{max.}$ 238 and 304 nm (log ε 4.23 and 3.75), $\nu_{max.}$ (film) 1 695 (propanoyl CO), 1 640, 1 616 and 1 565 cm^{-1} (chromone); δ 7.96 (1 H, br, 5-H), 7.51 (1 H, dd, *J* 8.5, 2 Hz, 7-H), 7.38 (1 H, d, *J* 8.5 Hz, 8-H), 3.43 (1 H, sept, *J* 7 Hz, 2-C*H*Me$_2$), 3.04 (1 H, septet, *J* 7 Hz, O=C–C*H*Me$_2$), 2.46 (3 H; Ar–*Me*), 1.34 (6 H, d, *J* 7 Hz, 2-CH*Me*$_2$), and 1.18 (6 H, d, *J* 7 Hz, O=C–CH*Me*$_2$) (Found: C, 74.8; H, 7.5%; M^+, 272.141 97. $C_{17}H_{20}O_3$ requires C, 75.0; H, 7.4%; *M*, 272.141 24).

The oily cyclopropabenzopyran derivative (0.24 g) was rather unstable and isomerised upon distillation at 120 °C (0.05 mmHg). Chromatography of the distillate (0.16 g on Kieselgel 60 (16 g) from trichloromethane furnished the *enol* (10) of 2,3-dihydro-6-methyl-3-(2-methylpropanoyl)-2-(1-methylvinyl)-1-benzopyran-4-one as a yellow oil, impart-

ing a deep wine-red colour to ethanolic iron(III) chloride; $\lambda_{max.}$ 222, 258, 313, and 360 nm (log ε 3.41, 3.07, 3.18, and 3.17); $\nu_{max.}$ (film) 1 600 (v br, enolised 1,3-diketone); δ 16.40 (1 H, H-bonded OH), 7.61 (1 H, br d, *J* 2 Hz, 5-H), 7.21 (1 H, dd, *J* 9. 2 Hz, 7-H), 6.80 (1 H, d, *J* 9 Hz, 8-H), 5.54 (1 H, 2-H), 5.01 and 4.91 (each 1 H, br s, MeC=C*H*$_2$), 2.65 (1 H, sept, *J* 7 Hz, C*H*Me$_2$), 2.27 (3 H, Ar–*Me*), 1.82 (3 H, br s, CH$_2$=C*Me*), 1.20 and 1.10 (each 3 H, d, *J* 7 Hz, CH*Me*$_2$). The mass spectrum gave for the molecular ion *m/e* 272.138 97 with a very prominent fragment ion at *m/e* 231.101 4; $C_{17}H_{20}O_3$ requires *m/e* 272.141 24 for the molecular ion and 231.102 1 for an ion $M^{+\cdot} - C_3H_7$.

Reactions of 6-*Methylchromone*-2-*carbonitrile* (11a).[17]—(i) *With diazomethane.* To a solution of the nitrile (0.3 g) in pure trichloromethane (20 ml) at 0 °C was added diazomethane (*ca.* 2 g) in ether (150 ml). As the mixture warmed to room temperature nitrogen was evolved and the reaction was followed by t.l.c. until it was complete (*ca.* 8 h). Evaporation of the volatile materials in the cold and chromatography of the residue on Kieselgel 60 (30 g) from trichloromethane gave first a little 2-cyano-6-methylchromone (<0.03 g) and then 6-*methyl*-2-(2-*methyl*-1,2,3-*triazol*-4-*yl*)*chromone* (12a) which separated from light petroleum as long needles (0.28 g), m.p. 198 °C; $\lambda_{max.}$ 256, 290, and 314 (sh) nm (log ε 4.36, 4.26, and 4.01); $\nu_{max.}$ 1 640, 1 612, and 1 570 cm^{-1} (chromone); δ 8.04 (1 H, triazole H), 8.03 (1 H, br d, *J* 2 Hz, chromone 5-H), 7.5 (2 H, mm, chromone 7-H and 8-H), 6.89 (1 H, chromone 3-H), 4.30 (3 H, NMe), and 2.45 (3 H, Ar–*Me*) (Found: C, 64.7; H, 4.5; N, 17.6%; M^+, 241.085 15. $C_{13}H_{11}N_3O_2$ requires C, 64.7; H, 4.6; N, 17.4%; *M*, 241.085 12).

(ii) *With diazoethane.* The reaction was conducted as in (i) and gave similar result except that the initial product was rather oily and chromatography was required to isolate from it 3-*ethyl*-6-*methylchromone*-2-*carbonitrile* (11b), which at first was oily but which crystallised from light petroleum as fine plates (0.12 g), m.p. 114—115 °C; $\lambda_{max.}$ 247 and 325 (log ε 4.23 and 3.69); $\nu_{max.}$ (KBr) 2 225 (CN), 1 640, 1 618 and 1 577 cm^{-1} (chromone); δ 7.96 (1 H, br, 5-H), 7.53 (1 H, br d, *J* 9 Hz, 7-H), 7.34 (1 H, d, *J* 9 Hz, 8-H), 2.75 (2 H, q, *J* 7 Hz, C*H*$_2$Me), 2.45 (3 H, Ar–*Me*), and 1.22 (3 H, t, *J* 7 Hz, CH$_2$*Me*) (Found: C, 73.5; H, 5.3; N, 6.7%; M^+, 213.080 35. $C_{13}H_{11}NO_2$ requires C, 73.7; H, 5.2; N, 6.6%; *M*, 213.078 97). Further elution furnished an orange solid that was re-chromatographed on silica (50 g) from benzene–ether (5 : 1 v/v) to give an orange fraction (rejected) and then an oil which crystallised from light petroleum to give 2-(2-*ethyl*-5-*methyl*-1,2,3-*triazol*-4-*yl*)-6-*methylchromone* (12b) as small yellow needles (0.26 g), m.p. 135 °C; $\lambda_{max.}$ 255 and 297 nm (log ε 4.36 and 4.41); $\nu_{max.}$ (KBr) 1 635, 1 620, and 1 575 cm^{-1} (chromone); δ 8.02 (1 H, br, chromone 5-H), 7.47 (2 H, mm, chromone 7-H and 8-H), 6.88 (1 H, chromone 3-H), 4.50 (2 H, q, *J* 5 Hz, NC*H*$_2$Me), 2.62 (3 H, pyrazole Ar–*Me*), 2.48 (3 H, chromone Ar–*Me*), and 1.60 (3 H, t, *J* 5 Hz, NCH$_2$*Me*) (Found: C, 67.1; H, 5.7; N, 15.8%; *M*, 269.116 41. $C_{15}H_{15}N_3O_2$ requires C, 67.0; H, 5.6; N, 15.6%; *M*, 269.116 42).

Reactions of 2-*Formylchromone* (13a).—(i) *With diazomethane.* A reaction occurred immediately between 2-formylchromone (0.5 g) in pure trichloromethane and diazomethane (*ca.* 1 g) in ether (100 ml) at room temperature, but some evolution of nitrogen was still visible after 20 h. At that stage the product was a yellow oil which was chromatographed on silica (40 g), eluant ether, to remove strongly adsorbed substances (rejected). The eluate supplied semi-crystalline material which was separated into two fractions by chromatography on Kieselgel 60 (33 g) using benzene–ether (4 : 1 v/v). The first contained 2-acetylchromone (13b) which formed long needles (0.15 g), m.p. 135—136 °C (lit.,[11] 135—137 °C) from light petroleum–ethanol; $\nu_{max.}$ (KBr) 1 700, 1 650, and 1 614 cm^{-1}; δ 8.2 and 7.8—7.4 (mm, Ar-H), 6.98 (3-H), and 2.65 (COMe) (Found: C, 70.2; H, 4.3%. Calc. for $C_{11}H_8O_3$: C, 70.2; H, 4.3%). The second contained 2-*oxiranylchromone* (14) which was obtained from light petroleum as yellow plates (0.17 g), m.p. 104—105 °C; $\lambda_{max.}$ 226, 250, and 298 nm (log ε 4.06, 3.73, and 3.65); $\nu_{max.}$ (KBr) 1 643, 1 625, 1 607 and 1 573 (chromone); δ 8.19 (1 H, m), 7.67 (1 H, m) and 7.44 (2 H, mm) (Ar-H), 6.42 (chromone 3-H), and 3.77 (1 H) and 3.16 (2 H) (ABX system of oxiran; first order analysis gives J_{AX} 4.1, J_{BX} 2.4, and J_{AB} 5.9 Hz) (Found: C, 70.5; H, 4.3%; M^+, 188.048 42. $C_{11}H_8O_3$ requires C, 70.2; H, 4.3%; *M*, 188.047 34).

(ii) *With diazoethane.* A reaction as in (i) effected between 2-formylchromone (0.6 g) and diazoethane (*ca.* 0.5 g) for 24 h supplied a yellow oily product from which chromatography on Kieselgel 60, eluant benzene–ether (4 : 1 v/v), separated first a yellow oil A, then a colourless oil B, and finally unreacted 2-formylchromone (0.23 g).

Oil A (0.22 g) was again chromatographed on Kieselgel but eluted with benzene–trichloromethane (1 : 10 v/v) to give an oil, further purified by short-path distillation. This gave 4-*methyl*-2-*propanoyl*-1-*benzoxepin*-5(4H)-*one* (15) as a yellow oil (0.2 g), b.p. 106 °C (0.3 mmHg); $\lambda_{max.}$ 215 and 300 nm (log ε 3.16); $\nu_{max.}$ (film) 1 688 (v br, conj. C=O), 1 640 (br, vinyl ether), 1 611, 1 600, and 1 570 cm^{-1} (aromatic); δ 8.04 (1 H, dd, *J* 8, 2 Hz, H-6), 7.54 (1 H, m, Ar-H), 7.34 (1 H, br d, *J* 9 Hz, H-9), 7.22 (1 H, m, Ar-H), 6.22 (1 H, d, *J* 6 Hz, H-3), 3.85 (1 H, m, *J* 7, 6 Hz, 4-H), 2.80 (2 H, m, OC*H*$_2$Me), 1.45 (3 H, d, *J* 7 Hz, CH*Me*), and 1.12 (3 H, t, *J* 7 Hz, OCH$_2$*Me*) (assignments confirmed by decoupling experiments) (Found: C, 73.0; H, 6.2%; M^+, 230.094 88. $C_{14}H_{14}O_3$ requires C, 73.0; H, 6.1%; *M* 230.094 29).

Oil B crystallised from light petroleum giving 2-*propanoylchromone* (13c) as plates (0.19 g), m.p. 101 °C; $\lambda_{max.}$ 243 and 310 nm (log ε 4.13 and 3.70); $\nu_{max.}$ (KBr) 1 706 (conj. CO), 1 645 (vinyl ether), 1 616, 1 602 and 1 565 cm^{-1} (aromatic); δ 8.20 (1 H, m, H-5), 7.75 (1 H, m, Ar-H), *ca.* 7.5 (2 H, mm, Ar-H), 6.98 (1 H, 3-H), 3.05 (2 H, q, *J* 7 Hz, COC*H*$_2$Me), and 1.24 (3 H, t, *J* 7 Hz, CH$_2$*Me*) (Found: C, 71.3; H, 4.8%; M^+, 202.604 7. $C_{12}H_{10}O_3$ requires C, 71.3; H, 5.0%; *M*, 202.062 99).

(iii) *With* 2-*diazopropane.* 2-Formylchromone (1.0 g) in pure trichloromethane (30 ml) at room temperature was added to 2-diazopropane (*ca.* 1 g) in ether at −78 °C. After about 15 min all visible reaction had ceased and the product was isolated (without use of heat) as an orange oil. Chromatography on a short silica column removed immobile materials, the main eluate forming a yellow oil (0.67 g) which was further purified on a column of Kieselgel 60 (67 g) from trichloromethane. After the earliest fractions (discarded) elution provided 4,4-*dimethyl*-2-(2-*methylpropanoyl*)-1-*benzoxepin*-5(4H)-*one* (16a) as an oil (0.48 g); $\lambda_{max.}$ 220, 242infl., and 302 nm (log ε 4.04, 3.80, and 3.19); $\nu_{max.}$ 1 706 and 1 685 (conj. CO), 1 637 and 1 602 cm^{-1} (ene and aromatic); δ 8.05—7.18 (4 H, mm, Ar-H), 6.21 (1 H, 3-H), 3.40 (1 H, m, COC*H*Me$_2$), 1.35 (6 H, *gem*-Me$_2$), and 1.12 (6 H, d, *J* 7 Hz; CH*Me*$_2$) (Found: M^+, 258.125 06. $C_{16}H_{13}O_3$ requires *M*, 258.125 59).

Reactions of Ethyl 6-Methylchromone-2-carboxylate (17a).—(i) *With diazomethane.* Ethyl 6-methylchromone-2-carboxylate [17] (0.5 g) in pure chloroform (25 ml) was treated at room temperature with diazomethane (*ca.* 0.5 g) in ether (100 ml). More diazomethane was added at intervals during 1 month. Removal of volatile materials then left a yellow oil which was chromatographed on silica (60 g) using benzene–ether (25 : 1 v/v) giving ethyl 3,6-*dimethylchromone-2-carboxylate* (17b) which separated from light petroleum as fine needles (0.16 g), m.p. 90 °C; $\lambda_{max.}$ 245 and 322 nm (log ε 4.50 and 4.06); $\nu_{max.}$ (KBr) 1 724 (ester CO), 1 645 and 1 618 cm^{-1} (chromone); δ 7.99 (1 H, br, 5-H), 7.53 (1 H, br d, *J* 9 Hz, 7-H), 7.43 (1 H, d, *J* 7 Hz, 8-H), 4.48 (2 H, q, *J* 7 Hz, OCH_2Me), 2.46 (3 H, 6-Me), 2.37 (3 H, 3-Me), and 1.45 (3 H, t, *J* Hz, CH_2Me) (Found: C, 68.3; H, 5.7%; M^+, 246.090 78. $C_{14}H_{14}O_4$ requires C, 68.3; H, 5.7%; *M*, 246.089 20). Further elution recovered ethyl 6-methylchromone-2-carboxylate (0.25 g).

(ii) *With diazoethane.* A reaction similar to that described in (i) was conducted using diazoethane instead of diazomethane and continued for 2 months. The product was a reddish oil consisting of more than eight components. The ^1H n.m.r. spectrum of the oil indicated the presence of ethyl 3-ethyl-6-methylchromone-2-carboxylate, but no fraction was obtained pure.

(iii) *With 2-diazopropane.* Ethyl 6-methylchromone-2-carboxylate (0.5 g) in pure trichloromethane (25 ml) at room temperature was added to 2-diazopropane (*ca.* 0.3 g) in ether (50 ml) at −70 °C. Nitrogen was evolved steadily. After 15 min visible reaction ceased and the solvent and excess of reagent were removed *in vacuo*. The residual oil was chromatographed over Kieselgel 60 (89 g) using trichloromethane, giving in the earlier fractions *ethyl 4,5-dihydro-4,4,7-trimethyl-5-oxo-1-benzoxepin-2-carboxylate* (16b) as an oil (0.23 g); $\lambda_{max.}$ 224, 248infl., and 310 nm (log ε 4.02, 3.71, and 3.22); $\nu_{max.}$ (film) 1 730 (br, ester), 1 680 (br, ketone), 1 650, 1 610, and 1 575 cm^{-1} (ene and aromatic); δ 7.79 (1 H, br, 6-H), 7.34 (1 H, br d, *J* 9 Hz, 8-H), 7.25 (1 H, d, 9 Hz, 9-H), 6.31 (1 H, 3-H), 4.29 (2 H, q, *J* 7 Hz; OCH_2Me), 2.36 (3 H, 7-Me), 1.38 (6 H; *gem*-Me_2), and 1.34 (3 H, t, *J* 7 Hz; CH_2Me) (Found: M^+, 274.119 89. $C_{16}H_{18}O_4$ requires *M*, 274.120 50). Further elution supplied another fraction (discarded) and then ethyl 1,1a,7,7a-*tetrahydro-1,1,5-trimethyl-7-oxocyclopropa*[b][1]*benzopyran-1a-carboxylate* (18) as an oil which crystallised from pentane as sticky crystals (0.15 g), m.p. 75—76 °C; $\lambda_{max.}$ 222, 254, and 325 nm (log ε 3.99, 3.82, and 3.25); $\nu_{max.}$ (film) 1 730 (ester), 1 680 (ketone), 1 615 cm^{-1} (aromatic); δ 7.65 (1 H, br, 6-H), 7.42 (1 H, dd, *J* 9, 2 Hz, 4-H), 7.07 (1 H, d, *J* 9 Hz, 3-H), 4.43 (2 H, q, *J* 7 Hz, OCH_2Me), 2.96 (1 H, 7a-H), 2.33 (3 H, Ar-*Me*), 1.80 (3 H, Me *cis* to ester), 1.30 (3 H, t, *J* 7 Hz, CH_2Me), and 1.15 (3 H, Me *trans* to ester) (Found: M^+, 274.119 86. $C_{16}H_{18}O_4$ requires *M*, 274.120 25).

The Reaction of Diazomethane with 2-Propanoylchromone.—The reaction between 2-propanoylchromone (0.08 g) in pure trichloromethane (10 ml) and diazomethane (*ca.* 1 g) in ether (100 ml) was terminated after 45 h. The product was a yellow oil, which, when chromatographed on Kielselgel 60 using benzene–ether (25 : 1 v/v), gave in the main fraction material that separated from light petroleum to give *3-methyl-2-propanoylchromone* (13d) as plates (0.06 g), m.p. 139 °C; $\lambda_{max.}$ 244 and 315 nm (log ε 3.76 and 3.39); $\nu_{max.}$ (KBr) 1 708 (propanoyl C=O), 1 631, 1 612, 1 595, and 1 569 cm^{-1} (chromone); δ 8.22 (1 H, dd, *J* 8, 2 Hz, 5-H), 7.72 (1 H, m, Ar-H), *ca.* 7.45 (2 H, mm, Ar-H), 3.07 (2 H, q, *J* 7 Hz, $COCH_2Me$), 2.35 (3 H, 3-Me) and 1.23 (3 H, t, *J* 7 Hz, CH_2Me) (Found: C, 72.0; H, 5.4%; M^+, 216.080 99. $C_{13}H_{12}O_2$ requires C, 72.2; H, 5.6%; *M*, 216.078 64).

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