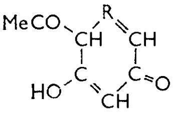
462. *The Chemistry of β-Polycarbonyl Compounds. Part I. Cyclisation to Furan and Coumarin Derivatives*

By K. Anderton and R. W. Rickards

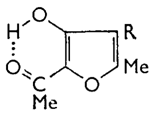
In the presence of a base and the appropriate halogen, heptane-2,4,6-trione undergoes intramolecular cyclisation to the furans (II) and (III), which exist exclusively as the enolic tautomers. Intermolecular condensation of ethyl acetoacetate in the presence of sodium ethoxide leads to the coumarin (XIII).

THE synthesis and reactivity of β-polycarbonyl compounds are of interest from purely chemical aspects, where relatively little work has been done,[1] and also from the biochemical viewpoint, where such compounds may be intermediates in biosynthetic processes.[2] One of the first to study di- and tri-carbonyl compounds in detail was Collie. Among the cyclisation reactions he observed were the formation of the compounds $C_7H_7IO_3$ and $C_7H_7BrO_3$ from treatment of heptane-2,4,6-trione with iodine[3-5] or bromine[6] in the presence of bases, and of the compound $C_{16}H_{16}O_6$ from reaction of ethyl acetoacetate with sodium ethoxide.[7] Collie formulated these products as (I; R = I), (I; R = Br), and (X), respectively.[4,6,7] We have now re-investigated the structures of these compounds.

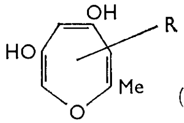
Collie's Compounds $C_7H_7IO_3$ *and* $C_7H_7BrO_3$.—By treatment of the barium salt of heptane-2,4,6-trione with iodine, Collie and his co-workers[3,4] obtained a barium salt, $(C_7H_6IO_3)_2Ba,2H_2O$, which upon acidification afforded a compound $C_7H_7IO_3$, m. p. 110—111°. The same compound was also obtained from the reaction of heptane-2,4,6-trione with iodine in the presence of sodium hydroxide[3] or triethylamine.[5] Although the corresponding bromo-analogue, $C_7H_7BrO_3$, m. p. 106°, resulted when the barium or sodium salt of the trione was treated with bromine,[6] no chloro-analogue could be obtained in this manner.[6] Consideration of Collie's evidence[4,6] for the substances $C_7H_7IO_3$ and $C_7H_7BrO_3$ leads us to the revised structures (II) and (III) for these compounds, which are fully confirmed by spectroscopic studies.



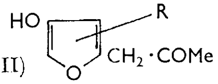
(I)

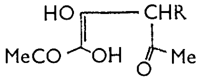


(II: R = I)
(III: R = Br)
(IV: R = H)
(V: R = Cl)

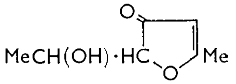


(VI)

(VII)




(VIII)



(IX)

The compounds $C_7H_7IO_3$ and $C_7H_7BrO_3$ were monobasic acids, soluble in sodium carbonate. Formation of purple or red precipitates with ferric chloride suggests phenolic or enolic systems, the chelating actions of which were blocked by conversion into the monoacetate, $C_9H_9IO_4$, and the monobenzoate, $C_{14}H_{11}BrO_4$. The compounds were oxidised by cold potassium permanganate or bleaching powder, and, on bromination followed by hydrolysis, the iodo-analogue afforded " a bromo-acetone." Most important is the sensitivity of the compounds to hot dilute acids, in contrast with their extreme

---

[1] M. Miles, T. M. Harris, and C. R. Hauser, *J. Amer. Chem. Soc.*, 1963, **85**, 3884; A. J. Birch, P. Fitton, D. C. C. Smith, D. E. Steere, and A. R. Stelfox, *J.*, 1963, 2209; A. J. Birch, D. W. Cameron, and R. W. Rickards, *J.*, 1960, 4395.

[2] A. J. Birch and F. W. Donovan, *Austral. J. Chem.*, 1953, **6**, 360; F. Lynen and M. Tada, *Angew. Chem.*, 1961, **73**, 513; A. J. Birch, *Proc. Chem. Soc.*, 1962, 3.

[3] J. N. Collie and B. D. Steele, *J.*, 1900, **77**, 1114.

[4] J. N. Collie and A. A. B. Reilly, *J.*, 1921, **119**, 1550.

[5] J. N. Collie and A. A. B. Reilly, *J.*, 1922, **121**, 1984.

[6] J. N. Collie and L. Klein, *J.*, 1927, **130**, 2162.

[7] J. N. Collie and E. R. Chrystall, *J.*, 1907, **91**, 1802.

stability to boiling concentrated sodium hydroxide or sodium ethoxide. This behaviour eliminates phenolic and polyketonic systems as such, and suggests the presence of an oxygen heterocycle. Possible structures, arising by base-catalysed halogenation of the trione followed by internal halide-ion displacement by an enolate anion, include the oxepins (VI; R = I or Br) (cf. Vogel, Schubart, and Böll[8]), and the furans (VII; R = I or Br), (II), and (III). Of these, only the 2-acetyl-3-hydroxyfuran structures (II) and (III) accommodate the observed properties.

The compound $C_7H_7IO_3$ (II) was prepared by Collie and Reilly's method[4] from the barium salt of heptane-2,4,6-trione. Hydrogenolysis with Raney nickel alloy in aqueous alkali[9] afforded the deiodo-compound (IV). These compounds (II) and (IV) had similar ultraviolet spectra, with $\lambda_{max.}$ 290 and 288 mμ (log ε 4·18, 4·29), respectively, shifted to 326 and 322 mμ upon addition of alkali, closely resembling the spectrum of the known 2-acetyl-3-hydroxyfuran (" isomaltol "),[10] $\lambda_{max.}$ 283 mμ (log ε 4·24) shifting to 318 mμ in alkali. Infrared absorption (in Nujol) at 3230 (broad) and 1630 cm.$^{-1}$ in the case of the iodofuran (II), and at 3280 (broad) and 1624 cm.$^{-1}$ in its reduction product (IV), indicated the presence of hydrogen-bonded aromatic carbonyl systems in these compounds. As expected, the acetate of (II) showed ultraviolet maxima at 244 and 287 mμ (log ε 3·86, 4·01) compared with those of 2-acetyl-5-methylfuran[11] at 216 and 289 mμ (log ε 3·48, 4·12), whilst carbonyl absorption in the infrared region occurred at 1784 and 1676 cm.$^{-1}$, frequencies characteristic of a vinyl ester and an aromatic ketone, respectively.

The proton magnetic resonance (p.m.r.) spectrum of Collie's compound (II) showed singlet absorptions at τ 1·42, 7·61, and 7·63 corresponding in intensity and chemical shift to protons of the hydrogen-bonded hydroxyl (cf. ref. 12) and the two methyl groups. The relationship of the iodine substituent to the furanoid methyl group follows from the p.m.r. spectrum of the deiodo-compound (IV). Here, the introduced hydrogen and the adjacent methyl group are mutually spin-coupled at long range (J = 0·9 c./sec.) and appear as a quartet at τ 4·08 and a doublet at τ 7·70, respectively. The hydrogen-bonded hydroxyl and methyl ketone protons of the deiodo-compound (IV) remain as singlets at τ 1·26 and 7·66. These resonance positions are all in close agreement with those reported[13] for 2-acetyl-3-hydroxyfuran, where the hydroxyl, 4-proton, and methyl proton resonances occur, respectively, at τ 1·05, 3·77, and 7·65.

These spectroscopic data provide unequivocal confirmation of the 2-acetyl-3-hydroxy-4-iodo-5-methylfuran structure (II) for Collie's compound $C_7H_7IO_3$. The bromo-compound closely paralleled the iodo-compound in its properties and reactions,[6] and is clearly 2-acetyl-4-bromo-3-hydroxy-5-methylfuran (III). Acid hydrolysis of the furan ring in these compounds would yield the enediol system (VIII; R = I or Br) with the reducing properties described by Collie and Reilly,[4] and which would afford acetic acid on further hydrolysis.[4] The compounds $C_{13}H_{13}BrN_2O_2$ and $C_{19}H_{19}IN_4O,3H_2O$, formed on reaction with phenylhydrazine,[6,4] are probably the monophenylhydrazone, and the bisphenylhydrazone of the tautomeric 3-keto-form, respectively.

Morgan and Porter[14] described the reaction of 3,5-dichloro-2,6-dimethylpyrone with barium hydroxide to yield a substance $C_7H_7ClO_3$, m. p. 83—84°. Their suggestion, made in the absence of experimental evidence, that this product may be 2-acetyl-4-chloro-3-hydroxy-5-methylfuran (V), is clearly correct. This chloro-analogue of the furans (II) and (III), which Collie was unable to obtain,[6] was enolic, gave a red ferric test, and would

[8] E. Vogel, R. Schubart, and W. A. Böll, *Angew. Chem. Internat. Edn.*, 1964, **3**, 510.

[9] E. Schwenk, D. Papa, B. Whitman, and H. F. Ginsberg, *J. Org. Chem.*, 1944, **9**, 1.

[10] J. E. Hodge and E. C. Nelson, *Cereal Chem.*, 1961, **38**, 207; B. E. Fisher and J. E. Hodge, *J. Org. Chem.*, 1964, **29**, 776.

[11] R. Andrisano and R. Passerini, *Gazzetta*, 1950, **80**, 730.

[12] L. M. Jackman, " Applications of Nuclear Magnetic Resonance Spectroscopy in Organic Chemistry," Pergamon, Oxford, 1959, p. 69.

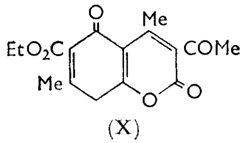
[13] R. E. Rosenkranz, K. Allner, R. Good, W. von Philipsborn, and C. H. Eugster, *Helv. Chim. Acta*, 1963, **46**, 1259.

[14] G. T. Morgan and C. R. Porter, *J.*, 1924, **125**, 1269.

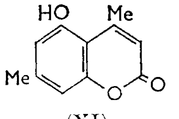
be formed similarly to Collie's compounds by an intramolecular displacement reaction in the 3,5-dichloroheptane-2,4,6-trione resulting from alkaline hydrolysis of the pyrone ring. Direct chlorination of the barium salt of heptane-2,4,6-trione in chloroform gave not this furan (V), however, but a trichloroheptane-2,4,6-trione.[14]

The furans (II) and (IV) and probably also (III) and (V), like 2-acetyl-3-hydroxyfuran,[10,13] exist virtually exclusively in the enolic forms, as shown by the absence of absorption corresponding to the Δ^2-furenidone-4 tautomers [13,15] in their p.m.r., infrared, and ultraviolet spectra. Stabilisation of the enol in these cases is probably the combined result of resonance involving the 2-acetyl group and the oxygen atoms of both the 3-hydroxyl group and the furan ring, together with strong intramolecular hydrogen bonding. The importance of these factors was demonstrated upon reduction of the 2-acetyl function, when ketonisation of the 3-hydroxyl group ensued. Treatment of the acetate of (II) with sodium borohydride in methanol resulted only in solvolysis of the ester, with formation of the parent compound (II). Whilst the iodofuran (II) and its acetate gave mixtures on reduction with lithium aluminium hydride because of incomplete hydrogenolysis of the iodine, similar reduction of the deiodo-compound (IV) proceeded smoothly. The freshly-prepared product, although too unstable to be purified by chromatography, had ultraviolet absorption with $\lambda_{\max.}$ 261 mμ (log ε 3·95) and infrared maxima (in CCl_4) at 1697 (αβ-unsaturated 5-ring ketone) and 1608 cm.$^{-1}$ (conjugated enol ether), values characteristic of the Δ^2-furenidone-4 systems studied by Eugster and his co-workers.[13,15] The product is clearly the expected ketone (IX). This resists hydride reduction since it is produced in the reaction as its lithium aluminium enolate, which only yields the free ketone on acidification.[16]

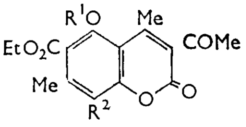
Collie's Compound $C_{16}H_{16}O_6$.—From the reaction of ethyl acetoacetate with hot sodium ethoxide Collie and Chrystall [7] obtained a compound $C_{16}H_{16}O_6$, m. p. 168—169°, to which they assigned the possible structure (X). The compound, although soluble in alkali, was not acetylated with boiling acetic anhydride, but afforded a bromination product, $C_{16}H_{15}Br_3O_6$, with bromine in acetic acid. Hydrolysis with boiling aqueous barium hydroxide gave ethanol, acetic acid, and carbon dioxide (2 moles), while with hot concentrated sulphuric acid, carbon dioxide (1 mole) and a phenol, $C_{11}H_{10}O_3$, m. p. 250°, were obtained. This phenol was identical with " dimethylumbelliferone," prepared previously [17] by the reaction of orcinol and ethyl acetoacetate with concentrated sulphuric acid, and suggested by von Pechmann and Cohen [17] to be 7-hydroxy-4,5-dimethylcoumarin. However, the colour reactions of this compound differed from those of the known 7-hydroxy-4-methylcoumarin, leading Collie and Chrystall [7] tentatively to revise von Pechmann's formulation of " dimethylumbelliferone " to that of the isomeric 5-hydroxy-4,7-dimethylcoumarin (XI). The English authors rejected the alternative 5-hydroxy-2,7-dimethylchromone structure since the compound gave a barium salt $(C_{11}H_{11}O_4)_2Ba$, an argument which is not valid since the 1,3-diketone formed by opening the heterocycle with boiling aqueous barium hydroxide could also give such a salt.



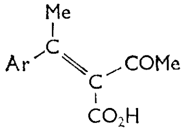
(X)



(XI)



(XIII: $R^1 = R^2 = H$)
(XIV: $R^1 = Me, R^2 = H$)
(XV: $R^1 = H, R^2 = NO_2$)
(XVI: $R^1 = Me, R^2 = NO_2$)



(XII)

---

[15] C. H. Eugster, K. Allner, and R. E. Rosenkranz, *Chimia (Switz.)*, 1961, **15**, 516.

[16] Cf. N. G. Gaylord, " Reduction with Complex Metal Hydrides," Interscience, New York, 1956, pp. 690, 960.

[17] H. von Pechmann and J. B. Cohen, *Ber.*, 1884, **17**, 2187.

The products from condensation of orcinol with acetonedicarboxylic acid and ethyl cyclohexanone-2-carboxylate in the presence of concentrated sulphuric acid were shown by Dey[18] and by Adams and Baker,[19] respectively, to have the 5-hydroxycoumarin structures. By analogy, von Pechmann's "dimethylumbelliferone" is regarded in Beilstein's "Handbuch" as the corresponding 5-hydroxycoumarin (XI).[20] Muller[21] also condensed orcinol with acetonedicarboxylic acid and, apparently unaware of the earlier work of Dey[18] and of Collie and Chrystall,[7] formulated the product as 7-hydroxy-5-methylcoumarin-4-acetic acid on the grounds of its decarboxylation to von Pechmann's "dimethylumbelliferone." If the condensation products of Dey[18] and Muller[21] are the same, as seems likely from their similar preparation and melting points, then "dimethylumbelliferone" must be correctly represented as 5-hydroxy-4,7-dimethylcoumarin (XI). However, a rigorous proof of the carbon skeleton of both "dimethylumbelliferone" and Collie's compound $C_{16}H_{16}O_6$ was clearly necessary.

The compound $C_{16}H_{16}O_6$, prepared by Collie and Chrystall's procedure,[7] had m. p. 172—173°, and showed p.m.r. absorption corresponding to a phenolic hydroxyl group (singlet, τ —3·30), a methyl ketone (singlet, τ 7·47), an ethoxyl group (quartet, $J =$ 7·2 c./sec., τ 5·50, and triplet, $J = 7{\cdot}2$ c./sec., τ 8·54), and an aromatic hydrogen (quartet, τ 3·37) necessarily *ortho*-related to an aromatic methyl group (doublet, τ 7·41) in view of the long-range spin coupling ($J = 0{\cdot}6$ c./sec.) observable between them.[22] Its ultraviolet spectrum, $\lambda_{\max.}$ 257 and 312 mμ, $\lambda_{\text{infl.}}$ 338 mμ (log ε 4·31, 4·10, 4·02), resembled that of 5-hydroxy-4-methylcoumarin,[23] $\lambda_{\max.}$ 251 and 296 mμ (log ε 3·96, 4·15), although shifted to somewhat longer wavelengths, and was quite distinct from that of 7-hydroxy-4-methylcoumarin,[23] $\lambda_{\text{infl.}}$ 228 mμ, $\lambda_{\max.}$ 325 mμ (log ε 4·13, 4·09).

The compound $C_{16}H_{16}O_6$ on being refluxed with concentrated potassium hydroxide afforded acetone (0·2 mole, isolated as the 2,4-dinitrophenylhydrazone derivative) together with a high-melting substance (not further studied), probably the amorphous polymeric product described by Collie.[7] Modification of this reaction by the use of barium hydroxide under nitrogen yielded three products: acetone (0·5 mole), carbon dioxide (1·82 mole), and a phenol, $C_9H_{10}O_3$, m. p. 144—145·5° (0·93 mole). This last compound, $\lambda_{\max.}$ 225, 274, and 339 mμ, showed infrared absorption at 3268 and 1635 cm.$^{-1}$ characteristic of a hydrogen-bonded aromatic ketone, and was identified as 2,6-dihydroxy-4-methylacetophenone by preparation of the *p*-nitrophenylhydrazone. Treatment of the acetophenone with hydroxylamine hydrochloride in pyridine afforded a compound which analysed as the desired oxime. However, the melting point of this product, 138—140°, differed greatly from the recorded value[24] of 211—212°, and the two compounds may represent different crystalline forms or even geometrical isomers.

The yields of 2,6-dihydroxy-4-methylacetophenone, acetone and carbon dioxide, produced simultaneously on alkaline hydrolysis, exclude the possibility that they could have arisen by different degradative routes from a common section of the parent compound. Thus, they eliminate chromone-type structures and establish the nucleus of Collie's compound $C_{16}H_{16}O_6$ as that of 5-hydroxy-4,7-dimethylcoumarin (XI). (It follows that this is also the correct structure of von Pechmann's "dimethylumbelliferone," as assumed in Beilstein's "Handbuch."[20]) The acetyl group must occupy the 3-position, as in (XIII), enabling the ring-opened coumarin system (XII) to yield carbon dioxide and acetone on base-catalysed decarboxylation and retro-aldol cleavage.

The presence in the p.m.r. spectrum of the compound, $C_{16}H_{16}O_6$, of the phenolic

---

[18] B. B. Dey, *J.*, 1915, **107**, 1606.

[19] R. Adams and B. R. Baker, *J. Amer. Chem. Soc.*, 1940, **62**, 2405.

[20] Beilstein, "Handbuch der Organischen Chemie," 1934, vol. XVIII, p. 37; 1952, vol. XVIII, p. 23.

[21] A. Muller, *Ber.*, 1925, **58**, 2202.

[22] P. M. Nair and G. Gopakumar, *Tetrahedron Letters*, 1964, 709, and references cited therein.

[23] K. Sen and P. Bagchi, *J. Org. Chem.*, 1959, **24**, 317.

[24] R. D. Desai and V. M. Vakil, *Proc. Indian Acad. Sci.*, 1940, **12**, *A*, 391.

hydroxyl proton at the low-field value of τ −3·30, indicative[12] of intramolecular hydrogen bonding, suggests that the remaining ethoxycarbonyl substituent is located at the 6-position as in (XIII). Consideration of infrared spectra unequivocally confirms this 3-acetyl-6-ethoxycarbonyl-5-hydroxy-4,7-dimethylcoumarin structure (XIII), which is, in fact, the enol of Collie's suggested formula (X). The spectrum (in Nujol) of the coumarin (XIII) shows, in addition to absorption at 1702 cm.$^{-1}$ due to the acetyl and coumarin carbonyl groups, absorption between 3350 and 2400 cm.$^{-1}$ and at 1654 cm.$^{-1}$, characteristic of a strongly hydrogen-bonded aromatic ester. This assignment was verified by preparation of the methyl ether (XIV), which showed normal free aromatic ester absorption at 1690 cm.$^{-1}$. Reaction of the hydroxy-coumarin (XIII) with fuming nitric acid afforded the nitro-derivative (XV). Here, suppression by the nitro-function of normal mesomerism[25] increased the frequency of the coumarin carbonyl group to 1722 cm.$^{-1}$, clearly differentiating it from the acetyl and hydrogen-bonded ester absorptions at 1703 and 1655 cm.$^{-1}$, respectively. Methylation now gave the nitro-methyl ether (XVI), in which the aromatic ester absorption was again raised to 1697 cm.$^{-1}$.

Of interest is the relatively strong (0·6 c./sec.) "benzylic coupling" between the aromatic methyl group and the adjacent ring proton observable in the p.m.r. spectrum of the coumarin (XIII). Such coupling is proportional to the square of the π-bond order between the aromatic carbon atoms involved,[22] and in this case reflects the considerable extent of "fixation" of the π-bonds in the coumarin system.

EXPERIMENTAL

Melting points were determined on a Kofler hot-stage microscope. Infrared spectra were measured on a Unicam S.P. 200 spectrophotometer, and ultraviolet spectra in ethanol solutions on a Unicam S.P. 500 spectrophotometer. P.m.r. spectra were recorded for *ca.* 11% solutions in deuterochloroform containing tetramethylsilane as internal reference, on a Varian Associates A60 machine.

2-Acetyl-3-hydroxy-4-iodo-5-methylfuran (II).—Prepared from 2,6-dimethylpyrone (5·00 g.) by Collie and Reilly's method[4] and purified by sublimation at 50—55°/0·02 mm., the iodofuran (II) (2·25 g., 19%) had m. p. 111—113° (lit.,[3] 110—111°), $\lambda_{max.}$ 290 mμ (log ε 4·18) changing to 326 mμ upon addition of alkali, $\nu_{max.}$ (in Nujol) 3230 (broad, H-bonded hydroxyl) and 1630 cm.$^{-1}$ (H-bonded aromatic ketone).

Acetylation of the iodofuran (II) with acetic anhydride and pyridine overnight gave 3-acetoxy-2-acetyl-4-iodo-5-methylfuran, m. p. 66·5—68° (lit.,[4] 68·5°) after sublimation at 50—55°/0·02 mm., $\lambda_{max.}$ 244 and 287 mμ (log ε 3·86, 4·01), $\nu_{max.}$ (in CCl_4) 1784 (vinyl ester) and 1676 cm.$^{-1}$ (aromatic ketone).

2-Acetyl-3-hydroxy-5-methylfuran (IV).—Raney nickel alloy (400 mg.) was added in portions during 1 hr. to the iodofuran (II) (73 mg.) in 5% aqueous sodium hydroxide (20 ml.), the reaction being stirred and maintained at 10°. After a further hour, the nickel was filtered off and the filtrate was extracted with ether. The cooled filtrate was poured with stirring into concentrated hydrochloric acid (150 ml.) and ether (40 ml.) at 0°. The separated ether layer, upon drying and evaporation, afforded *2-acetyl-3-hydroxy-5-methylfuran* (IV) (21 mg., 55%), m. p. 91·5—92·5° after sublimation at 45°/20 mm., $\lambda_{max.}$ 288 mμ (log ε 4·29) changing to 322 mμ upon addition of alkali, $\nu_{max.}$ (in Nujol) 3280 (broad, H-bonded hydroxyl) and 1624 cm.$^{-1}$ (H-bonded aromatic ketone) [Found: C, 60·2; H, 6·0%; *M* (Rast), 141. $C_7H_8O_3$ requires C, 60·0; H, 5·8%; *M* (Rast), 140]. The compound gave a deep violet ferric test.

Reduction of the Furan (IV) *with Lithium Aluminium Hydride.*—The deiodo-furan (IV) (212 mg.) and lithium aluminium hydride (60 mg.) were refluxed in ether (11 ml.) for 1 hr. After the excess of hydride had been decomposed with water, the mixture was extracted with ether. Recovery afforded a colourless oil (99 mg.), $\nu_{max.}$ (in CCl_4) 1697 (αβ-unsaturated 5-ring ketone) and 1608 cm.$^{-1}$ (conjugated enol ether). Chromatography on "Florex" caused some decomposition. Elution with benzene changing to 30% ether in benzene gave an oil (42 mg.) which showed $\nu_{max.}$ (in CCl_4) 1748 cm.$^{-1}$, in addition to the previous maxima. A clear oil (26 mg.)

---

[25] R. S. Rasmussen and R. R. Brattain, *J. Amer. Chem. Soc.*, 1949, **71**, 1073; L. J. Bellamy, "Infrared Spectra of Complex Molecules," Methuen, London, 1958, p. 182.

was eluted with 5% methanol in chloroform, and after rechromatography showed $\lambda_{\max.}$ 261 mμ (log ε 3·95) unchanged upon addition of alkali, $\nu_{\max.}$ (in CCl_4) 1697 and 1608 cm.$^{-1}$.

3-*Acetyl*-6-*ethoxycarbonyl*-5-*hydroxy*-4,7-*dimethylcoumarin* (XIII).—The coumarin (XIII), prepared from ethyl acetoacetate and sodium in ethanol as described by Collie and Chrystall,[7] had m. p. 172—173° (lit.,[7] 168—169°) from benzene–light petroleum, $\lambda_{\max.}$ 257, 312 mμ, $\lambda_{\text{infl.}}$ 338 mμ (log ε 4·31, 4·10, 4·02), $\nu_{\max.}$ (in Nujol) 3350—2400 (H-bonded hydroxyl), 1702 (acetyl and coumarin), and 1654 cm.$^{-1}$ (H-bonded aromatic ester), $\nu_{\max.}$ (in CCl_4) 3400—2400 (H-bonded hydroxyl), 1727 (coumarin), 1700 (acetyl), and 1651 cm.$^{-1}$ (H-bonded aromatic ester).

Reaction of the Coumarin (XIII) *with Barium Hydroxide*.—(*a*) A solution of the coumarin (XIII) (194 mg.) in carbonate-free aqueous barium hydroxide (saturated, 60 ml.) was steam-distilled under nitrogen into 2,4-dinitrophenylhydrazine solution (0·5% in 2N-hydrochloric acid). Precipitation was complete after 1·5 hr. Collection of the precipitate and recrystallisation from aqueous methanol gave acetone 2,4-dinitrophenylhydrazone (76 mg., 0·5 mole), m. p. and mixed m. p. 126—128°. The carbon dioxide liberated upon acidifying the mixture was carried with nitrogen into aqueous barium hydroxide, affording barium carbonate (230 mg., 1·82 moles).

(*b*) The coumarin (XIII) (200 mg.) in alkali as in (*a*) was refluxed for 1·5 hr. Acidification and extraction with chloroform yielded 2,6-dihydroxy-4-methylacetophenone (101 mg., 93%), needles, m. p. 144—145·5° (from aqueous ethanol) (lit.,[26] 146°), $\lambda_{\max.}$ 225, 274, and 339 mμ, $\nu_{\max.}$ (in Nujol) 3268 (H-bonded hydroxyl) and 1635 cm.$^{-1}$ (H-bonded aromatic ketone) [Found: C, 64·9; H, 5·9%; *M* (Rast), 158. Calc. for $C_9H_{10}O_3$: C, 65·0; H, 6·1%; *M*, 166]. The product afforded a *p*-nitrophenylhydrazone, m. p. 245·5—247° (from ethanol) (lit.,[26] 245°). Warming for 1 hr. on a steam-bath with hydroxylamine hydrochloride in pyridine gave 2,6-*dihydroxy*-4-*methylacetophenone oxime* (89%), m. p. 138—140° (from benzene–light petroleum after chromatography on " Florisil " in ether), $\lambda_{\max.}$ 268 mμ (log ε 4·22) $\nu_{\max.}$ (in Nujol) 3410 (OH) and 1628 cm.$^{-1}$ (C=N) (Found: C, 59·4; H, 6·1. $C_9H_{11}NO_3$ requires C, 59·7; H, 6·2%). Desai and Vakil [24] recore m. p. 211—212° for this derivative.

Ethyl 3-*Acetyl*-5-*methoxy*-4,7-*dimethylcoumarin*-6-*carboxylate* (XIV).—Methylation of the coumarin (XIII) (159 mg.) with methyl iodide (10 ml.) and anhydrous potassium carbonate (2 g.) by refluxing in acetone (25 ml.) for 6·5 hr. with stirring afforded the *methoxycoumarin* (XIV) (160 mg., 96%), plates, m. p. 82—83° (from light petroleum), $\lambda_{\max.}$ 294 mμ (log ε 4·20), $\nu_{\max.}$ (in Nujol) 1717 and 1708 (coumarin, acetyl), 1690 cm.$^{-1}$ (aromatic ester) (Found: C, 63·9; H, 5·8. $C_{17}H_{18}O_6$ requires C, 64·1; H, 5·7%).

Ethyl 3-*Acetyl*-5-*hydroxy*-4,7-*dimethyl*-8-*nitrocoumarin*-6-*carboxylate*. (XV).—The coumarin (951 mg.) in acetic acid (200 ml.) was added during 1 hr. to a mixture of fuming nitric acid (0·75 ml.) and acetic acid (0·75 ml.) at 15°. The precipitate formed on dilution of the mixture with ice and water (500 ml.) was collected, dissolved in chloroform, and washed with aqueous sodium hydrogen carbonate. Acidification of the washings and extraction with chloroform gave the *nitrocoumarin* (XV) (789 mg., 72%), pale yellow needles, m. p. 196—198° (from benzene–light petroleum), $\lambda_{\max.}$ 255 mμ, $\lambda_{\text{infl.}}$ 293 mμ (log ε 4·24, 4·04), $\nu_{\max.}$ (in Nujol) 3100—2400 (H-bonded hydroxyl), 1722 (nitrocoumarin), 1703 (acetyl), 1655 (H-bonded aromatic ester), and 1549 cm.$^{-1}$ (nitro) (Found: C, 55·2; H, 4·1; N, 4·3. $C_{16}H_{15}NO_8$ requires C, 55·0; H, 4·3; N, 4·0%). The compound gave an orange-red ferric test.

Ethyl 3-*Acetyl*-5-*methoxy*-4,7-*dimethyl*-8-*nitrocoumarin*-6-*carboxylate* (XVI).—Methylation of the nitrocoumarin (XV) (113 mg.) with methyl iodide (10 ml.) and anhydrous potassium carbonate (2 g.) by refluxing in acetone (25 ml.) for 4 hr. with stirring gave the *methoxynitrocoumarin* (XVI) (110 mg., 93%), needles, m. p. 136—138° (from light petroleum), $\lambda_{\max.}$ 294 mμ (log ε 4·15), $\nu_{\max.}$ (in Nujol) 1728 and 1720 (nitrocoumarin, acetyl), 1697 (aromatic ester), and 1540 cm.$^{-1}$ (nitro), $\nu_{\max.}$ (in CCl_4) 1740—1730 (nitrocoumarin, acetyl), and 1710 cm.$^{-1}$ (aromatic ester) (Found: C, 56·1; H, 4·6; N, 4·3. $C_{17}H_{17}NO_8$ requires C, 56·2; H, 4·7; N, 3·9%).

We thank the D.S.I.R. for the award of a research studentship (to K. A.), and Mr. R. Warren for the determination of p.m.r. spectra.

DEPARTMENT OF CHEMISTRY, UNIVERSITY OF MANCHESTER. [*Received, October 9th*, 1964.]

---

[26] I. Heilbron and H. M. Bunbury, " Dictionary of Organic Compounds," 1953, vol. II, p. 231.