of 2.5 ml. of pyridine to the mixture, the yield was increased to 611 mg. and the product crystallized more readily.

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Synthetic Furocoumarins. VI.[1] Analogs of Psoralene Derived from Hydroquinone

KURT D. KAUFMAN, JOHN F. W. KEANA, ROBERT C. KELLY, DAVID W. MCBRIDE, AND GEORGE SLOMP

Department of Chemistry, Kalamazoo College, Kalamazoo, Mich.

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Angular furocoumarins have been obtained from 6-hydroxy-4-methylcoumarin *via* substitution in the 5-position, despite any steric hindrance by the 4-methyl group as previously reported. Linear isomers have been synthesized by blocking the reactive 5-position and from 5-hydroxy-2-methylcoumarin, which eliminates the need for a blocking group. NMR studies have provided corroboration of the structures assigned.

The synthesis of furocoumarins theoretically derived from resorcinol, such as psoralene and isopsoralene, has been extensively investigated because of the photosensitizing activity associated with many of those compounds.[2] In contrast, very little has been published concerning the synthesis or natural occurrence of furocoumarins derived from hydroquinone and nothing is reported about their biological activity. Three triphenylfurocoumarins have been obtained by a three step process involving condensation of hydroquinone[3] with benzoin followed by oxidation and treatment with sodium acetate and acetic anhydride. These compounds are not of very much interest as potential photosensitizing agents because Musajo, *et al.*,[4] have reported that the introduction of a phenyl substituent on the furan ring of psoralene eliminates its photosensitizing activity. Although the structure of the naturally occurring compound Halfordin[5] is still in doubt, it may be another example of a furocoumarin theoretically derived from hydroquinone. No other furocoumarins of this type have been reported up to the present time.

This paper describes the syntheses of several hydroquinone type furocoumarins, including examples of both angular and linear ring arrangements. The photosensitizing activity of these compounds is currently being evaluated and will be reported elsewhere. An angular furocoumarin (IIa) was obtained readily from 5-formyl-6-hydroxy-4-methylcoumarin (Ib), which has been described by Sastri, *et al.*,[6] and also by Naik and Thakor.[7] Their disagreement about the melting point of this compound was resolved when it was found that their procedures give a mixture of compounds, from which pure Ib, m.p. 208°, can be extracted by aqueous potassium carbonate. In contrast to the observation of Naik and Thakor,[7] the 5-formyl compound is very soluble in 5% aqueous sodium hydroxide, although the solution rapidly becomes an intense orange color and the compound cannot then be reprecipitated by acidification. The identity of our sample was established by Dakin oxidation[6,7] to 5,6-dihydroxy-4-methylcoumarin (Ic), from which a dimethyl ether and a diacetate were obtained. The melting points of all three compounds agreed closely with the reported values.[6,8]

Condensation of 5-formyl-6-hydroxy-4-methylcoumarin with methyl bromoacetate gave methyl 5 - formyl - 4 - methylcoumarin - 6 - oxyacetate (Id), which was hydrolyzed to the corresponding acid (Ie) by hot 10% aq. sulfuric acid. Heating (Ie) with acetic anhydride and sodium acetate gave 9-methyl-7*H*-furo[3,2-*f*][1]benzopyran-7-one

(1) Part V. K. D. Kaufman, W. E. Russey, and L. R. Worden, *J. Org. Chem.*, **27**, 875 (1962).

(2) K. D. Kaufman, *J. Org. Chem.*, **26**, 117 (1961), gives a brief review of the synthetic methods employed and of some of the biological studies, particularly on the enhancement of human skin pigmentation.

(3) O. Dischendorfer and W. Limonstchew, *Monatsh.*, **80**, 58 (1949), and **81**, 737 (1950). *Chem. Abstr.*, **43**, 7016g (1949), erroneously gives the formula of benzoquinone instead of hydroquinone.

(4) L. Musajo, G. Rodighiero, G. Caporale, and C. Antonello, *Farmaco (Pavia) Ed. Sci.*, **13**, 355 (1958).

(5) M. P. Hegarty and F. N. Lahey, *Australian J. Chem.*, **9**, 120 (1956).

(6) V. D. N. Sastri, N. Narasimhachari, P. Rajagoplan, T. R. Seshadri, and T. R. Thiruvengadam, *Proc. Indian Acad. Sci.*, **37A**, 681 (1953).

(7) R. M. Naik and V. M. Thakor, *J. Org. Chem.*, **22**, 1626 (1957).

(8) V. J. Dalvi, R. B. Desai, and S. Sethna, *J. Indian Chem. Soc.*, **28**, 366 (1951). It should perhaps be mentioned that they obtained these compounds from the Elbs persulfate oxidation of 5-methoxy-4-methylcoumarin, which was assumed to occur in the 6-position. If their oxidation occurred at the 8-position, demethylation would give the unknown 5,8-dihydroxy-4-methylcoumarin. Dakin oxidation of 5-formyl-6-hydroxy-4-methylcoumarin could also give the 5,8 isomer because, in the alkaline medium, the pyrone ring might be opened and upon acidification could close in either of two directions. The 5,6-dihydroxy structure seems much more probable, particularly because the compound gives a green color with ferric chloride in alcohol. In either case, the structure of 5-formyl-6-hydroxy-4-methylcoumarin is definitely established.

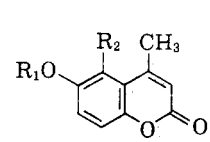
(IIa) in 31% yield and its 2-carboxy derivative (IIb) in 43% yield.

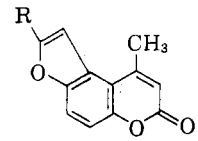
Efficient syntheses of furocoumarins of the psoralene or isopsoralene type have recently been reported from *o*-allyl-7-hydroxycoumarins.[2,9] In order to utilize the same approach, 6-hydroxy-4-methylcoumarin (Ia)[10] was treated with allyl bromide and potassium carbonate in acetone to obtain 6-allyloxy-4-methylcoumarin (If) in 89% yield. The Claisen rearrangement of If was carried out in two different ways with very different results. Heating without solvent in an oil bath at 216° gave a 53% yield of an alkali-insoluble compound $C_{13}H_{12}O_3$, m.p. 185–186°. Its infrared spectrum showed no hydroxyl absorption and the structure of 1,2-dihydro-2,9-dimethyl-7*H*-furo[3,2-*f*][1]benzopyran-7-one (III) has been assigned to it. Corroboration of the structure was obtained by dehydrogenation to 2,9-dimethyl-7*H*-furo[3,2-*f*][1]benzopyran-7-one (IIc), which was unambiguously synthesized by another route (*vide infra*).

When the Claisen rearrangement of 6-allyloxy-4-methylcoumarin (If) was carried out in refluxing dimethylaniline, the expected *o*-allyl-6-hydroxy-4-methylcoumarin was obtained in 75% yield. This is reminiscent of the superior results with the Claisen rearrangement in refluxing diethylaniline reported earlier.[1] Although substitution reactions of 6-hydroxycoumarin occur preferentially in the 5-position, several reports[11] of steric interference in 6-hydroxy-4-methylcoumarin made it impossible to predict with certainty the position occupied by the allyl group after Claisen rearrangement. Our results show that, despite any steric hinderance by the 4-methyl group, the allyl moiety migrates to the 5-position, giving 5-allyl-6-hydroxy-4-methylcoumarin (Ig), m.p. 176–177°. In an initial, unsuccessful attempt to establish its structure, Ig was converted to its methyl ether (Ih), which was treated with dimethyl sulfate and sodium hydroxide to obtain 2-allyl-3,6-dimethoxy-β-methylcinnamic acid (IV). Several attempts to oxidize IV to 3,6-dimethoxyphthalic acid were unsuccessful, perhaps because of the inaccessibility of the β-carbon atom.

Conclusive proof of the structure of 5-allyl-6-hydroxy-4-methylcoumarin (Ig) was obtained by converting it to a furocoumarin which was identical (mixed m.p. and infrared spectra) with the furocoumarin (IIa), obtained from 5-formyl-6-hydroxy-4-methylcoumarin (Ib). The conversion was accomplished by ozonizing Ig and reducing catalytically to obtain a compound $C_{12}H_{10}O_4$. Earlier workers[9] have assigned *o*-hydroxyphenylacetaldehyde structures to compounds similarly produced, but its infrared spectrum (Nujol mull) showed no carbonyl absorption other than the lactone carbonyl peak at 1700 cm.$^{-1}$ and no aldehyde C—H absorption in the region 2695–2720 cm.$^{-1}$. Although the evidence is not definitive, the compound more probably exists as a hemiacetal (V), at least in the solid state. Heating V with 85% *o*-phosphoric acid produced the angular furocoumarin (IIa) in excellent yield.

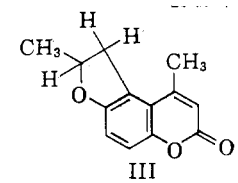
In order to establish the structure of the compound (III) from the anomalous Claisen rearrangement, 5-allyl-6-hydroxy-4-methylcoumarin was acetylated and treated with one molar equivalent of bromine. The crude dibromo compound (Ij) was refluxed with sodium ethoxide in absolute ethanol, giving 2,9-dimethyl-7*H*-furo[3,2-f][1]benzopyran-7-one (IIc). This procedure has been used extensively and is known to produce α-methylfurocoumarins.[1,2] The product was identical (mixed m.p. and infrared spectra) with the sample obtained by the dehydrogenation of III, which proves the structure of the latter compound. Corroboration of the angular furocoumarin structure (IIc) was obtained by a study of its NMR spectrum (*vide infra*).



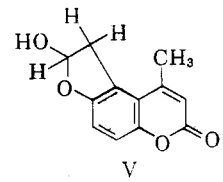


Ia. $R_1 = R_2 = H$
b. $R_1 = H$, $R_2 = -CHO$
c. $R_1 = H$, $R_2 = OH$
d. $R_1 = -CH_2COOCH_3$, $R_2 = -CHO$
e. $R_1 = -CH_2COOH$, $R_2 = -CHO$
f. $R_1 = $ allyl, $R_2 = H$
g. $R_1 = H$, $R_2 = $ allyl
h. $R_1 = CH_3$, $R_2 = $ allyl
i. $R_1 = $ acetyl, $R_2 = $ allyl
j. $R_1 = $ acetyl, $R_2 = CH_2Br—CHBr—CH_2—$
k. $R_1 = H$, $R_2 = n\text{-}C_3H_7$
m. $R_1 = $ allyl, $R_2 = n\text{-}C_3H_7$

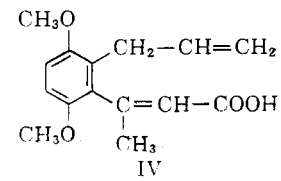
IIa. R = H
b. R = COOH
c. R = CH_3



III



V



IV

At the beginning of experimental work on this project, the reports[11] of a steric effect in 6-hydroxy-4-methylcoumarin gave some hope of obtaining linear furocoumarins of type VIII by substitution in the 7-position in preference to the sterically hindered 5-position. The results of

(9) R. Aneja, S. K. Mukerjee, and T. R. Seshadri, *Tetrahedron*, **2**, 203 (1958); **3**, 230 (1958); and **4**, 256 (1958).

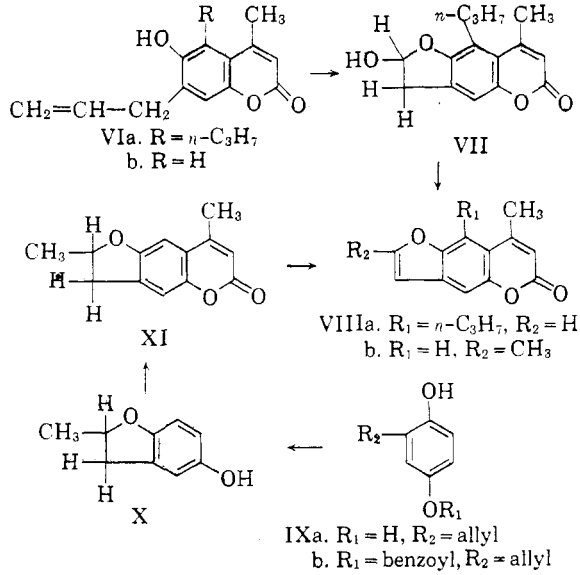
(10) W. Borsche, *Ber.*, **40**, 2731 (1907).

(11)(a) V. M. Thakor, *Current Sci.* (India), **20**, 234 (1951). (b) R. N. Usgaonkar and G. V. Jadhav, *J. Indian Chem. Soc.*, **36**, 346 (1959). (c) R. D. Desai and C. K. Mavani, *Proc. Indian Acad. Sci.*, **25A**, 327 (1947).

formylation and Claisen rearrangement, however, indicated that such an approach was not likely to be successful. Type VIII furocoumarins have been obtained by two different routes, portrayed by structures VI–XI. In one case, 5-allyl-6-hydroxy-4-methylcoumarin (Ig) was catalytically hydrogenated to 6-hydroxy-4-methyl-5-*n*-propylcoumarin (Ik), which was converted to an allyl ether (Im) by reaction with allyl bromide. Refluxing in diethylaniline caused the Claisen rearrangement and, with the 5-position occupied, the allyl group was forced to the 7-position giving 7-allyl - 6 - hydroxy - 5 - *n* - propyl - 4 - methylcoumarin (VIa) in good yield. Ozonization, catalytic reduction, and heating with *o*-phosphoric acid gave 8 - methyl - 9 - *n* - propyl - 6*H* - furo[2,3 - *g*][1]-benzopyran-6-one (VIIIa).

Another route to linear furocoumarins, which eliminates the need for a blocking group, involves the use of 2-allylhydroquinone (IXa) which, on Pechmann condensation with ethyl acetoacetate, was expected to give 7-allyl-6-hydroxy-4-methylcoumarin (VIb) just as 2-methylhydroquinone has been reported to give 4,7-dimethyl-6-hydroxycoumarin.[12] 2-Allylhydroquinone was efficiently prepared by Claisen rearrangement of hydroquinone monobenzoate allyl ether.[13] When the rearrangement was carried out in a large volume of refluxing diethylaniline, 2-allyl-4-benzoyloxyphenol (IXb) was obtained in 81% yield, without the disproportionation encountered by earlier workers[13] when they heated to 280° without a solvent. When a small volume of diethylaniline was used, disproportionation accompanied rearrangement, producing a mixture of 2-allylhydroquinone (IXa) and its mono- and dibenzoates. Alkaline hydrolysis of the mixture gave 2-allylhydroquinone in 78% yield from hydroquinone monobenzoate allyl ether. Unfortunately, 2-allylhydroquinone did not condense with ethyl acetoacetate in acetic acid, using dry hydrogen chloride as a catalyst and, when the condensation was carried out in concentrated sulfuric acid, a mixture of products was obtained from which the angular dihydrofurocoumarin (III) was isolated in low yield. Obviously, sulfuric acid has caused cyclization of the *o*-allylphenol system, but surprisingly the Pechmann condensation has occurred in the more hindered 3-position of 2-allylhydroquinone.

It appears that cyclization of 2-allylhydroquinone does not preceed its condensation with ethyl acetoacetate to give III because 5-hydroxy-2-methylcoumaran (X), prepared by the cyclization of IXa with hydrobromic acid,[14] condensed with ethyl acetoacetate in concentrated sulfuric acid to give the linear dihydrofurocoumarin (XI). Dehydrogenation of XI over palladium on charcoal in diphenyl ether gave the desired linear compound, 2,8 - dimethyl - 6*H* - furo[2,3 - *g*][1]benzopyran-6-one (VIIIb), which is an isomer of the angular furocoumarin (IIc) already described. An examination of the nuclear magnetic resonance spectra of these two isomers corroborated the structures assigned (*vide infra*).



Proton Magnetic Resonance Spectroscopy.—The proton magnetic resonance spectra obtained on two isomeric dimethylfurocoumarins are shown in Fig. 1 and 2. The two possible structures were

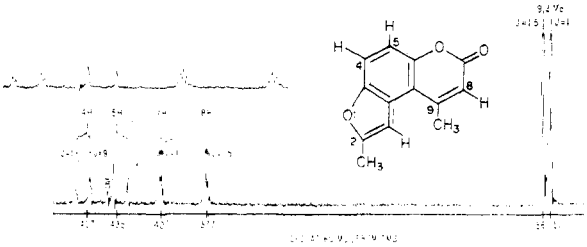


Fig. 1.—Proton magnetic resonance spectrum of 2,9-dimethyl-7*H*-furo[3,2-*f*][1]benzopyran-7-one (IIc) in deuterochloroform.

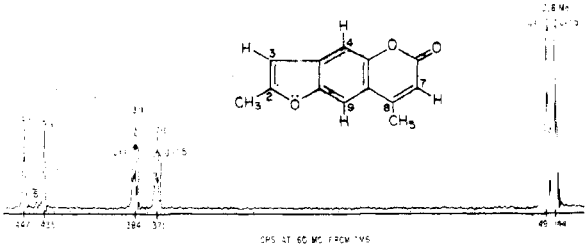


Fig. 2.—Proton magnetic resonance spectrum of 2,8-dimethyl-6*H*-furo[2,3-*g*][1]benzopyran-6-one (VIIIb) in deuterochloroform.

(12) R. D. Desai and C. K. Mavani, *Proc. Indian Acad. Sci.*, **15A**, 11 (1942).

(13) G. Hahn and W. Stenner, *Z. Physiol. Chem.*, **181**, 88 (1929).

(14) L. I. Smith, H. H. Hoehn, and A. G. Whitney, *J. Am. Chem. Soc.*, **62**, 1863 (1940).

easily assigned on the basis of their aromatic hydrogen absorptions. In the angular isomer (IIc) these two hydrogens are situated *ortho* (positions 4 and 5) to each other and hence should split each other by spin coupling into an AB multiplet with a coupling constant of 6–9 c.p.s.[15] Such an AB multiplet ($J=9$ c.p.s.) is clearly seen in Fig. 1 and this sample was therefore assigned the angular structure (IIc).

In the linear isomer (VIIIb) these two aromatic hydrogens are *para* and should be split less than 1 c.p.s. if at all.[15] The two hydrogens were identified in Fig. 2 as broad singlets in agreement with the linear structure.

It is noteworthy that the 4-hydrogen of (IIc) is very favorably situated, for maximum *p*-orbital overlap[16] with the β-furan hydrogen and a coupling of 1 c.p.s. across this 6-atom system are clearly seen in Fig. 1. Thus the 4-hydrogen is actually a quadruplet and the β-furan hydrogen is actually a quintuplet. The 4-hydrogen of VIIIb had a less favorable angle but was one atom closer to the β-furan hydrogen. Even so it was not clearly resolved but was broadened (see Fig. 2).

In both cases, the pyrone-ring hydrogen was coupled to the pyrone methyl hydrogens as expected ($J=1.5$ c.p.s.) and the methyl absorptions were identified from their coupling constants. In the angular isomer both methyl absorptions were about 8 c.p.s. lower than those observed for the linear isomer. This is in accordance with an enhanced π-electron current[17] effect in the angular configuration.

Experimental

When several compounds have been prepared by a similar procedure, complete details are given for one example, with significant deviations noted for analogous compounds. All melting points are corrected and were determined on a Fisher-Johns melting point apparatus. Infrared and ultraviolet spectra were determined for all the furocoumarins and most of the intermediate coumarins described. NMR spectra were observed on a Varian DP-60 spectrometer operating at 60 Mc. on solutions (*ca.* 0.3 ml., *ca.* 0.15 *M*) of the samples in d_3-chloroform. The spectra were calibrated against internal tetramethylsilane by the interpolation of audiofrequency side-bands calibrated by a frequency counter. The precision of the $\Delta\nu$ is ± 1 c.p.s. The spectra were calibrated in c.p.s. downfield from tetramethylsilane to obviate the need for factoring unknown multiplets.

5-Formyl-6-hydroxy-4-methylcoumarin (Ib).—A solution of 6-hydroxy-4-methylcoumarin[10] (28.20 g., 0.160 mole) and hexamethylenetetramine (56.4 g., 0.402 mole) in glacial acetic acid (570 ml.) was stirred and refluxed for 10 hr. Hot, aqueous hydrochloric acid (473 ml. of conc. hydrochloric acid and 473 ml. of water) was added to the hot solution which was then heated on a steam bath for 2 hr. Extraction with ether (1500 ml.) in several portions gave a yellow solid (9.56 g.), m.p. 145–210°. A solution of this solid in chloroform was extracted thoroughly with aqueous potassium carbonate (90 g. in 980 ml. water) and the aqueous layer was immediately poured into a mixture of ice and conc. hydrochloric acid. Filtration gave 5.14 g. (15.7%) of a yellow solid, m.p. 187–193°. Recrystallization from methanol gave yellow prisms, m.p. 208° (reported[6,7]: 202° or 191°).

Anal. Calcd. for $C_{11}H_8O_4$: C, 64.70; H, 3.95. Found: C, 64.60; H, 3.97.

The 2,4-dinitrophenylhydrazone was prepared in 93% yield, m.p. 315° (dec.) (reported[7]: 315°).

5,6-Dihydroxy-4-methylcoumarin (Ic).—This compound was obtained in 97% yield from 0.500 g. of 5-formyl-6-hydroxy-4-methylcoumarin by treatment with 6% hydrogen peroxide according to the procedure of Naik and Thakor.[7] It had m.p. 251–252° (reported[8]: 248–249°) when determined instantaneously on a Fisher-Johns apparatus. After a few seconds at its m.p., the melt resolidifies and does not remelt below 300°. A warm alcohol solution gave an intense green color with aqueous ferric chloride. Crystallization from an ethanol–water mixture did not change the m.p. but gave an analytical sample.

Anal. Calcd. for $C_{10}H_8O_4$: C, 62.50; H, 4.20. Found: C, 62.56; H, 4.11.

The dimethyl ether was obtained in 83% yield by the action of dimethyl sulfate and potassium carbonate in acetone. It had m.p. 128° (reported[8]: 126–128°).

The diacetate was obtained in 65% yield by treatment with acetic anhydride in pyridine and had m.p. 173–175° (reported[8]: 175–176°).

Methyl 5-Formyl-4-methylcoumarin-6-oxyacetate (Id).—A mixture of 5-formyl-6-hydroxy-4-methylcoumarin (0.987 g., 0.00484 mole), anhydrous potassium carbonate (3.39 g., 0.0245 mole), methyl bromoacetate (3.75 g., 0.0245 mole), and acetone (93 ml.) was refluxed for 1 hr., allowed to cool, and filtered. The filtrate was concentrated on a steam bath to *ca.* 25 ml. and diluted with 100 ml. of petroleum ether (b.p. 30–60°). The white precipitate which deposited weighed 1.137 g. (85%) and had m.p. 134–137°. Recrystallization from ether gave colorless crystals, m.p. 137–137.5°.

Anal. Calcd. for $C_{14}H_{12}O_6$: C, 60.87; H, 4.38. Found: C, 61.08; H, 4.39.

5-Formyl-4-methylcoumarin-6-oxyacetic Acid (Ie).—A suspension of methyl 5-formyl-4-methylcoumarin-6-oxyacetate (1.612 g.) in 10% aq. sulfuric acid (70 ml.) was heated on a steam bath for 45 min. The hot solution was decanted from a small amount of dark oil and filtered. On cooling, the filtrate deposited colorless crystals (1.23 g., 80%), m.p. 185–187°, and recrystallization from benzene gave an analytical sample, m.p. 186–187°.

Anal. Calcd. for $C_{13}H_{10}O_6$: C, 59.54; H, 3.84; Found: C, 59.62; H, 3.65.

6-Allyloxy-4-methylcoumarin (If).—A mixture of 6-hydroxy-4-methylcoumarin[10] (10.0 g., 0.0568 mole), allyl bromide (25 ml., 0.28 mole), anhydrous potassium carbonate (30.0 g., 0.22 mole), and acetone (250 ml.) was refluxed for 3 hr., filtered, and the filtrate was concentrated on a steam bath. The residue was recrystallized from ligroin (*d* 0.67–0.69) to obtain colorless needles (11.0 g., 90%), m.p. 80°.

Anal. Calcd. for $C_{13}H_{12}O_3$: C, 72.20; H, 5.60. Found: C, 72.38; H, 5.78.

5-Allyl-6-hydroxy-4-methylcoumarin (Ig).—A solution of 6-allyloxy-4-methylcoumarin (20.0 g.) in dimethylaniline (100 ml.) was refluxed for 2 hr. and poured into 5% aq. hydrochloric acid (*ca.* 1 l.). The solid which separated was collected by filtration and recrystallized from toluene to obtain colorless plates (15.1 g., 75%), m.p. 176–177°, which were completely soluble in 5% aq. sodium hydroxide.

Anal. Calcd. for $C_{13}H_{12}O_3$: C, 72.20; H, 5.60. Found: C, 72.34; H, 5.60.

5-Allyl-6-methoxy-4-methylcoumarin (Ih).—Methylation of 5-allyl-6-hydroxy-4-methylcoumarin (195 g., 0.902 mole)

(15) H. S. Gutowsky, C. H. Holm, A. Saika, and G. A. Williams, *J. Am. Chem. Soc.*, **79**, 4596 (1957).

(16) M. Karplus, *J. Chem. Phys.*, **30**, 11 (1959); D. R. Davis, R. P. Lutz, and J. D. Roberts, *J. Am. Chem. Soc.*, **83**, 246 (1961).

(17) J. A. Pople, W. G. Schneider, and H. J. Bernstein, "High Resolution Nuclear Magnetic Resonance," McGraw-Hill Book Co., New York, 1959, p. 251.

with methyl iodide (710 g., 5.0 moles) was accomplished in a manner analogous to the allylation procedure already described except that refluxing continued for 47 hr. An ether solution of the crude product was extracted with 5% aq. sodium hydroxide and water and concentrated to a solid (180 g., 87%), m.p. 83–88°. Recrystallization from *n*-hexane gave yellow prisms, m.p. 88.5–91°.

Anal. Calcd. for $C_{14}H_{14}O_3$: C, 73.02; H, 6.13. Found: C, 72.89; H, 6.03.

2-Allyl-3,6-dimethoxy-β-methylcinnamic Acid (IV).—5-Allyl-6-methoxy-4-methylcoumarin (4.12 g., 0.018 mole) was dissolved in a boiling mixture of 20% aq. sodium hydroxide (50 ml.) and methanol (50 ml.) and, after cooling to 50–55°, dimethyl sulfate (30 g., 0.24 mole) was added, followed by an additional 100 ml. of 20% aq. sodium hydroxide. After 3 hr., the mixture was acidified with 5% hydrochloric acid and the oil, isolated by ether extraction, was refluxed for 3 hr. in a solution of potassium hydroxide (10 g.) in 75% ethanol (100 ml.). The alkaline solution was diluted with water (200 ml.), acidified with conc. hydrochloric acid, and the resultant precipitate was dissolved in 5% aq. sodium bicarbonate. The solution was filtered and acidified to precipitate a white solid (3.15 g., 67%), m.p. 110–113°. Recrystallization from water gave colorless prisms, m.p. 113.5–115°.

Anal. Calcd. for $C_{15}H_{18}O_4$: C, 68.68; H, 6.92. Found: C, 69.19; H, 6.89.

1,2-Dihydro-2-hydroxy-9-methyl-7*H*-furo[3,2-*f*][1]benzopyran-7-one (V).—A stream of 3.1% ozonized oxygen was passed at the rate of 0.6 ft.³/min. for 27 min. (0.030 mole O_3) through a solution of 5-allyl-6-hydroxy-4-methylcoumarin (5.60 g., 0.026 mole) in ethyl acetate (300 ml.) cooled to −5°. The white solid which separated was dissolved in dimethylformamide (200 ml.) and the solution was shaken with hydrogen (60 p.s.i.) in the presence of 5% palladium on charcoal (0.5 g.) until rapid absorption ceased. After filtration, the solution was diluted with water to obtain a precipitate, which crystallized from 95% ethanol as white needles (2.31 g., 41%), m.p. 265–266°.

Anal. Calcd. for $C_{12}H_{10}O_4$: C, 66.05; H, 4.62; Found: C, 66.45; H, 5.00.

9-Methyl-7*H*-furo[3,2-*f*][1]benzopyran-7-one (IIa).—A. A mixture of 1,2-dihydro-2-hydroxy-9-methyl-7*H*-furo [3,2-*f*][1]benzopyran-7-one (V, 1.96 g., 0.0090 mole) and 85% *o*-phosphoric acid (80 ml.) was heated on a steam bath for 45 min. and poured into water (400 ml.). After warming the solution for an hour, a solid was collected by filtration and recrystallized from acetic acid to obtain off-white prisms (1.72 g., 95%), m.p. 237–238°.

Anal. Calcd. for $C_{12}H_8O_3$: C, 71.99; H, 4.03. Found: C, 72.10; H, 4.20.

B. A mixture of 5-formyl-4-methylcoumarin-6-oxyacetic acid (Ie, 0.502 g., 0.00192 mole), acetic anhydride (8.0 g.), and sodium acetate (1.0 g.) was refluxed for 90 min., cooled, and poured into 2.5% aq. hydrochloric acid (100 ml.). After the decomposition of excess acetic anhydride, a solid was collected by filtration and washed thoroughly with 5% aq. sodium bicarbonate. The insoluble residue (0.122 g., 31%), m.p. 236–238°, crystallized from ethanol as colorless prisms, m.p. 237–238°, which did not depress the melting point of the sample obtained in A, above. The infrared spectra of the two samples were identical.

2-Carboxy-9-methyl-7*H*-furo [3,2-*f*][1]benzopyran-7-one (IIb).—The 5% aq. sodium bicarbonate wash liquors from above were acidified with conc. hydrochloric acid and a white solid (0.204 g., 43%) was collected by filtration. Recrystallization from methyl ethyl ketone gave colorless prisms, m.p. 330–333° (dec.).

Anal. Calcd. for $C_{13}H_8O_5$: C, 63.94; H, 3.30. Found: C, 63.50; H, 3.44.

6-Acetoxy-5-allyl-4-methylcoumarin (Ii).—5-Allyl-6-hydroxy-4-methylcoumarin (12.0 g., 0.055 mole) was acetylated in acetic anhydride (30 ml.) containing sodium acetate (1.0 g.). Recrystallization from a mixture of *n*-hexane and benzene gave 13.1 g. (92%), m.p. 94°.

Anal. Calcd. for $C_{15}H_{14}O_4$: C, 69.75; H, 5.46. Found: C, 69.88; H, 5.51.

2,9-Dimethyl-7*H*-furo[3,2-*f*][1]benzopyran-7-one(IIc).—A. A solution of bromine (6.22 g., 0.0389 mole) in chloroform (15 ml.) was added dropwise to one of 6-acetoxy-5-allyl-4-methylcoumarin (10.05 g., 0.0389 mole) in chloroform (75 ml.). The solution was concentrated on a steam bath to a white residue (16.22 g.), 10 g. of which was refluxed in a solution of sodium (2.8 g.) in absolute ethanol (100 ml.) for 2 hr. The hot solution was poured into a mixture of 5% aq. hydrochloric acid and ice and a solid was collected by filtration. After washing with 5% aq. sodium hydroxide, it was recrystallized from benzene to obtain colorless needles (5.4 g., 95% yield), m.p. 207°.

Anal. Calcd. for $C_{13}H_{10}O_3$: C, 72.89; H, 4.70. Found: C, 72.80; H, 4.77.

B. A mixture of 1,2-dihydro-2,9-dimethyl-7*H*-furo [3,2-*f*][1]benzopyran-7-one (III, 3.0 g.), 5% palladium on charcoal (3.0 g.), and diphenyl ether (30 ml.) was refluxed for 4 hr. The hot solution was filtered and, after cooling, the filtrate was diluted with ether. The solid (1.75 g., 59%), which separated, was recrystallized from benzene to obtain colorless needles, m.p. 207°, which did not depress the m.p. of the sample from A. The infrared spectra of the two samples were identical.

6-Hydroxy-4-methyl-5-*n*-propylcoumarin (Ik).—A solution of 5-allyl-6-hydroxy-4-methylcoumarin (Ig, 25.0 g., 0.116 mole) in dimethylformamide (300 ml.) was shaken with 5% palladium on charcoal (0.5 g.) at 60 p.s.i. hydrogen pressure until 0.12 mole of hydrogen had been absorbed. The solution was filtered, diluted with water, and a tan precipitate (25.0 g., 99%), m.p. 206–207°, was recrystallized from xylene to obtain yellow needles, m.p. 209.5–210.5°.

Anal. Calcd. for $C_{13}H_{14}O_3$: C, 71.54; H, 6.46. Found: C, 71.56; H, 6.22.

6-Allyloxy-4-methyl-5-*n*-propylcoumarin (Im).—Allylation of 6-hydroxy-4-methyl-5-*n*-propylcoumarin (20.00 g., 0.092 moles) gave 23.7 g. (quant.), m.p. 70–75°. Recrystallization from ligroin (*d* 0.67–0.69) gave colorless flakes, m.p. 73.5–75.5°.

Anal. Calcd. for $C_{16}H_{18}O_3$: C, 74.39; H, 7.02. Found: C, 74.61; H, 7.14.

7-Allyl-6-hydroxy-4-methyl-5-*n*-propylcoumarin (VIa).—A solution of 6-allyloxy-4-methyl-5-*n*-propylcoumarin (17.0 g.) in boiling diethylaniline (170 ml.) was refluxed for 2 hr. After cooling, the solution was diluted with petroleum ether and the solid, which separated, was recrystallized from a mixture of *n*-hexane and benzene to obtain tan prisms (9.6 g., 56%), m.p. 116–122°. Two recrystallizations from ligroin (*d* 0.70) gave yellow prisms, m.p. 122–124°.

Anal. Calcd. for $C_{16}H_{18}O_3$: C, 74.39; H, 7.02. Found: C, 74.16; H, 6.92.

The acetate, m.p. 107.5–109°, was obtained in 76% yield by treatment with acetic anhydride in pyridine and recrystallization from *n*-hexane.

Anal. Calcd. for $C_{18}H_{20}O_4$: C, 71.98; H, 6.71. Found: C, 71.58; H, 6.57.

2,3-Dihydro-2-hydroxy-8-methyl-9-*n*-propyl-6*H*-furo-[2,3-*g*][1]benzopyran-6-one (VII). Ozonization and reduction of 7-allyl-6-hydroxy-4-methyl-5-*n*-propylcoumarin (3.00 g., 0.0116 mole) in ethyl acetate (250 ml.) gave colorless prisms (1.4 g., 46%), m.p. 174–176°. Recrystallization from ethyl acetate did not change the m.p.

Anal. Calcd. for $C_{15}H_{16}O_4$: C, 69.21; H, 6.20. Found: C, 69.15; H, 6.29.

8-Methyl-9-*n*-propyl-6*H*-furo[2,3-*g*][1]benzopyran-6-one (VIIIa).—Heating 2,3-dihydro-2-hydroxy-8-methyl-9-*n*-propyl 6*H*-furo[2,3-*g*][1]benzopyran-6-one (1.00 g., 0.00384 mole) with 85% *o*-phosphoric acid gave a yellow solid (0.90 g., 97%), m.p. 140.5–149.5°. Recrystallization from ligroin (*d* 0.67–0.69) gave yellow prisms, m.p. 158–160°.

Anal. Calcd. for $C_{15}H_{14}O_3$: C, 74.36; H, 5.82. Found: C, 74.20; H, 5.81.

2-Allyl-4-benzoyloxyphenol (IXb).[18]—A solution of

hydroquinone monobenzoate allyl ether[13] (50 g.) in diethylaniline (150 ml.) was refluxed for 90 min., allowed to cool, and dissolved in ether (500 ml.). After thorough washing with 5% hydrochloric acid, the ether solution was concentrated to an oil which crystallized from *n*-hexane. The crystals (40.46 g., 81%), m.p. 70–72°, were recrystallized from *n*-hexane to obtain an analytical sample, m.p. 72–73°.

Anal. Calcd. for $C_{16}H_{14}O_3$: C, 75.57; H, 5.55. Found: C, 75.60; H, 5.77.

The acetate, m.p. 77.5–78°, was obtained in 93% yield by treatment with acetic anhydride in pyridine and recrystallization from ethanol.

Anal. Calcd. for $C_{18}H_{16}O_4$: C, 72. 96; H, 5.44. Found: C, 72.79; H, 5.46.

2-Allylhydroquinone (IXa).—The Claisen rearrangement of hydroquinone monobenzoate allyl ether (800 g.) was carried out as described above, except that proportionately less diethylaniline (200 ml.) was used. A brown solid (756.5 g.) was obtained, which was only partially soluble in 5% aq. sodium hydroxide. It is undoubtedly a mixture of 2-allylhydroquinone and its mono- and dibenzoate. The crude solid (200 g.) was heated for 1 hr. in a refluxing solution (1500 ml.) of 20% aq. sodium hydroxide containing sodium hydrosulfite (20 g.) to prevent oxidation. The solution was acidified (pH *ca.* 2) with conc. hydrochloric acid and the benzoic acid, which precipitated, was removed by filtration. The filtrate was repeatedly extracted with ether and the ether solution was washed with 5% aq. sodium bicarbonate and water. The ether was removed on a steam bath and the residue was recrystallized from benzene to obtain colorless crystals (98 g., 79%), m.p. 86–89° (reported[19]: 93°).

1,2-Dihydro-2,9-dimethyl-7*H*-furo[3.2-f][1]benzopyran-7-one (III).—A. 6-Allyloxy-4-methylcoumarin (94.6 g.) was heated to 216° in a closed container in an oil bath for 3 hr. and the hot melt was poured into xylene (500 ml.). The crystals that deposited on cooling were collected, washed with 5% aq. sodium hydroxide, and recrystallized from 95% ethanol to obtain colorless needles (50 g., 53%), m.p. 185–186°.

Anal. Calcd. for $C_{13}H_{12}O_3$: C, 72.20; H, 5.60. Found: C, 71.82; H, 5.93.

B. Conc. sulfuric acid (15 ml.) was added slowly to a solution of 2-allylhydroquinone (5.00 g., 0.0333 mole) in ethyl acetoacetate (5.40 g., 0.0415 mole), keeping the temperature below 10° by cooling in an ice salt bath. After 5 hr., the solution was poured into ice water (*ca.* 150 ml.). Decantation left a brown gum which crystallized from 95% ethanol as yellow needles (0.70 g.), m.p. 180–186°, which were insoluble in 5% aq. sodium hydroxide. An ether solution of the recrystallization mother liquors was thoroughly washed with 5% aq. sodium hydroxide and then with water. Concentration on a steam bath left a residue, which crystallized from 95% ethanol as yellow needles (0.585 g.), m.p. 183–185°. The total yield of nearly pure material was 1.285 g. (18%). An additional recrystallization from 95% ethanol (Norit-A) gave colorless needles, m.p. 186–187°, which did not depress the m.p. of the sample described in A. The infrared spectra of the two samples were identical.

2,3-Dihydro-2,8-dimethyl-6*H*-furo[2,3-g][1]benzopyran-6-one (XI).—Heating 2-allylhydroquinone in 47% hydrobromic acid gave 5-hydroxy-2-methylcoumaran (X) as reported.[14] The latter (10.33 g., 0.0688 mole) with ethyl acetoacetate (8.94 g., 0.0687 mole) in conc. sulfuric acid for 46 hr. gave a crude product, which was dissolved in chloroform and washed with 5% aq. sodium hydroxide. Evaporation of the chloroform left a residue, which was recrystallized from ligroin (D. 0.70) to obtain yellow prisms (3.30 g., 22%), m.p. 131.5–132.5°.

Anal. Calcd. for $C_{13}H_{12}O_3$: C, 72.20; H, 5.60. Found: C, 72.12; H, 5.66.

2,8-Dimethyl-6*H*-furo[2,3-g][1]benzopyran-6-one (VIIIb).—A mixture of 2,3-dihydro-2,8-dimethyl-6*H*-furo[2,3-g][1]benzopyran-6-one (3.30 g.), 5% palladium on charcoal (3.30 g.), and diphenyl ether (30 ml.) was refluxed for 3 hr. and the hot solution was filtered. The colorless needles (1.10 g.), which crystallized on cooling, were collected by filtration. Diphenyl ether was removed from the filtrate in a rotary evaporator under vacuum (3 mm.), heated in an oil bath at 135–140°, to leave a residue. Extraction of the catalyst with 95% ethanol gave an additional 0.5 g. The combined solids (2.10 g.) were recrystallized from 95% ethanol to obtain off-white crystals (1.53 g., 46%), m.p. 175–179°. Another recrystallization gave an analytical sample, m.p. 178–180°.

Anal. Calcd. for $C_{13}H_{10}O_3$: C, 72.89; H, 4.70. Found: C, 73.00; H, 4.99.

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(18) This compound and its acetate were prepared by Mr. C. P. Lillya.

(19) C. Cardani and P. Grunanger, *Gazz. chim. ital.*, **85**, 252 (1955).