147. *The Chemistry of the "Insoluble Red" Woods. Part I. Pterocarpin and Homopterocarpin.*

By ALEXANDER MCGOOKIN, ALEXANDER ROBERTSON, and WILLIAM B. WHALLEY.

On oxidation with potassium permanganate homopterocarpin, which is devoid of hydroxyl or carbonyl groups, yields 2-hydroxy-4-methoxybenzoic acid (II) and 5-methoxy-2-carboxyphenoxyacetic acid (III). *l*-Dihydrohomopterocarpin, containing a phenolic group, is formed by the reduction of homopterocarpin by Clemmensen's method as well as by catalytic procedures, and on oxidation with potassium permanganate gives rise to 7-methoxychroman-3-carboxylic acid (V), identified by comparison with a synthetical specimen. Oxidation of the methyl ether of the dihydro-compound affords a product believed to be the *iso*flavanone (VII). The structures (I) and (IV, R = H) respectively have been developed for homopterocarpin and its dihydro-derivative.

Pterocarpin, which closely resembles homopterocarpin, gives on reduction a phenolic dihydro-derivative and on oxidation the acids (II) and (III). Dihydropterocarpin yields on oxidation the chroman acid (V), and its methyl ether furnishes a ketonic product corresponding to (VII). Structures (X) and (XI, R = H) have been deduced for pterocarpin and dihydropterocarpin respectively.

The syntheses of 7-methoxychroman-3-carboxylic acid (V) and its isomeride 6-methoxycoumarone-2-acetic acid (XX, R = OH) are described.

OWING to the sparingly soluble nature of their colouring matters in warm water, red sandalwood (*Pterocarpus santalinus* Linn.), camwood (variety of *Baphia nitida*), barwood (*Baphia nitida*, Lodd), and narrawood (*Pterocarpus spp.*) have been classified as " insoluble red " woods to distinguish them from the " soluble red " woods of the logwood type (Perkin and Everest, " Natural Organic Colouring Matters," 1918, p. 80). Though the chemistry of the " insoluble red " woods has been the subject of numerous investigations (compare Perkin and Everest, *loc. cit.*), the results appear to be inconclusive and somewhat contradictory and consequently in 1938 we embarked on an extensive investigation of this topic. Since the woods invariably contain the colourless constituents pterocarpin and homopterocarpin, it appeared probable that a knowledge of the constitution of the latter compounds might prove of assistance in determining the structures of the dyes. Accordingly, the present communication deals with the chemistry of pterocarpin and homopterocarpin, of which the latter is the more abundant and was investigated in the first instance.

Homopterocarpin.

A mixture of pterocarpin and homopterocarpin appears to have been first isolated from red sandalwood by Cazeneuve (*Ber.*, 1874, **7**, 1798; *Bull. Soc. chim.*, 1875, **23**, 97), who with Hugounenq succeeded in separating the two compounds, which they found to be optically active (*Comp. rend.*, 1887, **104**, 1722; 1888, **107**, 737; *Ann. Chim.*, 1889, **17**, 113). Homopterocarpin has been subsequently investigated by Brooks (*Phillipine J. Sci.*, 1910, **5**, *A*, 448), Ryan and Fitzgerald (*Proc. Roy. Irish Acad.*, 1913, **30**, *B*, 106; compare Anderson, J., 1876, **30**, 582), Dieterle and Leonhardt (*Arch. Pharm.*, 1929, **267**, 81), Leonhardt and Oechler (*ibid.*, 1935, **273**, 447), and Raudnitz and Perlmann (*Ber.*, 1935, **68**, 1862). The empirical formula $C_{17}H_{16}O_4$, which was first suggested for the compound by Brooks (*loc. cit.*) and supported by Ryan and Fitzgerald (*loc. cit.*), has been confirmed by subsequent workers, who have also shown that the substance contains two methoxyl groups. Cazeneuve and Hugounenq (*loc. cit.*), who observed the stability of the substance towards alkalis, state that it did not yield a phenylhydrazone or an acetate, but Leonhardt and his co-workers (*loc. cit.*) describe the formation of an acetyl derivative and a 2 : 4-dinitrophenylhydrazone. Further, by the action of nitric acid on homopterocarpin the latter authors obtained styphnic acid and considered that resorcinol and probably phloroglucinol were formed by fusion with alkalis.

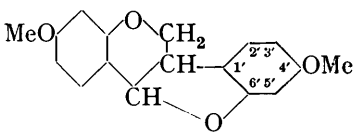
With the specimens of red sandalwood available it was found difficult to obtain consistent yields of homopterocarpin by the method employed by the aforementioned workers, but by a simpler procedure the compound has been isolated along with pterocarpin in satisfactory yield from barwood. The analytical data obtained are in excellent agreement with the formula $C_{15}H_{10}O_2(OMe)_2$ for homopterocarpin, which we have observed to be extremely sensitive to mineral acids and remarkably stable in boiling alcoholic sodium hydroxide. All attempts to detect the presence of hydroxyl or carbonyl groups in the compound have given negative results and it appears probable that the process of acetylation employed by Dieterle and Leonhardt (*loc. cit.*) effects a change in the structure of the molecule. Similarly the 2 : 4-dinitrophenylhydrazone described by these authors is considered to be a derivative of a transformation product of homopterocarpin. In consequence it seemed probable that the third and fourth oxygen atoms of homopterocarpin are present in ether systems.

On oxidation with potassium permanganate in aqueous acetone homopterocarpin gives rise to a mixture of 2-hydroxy-4-methoxybenzoic acid (II) and 5-methoxy-2-carboxyphenoxyacetic acid (III), thus affording clear proof that the molecule contains an *O*-monomethyl resorcinol nucleus. Further, the production of (III) requires the presence of

the system :C·O·CH_2·C: in the homopterocarpin molecule (compare Perkin and Robinson, J., 1908, **93**, 492) and clearly establishes the function of the third oxygen atom.

The view expressed by Leonhardt and his co-workers (*loc. cit.*) that the catalytic reduction of homopterocarpin to *l*-dihydrohomopterocarpin is accompanied by the production of a phenolic hydroxyl group has been confirmed and the same result obtained by application of Clemmensen's method. On oxidation the dihydro-derivative gives rise to *7-methoxychroman-3-carboxylic acid* (V), identical with a synthetical specimen, a result which definitely establishes the presence of a 7-methoxychroman residue in *l*-dihydrohomopterocarpin, thus accounting for ten carbon atoms in the molecule. Further, it is clear that the carboxyl group of (V) arises by oxidation of a phenyl radical united to the chroman residue at the 3-position and carrying the second methoxyl group and the phenolic hydroxyl group, the oxygen atom of which we consider to be originally present in an ether system in homopterocarpin. Thus *l*-dihydrohomopterocarpin may be formulated as (IV, R = H) and its methyl ether as (IV, R = Me).

Our observations on the properties of dihydrohomopterocarpone, formed by the oxidation of *l*-dihydrohomopterocarpin with chromic anhydride, confirm the view expressed by Leonhardt and Oechler (*loc. cit.*) that this derivative is a quinone, which is now formulated as (VI). The quinone structure (VI) clearly implies that the free hydroxyl group in *l*-dihydrohomopterocarpin is in the 3'- or the 6'-position and of these we prefer the latter as indicated in formula (IV, R = H). When this hydroxyl group is protected by methylation, oxidation of the resulting ether (IV, R = Me) yields a product, $C_{15}H_9O_2(OMe)_3$, which readily furnishes an *oxime* and a 2 : 4-*dinitrophenylhydrazone* and therefore is in all probability the iso*flavanone* (VII). In agreement with this structure the compound is readily decomposed by boiling alcoholic sodium hydroxide and does not form an *iso*-nitroso- or a benzylidene derivative, indicating the absence of a methylene group adjacent to the carbonyl group; the ketonic properties of this compound clearly exclude the alternative dihydrocoumarin structure which could arise by the oxidation of the methylene group in the 2-position of the chroman system. Oxidation of (VII) with alkaline potassium permanganate gives a product which appears to have the formula $C_{15}H_9O_3(OMe)_3$, but which owing to lack of material has not yet been fully investigated.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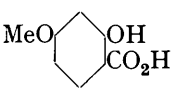
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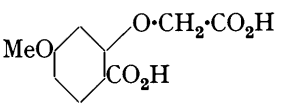
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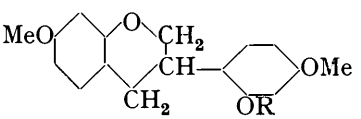
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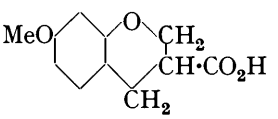
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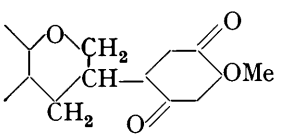
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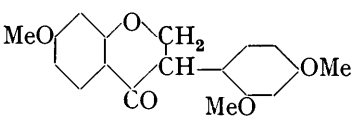
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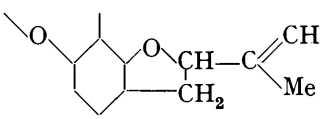
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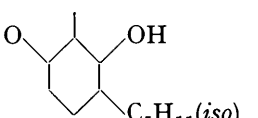
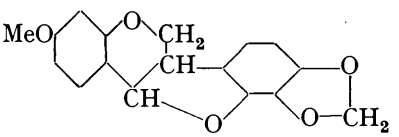

(IX.)

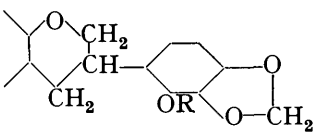
Since homopterocarpin does not possess a hydroxyl or a carbonyl group, it seems reasonably certain that the fourth oxygen atom, which appears in the phenolic hydroxyl group of the dihydro-derivative, forms an ether system with a carbon atom of the chroman residue. In view of the production of (III) by the oxidation of homopterocarpin it is clear that the carbon atom in the 2-position of the chroman system is not involved, and of the remaining possibilities, *viz.*, the carbon atoms in the 3- and 4-positions, the latter is considered to be the more likely. Thus homopterocarpin may be represented by formula (I) in which the fourth oxygen atom is present in a dihydrofuran system. The reductive

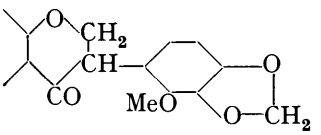
fission of the latter to give (IV, R = H) by catalytic methods finds a close analogy in the conversion of the tubanol residue of rotenone (VIII) into the tetrahydro-derivative (IX) (La Forge and Smith, *J. Amer. Chem. Soc.*, 1929, **51**, 2574), and although the behaviour of (I) in giving rise to (IV, R = H) by application of Clemmensen's method of reduction is somewhat unexpected, it may be noted that Marker and Rohrmann (*J. Amer. Chem. Soc.*, 1939, **61**, 846) have recorded a similar result where an oxygen system in sarsasapogenin is opened by Clemmensen's reagent. With regard to the structure (I), the position of the methoxyl group in the dihydrobenzofuran residue, *i.e.*, in the 3-phenyl radical of (IV, R = H), has not been conclusively established, but the ease of oxidation of (IV, R = H) to the quinone (VI) implies that the latter is a *p*-quinone and hence the methoxyl group is not in the 3′-position. Of the remaining possibilities, the 4′-position is preferred at present.

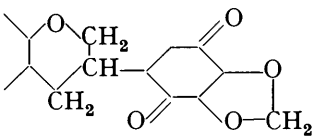
Pterocarpin.

The empirical formula $C_{16}H_{11}O_4(OMe)$ adopted by Leonhardt and Fay (*Arch. Pharm.*, 1935, **273**, 53; compare Brooks, *loc. cit.*, and Dieterle and Leonhardt, *loc. cit.*) and by Raudnitz and Perlmann (*loc. cit.*) has been substantiated in the present work and, as suggested by the former authors, this compound, unlike homopterocarpin, appears to contain a methylenedioxy-group. In all other respects pterocarpin closely resembles homopterocarpin and though Leonhardt and Fay (*loc. cit.*) claim that the substance forms a 2 : 4-dinitrophenylhydrazone, we consider that the latter is derived from a transformation product as in the case of the corresponding substance obtained from homopterocarpin. Oxidation of pterocarpin with potassium permanganate yields a mixture of the acids (II) and (III) together with a small amount of a neutral compound, m. p. 272°. Similarly dihydropterocarpin, which is phenolic, furnishes 7-methoxychroman-3-carboxylic acid (V) and its methyl ether yields a ketonic *product* corresponding to (VII) which is formed from *O*-methyldihydrohomopterocarpin. Oxidation of dihydropterocarpin with chromic acid in acetic acid gave a product, which has not been obtained pure but presumably consists mainly of dihydropterocarpone. This material gave a 2 : 4-*dinitrophenylhydrazone*.

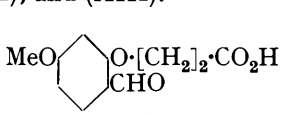
(X.) 

 (XI.)

(XII.) 

 (XIII.)

From the formation of these oxidation products and by analogy with homopterocarpin, we consider that pterocarpin, dihydropterocarpin, and *O*-methyldihydropterocarpin and its ketonic oxidation product are represented respectively by the formulæ (X), (XI, R = H), (XI, R = OMe) and (XII). The production of the acid (V) from dihydropterocarpin clearly shows that the phenyl residue which contains the hydroxyl group also carries the methylenedioxy-group and further, because dihydropterocarpin yields a quinone-like oxidation product (XIII), (corresponding to VI), it seems reasonably certain that the methylenedioxy-group is attached at the 4′ : 5′-positions as in the structures (X), (XI), (XII), and (XIII).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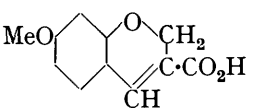
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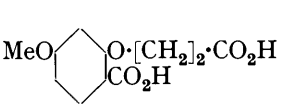
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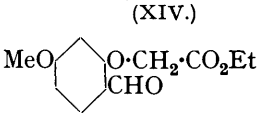
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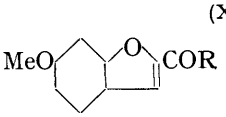
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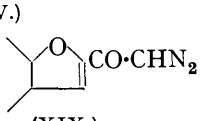
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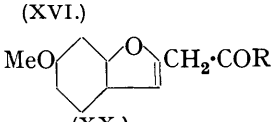
(XX.)

The authentic 7-methoxychroman-3-carboxylic acid (V) was synthesised as follows: Interaction of the sodium salt of 2-hydroxy-4-methoxybenzaldehyde and sodium β-chloropropionate in aqueous solution gave rise to the β-phenoxypropionic acid (XIV) and by cyclisation by means of boiling acetic anhydride and sodium acetate this substance gave *7-methoxy-Δ^3-chromen-3-carboxylic acid* (XV) in small yield, which on hydrogenation furnished the acid (V), identical with the natural specimen. In exploring an alternative route to this acid attempts were made to cyclise the ester of *5-methoxy-2-carboxy-β-phenoxypropionic acid* (XVI), formed by the oxidation of (XIV), but the use of sodium or sodium ethoxide for this purpose under a variety of conditions invariably led to the production of ethyl 2-hydroxy-4-methoxybenzoate. In order to eliminate the possibility of the acid resulting from the cyclisation of (XIV) being the isomeric *coumarone-2-acetic acid* (XX, R = OH), the latter compound was synthesised from the ester (XVII, R = OEt) by way of the stages (XVIII, R = OEt), (XVIII, R = OH), (XVIII, R = Cl), (XIX) and (XX, R = NH_2).

Experimental.

Homopterocarpin.—Finely powdered barwood (300 g.) was extracted with boiling carbon tetrachloride (2·5 l.) for 6 hours, the hot extract was filtered, the volume was reduced to about 37—40 c.c. by evaporation of the solvent in a vacuum at a temperature not above 50°, the red solid (1·5 g.) was removed by filtration, and the viscous red liquid left on evaporation of the solvent was dissolved in 96% alcohol (20 c.c.). The product which separated from this solution in the course of 24 hours was a mixture of pterocarpin and homopterocarpin, which were separated by fractional crystallisation from 96% alcohol. After the isolation of pterocarpin (0·15 g.), which on purification had m. p. 164·5°, the more soluble homopterocarpin was obtained on concentration of the alcoholic liquors and on repeated crystallisation from alcohol and then light petroleum (b. p. 60—80°) formed colourless needles (1 g.), m. p. 87°, $[\alpha]_{5461}^{20\cdot5°}$ −236·6° in chloroform (*c*, 0·898 g. in 100 c.c.; *l* = 1) [Found: C, 71·9; H, 5·7; OMe, 20·7; *M* (Rast), 276, 291. Calc. for $C_{15}H_{10}O_2(OMe)_2$: C, 71·8; H, 5·7; OMe, 21·8%; *M*, 284] (Leonhardt and Oechler, *loc. cit.*, give m. p. 83—84°, $[\alpha]_D^{20°}$ −216·3° for material from sandalwood). On being heated at 80°/0·1 mm. this compound sublimed unchanged.

Oxidation of Homopterocarpin with Potassium Permanganate.—5% Aqueous potassium permanganate (125 c.c.) was added to a solution of the compound (1 g.) in acetone (100 c.c.) (agitate vigorously) in the course of 6 hours and next day the solution was cleared with sulphur dioxide, treated with dilute sulphuric acid (10 c.c.), warmed on the water-bath for 10 minutes, cooled, saturated with ammonium sulphate, and extracted with ether (160 c.c. × 8). The combined ethereal extracts were washed with aqueous sodium bicarbonate (110 c.c. × 4), dried and evaporated, leaving unchanged homopterocarpin. After acidification with dilute hydrochloric acid the combined aqueous sodium bicarbonate liquors were extracted with ether (145 c.c. × 7), the dried extracts evaporated, and the combined residues from eight experiments dissolved in warm benzene (125 c.c.). On being kept, this solution gradually deposited 5-methoxy-2-carboxyphenoxyacetic acid (0·05 g.) in needles, m. p. 174°, after purification from warm water, identical with a synthetical specimen (Perkin and Robinson, J., 1908, **93**, 504) [Found: C, 53·2; H, 4·6; OMe, 13·8. Calc. for $C_9H_7O_5(OMe)$: C, 53·1; H, 4·4; OMe, 13·7%]. Prepared by means of excess of ethereal diazomethane, the methyl ester separated from light petroleum (b. p. 60—80°) in squat prisms, m. p. 62°, undepressed on admixture with an authentic specimen. On evaporation of the greater part of the solvent the benzene filtrate from the foregoing acid gradually deposited 2-hydroxy-4-methoxybenzoic acid (4·5 g.), which formed colourless needles, m. p. 154°, from warm benzene, having a violet ferric reaction, identical with an authentic specimen [Found: C, 57·0; H, 4·8; OMe, 18·6. Calc. for $C_7H_5O_3(OMe)$: C, 57·1; H, 4·8; OMe, 18·5%].

Prolonged extraction of the aqueous liquors left on separation of 2-hydroxy-4-methoxybenzoic acid and 5-methoxy-2-carboxyphenoxyacetic acid in a continuous extraction apparatus with ether gave only oxalic acid.

Reduction of Homopterocarpin.—The substance (0·5 g.), dissolved in alcohol (100 c.c.) containing a palladium–charcoal catalyst (from 0·2 g. of palladium chloride and 2 g. of charcoal), absorbed hydrogen (1 mol.) in the course of 5 hours, and the resulting *l*-dihydrohomopterocarpin formed stout prisms (0·3 g.), m. p. 154°, identical with the product (0·87 g.), m. p. 154°, obtained when the hydrogenation of homopterocarpin (1 g.) was effected in acetic acid (30 c.c.) with the same catalyst at 95°, a procedure more suitable for the production of larger quantities [Found:

C, 71·4; H, 6·4; OMe, 21·0. Calc. for $C_{15}H_{12}O_2(OMe)_2$: C, 71·3; H, 6·3; OMe, 21·7%]. This substance, which is soluble in most organic solvents and in cold dilute aqueous sodium hydroxide, has a negative ferric reaction in alcohol.

A mixture of homopterocarpin (1 g.), amalgamated zinc (10 g.), water (20 c.c.), concentrated hydrochloric acid (40 c.c.), and toluene (25 c.c.) was refluxed for 8 hours; three further portions of hydrochloric acid (2 c.c. each) were added after 2, 4, and 6 hours. After removal of the zinc (wash with 10 c.c. of toluene) the toluene layer was separated and evaporated to a small volume, giving the dihydro-derivative, m. p. 154°, $[\alpha]_{5461}^{20°}$ −12·7° in alcohol (*c*, 0·295 g. in 100 c.c.; *l* = 1), after purification from dilute alcohol (Found: C, 71·4; H, 6·4; OMe, 21·3%) (Leonhardt and Oechler give m. p. 153—154°, $[\alpha]_D^{20°}$ −5·8°). Methylation of this compound (1 g.) with excess of methyl iodide and potassium carbonate in boiling acetone (30 c.c.) for 4 hours gave rise to the methyl ether, which formed colourless prisms (1 g.), m. p. 61°, from aqueous alcohol, insoluble in aqueous sodium hydroxide [Found: C, 72·2; H, 6·7; OMe, 30·9. Calc. for $C_{15}H_{11}O(OMe)_3$: C, 72·0; H, 6·7; OMe, 31·0%] (Leonhardt and Dieterle, *loc. cit.*, give m. p. 57—58°).

Oxidation of dihydrohomopterocarpin (1 g.), dissolved in acetic acid (25 c.c.), with a solution of chromic oxide (0·35 g.) in the same solvent gave dihydrohomopterocarpone, forming orange needles (0·2 g.), m. p. 177·5—178·5°, from acetone, soluble in alcohol and ethyl acetate, sparingly soluble in light petroleum, and insoluble in aqueous sodium hydroxide and having a negative ferric reaction (Found: C, 68·0; H, 5·3. Calc. for $C_{17}H_{16}O_5$: C, 68·0; H, 5·3%). The oxime formed pale yellowish-green needles (0·2 g.), m. p. 229° (decomp.), from alcohol (Found: N, 4·5. Calc. for $C_{17}H_{17}O_5N$: N, 4·4%) (compare Leonhardt and Oechler, *loc. cit.*). Reduction of dihydrohomopterocarpone with zinc dust and acetic acid on the water-bath gave a colourless product (the quinol?), m. p. about 145°, which readily dissolved in aqueous sodium hydroxide and rapidly oxidised in air.

A solution of dihydrohomopterocarpin (1 g.) in acetone (100 c.c.) was treated with 5% aqueous potassium permanganate (75 c.c.) in the course of 25 minutes and next day the product was isolated by the procedure adopted for the oxidation mixture from homopterocarpin. Repeated crystallisation of the acidic fraction from benzene and then aqueous alcohol gave *7-methoxychroman-3-carboxylic acid* (0·1 g.) in almost colourless leaflets, m. p. 149°, forming a yellow solution in concentrated sulphuric acid which exhibited a brilliant green fluorescence [Found: C, 63·5; H, 5·8; OMe, 14·9. $C_{10}H_9O_3(OMe)$ requires C, 63·5; H, 5·8; OMe, 14·9%].

Oxidation of O-*Methyldihydrohomopterocarpin.*—5% Aqueous potassium permanganate (100 c.c.) was added to a solution of the ether (1 g.) in acetone (150 c.c.) in the course of 4 hours and next day the mixture was cleared with sulphur dioxide, treated with 2N-hydrochloric acid (15 c.c.), warmed on the water-bath for 10 minutes, cooled, and extracted with ether (125 c.c. × 8). The ethereal extracts were washed several times with aqueous sodium bicarbonate, dried, and evaporated, leaving an oily residue which gradually solidified and then on crystallisation from 50% alcohol and subsequently light petroleum gave a *ketone* in thick colourless prisms (0·5 g.), m. p. 127°, readily soluble in alcohol, acetone, or ethyl acetate, sparingly soluble in light petroleum, and insoluble in aqueous sodium hydroxide [Found: C, 68·7; H, 5·8; OMe, 29·1. $C_{15}H_9O_2(OMe)_3$ requires C, 68·8; H, 5·7; OMe, 29·6%]. This substance, which had a negative ferric reaction, gave rise to a 2 : 4-*dinitrophenylhydrazone*, forming small red prisms, m. p. 184°, from alcohol (Found: N, 11·3. $C_{24}H_{22}O_8N_4$ requires N, 11·3%). The *oxime* separated from dilute alcohol in colourless needles, m. p. 185·5° (Found: N, 4·0. $C_{18}H_{19}O_5N$ requires N, 4·3%).

From the mother-liquors left on purification of the ketone, unchanged *O*-methyldihydrohomopterocarpin (0·2 g.) was recovered, and extraction of the acidified aqueous sodium bicarbonate extracts with ether gave only a trace of material.

A solution of potassium permanganate (4 g.) in water (100 c.c.) was added to boiling 2N-sodium hydroxide (100 c.c.) containing a suspension of the foregoing ketone (1 g.) in the course of 55 minutes and, on cooling, the manganese dioxide was removed with sulphur dioxide. Crystallisation of the solid from alcohol gave a *product* in stout, colourless prisms (0·6 g.), m. p. 178°, insoluble in aqueous sodium hydroxide and having a negative ferric reaction [Found: C, 65·6; H, 5·6; OMe, 26·8. $C_{15}H_9O_3(OMe)_3$ requires C, 65·5; H, 5·5; OMe, 28·2%]. The yellow solution of this substance in concentrated sulphuric acid exhibited a faint green fluorescence.

Pterocarpin.—This separated from alcohol or light petroleum (b. p. 60—80°) in colourless leaflets, m. p. 164·5°, $[\alpha]_{5461}^{20·5°}$ −207·5° in chloroform (*c*, 0·530 g. in 100 c.c.; *l* = 1) [Found: C, 68·5; H, 4·9; OMe, 9·8; *M*, 295, 290. Calc. for $C_{16}H_{11}O_4(OMe)$: C, 68·5; H, 4·7; OMe,

10·4%; *M*, 298] (Leonhardt and Fay, *loc. cit.*, give m. p. 165°, $[\alpha]_D^{24°}$ −224·1° for material from sandalwood).

Hydrogenation of pterocarpin (2 g.), dissolved in acetic acid (60 c.c.) at 95°, with hydrogen and a palladium–charcoal catalyst (from 0·2 g. of palladium chloride and 2 g. of charcoal) was complete in 7 minutes and on isolation the dihydro-product formed colourless needles (1·7 g.), m. p. 140°, soluble in aqueous sodium hydroxide, giving a dark green coloration in warm sulphuric acid, and having a negative ferric reaction [Found: C, 68·0; H, 5·4; OMe, 12·0. Calc. for $C_{16}H_{13}O_4(OMe)$: C, 68·0; H, 5·3; OMe, 10·3%] (compare Leonhardt and Fay, *loc. cit.*). The same compound was obtained when a mixture of pterocarpin (0·5 g.), toluene (20 c.c.), amalgamated zinc dust (5 g.), and 2N-hydrochloric acid was boiled for 8 hours; more acid (1 c.c.) was added at intervals of 1 hour. On isolation the product formed needles (0·3 g.), m. p. 140°, $[\alpha]_{5461}^{21°}$ −19·5° in alcohol (*c*, 1·714 g. in 100 c.c.; *l* = 1) (Found: C, 68·1; H, 5·5; OMe, 10·2%). Prepared quantitatively by the methyl iodide–potassium carbonate method, the methyl ether of dihydropterocarpin separated from aqueous alcohol in slender needles, m. p. 106·5° [Found: C, 69·0; H, 5·7; OMe, 20·5. Calc. for $C_{16}H_{12}O_3(OMe)_2$: C, 68·8; H, 5·7; OMe, 19·7%] (compare Leonhardt and Fay, *loc. cit.*, who give m. p. 107—108°).

Oxidation of Pterocarpin.—A solution of potassium permanganate (7 g.) in water (125 c.c.) was added to pterocarpin (1 g.), dissolved in acetone (100 c.c.), in the course of 4 hours; 24 hours later the mixture was cleared with sulphur dioxide, the greater part of the acetone removed in a vacuum, the residual liquor treated with a little hydrochloric acid, and the product isolated with ether. An ethereal solution (1 l.) of the products from three experiments was washed with aqueous sodium bicarbonate (100 c.c. × 5), the combined washings acidified with concentrated hydrochloric acid, and the product isolated with ether and extracted with boiling benzene (40 c.c.). On cooling, the extract slowly deposited 5-methoxy-2-carboxyphenoxyacetic acid in needles (10 mg.), m. p. 172·5°, after purification from water, identical with a synthetical specimen, m. p. 174° (Found: C, 53·5; H, 4·8%).

On being concentrated, the benzene liquors from 5-methoxy-2-carboxyphenoxyacetic acid gave 2-hydroxy-4-methoxybenzoic acid in needles, m. p. 157°, after purification, having a violet ferric reaction and identical with an authentic specimen (Found: C, 57·2; H, 4·7; OMe, 18·4%). Further extraction of the residual acidic aqueous liquors with ether in a continuous extractor gave, in addition to oxalic acid, a small amount of 5-methoxy-2-carboxyphenoxyacetic acid.

Evaportion of the dried ethereal solution which had been extracted with aqueous sodium bicarbonate left a residue which, on repeated purification from alcohol and then ethyl acetate, gave a small amount of a product in slender colourless needles, m. p. 272°, exhibiting an intense blue fluorescence in these solvents (Found: C, 69·5; H, 5·6%). The pale yellow solution of this compound in concentrated sulphuric acid was unchanged on addition of alcoholic gallic acid.

Oxidation of Dihydropterocarpin.—The compound (1 g.), dissolved in acetone (maintained at room temperature), was oxidised with a solution of potassium permanganate (3 g.) in water (75 c.c.), and the acidic material isolated as in the oxidation of pterocarpin. Crystallisation of the product from aqueous alcohol gave 7-methoxychroman-3-carboxylic acid in leaflets, m. p. 149°, identical with a synthetical specimen (Found: C, 63·1; H, 5·6%).

Oxidation of dihydropterocarpin (0·8 g.) with chromic anhydride (0·3 g.) in acetic acid (15 c.c.) gave rise to a yellow resinous product which has not so far crystallised but which on treatment with alcoholic 2 : 4-dinitrophenylhydrazine hydrochloride gave a *product* forming tiny maroon-coloured needles, m. p. 202—203° (decomp.), from ethyl acetate (Found: N, 9·8. $C_{23}H_{18}O_{10}N_4$ requires N, 11·0%).

Oxidation of O-*Methydihydropterocarpin.*—1 G., dissolved in acetone (60 c.c.), with 7% aqueous potassium permanganate (50 c.c.) in the course of 3 hours gave a neutral and an acidic fraction. Extraction of the latter with a little boiling benzene gave 2-hydroxy-4-methoxybenzoic acid (20 mg.), identified by comparison with an authentic specimen. Spontaneous evaporation of an aqueous-alcoholic solution of the neutral product left a mixture of clusters of colourless needles and rosettes of compact crystals, which were separated manually. The former material consisted of unchanged ether, m. p. and mixed m. p. 106°, after purification from aqueous alcohol. Repeated crystallisation of the second product from alcohol gave a ketonic substance in rosettes of colourless stout prisms (80 mg.), m. p. 118—119° [Found: C, 65·9; H, 5·1; OMe, 15·2. $C_{16}H_{10}O_4(OMe)_2$ requires C, 65·9; H, 4·9; OMe, 18·9%]. The 2 : 4-*dinitrophenylhydrazone* formed short scarlet prisms, m. p. 248°, from alcohol and then ethyl acetate (Found: N, 11·4. $C_{24}H_{20}O_9N_4$ requires N, 11·0%).

5-*Methoxy*-2-*formyl*-β-*phenoxypropionic Acid* (XIV).—A solution of 4-*O*-methyl-β-resorcyl-

aldehyde (2 g.) in 8% aqueous potassium hydroxide (10 c.c.) was added to a solution of β-chloropropionic acid (2 g.) in water (20 c.c.), containing sodium bicarbonate (1·6 g.), and the mixture heated on the steam-bath for 2½ hours; the small amount of precipitate formed at first was dissolved by the addition of the minimum amount of 8% aqueous sodium hydroxide. The reaction mixture was acidified (Congo-red) with concentrated hydrochloric acid and extracted with ether (100 c.c. × 10), the ethereal extracts washed with saturated aqueous sodium bicarbonate (100 c.c. × 5), and the combined washings acidified with concentrated hydrochloric acid. Repeated crystallisation of the pale brown precipitate from water (charcoal) gave the *acid* (XIV) in colourless needles, m. p. 159°, having a negative ferric reaction [Found: C, 58·9; H, 5·4; OMe, 13·4. $C_{10}H_9O_4(OMe)$ requires C, 58·9; H, 5·4; OMe, 13·8%]. Prepared by means of alcoholic 2 : 4-dinitrophenylhydrazine, the 2 : 4-*dinitrophenylhydrazone* formed feathery needles, m. p. 241·5°, from alcohol (Found: N, 13·6. $C_{17}H_{16}O_8N_4$ requires N, 13·9%). The *semicarbazone* separated from aqueous alcohol in needles, m. p. 218° (decomp.) (Found: N, 15·1. $C_{12}H_{15}O_5N_3$ requires N, 14·9%).

Oxidation of the acid (XIV) (1 g.), dissolved in 2N-sodium bicarbonate (50 c.c.) and water (25 c.c.) at 50°, was effected with a solution of potassium permanganate (1·5 g.) in water (50 c.c.), added in the course of 15 minutes, and 3 hours later the mixture was cleared with sulphur dioxide and treated with concentrated hydrochloric acid (15 c.c.). 5-*Methoxy*-2-*carboxy*-β-*phenoxypropionic acid* (XVI) slowly separated and on recrystallisation from water and then ethyl acetate formed stout prisms (0·7 g.), m. p. 143°, having a negative ferric reaction (Found: C, 55·3; H, 5·2. $C_{11}H_{12}O_6$ requires C, 55·0; H, 5·0%). The methyl ester was prepared by means of excess of ethereal diazomethane and obtained as a colourless oil, b. p. 78—80°/95 mm.

7-*Methoxy*-Δ^3-*chromen*-3-*carboxylic Acid* (XV).—A mixture of 5-methoxy-2-formyl-β-phenoxypropionic acid (2 g.), sodium acetate (3 g.), and acetic anhydride (25 c.c.) was refluxed (oil-bath at 145°) for 1 hour, treated with water, and extracted with ether (100 c.c. × 6). 24 Hours later, the solvent and the acetic acid were removed in a vacuum and a solution of the residue in ether (250 c.c.) was washed with saturated aqueous sodium bicarbonate (50 c.c. × 5). On being acidified with hydrochloric acid, the combined washings slowly deposited a light brown solid, which on repeated crystallisation from hot water gave the *acid* (0·03 g.) in small, stout, colourless octahedra, m. p. 201°, soluble in the usual organic solvents except light petroleum (Found: C, 64·3; H, 5·0. $C_{11}H_{10}O_4$ requires C, 64·1; H, 4·9%). The yellow solution of this substance in concentrated sulphuric acid had an intense green fluorescence.

Hydrogenation of 7-methoxy-Δ^3-chromen-3-carboxylic acid (0·08 g.), dissolved in alcohol (125 c.c.), was effected with a palladium–charcoal catalyst (from 0·1 g. of palladium and 0·5 g. of charcoal) and hydrogen at 40 lb./sq. in. and on isolation 7-methoxychroman-3-carboxylic acid formed almost colourless leaflets (0·05 g.), m. p. 149°, from aqueous alcohol and was identical in every way with a natural specimen (Found: C, 63·4; H, 5·9%).

6-*Methoxycoumarone*-2-*carboxylic Acid* (XVIII, R = OH).—Ethyl 2-aldehydo-5-methoxyphenoxyacetate (J., 1936, 419) gave a 2 : 4-*dinitrophenylhydrazone*, forming crimson plates, m. p. 176·5°, from ethyl acetate (Found: N, 13·4. $C_{18}H_{18}O_8N_4$ requires N, 13·4%). Cyclisation of this ester (5 g.), dissolved in alcohol (30 c.c.), with sodium ethoxide (from 0·1 g. of sodium) in the course of 1 hour gave *ethyl* 6-*methoxycoumarone*-2-*carboxylate* (XVIII, R = OEt), which was precipitated with water and then formed colourless prisms (1·4 g.), m. p. 87°, from dilute alcohol, giving a cherry-red and then a purple sulphuric acid reaction [Found: *O*-Alkyl, 34·3. $C_9H_4O_2(OMe)(OEt)$ requires *O*-Alkyl, 34·5%]. Acidification of the alkaline liquors left on separation of this product gave 2-aldehydo-5-methoxyphenoxyacetic acid, m. p. 138°, identical with an authentic specimen (Kostanecki, *Ber.*, 1909, **42**, 911, gives m. p. 144°). This acid gave a 2 : 4-*dinitrophenylhydrazone*, forming slender light red needles, m. p. 273°, from ethyl acetate (Found: N, 14·6. $C_{16}H_{14}O_8N_4$ requires N, 14·4%).

Hydrolysis of ethyl 6-methoxycoumarone-2-carboxylate (5 g.) with warm 10% aqueous alcoholic potassium hydroxide (100 c.c.) for ½ hour gave rise to the acid, which separated from aqueous alcohol in colourless needles (3·9 g.), m. p. 206°, having a crimson and then a brilliant purple sulphuric acid reaction [Found: OMe, 16·1. Calc. for $C_9H_5O_3(OMe)$: OMe, 16·1%] (compare Will and Beck, *Ber.*, 1886, **19**, 1783, who give m. p. 195·5—196·5°).

Phosphorus pentachloride (8 g.) was gradually added to a solution of 6-methoxycoumarone-2-carboxylic acid (7 g.) in chloroform (8 c.c.) and when the vigorous reaction had almost ceased, the mixture was gently warmed on the water-bath for a few minutes. After the removal of the solvent and phosphoryl chloride in a vacuum the residual acid chloride (XVIII, R = Cl) was purified by distillation and obtained as a colourless crystalline mass (7·4 g.), b. p. 165°/15 mm., m. p. 101°. To a solution of the chloride (7·4 g.) in absolute ether (400 c.c.) at −10°, anhydrous

hydrogen cyanide (4·5 c.c.) was added (agitate), followed by a mixture of pyridine (5 c.c.) and ether (25 c.c.). Two hours later the pyridine hydrochloride (wash with ether) was separated, and the ethereal solution rapidly washed several times with cold dilute hydrochloric acid to remove pyridine and then with cold 0·2N-sodium hydroxide. Evaporation of the dried ethereal solution and distillation of the residue in a high vacuum gave the *nitrile* (XVIII, R = CN) as a pale yellow solid (2·1 g.), b. p. 162°/1·5 mm., which formed stout tablets, m. p. 101°, from benzene (Found : N, 6·8. $C_{11}H_7O_3N$ requires N, 7·0%). Attempts to convert the nitrile into the corresponding pyruvic acid according to the method of Reichstein and Reichstein (*Helv. Chim. Acta*, 1930, **13**, 1275) were unsuccessful.

6-*Methoxycoumarone-2-acetic Acid* (XX, R = OH).—Ethereal diazomethane (3 mols. in 100 c.c. of ether) was added in the course of 5 minutes to a solution of the foregoing chloride (XVIII, R = Cl) (1 g.), dissolved in ether (125 c.c.), and 2 hours later the solvent was evaporated and the *diazo-ketone* (XIX) crystallised from benzene–light petroleum (b. p. 60—80°), forming thick, pale yellow tablets, m. p. 90—91° (with slight decomp.) (Found : N, 13·1. $C_{11}H_8O_3N_2$ requires N, 13·0%). Attempts to convert this product into the acetic acid (XX, R = OH) by the method of Eistert and Arndt (*Ber.*, 1935, **68**, 200) gave an intractable resin, from which a little 6-methoxycoumarone-2-carboxylic acid could be isolated.

To a vigorously agitated solution of the diazo-ketone (1 g.) in dioxan (70 c.c.) on the steam-bath, concentrated aqueous ammonia (14 c.c., *d* 0·880) was added, followed by 10% aqueous silver nitrate (8 c.c.); 45 minutes later more ammonia (5 c.c.) was added. After having been heated for 45 minutes, the solution was filtered, cooled, and extracted with ether (100 c.c. × 5). Evaporation of the dried extracts left a light orange oil, which slowly solidified and then on crystallisation from benzene (charcoal) gave the *amide* (XX, R = NH_2) of 6-methoxycoumarone-2-acetic acid in elongated prisms (0·43 g.), m. p. 148°, having a red and then reddish-brown sulphuric acid reaction (Found : N, 7·0. $C_{11}H_{11}O_3N$ requires N, 6·8%). A mixture of the amide (0·4 g.), 25% methyl-alcoholic potassium hydroxide (6 c.c.), alcohol (2 c.c.), and water (6 c.c.) was refluxed for 4 hours, diluted with water (25 c.c.), and acidified with concentrated hydrochloric acid. Isolated with ether (100 c.c. × 5), the product was crystallised from a little benzene and then repeatedly from benzene–light petroleum (b. p. 60—80°), giving 6-*methoxycoumarone-2-acetic acid* (XX, R = OH) in rhombic prisms, m. p. 104°, having a negative ferric reaction [Found : C, 64·3; H, 5·2; OMe, 14·4. $C_{10}H_7O_3(OMe)$ requires C, 64·1; H, 4·9; OMe, 15·0%].

The authors are indebted to Imperial Chemical Industries Limited for a grant in aid of this work and to the Department of Scientific and Industrial Research for a maintenance grant to one of them (W. B. W.).

UNIVERSITY OF LIVERPOOL. [*Received, April 26th*, 1940.]