0.60 g. (92%), m.p. 80–85°. Repeated crystallization from methanol afforded aldehyde **14**: m.p. 97–98°; infrared bands at 2700, 1720, and 1720 cm.$^{-1}$ (aldehyde), no hydroxyl absorption; n.m.r. signals at 9.95 (singlet, 1 proton, C*H*O), 1.06, 0.80, 0.72 (methyl singlets), and 0.76 p.p.m. (methyl triplet, J = 6.5 c.p.s.). On exposure to air for 12 hr. it collapsed to an oil whose infrared spectrum ($CHCl_3$) now contained marked hydroxyl absorption and showed a considerable decrease in intensity of the carbonyl band at 1720 cm.$^{-1}$. The compound was therefore characterized as its azine (**15**) which crystallized from acetone as colorless needles, m.p. 201–202.5°, infrared bands at 1640 cm.$^{-1}$ (C=N).

Anal. Calcd. for $C_{40}H_{68}N_2$: N, 4.85. Found: N, 5.20.

Reduction of 14 to Rimuane 2.—A mixture of 0.45 g. of freshly prepared aldehyde **14**, 25 ml. of ethylene glycol, and 1 ml. of 95% hydrazine was refluxed for 1 hr., concentrated to b.p. 192°, and then allowed to cool for 10 min. Potassium hydroxide (3.2 g.), 0.5 ml. of hydrazine, and an additional 7 ml. of ethylene glycol were added and the mixture was refluxed for 2 hr., then cooled, diluted with water, and extracted with three 50-ml. portions of hexane. The organic extract was washed with aqueous sodium chloride and water, dried, concentrated to about 10 ml., and poured onto a column of 25 g. of alumina prepared in hexane. Elution with hexane gave 0.09 g. of rimuane **2** (20%) which crystallized from methanol as colorless needles: m.p. 85–86°; $[\alpha]^{26}D$ −75° (*c* 0.74); infrared bands (CCl_4) at 1390 and 1370 cm.$^{-1}$ (*gem*-dimethyl group); n.m.r. signals at 0.87, 0.80, 0.79, 0.71 (methyl singlets), and 0.76 p.p.m. (center peak of methyl triplet).

Anal. Calcd. for $C_{20}H_{36}$: C, 86.88; H, 13.12. Found: C, 87.12; H, 12.78.

Elution with ether gave 0.35 g. of a colorless solid which crystallized from acetone as colorless needles, m.p. and m.m.p. 200–202°, identical with azine **15** described above.

Notes

Resin Acids. VI. Stereochemistry of the Tetrahydropimaric Acids[1]

WERNER HERZ AND R. N. MIRRINGTON

Department of Chemistry, The Florida State University, Tallahassee, Florida 32306

Received April 30, 1965

Because of our interest in the mode of hydrogenation of substituted resin acids[2] our attention was attracted to a recent report[3] that hydrogenation of dihydropimaric acid **1** using a platinum catalyst gave two different tetrahydro acids depending on conditions employed. The first, m.p. 235–240°, $[\alpha]D$ +13°, was formed at 20° and at atmospheric pressure and was apparently identical with a tetrahydropimaric acid, m.p. 238–240°, $[\alpha]D$ +18°, previously obtained by Edwards and Howe[4] under similar conditions. The second, m.p. 166–168°, $[\alpha]D$ +10°, was formed at 60° under 100 kg. pressure and was tentatively assigned[3] the *trans-anti-cis* structure **3**. Neither the French[3] nor Canadian[4] groups were definite about the stereochemistry of the high-melting acid which, it was suggested,[3] might be the *trans-anti-trans* isomer **12**. In an attempt to clarify the situation and, in particular, the seemingly unusual attack from the more hindered β side, we have effected an unambiguous synthesis of the tetrahydro acid **12** in the following way.

Hydroboration of methyl dihydropimarate **2** with diborane in diglyme followed by peroxide oxidation of the resultant alkyl boranes gave an approximately 1:1 mixture (see below) of alcohols **4** and **6** which could not be separated by chromatography on alumina and cocrystallized from aqueous methanol as colorless needles, m.p. 98–100°. The ratio of components was established by acetylation to the mixture of acetates **5** and **7** whose nuclear magnetic resonance (n.m.r.) spectrum contained doublets centered at 5.21 (0.55 proton, J = 12 c.p.s.) and 4.55 p.p.m. (0.45 proton, J = 10 c.p.s.) corresponding to H-14 in **5** and **7**, respectively. The slight predominance of **4** over **6** (55:45) was consistent with the expected, more favorable attack from the slightly less hindered α side of the molecule. The n.m.r. spectrum of the mixture of acetates **5** and **7** arising from acetylation of a *crude* alcohol mixture was essentially identical with that described above, confirming that no separation of the alcohols **4** and **6** had been achieved by chromatography or crystallization procedures.

The doublet at higher field (4.55 p.p.m.) was assigned to H-14 in acetate **7** rather than **5** for the following reason. Jones oxidation of the alcohol mixture gave an oil (obviously a mixture as indicated by its n.m.r. spectrum), alkaline treatment of which yielded a single ketone which represented the more stable isomer, presumably the *trans-anti-trans* isomer **8**. Reduction of **8** with sodium borohydride furnished the expected equatorial alcohol **6**, m.p. 150–152°, whose acetate **7** showed a one-proton doublet at 4.55 p.p.m. (J = 10 c.p.s.) in the n.m.r. spectrum but no trace of signals at 5.2 p.p.m.

The assignment of structure **7** to this acetate obviously depends on the establishment of the stereochemistry at C-8 in ketone **8**. Firstly, the optical rotatory dispersion (o.r.d.) curve of **8** showed the expected[5] negative Cotton effect, whereas a positive effect would be predicted from the octant rule[5] for the alternative 8α,9αH- (BC *cis*-fused) 14-one. Secondly, the n.m.r. spectrum of **8** (methyl singlets at 1.19, 1.00, and 0.96 p.p.m.) showed no shielded methyl signal which would be expected of the C-10 methyl

(1) Previous paper: W. Herz and R. N. Mirrington, *J. Org. Chem.*, **30**, 3195 (1965). Work supported in part by grants from the Petroleum Research Fund, administered by the American Chemical Society, and the National Science Foundation (GP-1962).

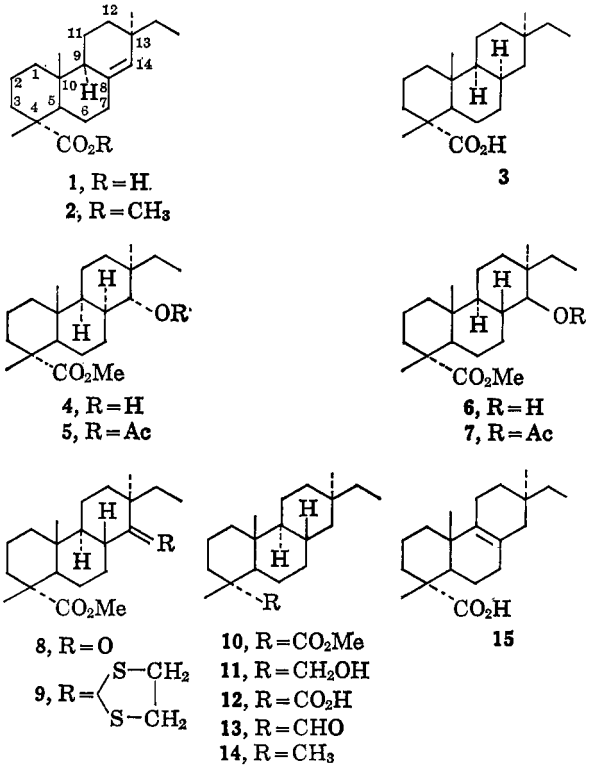
(2) W. Herz, H. J. Wahlborg, W. D. Lloyd, W. H. Schuller, and G. W. Hedrick, *ibid.*, **30**, 3190 (1965).

(3) C. Asselineau, S. Bory, and A. Diara, *Bull. soc. chim. France*, 1197 (1964).

(4) O. E. Edwards and R. Howe, *Can. J. Chem.*, **37**, 760 (1959).

(5) W. Moffitt, A. Moscowitz, R. B. Woodward, W. Klyne, and C. Djerassi, *J. Am. Chem. Soc.*, **83**, 4013 (1961).

group in the alternative *trans-anti-cis* ketone where the C-10 methyl protons lie in the shielding cone[6] of the carbonyl group at C-14. Furthermore, comparison of the n.m.r. spectrum of **8** with that of the ester **10** described below (methyl singlets at 1.12, 0.85, 0.75 p.p.m.) indicated upfield shifts of both the C-10 and C-13 methyl protons on removal of the carbonyl function. This effect may be satisfactorily explained for structure **8** where the methyl group at C-13 lies in the plane of the carbonyl group and is hence deshielded,[6] the effect being removed on reduction of the carbonyl function to a methylene group.



Ketone **8** slowly formed the thioketal **9** which was desulfurized[7] with Raney nickel to *trans-anti-trans*-methyl tetrahydropimarate (**10**), m.p. 74.5–75.5°, $[\alpha]_D$ +10°.[8] Lithium aluminum hydride reduction of **10** gave alcohol **11**, m.p. 93–94°, $[\alpha]_D$ +12°, in good agreement with reported figures[9] (m.p. 90°, $[\alpha]_D$ +11°). Finally, chromic acid oxidation of **11** furnished authentic *trans-anti-trans*-tetrahydropimaric acid (**12**), m.p. 246–247°, $[\alpha]_D$ +16°, identical (mixture melting point and infrared analysis) with a sample of tetrahydropimaric acid obtained by hydrogenation of dihydropimaric acid at atmospheric pressure.[3,4] Alcohol **11** was converted *via* a Wolff–Kishner reduction of aldehyde **13** to pimarane (**14**) whose properties also corresponded to those reported in the literature.[9]

Since **12** has also been obtained by hydrogenation of $\Delta^{8,9}$-dihydropimaric acid (**15**) at atmospheric pressure,[3,4] whereas **3** is the product at high pressure,[10] it appears that the former conditions favor the thermodynamically stable product rather than the kinetically favored acid arising by *cis* addition of hydrogen from the less hindered (α) side of the molecule.

This appears to be an extreme case of the observations made by Siegel and co-workers[11] who concluded that during the hydrogenation of disubstituted cycloalkenes the ratio of isomers produced in the low-pressure range is governed by the energetics of transition states leading to a half-hydrogenated state, while at high pressure the ratio is determined by the energetics of the transition states leading to the adsorbed olefins.

Experimental[12]

Hydroboration–Oxidation of Methyl Dihydropimarate (2).—A solution of 3.5 g. (1.3 equiv.) of boron trifluoride etherate in 10 ml. of diglyme was added dropwise to a stirred mixture of 6.0 g. of methyl dihydropimarate[13] and 0.71 g. (1.3 equiv.) of sodium borohydride in 50 ml. of diglyme during 1.5 hr. and stirring was continued for 1 additional hr. A gelatinous precipitate formed during early stages of addition. The ice-cooled mixture was treated successively with 5 ml. of water, 15 ml. of 3 *N* aqueous sodium hydroxide and 15 ml. of 30% hydrogen peroxide, then allowed to warm to room temperature and stirred for 18 hr. The almost homogeneous solution was poured into water and extracted with ether three times. The combined extracts were washed thoroughly with water, dried, and evaporated to furnish 6.8 g. of a crystalline solid: infrared bands at 3600, 3450, and 1715 cm.$^{-1}$. Acetylation of 0.25 g. of this product gave an oil: n.m.r. signals at 5.21 d (0.52 protons, H-14 in **5**, J = 12 c.p.s.), 4.55 d (0.48 protons, H-14 in **7**, J = 10 c.p.s.), 3.62 (methoxyl), 2.04 p.p.m. (acetate).

Attempted separation of the crude alcohols by chromatography on 180 g. of alumina was not successful. Elution with benzene–ether (2:1 and 1:1) gave a solid which crystallized from aqueous methanol as colorless needles: m.p. 98–100°; n.m.r. signals at 3.65 (methoxyl) and 2.92 p.p.m. doublet (0.45 protons, H-14 in **6**, J = 10 c.p.s.), no resonances downfield from 3.65 due to olefinic protons. The doublet due to H-14 in alcohol **4** was superimposed on the methoxyl signal. Acetylation of the chromatographed product gave an oil: infrared bands (CCl_4) at 1735 and 1250 cm.$^{-1}$ (broad) (acetate), no hydroxyl absorption; n.m.r. signals at 5.21 d (0.55 protons, H-14 in **5**, J = 12 c.p.s.), 4.55 d (0.45 protons, H-14 in **7**, J = 10 c.p.s.), 3.63 (methoxyl), and 2.06 p.p.m. (acetate). Chromatographic separation of the oily acetate mixture was also unsuccessful.

Ketone 8.—A stirred solution of 6.55 g. of the foregoing alcohol mixture in 50 ml. of acetone was treated dropwise with Jones reagent until a brown color persisted for 10 min., then diluted with water and extracted with ether. The washed and dried combined extracts were evaporated to furnish an oil which was taken up in 100 ml. of ethanol and treated with 15 ml. of 2 *N* aqueous sodium hydroxide on a steam bath for 10 min. Dilution with water, extraction with ether, and working up as above gave ketone **8** which crystallized from aqueous methanol as colorless needles: m.p. 102–103°; yield 5.25 g. (80%); infrared bands ($CHCl_3$) at 1725 (ester) and 1705 cm.$^{-1}$ (ketone), no hydroxyl absorption; n.m.r. signals at 3.67 (methoxyl), 1.19, 1.00, and 0.96 p.p.m. (methyl singlets); o.r.d. [*c* 0.0595 $[\alpha]_{600}$ −30°, $[\alpha]_{589}$ −30°, $[\alpha]_{314}$ −1710°, $[\alpha]_{274}$ +1670°, and $[\alpha]_{260}$ +1460° (last reading).

(6) L. M. Jackman, "Applications of Nuclear Magnetic Resonance Spectroscopy in Organic Chemistry," Pergamon Press Ltd., London, 1959, 124.

(7) This procedure does not affect the stereochemistry at carbon atoms α to the thioketal function: see R. E. Ireland and J. A. Marshall, *J. Org. Chem.*, **27**, 1620 (1962).

(8) Asselineau, *et al.*,[3] reported m.p. 65–68°, $[\alpha]_D$ +6°, for the methyl ester of their high-melting acid.

(9) S. Bory and C. Asselineau, *Bull. soc. chim. France*, 1355 (1961).

(10) Since the high-melting acid has now been identified as **12**, the conclusion that the acid, m.p. 166–168°, is the *trans-anti-cis* isomer **3** is almost inescapable, although two other quite unlikely possibilities, *trans-syn-anti* and *trans-syn-cis* have not been rigorously excluded.

(11) S. Siegel and G. V. Smith, *J. Am. Chem. Soc.*, **82**, 6082, 6087 (1960); S. Siegel and B. Dmuchovsky, *ibid.*, **84**, 3132 (1962); **86**, 2192 (1964).

(12) Melting points are uncorrected. Analyses were by Dr. F. Pascher, Bonn, Germany. Infrared spectra were run as Nujol mulls unless otherwise specified, rotations in chloroform. O.r.d. curves are for methanolic solutions and were run by Dr. L. R. Tether. N.m.r. spectra were run on an A-60 spectrometer in deuteriochloroform with tetramethylsilane as internal standard. Chemical shifts are recorded as δ values.

(13) Dihydropimaric acid was isolated from Staybelite resin kindly supplied by Dr. T. F. Sanderson, Hercules Powder Co.

Anal. Calcd. for $C_{21}H_{34}O_3$: C, 75.40; H, 10.25. Found: C, 75.28; H, 9.97.

Alcohol 6.—Sodium borohydride (0.3 g.) was added slowly to an ice-cold solution of 0.4 g. of ketone **8** in 50 ml. of methanol and the mixture was kept at room temperature for 0.5 hr, then diluted with water and extracted with ether. The washed and dried extract on evaporation furnished 0.28 g. of a colorless solid which crystallized from aqueous methanol as colorless needles of alcohol **6**: m.p. 150–152°; infrared bands at 3600 (OH) and 1710 cm.$^{-1}$ (ester); n.m.r. signals at 3.67 (methoxyl), 2.9 (diffuse doublet, one proton, H-14, $J \sim 10$ c.p.s.), 1.18, 0.90, and 0.89 p.p.m. (methyl singlets).

Anal. Calcd. for $C_{21}H_{36}O_3$: C, 74.95; H, 10.78. Found: C, 74.77; H, 10.52.

Acetylation of 70 mg. of **6** with acetic anhydride–pyridine at 80° for 3 hr gave acetate **7** as an oil: n.m.r. signals at 4.55 d (1 proton, H-14, J = 10 c.p.s.), 3.65 (methoxyl), 2.06 (acetate), 1.17, 0.89, 0.78 ppm (methyl singlets).

Methyl *trans-anti-trans*-Tetrahydropimarate (10).—A solution of 2.1 g. of ketone **8** in 6 ml. of ethanedithiol was treated with 4 ml. of boron trifluoride etherate for 16 hr at 25°. No reaction was apparent at first but a white precipitate slowly formed after several hours. Methanol was added and the thioketal **9** collected by filtration and crystallized from chloroform–methanol to give colorless needles: yield 2.16 g. (84%); m.p. 239–240°; infrared bands at 1725 and 1250 cm.$^{-1}$ (ester); n.m.r. signals at 3.62 (methoxyl), 3.09 s (four protons, thioketal), 1.17, 1.10, and 0.88 p.p.m. (methyl singlets).

Anal. Calcd. for $C_{23}H_{38}O_2S_2$: C, 67.26; H, 9.33. Found: C, 67.48; H, 9.21.

A suspension of 1.60 g. of the above thioketal and 6 teaspoonsfull of Raney nickel in 500 ml. of absolute ethanol was refluxed for 50 hr., then filtered through celite, and the filtrate was evaporated to give an oil which rapidly solidified. Crystallization from methanol yielded 1.14 g. (91%) of methyl tetrahydropimarate **10** as colorless needles: m.p. 74.5–75.5°; $[\alpha]_D$ +10° (*c* 2.4) (lit.[3] m.p. 65–68°, $[\alpha]_D$ +6°); infrared bands at 1720 and 1250 cm.$^{-1}$ (ester); n.m.r. signals at 3.55 (methoxyl), 1.12, 0.85, and 0.75 p.p.m. (methyl singlets).

Anal. Calcd. for $C_{21}H_{36}O_2$: C, 78.69; H, 11.32. Found: C, 78.38; H, 11.37.

***trans-anti-trans*-Tetrahydropimaric Acid (12).**—A solution of 0.47 g. of ester **10** in 20 ml. of anhydrous ether was added to a suspension of 0.5 g. of lithium aluminum hydride in 100 ml. of anhydrous ether and the mixture was refluxed for 2 hr. The excess reagent was decomposed by careful addition of water, then dilute hydrochloric acid. The washed and dried ether layer was evaporated to give 0.41 g. of alcohol **11** which crystallized from pentane as colorless prisms: m.p. 93–94°; $[\alpha]_D$ +12° (*c* 2.17) (lit.[9] m.p. 90°, $[\alpha]_D$ +11°); infrared bands at 3350 and 1060 cm.$^{-1}$ (OH); n.m.r. signals at 3.41, 3.08 (AB quartet, two protons, CH_2OH, J_{AB} = 11 c.p.s.), 1.58 s (one proton, O*H*) (removed on exchange with D_2O), 0.89, 0.78, and 0.77 p.p.m. (methyl singlets).

A solution of 0.30 g. of alcohol **11** in 30 ml. of acetone was stirred at room temperature in the presence of 1 ml. of Jones reagent for 0.5 hr., then diluted and the precipitate was collected and washed well with water. Three recrystallizations of the crude product, m.p. 230–240°, yield 0.29 g., from methanol gave colorless needles of **12**: m.p. 246–247°; $[\alpha]_D$ +16° (*c* 1.84); infrared bands at 1695 cm.$^{-1}$ (acid); n.m.r. signals at 1.18, 0.87, and 0.77 p.p.m. (methyl singlets).

Anal. Calcd. for $C_{20}H_{34}O_2$: C, 78.38; H, 11.18. Found: C, 77.98; H, 11.18.

Pimarane (14).—A solution of 0.41 g. of alcohol **11** in 50 ml. of acetone was treated dropwise at 0° with deaerated Jones reagent under nitrogen until a brown color persisted. The mixture was then diluted with water and extracted with ether, and the washed and dried extract was evaporated to furnish the oily aldehyde **13**, infrared bands (CCl_4) at 2700 and 1730 cm.$^{-1}$. The crude aldehyde, 20 ml. of diethylene glycol, 3 ml. of hydrazine hydrate, and 3 g. of potassium hydroxide were heated under reflux for 4 hr. then cooled, diluted, and extracted thrice with hexane. The combined extracts were washed successively with water, 1 *N* hydrochloric acid, and water, dried, and evaporated to yield a yellow oil. Chromatography of this residue on 50 g. of alumina and elution with hexane furnished 0.27 g. (70% from **11**) of pimarane **14** as a colorless oil which slowly solidified and was collected with the aid of methanol: m.p. 33–34° (lit.[9] m.p. 32–34°), infrared bands (film) at 1385 and 1370 cm.$^{-1}$ (*gem*-dimethyl), n.m.r. signals at 0.80 (nine protons, three methyl singlets) and 0.73 p.p.m. (three protons, methyl singlet).

Hydrogenation of Dihydropimaric Acid.—A mixture of 0.21 g. of dihydropimaric acid and 0.45 g. of platinum oxide in 50 ml. of acetic acid was shaken under hydrogen at 14 lb. for 26 hr. at room temperature. The catalyst was removed by filtration through celite and the filtrate was evaporated to give a solid residue which crystallized from methanol as colorless needles, m.p. 239–241°, m.m.p. 239–242°, infrared and n.m.r. spectra identical with that of acid **12** described above.

Steroids. CCLXXXI.[1a] Spectra and Stereochemistry. XXI.[1b] Nuclear Magnetic Resonance Spectra of Methylated Phenanthrenes

ALEXANDER D. CROSS AND LOIS J. DURHAM

Syntex Research Center, Palo Alto, California

Received March 16, 1965

Newman, Meutzer, and Slomp recently reported that benzo[*c*]phenanthrenes bearing methyl groups at the 1- or 1,12-positions (Ia and Ib) show smaller downfield shifts, or even upfield shifts, of methyl proton resonances (relative to toluene) than would be expected if the methyl protons lay in or near the plane of the aromatic system.[2] Interactions leading to displacement of the methyl group away from the plane of the rings with consequent increased shielding were postulated to account for the observed shifts. We recently reported on the n.m.r. spectra of several phenanthrenes noting the paramagnetic shifts of resonances for the "inside" protons (at C-1 and C-11 on the steroid numbering system) relative to those for other aromatic protons due to extra deshielding by the proximate rings A and C.[3] We have since examined several methylated phenanthrenes, some derived by dehydrogenation of steroids. Collected n.m.r. data are presented in Table I together with relevant comparative data gleaned from the literature.[4] Comparison of the methyl proton shift values for toluene and 1-methylestra-1,3,5(10)-trien-17-one (IIa) with values for the 6-methylphenanthrene derivatives IIIa and IIIb shows that the more extensive aromatic system of phenanthrene shifts the 6-methyl proton resonance downfield by approximately 0.2 p.p.m. For the "inside" 5-methyl group R_3 in the phenanthrene IIIc a pronounced paramagnetic shift of 0.68 p.p.m. relative to toluene is observed, consistent with deshielding of the methyl protons by all three proximate aromatic

(1) (a) Steroids. CCLXXX: A. D. Cross and I. T. Harrison, manuscript in preparation. (b) Spectra and Stereochemistry. XX: A. D. Cross, C. Djerassi, A. El-Hamidi, L. Pijewska, and F. Santavý, *Collection Czech. Chem. Comm.*, in press.

(2) M. S. Newman, R. G. Meutzer, and G. Slomp, *J. Am. Chem. Soc.*, **85**, 4018 (1963).

(3) A. D. Cross, H. Carpio, and P. Crabbé, *J. Chem. Soc.*, 5539 (1963).

(4) N.m.r. spectra were recorded at 60 or 100 Mc. using 8–10% solutions in deuteriochloroform containing tetramethylsilane as an internal reference. Chemical shifts are expressed in parts per million downfield from the reference standard. One of us (A. D. C.) thanks the Universidad Nacional de México for time on a Varian A-60 spectrometer.