

CONFORMATION OF RING A OF 19 β ,28-EPOXY-18 α -OLEANAN-3-ONE IN SOLUTION AND IN THE SOLID STATE. CRYSTAL STRUCTURE AND CARBON-DEUTERIUM STRETCHING FREQUENCIES*

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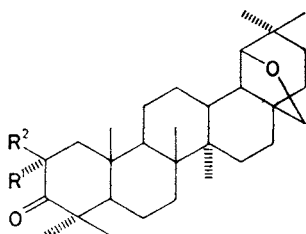
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The crystal structure of allobetulone (*I*) has been determined. The compound is orthorhombic, $P2_12_12_1$, $a = 14.824(4)$, $b = 25.701(7)$, $c = 6.545(2)$ Å, $Z = 4$, $R = 0.050$ for 2 303 observed reflections. The rings B, C, D and E assume chair conformation, the chair of the ring E being considerably deformed by the ether bridge. The five-membered ether ring exists in an envelope form. The ring A assumes a boat form of an unusual type: one half has a typical classical boat geometry with coplanar atoms C(10), C(1), C(2) and C(3) whereas the other half resembles a twist boat. This conformation does not correspond to the published physical data found in solution. The conformation of ring A in crystal and in solution was further studied using IR spectra of 2 α - and 2 β -deuterio derivatives of allobetulone (*II* and *III*, respectively) in the carbon–deuterium stretching vibration region. The solid phase spectra are compatible with the boat form of ring A. Comparison of the solid phase spectra with solution spectra clearly indicates a chair–boat equilibrium in solution of the 3-oxo derivatives *I–III*. The carbon–deuterium stretching frequencies of other deuterium-labelled triterpenoid ketones (*IV–VI*) and alcohols (*VII–X*) are also discussed.

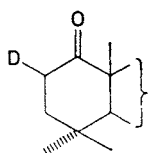
Although the conformation of ring A in triterpenoid 3-ketones in solution has been studied by many physical methods during the last 30 years (see refs^{1–6} and references therein), no unequivocal answer can be given to the question whether the A-ring is conformationally homogeneous or whether it exists as a mixture of interconverting chair and boat forms. The published ¹H NMR spectra have been interpreted in terms of either rapid chair–boat equilibrium¹ or of a single conformation (half-chair form²). Similarly, dipole moments of pentacyclic 3-oxotriterpenoids with an ether bridge or a nitrile group attached to the ring E were explained either by a chair–boat equilibrium³, or by distorted⁷ or deformed⁸ chair conformation. Also CD data have been interpreted in both ways^{3–5,9}. Although the presence of two maxima – a positive and a negative one – in the CD spectra of some 3-ketones seems to indicate a chair–boat equilibrium^{4,5}, it may also be explained by solvation equilibria of

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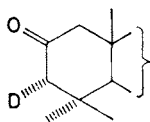
a conformationally homogeneous ketone. Isomerisation of model compounds³, as well as comparison with 3-oxo-4,4-dimethylsteroids and 1-oxotriterpenoids¹, suggests that the chair and boat forms in 3-oxotriterpenoids have similar energy and may be thus comparably populated. On the other hand, no temperature dependence of NMR parameters (such as methyl proton shifts and vicinal coupling constants of the C(1) and C(2) protons) has been observed: this was interpreted^{2,7} as a proof of conformational homogeneity of ring A. However, even this fact does not lead to an unequivocal conclusion; if the enthalpy difference ΔH between the chair and boat form in 3-oxotriterpenoids is close to zero (see refs^{1,3} and references in ref.¹) no significant temperature dependence of the mentioned parameters can be expected.



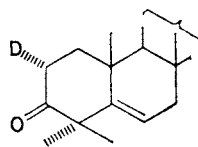
- I, R¹ = R² = H
 II, R¹ = D; R² = H
 III, R¹ = H; R² = D



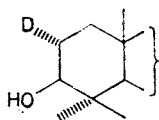
IV



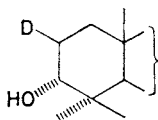
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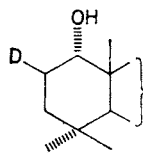
VI



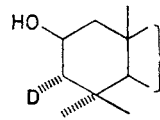
VII



VIII



IX



X

One possible way of confirming or excluding the chair-boat equilibrium alternative is to compare infrared spectra of 3-ketones in the solid state and in solution under

the assumption that in crystal the ring A exists in only one conformation. Unfortunately, in the fingerprint region the infrared spectra of crystalline (nujol mull) allobetulone (*I*, 19 β ,28-epoxy-18 α -oleanan-3-one) and similar triterpenoid ketones (e.g. 3-lupanone and 20(29)-lupen-3-one) differ only negligibly from the spectra obtained with chloroform, tetrachloromethane or carbon disulfide solutions, precluding thus identification of bands corresponding to the individual conformers.

Therefore, in the present investigation we have studied allobetulone selectively deuterated in position 2 α and 2 β (ketone *II* and *III*, respectively), using infrared spectra in the carbon–deuterium stretching vibration region. For comparison, we also measured the spectra of other ketones with deuterium in α -position to the carbonyl group (*IV*–*VI*), and of deuterated alcohols *VII*–*X*. All the studied compounds *I*–*X* are derived from 19 β ,28-epoxy-18 α -oleanane. To determine the ring A conformation in ketones *I*–*III* in the solid state, the crystal structure of ketone *I* was determined by X-ray diffraction and the X-ray powder patterns of ketones *I*–*III* were compared.

EXPERIMENTAL

Single crystals were grown by cooling slowly a hot 3% solution of ketone *I* (prepared according to ref.¹⁰) in benzene–heptane (1 : 4, v/v). The density was determined by flotation in an aqueous ZnBr₂ solution. Debye-Scherrer powder photographs were taken on a Mikrometa 2 (Chirana, Czechoslovakia) instrument using a Ni-filtered Cu-radiation.

Crystal data: orthorhombic, space group $P2_12_12_1$, $a = 14.824(4)$, $b = 25.701(7)$, $c = 6.545(2)$ Å, $V = 2.493(1)$ Å³, $Z = 4$, $\rho_m = 1.129(8)$, $\rho_c = 1.174$ g cm⁻³, $F(000) = 976$.

Measurement: a $0.25 \times 0.25 \times 0.55$ mm³ crystal, $\lambda(\text{CuK}\alpha) = 1.5418$ Å, $\mu = 0.485$ mm⁻¹ (absorption neglected), $T = 295$ K, Stoe diffractometer; 35 reflections ($15 < \theta < 17.5^\circ$) used for lattice-parameter determination, $\omega - 2\theta$ scan mode, max. value of $\sin \theta/\lambda = 0.583$ Å⁻¹; two standard reflections monitored after every 90 min showed no significant fluctuation; $0 \leq h \leq 17$, $0 \leq k \leq 29$, $0 \leq l \leq 7$; from a total of 2396 independent reflections, 2303 regarded as “observed” following $I > 1.96\sigma(I)$.

Structure solution and refinement: direct methods (SHELX-86, ref.¹¹), full-matrix least-squares refinement (SHELX-76, ref.¹²); H atoms fixed in calculated positions; scale factor, positions and anisotropic temperature factors of non-H atoms and group (CH₃, CH₂, CH) isotropic temperature factors for hydrogen atoms refined simultaneously in two blocks; scattering factors for neutral atoms from ref.¹³; the function minimized was $\sum w(|F_o| - |F_c|)^2$ with $w = 1.394/[\sigma^2 F_o - 0.0009F^2]$; in the last cycle, $(\Delta/\sigma)_{\max} = +0.17$; -0.09 , residual electron density = 0.43 ; -0.21 e Å⁻³, $R = 0.050$, $wR = 0.062$ from 2303 observed reflections.

The deuterated compounds II–IV and VII–X have already been described in ref.¹, the unsaturated ketone *VI* in ref.¹⁴. Ketone *V* was obtained by oxidation of alcohol *X*. All the alcohols were prepared by reduction of the corresponding epoxides with lithium aluminium deuteride. Ketones *II*–*VI* were prepared prior to the measurements by oxidation of the alcohols with sodium dichromate in acetic acid in the presence of sodium acetate¹ (room temperature, 2–3 h). Immediately after the work-up, the ketones were crystallized from benzene–heptane and their spectra were taken less than 48 h after the preparation.

The IR spectra in the 2 000–2 300 cm^{-1} region were measured on a PE 684 (Perkin-Elmer) spectrometer with a Data Station Model 3500. To obtain satisfactory signal: noise ratios, 50–80 spectra were accumulated. For all the measured compounds the first and the last of accumulated spectra were identical, indicating thus no isomerisation or loss of deuterium during the measurement. Crystals were measured in a nujol mull (capillary film), chloroform or tetrachloromethane solutions in 1 mm calcium fluoride cells (concentration $3-7 \cdot 10^{-2} \text{ mol l}^{-1}$).

RESULTS AND DISCUSSION

Crystal Structure of Allobetulone (I)

The final coordinates of non-hydrogen atoms are listed in Table I and bond distances and angles in Table II*. Fig. 1 depicts a perspective view of molecule *I* with atom numbering. The content of the unit cell is presented in Fig. 2. Endocyclic torsion angles are shown in Fig. 3.

The bond lengths and angles lie within normal limits and exhibit trends similar to those for analogous triterpenoid 3-ketones (see ref.¹⁵ and references therein). Of the endocyclic bond angles, the angle C(17)—C(18)—C(19) is worth notice: its anomalously small value ($98.7^\circ(2)$) is due to the skeletal deformation by the ether bridge. The torsion angles (Fig. 3) show that the five-membered ether ring exists in a nearly perfect envelope conformation with symmetry plane passing through the C(18) atom and bisecting the C(28)—O(2) bond. The atoms C(17), C(19), O(2) and C(28) are nearly coplanar ($\chi^2 = 11.4$) whereas C(18) is $0.700(5) \text{ \AA}$ apart from

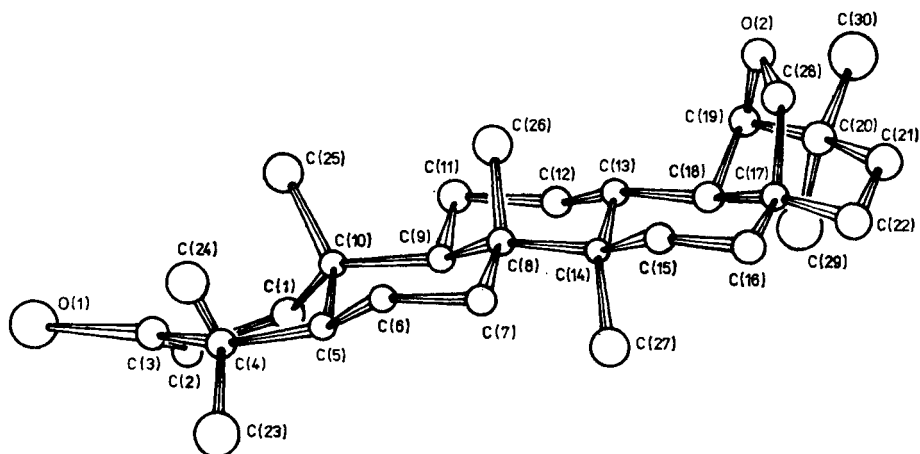


FIG. 1

Perspective view of molecule *I* with atom numbering

* Tables of structure factors, anisotropic thermal parameters and coordinates of hydrogen atoms are available from the authors on request.

this plane. The geometry of the chair form of ring E is close to the conformation whose plane of symmetry passes through the atoms C(18) and C(21). The chair is considerably deformed by the ether bridge: it is puckered at C(18) and flattened at C(22). Flattening also occurs in the ring D at the atoms C(17) and C(18).

The ring A exists in the boat form, the rings B, C and D in the chair conformation. The ring B has all the features characteristic of 3-ketones with a boat-shaped A-ring.

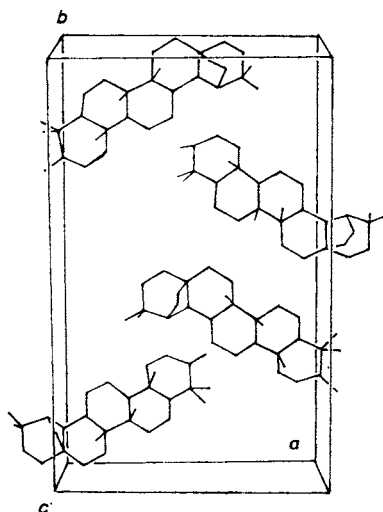


FIG. 2
Unit cell contents

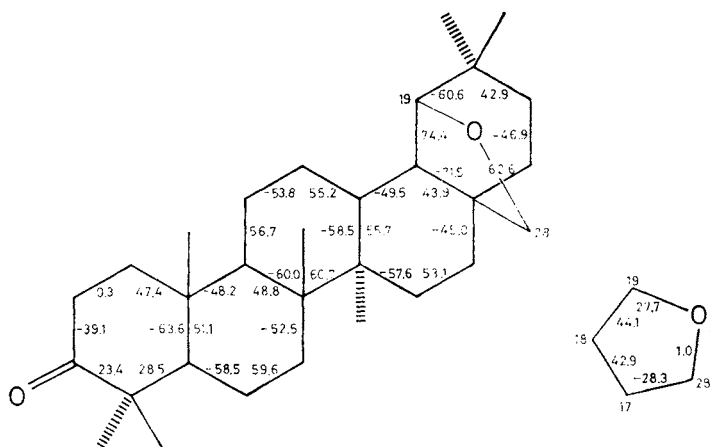


FIG. 3
Endocyclic torsion angles (°) in ketone I (mean estimated standard deviation 0.6°)

discussed in detail in ref.¹⁵. Thus, e.g. the ring B is more flattened at atoms C(5) and C(10) as compared with ketones with ring A in the chair form, the 10 β -methyl group is bent away from the 8 β -methyl (the angle between the C(25)—C(10) and C(26)—C(8) bonds is 23.7(7)° and between the C(25)—C(10) and C(27)—C(14) bonds 159.5(8)°).

TABLE I

Atomic coordinates ($\cdot 10^4$) of non-H atoms in ketone I with estimated standard deviations in parentheses. $U_{eq} = 1/3(U_{11} + U_{22} + U_{33})$

Atom	x/a	y/b	z/c	$U_{eq} \cdot 10^4, \text{\AA}^2$
C(1)	3164(2)	2462(1)	3796(5)	571(9)
C(2)	4017(2)	2730(1)	4533(5)	620(9)
C(3)	4900(2)	2535(1)	3680(4)	521(8)
C(4)	5008(2)	1953(1)	3367(4)	497(7)
C(5)	4077(1)	1673(1)	3175(4)	437(7)
C(6)	4148(2)	1146(1)	2144(5)	510(8)
C(7)	3270(2)	844(1)	2307(5)	514(8)
C(8)	2467(1)	1126(1)	1323(4)	382(6)
C(9)	2417(1)	1688(1)	2217(4)	386(6)
C(10)	3311(1)	2016(1)	2256(4)	410(6)
C(11)	1619(1)	1986(1)	1279(5)	487(8)
C(12)	723(2)	1699(1)	1616(5)	472(7)
C(13)	754(1)	1138(1)	868(4)	381(6)
C(14)	1545(2)	836(1)	1863(4)	390(6)
C(15)	1549(2)	274(1)	1029(5)	500(8)
C(16)	652(2)	-15(1)	1417(5)	543(8)
C(17)	-160(2)	280(1)	658(4)	461(7)
C(18)	-162(1)	866(1)	1198(4)	421(7)
C(19)	-892(2)	1046(1)	-281(4)	477(7)
C(20)	-1853(2)	890(1)	400(5)	543(9)
C(21)	-1883(2)	286(1)	513(5)	580(9)
C(22)	-1042(2)	47(1)	1507(5)	566(9)
C(23)	5476(2)	1756(1)	5365(6)	732(11)
C(24)	5655(2)	1860(1)	1595(5)	613(10)
C(25)	3568(2)	2246(1)	186(4)	519(8)
C(26)	2615(2)	1129(1)	-1009(4)	510(8)
C(27)	1400(2)	798(1)	4193(4)	496(8)
C(28)	-213(2)	308(1)	-1685(4)	559(8)
C(29)	-2079(2)	1133(1)	2470(6)	738(12)
C(30)	-2534(2)	1073(1)	-1181(6)	691(11)
O(1)	5509(1)	2833(1)	3332(4)	788(8)
O(2)	-677(1)	783(1)	-2170(3)	571(6)

TABLE II

Bond distances (Å) and angles (°) in ketone *I* with estimated standard deviations in parentheses

Distances		Angles	
C(1)—C(2)	1.519(4)	C(2)—C(1)—C(10)	115.3(2)
C(1)—C(10)	1.542(4)		
C(2)—C(3)	1.509(4)	C(1)—C(2)—C(3)	117.0(2)
C(3)—C(4)	1.517(4)	C(2)—C(3)—C(4)	117.8(2)
C(3)—O(1)	1.206(3)	C(2)—C(3)—O(1)	120.6(2)
		C(4)—C(3)—O(1)	121.6(2)
C(4)—C(5)	1.563(3)	C(3)—C(4)—C(5)	111.9(2)
C(4)—C(23)	1.554(5)	C(3)—C(4)—C(23)	105.3(2)
C(4)—C(24)	1.534(4)	C(3)—C(4)—C(24)	108.4(2)
		C(5)—C(4)—C(23)	108.6(2)
		C(5)—C(4)—C(24)	114.4(2)
		C(23)—C(4)—C(24)	107.9(2)
C(5)—C(6)	1.517(4)	C(4)—C(5)—C(6)	112.9(2)
C(5)—C(10)	1.558(3)	C(4)—C(5)—C(10)	114.7(2)
		C(6)—C(5)—C(10)	112.6(2)
C(6)—C(7)	1.519(4)	C(5)—C(6)—C(7)	111.4(2)
C(7)—C(8)	1.535(4)	C(6)—C(7)—C(8)	113.2(2)
C(8)—C(9)	1.560(4)	C(7)—C(8)—C(9)	108.5(2)
C(8)—C(14)	1.596(3)	C(7)—C(8)—C(14)	110.5(2)
C(8)—C(26)	1.542(4)	C(7)—C(8)—C(26)	107.9(2)
		C(9)—C(8)—C(14)	108.0(2)
		C(9)—C(8)—C(26)	111.9(2)
		C(14)—C(8)—C(26)	110.1(2)
C(9)—C(10)	1.571(3)	C(8)—C(9)—C(10)	117.6(1)
C(9)—C(11)	1.537(3)	C(8)—C(9)—C(11)	110.4(2)
		C(10)—C(9)—C(11)	112.9(2)
C(10)—C(25)	1.526(4)	C(1)—C(10)—C(5)	105.7(2)
		C(1)—C(10)—C(9)	106.9(2)
		C(1)—C(10)—C(25)	109.1(2)
		C(5)—C(10)—C(9)	108.5(2)
		C(5)—C(10)—C(25)	112.3(2)
		C(9)—C(10)—C(25)	113.8(2)
C(11)—C(12)	1.535(3)	C(9)—C(11)—C(12)	111.7(2)
C(12)—C(13)	1.523(4)	C(11)—C(12)—C(13)	112.5(2)
C(13)—C(14)	1.550(3)	C(12)—C(13)—C(14)	111.2(2)
C(13)—C(18)	1.542(3)	C(12)—C(13)—C(18)	110.9(2)
		C(14)—C(13)—C(18)	112.4(2)

TABLE II
 (Continued)

Distances		Angles	
C(14)—C(15)	1.544(4)	C(8)—C(14)—C(13)	108.7(2)
C(14)—C(27)	1.543(4)	C(8)—C(14)—C(15)	110.8(2)
		C(8)—C(14)—C(27)	111.6(2)
		C(13)—C(14)—C(15)	108.8(2)
		C(13)—C(14)—C(27)	110.0(2)
		C(15)—C(14)—C(27)	106.9(2)
C(15)—C(16)	1.544(4)	C(14)—C(15)—C(16)	112.9(2)
C(16)—C(17)	1.507(4)	C(15)—C(16)—C(17)	113.1(2)
C(17)—C(18)	1.547(4)	C(16)—C(17)—C(18)	114.6(2)
C(17)—C(22)	1.542(4)	C(16)—C(17)—C(22)	111.3(2)
C(17)—C(28)	1.537(4)	C(16)—C(17)—C(28)	113.2(2)
		C(18)—C(17)—C(22)	107.1(2)
		C(18)—C(17)—C(28)	100.5(2)
		C(22)—C(17)—C(28)	109.5(2)
C(18)—C(19)	1.524(4)	C(13)—C(18)—C(17)	114.1(2)
		C(13)—C(18)—C(19)	113.5(2)
		C(17)—C(18)—C(19)	98.7(2)
C(19)—C(20)	1.546(4)	C(18)—C(19)—C(20)	113.1(2)
C(19)—O(2)	1.445(3)	C(18)—C(19)—O(2)	104.2(2)
		C(20)—C(19)—O(2)	109.2(2)
C(20)—C(21)	1.555(4)	C(19)—C(20)—C(21)	107.4(2)
C(20)—C(29)	1.529(5)	C(19)—C(20)—C(29)	110.6(2)
C(20)—C(30)	1.520(5)	C(19)—C(20)—C(30)	109.6(2)
		C(21)—C(20)—C(29)	111.1(2)
		C(21)—C(20)—C(30)	108.8(2)
		C(29)—C(20)—C(30)	109.3(2)
C(21)—C(22)	1.535(4)	C(20)—C(21)—C(22)	113.4(2)
		C(17)—C(22)—C(21)	112.4(2)
C(28)—O(2)	1.437(4)	C(17)—C(28)—O(2)	106.5(2)
		C(19)—O(2)—C(28)	108.3(2)

The ring A has an unusual geometry: one half of the ring (atoms C(10), C(1), C(2) and C(3)) corresponds to a typical classical boat with atoms C(3) and C(10) in the stem-stern positions (conformation B^3 according to the notation of Tsuda and Kiuchi⁴) whereas the other half (atoms C(3), C(4), C(5) and C(10)) resembles a typical twist-boat T_1 . The atoms C(10), C(1), C(2) and C(3) lie in one plane, their distances

from the least-squares plane being less than the estimated standard deviations of these distances. The endocyclic torsion angle of the C(1)—C(2) bond ($0.3(6)^\circ$) differs from angles in the T_1 boat forms found in other triterpenoid and related 3-ketones^{4,15,16} ($10-30^\circ$). On the other hand, the torsion angle of the C(4)—C(5) bond ($28.5(7)^\circ$) agrees well with those found in other boat forms^{4,15,16} ($28-35^\circ$). Since there are numerous C...C intermolecular contacts of C(2), C(3) and C(24) at the 3.7 to 3.8 Å level and O(1)...C contacts around 3.4 Å, it can be reasonably assumed that the above-mentioned differences are caused by crystal packing. Hence, the present structure represents a further example of influencing the conformation of ring A by particular solid state arrangement¹⁵.

The powder patterns of *I*, *II* and *III* are indistinguishable, indicating the identical crystal structure and hence the same conformation of the ring A.

Interestingly, the geometry of the boat in ketones *I-III* in crystal does not correspond to the conformation of ring A in solution, following from the dipole moment³ and ¹H NMR spectral¹ measurements. Thus, the angle between the dipoles C=O and C—O—C, derived from the atomic positions (78°) disagrees with the value calculated from the found dipole moment of ketone *I* and from the group moments³ (102°) under the assumption of conformational homogeneity of the ring A. It also differs from the angle calculated from the dipole moment of a model compound (2β-methyl derivative of ketone *I*) which in solution exists in boat conformation of the ring A ($59-65^\circ$, see ref.³). Similarly, the vicinal coupling constants between the protons in positions 1 and 2 found¹ for ketones *I-III* in chloroform and benzene, do not correspond to the fully eclipsed conformation of the C(1)—C(2) bond in crystal. The eclipsed conformation is also not compatible with the torsion angles H(1α)—C(1)—C(2)—H(2α) and H(1β)—C(1)—C(2)—H(2α) ($\sim 18^\circ$ and $\sim 143^\circ$, respectively), estimated¹ from the coupling constants for the boat in the 2β-methyl derivative of *I*. Whereas in the case of ketones *I-III* the mentioned differences are caused by the chair-boat equilibrium in solutions (vide infra), in the case of the 2β-methyl derivative they show that the geometry of the boat in crystal differs from that in solution (see also ref.¹⁵).

Carbon-Deuterium Stretching Frequencies

Infrared spectra of monodeuterated compounds with axial or equatorial deuterium on a six-membered ring (also in rigid systems such as steroids) usually display two C—D stretching vibration bands¹⁷⁻²² in the region $2\ 100-2\ 200\text{ cm}^{-1}$. In some cases only one band was found¹⁸, in others several partially overlapping bands were observed¹⁸⁻²⁰. The frequencies of axial and equatorial C—D bands are different, the latter being usually (but not invariably) higher¹⁷.

The C—D stretching vibration bands are relatively weak. Moreover, in the given region there are overtone and combination bands which, in the spectra of such

complicated molecules as the deuterated ketones *II–VI* and alcohols *VII–X*, considerably affect the shape of the spectra. These bands are somewhat weaker than the C–D bands and occur as shoulders or very weak bands. They were identified using (as an approximation) the spectrum of the nondeuterated ketone *I*; (ϵ in parentheses): 2 260 (0.3), 2 222 (0.3), 2 184 (0.2), 2 152 (0.1), 2 103 (0.5) and 2 036 cm^{-1} (0.1). In the spectra of the deuterated compounds *II–X* the overlapping bands were separated using a described program²³. The Cauchy (Lorentz) function was employed for bands description and the background was approximated by a straight line. The bands, occurring also in the spectrum of ketone *I*, and some other very weak bands were then eliminated and the remaining stronger bands were ascribed to the C–D stretching vibrations. Their parameters are summarized in Table III.

The estimated standard deviations of the $\nu(\text{C–D})$ values obtained by the separation procedure are less than 1 cm^{-1} , only in cases of poor band resolution they are $2–3 \text{ cm}^{-1}$; however, for halfwidths and molar absorption coefficients they reach in some cases values up to 25% of those given in Table III. Therefore, the intensity parameters in Table III are only approximative and can be used only for crude comparison of band intensities. In general, the C–D bands in alcohols *VII–X* are stronger than in ketones *II–VI* with deuterium in the α -position to the carbonyl group.

Of hydroxy derivatives with the A-ring evidently in the chair form, the deuterium-equatorial 2α -deuterio- 3β -ol *VII* exhibits only one C–D band whereas the 2β -deuterio- 3α -ol *VIII* and 2β -deuterio- 1α -ol *IX* with axial deuterium display two bands. Spectrum of 3α -deuterio- 2β -ol *X* contains two bands of comparable intensity. According to ^1H NMR spectrum, the 2β -hydroxy derivative exists in solution as a 3 : 2 mixture of the boat and chair forms²⁴; it is thus possible that one of the bands is due to the chair-axial, and the second to the boat-equatorial deuterium, or that each conformer gives rise to two overlapping bands (see the assignment in Table III).

The 2β -deuterio-1-ketone *IV*, 3α -deuterio-2-ketone *V* and 5(6)-unsaturated 2α -deuterio-3-ketone *VI* exhibit two C–D bands in solution as well as in the solid. For all these ketones the spectral shape in nujol is similar to that in chloroform, the spectra differing only little in frequencies and intensity ratios of both bands. In solution, the ketones are conformationally homogeneous: according to ^1H NMR spectra the A-ring in the 1-oxo and 2-oxo derivatives exists as a chair^{1,25} (with axial D in *IV* and *V*) whereas in the 5(6)-unsaturated 3-ketone it assumes a boat conformation¹⁴ (boat-axial D in *VI*). The accord between the spectra in crystal and in solution indicates that the character of the C–D bonds, and thus also the conformation of ring A in crystal and in solution, are similar.

The spectra of 2α - and 2β -deuterio-3-ketones *II* and *III* in nujol also exhibit two bands. Since the conformation of ring A in crystal is known to be a boat, both bands in the spectrum of the 2α -epimer *II* can be unequivocally assigned to boat-axial deuterium and the bands found for the 2β -epimer *III* to boat-equatorial deuterium

TABLE III
Wavenumbers and intensities of C-D stretching vibrations

Compound	Medium	$\nu(\text{C-D})$ cm^{-1}	$\Delta\nu_{1/2}^a$ cm^{-1}	ε^a $\text{l mol}^{-1} \text{cm}^{-1}$	$B \cdot 10^{-2}^a$ $\text{l mol}^{-1} \text{cm}^{-2}$	Character ^b of C—D bond
II	nujol	2 163	14	(0.2)	(0.1)	ba
		2 147	35	(0.8)	(0.9)	ba
	CHCl ₃	2 200 ^c	44	2.3	1.6	e
		2 175	17	0.7	0.2	ba
	CCl ₄	2 154	28	2.1	0.9	ba
		2 198 ^c	43	2.5	1.7	e
		2 174	18	0.7	0.2	ba
		2 153	25	2.5	1.0	ba
III	nujol	2 203	36	(0.7)	(0.6)	be
		2 164	44	(0.3)	(0.4)	be
	CHCl ₃	2 202 ^c	64	1.5	1.5	be + a
		2 180	26	0.7	0.3	be
	CCl ₄	2 148	23	1.7	0.6	a
		2 201 ^c	66	1.5	1.6	be + a
		2 177	24	0.8	0.3	be
		2 148	19	1.8	0.5	a
IV	nujol	2 195	21	(0.8)	(0.8)	a
		2 168	21	(0.2)	(0.2)	a
	CHCl ₃	2 197	28	3.1	1.3	a
		2 169	42	0.9	0.6	a
V	nujol	2 152	21	(0.6)	(0.5)	a
		2 131	22	(0.4)	(0.5)	a
	CHCl ₃	2 157	20	1.2	0.4	a
		2 138	40	3.0	1.9	a
VI	nujol	2 173	21	(0.4)	(0.3)	ba
		2 148	37	(0.6)	(0.7)	ba
	CHCl ₃	2 177	19	1.9	0.6	ba
		2 148	30	2.7	1.3	ba
VII	CHCl ₃	2 157	34	11.8	6.3	e
VIII	CHCl ₃	2 184	37	3.2	1.8	a
		2 166	18	5.1	1.5	a
IX	CHCl ₃	2 190	28	3.1	1.4	a
		2 173	25	5.6	2.2	a
X	CHCl ₃	2 165	25	7.2	2.8	be + a
		2 140	38	8.0	4.8	be + a

^a Apparent values are given; $B = \pi/2 \cdot \Delta\nu_{1/2} \cdot \varepsilon$; the values in parentheses (in nujol) are relative and they are related to the sum of intensity parameters of both bands ($\sum \varepsilon = 1$, $\sum B = 100$);

^b a axial, b equatorial, ba boat-axial, be boat-equatorial; ^c probably overlap of two bands.

(see conformational formulae *I**b*** and *III**b***). Band frequencies of the 2 α -deuterio ketone *II* are similar to those of ketone *VI* which also contains a boat-axial deuterium. The frequencies of epimers *II* and *III* differ considerably and correspond to the rule formulated by Corey and co-workers¹⁸, stating that the high-frequency band of equatorial isomer occurs at a higher frequency than the high-frequency band of the corresponding axial isomer.

Contrary to the ketones *IV*–*VI*, the spectra of ketones *II* and *III* in solution differ substantially from those in the solid state. A comparison of spectra in nujol with the spectra in tetrachloromethane (spectra in chloroform and tetrachloromethane are almost identical) is given in Fig. 4. In solutions, the spectra exhibit at least one strong band more than in the crystalline state. The spectra were separated only into three bands; however, the bands at about 2200 cm⁻¹ are probably two overlapping bands as indicated by their shape and large widths.

Since the spectra of both epimers *II* and *III* in solutions are of similar shape, the differences between the solid state and solution could also be explained by rapid isomerization at C(2) in chloroform and tetrachloromethane. This possibility has been excluded by recovering the samples of *I* and *III* after spectral measurements in solution and by measuring the thus-obtained crystals in nujol. Therefore, the change of spectra on transition from the crystalline state into solution indicates conformational nonhomogeneity of the ring A in solutions and proves the existence of chair–boat equilibria in ketones *II* and *III*. These results strongly support the interpretation of other physical data for solutions of ketone *I* and similar triterpenoid 3-ketones, based on the suggested^{1,3–5} conformational equilibrium *Ic* \rightleftharpoons *Ib*.

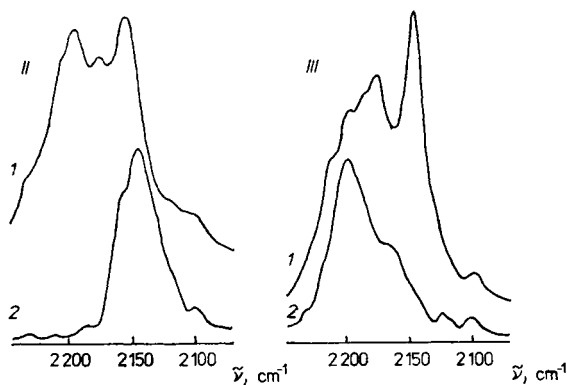
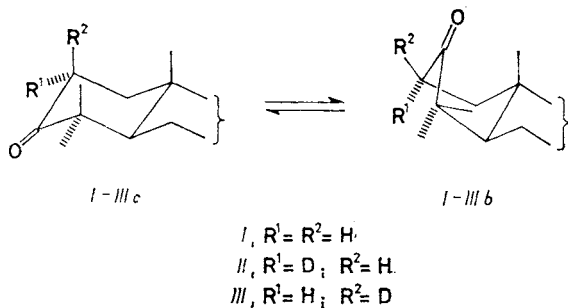


FIG. 4

C–D Stretching region of infrared spectra of 2 α - and 2 β -deuterio-3-ketones *II* and *III*, respectively; 1 in tetrachloromethane, 2 in nujol

The assignment of bands for solutions of *II* and *III* to the individual types of C—D bonds (Table III) is only tentative; for the boat form it is based on the similarity of the frequencies with those found for the solid state (boat-axial D in *IIb*, boat-equatorial D in *IIIb*). The remaining bands were ascribed to the chair conformation



(equatorial D in *IIc*, axial D in *IIIc*). It is worth notice that the sums of integrated intensities of the chair and boat C—D bands are similar, indicating that both conformers are comparably populated. This agrees with the results of other methods^{1,3} (¹H NMR, circular dichroism, dipole moments, isomerization of model compounds), i.e. about 40% of boat and 60 ($\pm 10\%$) chair. As seen from Table III and also from studies of deuterium-labelled steroids^{17,18,26}, there is no simple and general relationship between the character and stretching frequency of the C—D bonds. Also the presence of two bands in the spectra of rigid monodeuterated compounds remains unexplained¹⁸. It may be caused by Fermi resonance, e.g. with the C—D bending overtone (for analogy see ref.²⁷). Nevertheless, the results of this study show that a comparison of infrared C—D bands of solutions with those of crystals may be useful for demonstration of conformational equilibrium in six-membered ring compounds, particularly when other physical methods do not give unequivocal conclusions.

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