A Survey of the High-field ^{1}H NMR Spectra of the Steroid Hormones, their Hydroxylated Derivatives, and Related Compounds

David N. Kirk,* Harold C. Toms, Christal Douglas, and Karen A. White
Department of Chemistry, Queen Mary and Westfield College, Mile End Road, London E1 4NS
Kelvin E. Smith, Shahid Latif, and Robert W. P. Hubbard
School of Biological Sciences, Queen Mary and Westfield College, Mile End Road, London E1 4NS

^{1}H NMR chemical shifts are presented for virtually all the protons in 166 steroids. These comprise mainly the hormones testosterone, androst-4-ene-3,17-dione, progesterone, and a wide range of their hydroxylated derivatives, some corticosteroids including aldosterone and a series of its derivatives, together with miscellaneous steroids comprising a variety of androstane and pregnane derivatives, bile acids, and sterols, to provide the first extensive collection of data for use in correlating ^{1}H chemical shifts with structure.

Most of the spectra were assigned with the aid of two-dimensional ^{1}H homonuclear correlated spectroscopy (COSY), or in a few cases by use of ω_1-decoupled COSY (COSYDEC) spectroscopy. Limited use was made of other techniques, especially selective nuclear Overhauser effect difference spectroscopy (NOEDS), to complete the more difficult assignments. Procedures for the rapid analysis of high-field ^{1}H NMR spectra of steroids are suggested: they include the application of templates for the recognition of signals due to particular protons from their characteristic profiles, which generally vary only slightly between different steroids unless simplified by adjacent substitution. Substituent increments for *all* protons are reasonably additive, except where drastic conformational change occurs or adjacent substituents interact strongly. The conformational dependences of hydroxy-substitution increments are analysed empirically, and some regularities are identified.

Full assignment of ^{13}C NMR spectra of steroids has been a routine procedure for more than a decade. Tabulations of ^{13}C chemical-shift data for over 400 steroids were published in 1977,[1] and many more spectra have been analysed since that time.[2–4] The simplicity of proton-decoupled ^{13}C spectra, with a single line for each carbon atom, and the availability of various pulse sequences for distinguishing between carbon atoms according to the number of attached protons, facilitated early studies. More recently, carbon–carbon connectivities have been directly determined (*e.g.* INADEQUATE[5–9]). Large samples are required, however. The structural and substituent effects that control ^{13}C chemical shifts are well documented,[1,10] allowing good estimates to be made for individual carbon atoms.

^{1}H Spectra, in contrast, are complicated by extensive inter-proton coupling, and for compounds with the complexity of steroids, by overlap of multiplet signals which made resolution of the so-called 'methylene envelope' impossible with early spectrometers. Full assignments had to await the advent of high-field spectrometers operating in the pulsed Fourier transform mode under computer control. The first such assignment was reported in 1980[11] for 17β-hydroxyandrosta-1,4-dien-3-one (1-dehydrotestosterone) at 400 MHz, by use of a combination of one- and two-dimensional techniques, including decoupling-difference and nuclear Overhauser difference (NOEDS) methods, and two-dimensional *J* spectroscopy. Since that time, full assignments of ^{1}H spectra have been reported in a number of publications which present data either for single steroids or for small groups of related steroids.[11–36,40] Two-dimensional methods have been particularly useful, and are reviewed.[30,31] ^{1}H homonuclear two-dimensional shift-correlated spectroscopy (2D COSY)[9,19–24,26–36,40] offers the advantage of requiring samples at only the 1 mg level to give spectra of high quality.[21,30,32] A variation of the COSY method (COSY LR), which optimises the detection of weak couplings, reveals long-range ^{1}H–^{1}H couplings through specific bond paths in steroids and other alicyclic molecules:[34] such information can help greatly in the assignment of signals in ^{1}H spectra (see below). One group has used two-dimensional spin–echo *J*-correlated spectroscopy (SECSY) to good effect for some 19-nor steroids.[16–18] Two-dimensional ^{1}H–^{13}C heteronuclear correlated spectra[9,14–18,20–24,27–33,36,40] offer a particularly powerful method whenever the ^{13}C assignment is available, and provided that the sample size is adequate. This method alone, however, does not distinguish between the protons of geminal pairs (methylene groups). Completion of difficult ^{1}H assignments has often required the use of NOEDS, especially to distinguish signals from protons on the β-face of the steroid molecule by irradiation of the C-18 and/or C-19 methyl protons.[11–13] Accurate measurements of ^{1}H–^{1}H geminal[37–39] and vicinal coupling constants[38,39] have been shown to provide information on the conformation of ring A in steroidal 4-en-3-ones. Full ^{1}H assignments have also been reported for three pentacyclic triterpenes.[41]

Making full ^{1}H assignments is still not a trivial matter, however, since even at the highest field strengths routinely available, ^{1}H signals and 2D COSY cross-peaks are liable to overlap. Relayed coherence transfer 2D spectroscopy has recently been recommended[42] as an effective method for overcoming the problems of overlapping multiplets. The effects of substitution and structural changes on ^{1}H chemical shifts in essentially saturated polycyclic systems of steroid type have not yet been comprehensively analysed, even in an empirical way, although a few such effects have been recorded for miscellaneous functional groups.[21,24,25]

The aim of this paper is to begin an overview of the high-field ^{1}H NMR spectra of steroids by reporting and collating the results of an analysis of spectra of the steroid hormones testosterone (17β-hydroxyandrost-4-en-3-one), androstenedione (androst-4-ene-3,17-dione), and progesterone (pregn-4-ene-3,20-dione) and a wide range of hydroxylated and other

derivatives of these hormones; the principal Δ^4-3-oxo corticosteroids[24] as well as aldosterone[9] and a number of its derivatives are also included, as well as the limited data available for bile acids[20,27] and sterols.[32–34,36] Some of the compounds were available to us from the Steroid Reference Collection. Others came from a programme of microbiological hydroxylations[43–46] and from studies on aldosterone metabolism,[47–49] now in progress in our laboratories. To make the coverage as full as possible, we have included all data for steroids found in the literature to date, excluding only the oestrogens, which will be the subject of a later paper.

The present objective is not merely to tabulate and analyse spectra. We aim also to provide a basis, like that already existing for ^{13}C, for the more rapid assignment of such ^1H spectra in future. Given the very much improved sensitivity of modern high-field spectrometers, we are concerned to develop the use of ^1H spectroscopy as an efficient and routine tool for structural studies on new or unidentified steroids from biological sources, often available in amounts so small as to preclude use of the full panoply of NMR methods. Specifically, if the steroidal material available is at sub-milligram level, and contaminated by non-steroidal matter as is often the case with extracts from biological sources even after repeated chromatographic (HPLC or TLC) purification, ^{13}C spectroscopy and some of the more demanding, albeit more informative, methods for ^1H study and ^{13}C–^1H correlation are still beyond the routine capability of even the best modern spectrometers. Mass spectrometric methods, although applicable in principal to trace amounts of material, need either highly purified samples or combined gas chromatography–mass spectrometry on appropriate steroid derivatives (*e.g.* volatile esters or silyl derivatives). Although mass spectrometry is often a valuable tool for structural investigations, in our experience it may lead to incorrect assignments of configuration which have had to be corrected by subsequent NMR studies and synthesis.[50,51]

We find that even quite highly contaminated steroid samples, at levels as low as tens of micrograms, often give well resolved high-field (400 or 500 MHz) ^1H spectra in which most of the features associated with a particular steroid structure can be discerned with 'finger-print' precision. As a 'finger-printing' method, we now regard high-field NMR as more detailed and reliable than the long-established IR spectroscopy. High-field NMR is also more revealing than IR spectroscopy in that impurities, including solvent traces and contaminating steroids, can be more readily detected and often approximately quantified from their separate and weaker signals in the spectra.

Normally, only methyl proton signals can be observed clearly in the high-field region of steroid spectra determined at up to 100 MHz. Tables of 18-H_3 and 19-H_3 chemical shifts and increments for a wide range of steroid structures and substituents were compiled by Zürcher over 30 years ago,[52,53] and were refined subsequently by Oxford chemists.[54] The latter also published[54] an invaluable set of diagrams showing the profiles of signals from methine protons geminal to hydroxy groups at the various steroid locations. Profiles vary widely, according to the numbers of vicinal protons and the torsion dependence[55,56] established by Karplus.

It has been customary until very recently, in papers concerned with steroids, to report only the methyl-group chemical shifts, and any methine and other signals outside the methylene envelope (*e.g.* for aromatic, alkenic, carbinol, or epoxide protons). We feel that the time is now ripe for publications to include full tabulations of ^1H chemical-shift data for steroids and related compounds whenever possible, for inclusion in computerised databases to aid future studies. Any special features of these spectra relating to structure or conformation should be highlighted. We doubt, however, whether routine publication of all ^1H–^1H coupling constants would yet justify the much more demanding studies needed to derive them accurately. Precise J values are normally required only for detailed conformational investigations (*e.g.* refs. 37–39). In our experience, and as was pointed out recently,[30] J values and the resulting splitting patterns vary only slightly between related steroids in the great majority of cases: all that is normally required for structure determinations is a distinction between large axial–axial couplings and the smaller J values which result from other geometric relationships.[55,56]

In the hope of encouraging fuller publication of ^1H chemical-shift data, we suggest below how high-field spectra of steroids may now be relatively quickly analysed with sufficient precision for normal purposes.

Methods Used in this Study.—One-dimensional and two-dimensional (COSY) ^1H spectra were obtained, mainly at 400 or 500 MHz. In a few cases 250 MHz spectra proved adequate. Deuteriochloroform ($CDCl_3$) was chosen as the solvent for the broad range of steroids where solubility permitted. The more highly oxygenated steroids, mainly the corticosteroids including aldosterone and its derivatives, were examined in CD_3OD, being almost insoluble in $CDCl_3$. The few compounds studied in both $CDCl_3$ and CD_3OD, for comparison, showed that chemical shift differences for particular protons are normally quite small although not always negligible. Deuteriobenzene (C_6D_6)[13,26,36,57] and deuteriopyridine (C_5D_5N),[57,58] by contrast, are known to produce very large solvent effects especially for those protons in the vicinity of functional groups. These shifts may be exploited in special cases to improve spectral resolution (*e.g.* ref. 13), but have not been explored in the present study.

One-dimensional spectra were plotted on a uniform scale of 10 Hz cm^{-1} whatever the spectrometer frequency, for the reason explained below. 2D COSY spectra were also obtained in most cases, and were analysed graphically in the usual way to relate sets of mutually coupled protons. In a few of the more recent cases, ω_1-decoupled 2D COSY (COSYDEC) spectra[59] were recorded, either as an alternative or as a supplement to the normal 2D COSY spectrum. The potential of the COSYDEC method for resolving problems of COSY cross-peak overlap in steroid spectra is described elsewhere.[59]

The only other two-dimensional method readily applicable to very small samples, two-dimensional J-spectroscopy, has proved to be of little value compared with COSY and COSYDEC, despite its earlier use[11–13] and the suggestion[30] that 'pattern recognition' applied to J-resolved cross sections might be useful for signal assignment. In our experience and that of others,[21] cross-sections are often difficult to interpret, and artefacts may interfere,[57] especially when two or more protons resonate close together on the chemical-shift scale.

Graphical analysis of 2D COSY spectra has generally involved initial recognition of especially distinctive signals (*e.g.* those for 4-H in 4-en-3-ones, for protons geminal to hydroxy groups, and for 17-H in pregnan-20-ones and testosterone derivatives), and location of signals from protons coupled to these by recognition of their cross peaks. Sets of coupled protons were traced stepwise, as far as possible, from such starting points. Of particular value were the 4-H/6β-H correlation in 4-en-3-ones resulting from allylic coupling,[56] as the best pointer to the 6β-H signal, the 17-H/16-H_2 correlations for locating 16α-H and 16β-H, and often the 9-H/8-H, 7α-H/7β-H, and 7α-H/8-H correlations, since the 9-H and 7α-H multiplets, with characteristic profiles, frequently appear in the high-field region of the spectra especially of 4-en-3-ones and 5α-steroids, where they are usually well separated from other signals. Cross-peaks from long-range coupling[11,12,34] were also helpful when they appeared, particularly relating 18-H_3 to 12α-H and sometimes to 17α-H, and relating 19-H_3 to 1α-H and in some cases to 9-H.

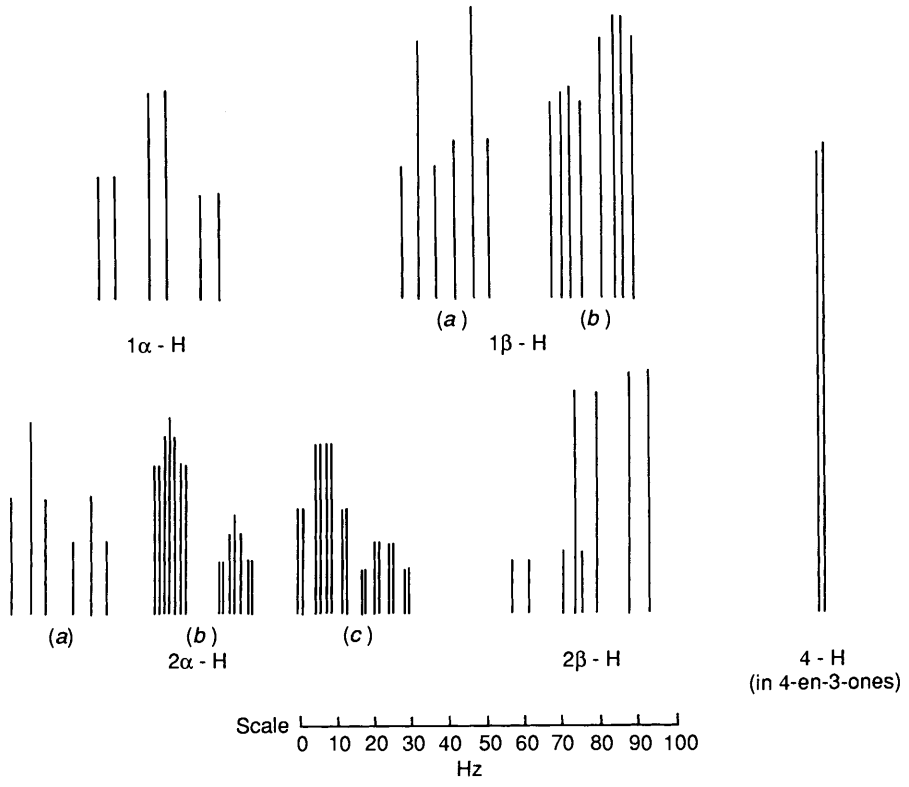


Figure 1. Templates for recognition of ^1H signals from their splitting patterns: Ring A. Vertical scales are not necessarily identical. Lines correspond to *centres* of component peaks of multiplets: (*a*), (*b*), and (*c*), illustrate common variations resulting from slight differences in coupling constants. Simplified profiles usually arise in the vicinity of substituents (see the text and Table 3).

COSYDEC spectra tend to show these long-range couplings very prominently,[59] in this respect resembling COSY LR.[34] Other, often distinctive and helpful features, unless strongly shifted by effects of adjacent subsituents, are the 1β-H double multiplet normally found at *ca.* δ 2.05 in 4-en-3-ones, and the 11β-H quartet of doublets normally at *ca.* δ 1.45. Recognition of cross peaks is often aided by noting their fine structure.[57] In favourable cases, and with adequate digitisation of spectral data, each cross peak comprises a two-dimensional array of contours representing the various pairs of connected transitions. In COSY-45 or COSY-60[57] spectra, fine-structured cross peaks often form a non-rectangular array: the direction of 'slant' in relation to the diagonal then indicates whether the cross peak results from geminal (*J* negative; *e.g.* 7α-H/7β-H) or vicinal coupling (*J* positive; *e.g.* 6β-H/7α-H).

As the range of fully assigned spectra has widened, recognition of regular features of one-dimensional and 2D COSY spectra has become increasingly a matter of inspection. Chemical-shift increments resulting from the presence of hydroxy groups, derived by comparison of data for monohydroxylated steroids with those for their parent compounds, have assumed considerable value. The increments depend upon geometric relationships between the hydroxy group and the affected protons (see below). Like substituent increments for 18-H_3 and 19-H_3,[52–54,56] and for ^{13}C spectra,[1,10] they are normally additive within the required limits of accuracy, and now prove to be extremely useful as an aid to locating particular ^1H signals.

In difficult cases, however, assignments could not be completed by inspection because of multiplet or COSY cross-peak overlap. Change of solvent is one way of resolving overlap problems,[13] but we have deliberately not resorted to this as a routine method, because we had set ourselves the task of devising assignment procedures which would be applicable within each series of related steroids all in the same solvent, for reasons of comparability of chemical shifts. Also, except when necessary to consolidate basic reference data for parent compounds of a series, we denied ourselves the luxury of employing pre-existing ^{13}C assignments, *via* two-dimensional heteronuclear ^1H–^{13}C correlated spectroscopy, one of our objectives being to devise procedures applicable to quantities of naturally occurring steroids below the levels necessary for such experiments. Similarly, we have used selective nuclear Overhauser effect difference measurements (NOEDS) only as a means for confirming or refining basic reference data obtained by other methods, and we made use of two-dimensional NOE methods (NOESY)[30,57] in only two particularly troublesome cases where the 5β-configuration made it difficult to locate signals for 8β-H and 9α-H (compounds **93** and **147**).

With the accumulation of more spectra, we came to accept that many proton signals have essentially the same profile across a wide range of related steroids, except when their multiplicities are reduced by the presence of geminal or vicinal substitution or unsaturation. We found it convenient to draw 'templates' corresponding to the characteristic appearances of proton signals, on a transparent plastic sheet which was then used as an overlay for matching multiplet profiles in the spectra. Templates (Figures 1–4) were drawn on a scale of 10 Hz cm^{-1}, which is why spectra were routinely plotted on this scale. Although signal splittings and widths may vary slightly as a consequence of small differences in coupling constants, the templates are a very valuable aid for signal recognition. Multiplets for protons at the 1α-, 1β-, 2β-, 7α-, 7β-, 8β-, 9α-, 11β-, and 17α-positions are usually the easiest to recognise by template fitting, even if partly overlapped by others. Those most liable to variations in profile or multiplicity are for protons at C-14, -15, and -16; this is a consequence of flexibility in the five-membered ring,[21,60] but even here templates are valuable, representing 'good average' signal splittings for compounds

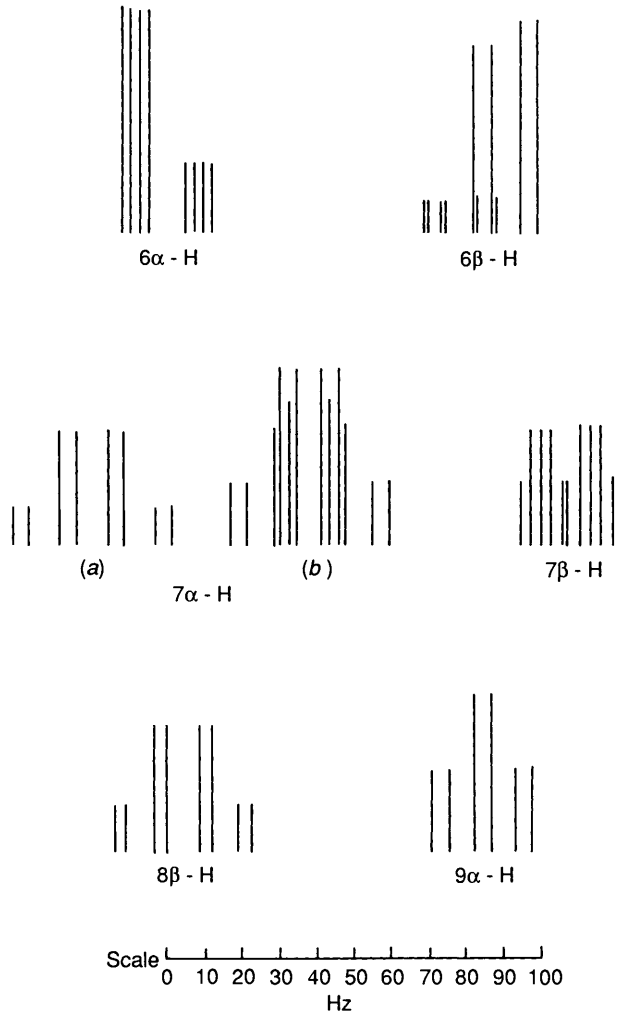


Figure 2. Templates for recognition of ^{1}H signals from their splitting patterns: Ring B. See the legend to Figure 1.

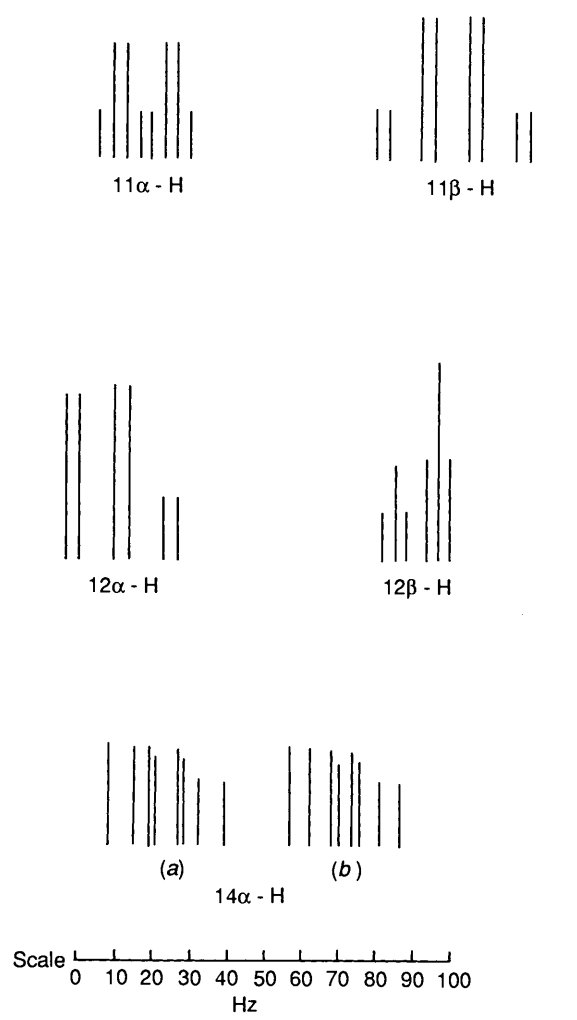


Figure 3. Templates for recognition of ^{1}H signals from their splitting patterns: Ring C. See the legend to Figure 1.

with C-17 either tetrahedral (pregnanes or androstan-17-ols) or trigonal (17-oxo). The 17α-H signal (C-17 tetrahedral) normally appears as either a triplet or a double doublet, depending upon the magnitudes of $J_{16\alpha,17}$ and $J_{16\beta,17}$. Another very variable signal profile is that for 2α-H in 4-en-3-ones (Figure 1): conformational differences[37–39] seem to influence the fine detail of the 2α-H signal more than any other in ring A, among the compounds which we have studied. The 2β-H signal appears more symmetrical in profile than is indicated in Figure 1 whenever deshielding substituent effects move it strongly away from that of 2α-H, reducing second-order effects. The most difficult multiplets to locate accurately were generally those for 11α-H and 14α-H; each signal is split by several spin couplings into a group of rather weak peaks which frequently underlie others; the 'slanted' 11α/11β cross peak in a COSY-45 or COSY-60 spectrum is often clearly visible, but may be obscured or too close to the diagonal in some cases.

In general, signals were first located as closely as possible from 2D COSY (or COSYDEC) spectra. Many could then be found, and their chemical shifts evaluated more exactly, by examining the normal one-dimensional spectrum with the aid of overlying templates. Where second-order effects due to similarity of chemical shifts of adjacent protons prevented template fitting, the best estimates of δ are those taken directly from COSY spectra. Frequent instances of this problem are the 11β/12α, 14/15β, and 15α/16α pairs of protons. Given sufficient material, the major part of a typical assignment task, performed manually on 400 or 500 MHz spectra, and accurate to the levels required for present purposes, can now often be substantially achieved in *ca.* 30 min. When NOEDS experiments are necessary to complete the more difficult assignments, these normally involve separate irradiation of the 18-methyl and/or 19-methyl signals to reveal adjacent protons on the β-face of the molecule,[11,12] irradiation of 4-H in 4-en-3-ones to locate the neighbouring 6α-H exactly, or in special cases irradiation of the C*H*OH or 17α-H to highlight nearby protons on the same face of the molecule.

Chemical shifts are reported in this paper to the nearest 0.01 ppm. We consider this to be sufficient precision for the applications envisaged, and especially having regard to the extent of additivity of substituent increments, as well as the experimental variables including digital resolution in the acquisition of data, solution concentration and temperature, and even the variety of spectrometers in use, with their differing capabilities. We have, whenever possible, obtained spectra for solutions under standardised conditions (see the Experimental section). Some workers have reported chemical shifts with greater precision,[14–19,37–40] especially when evaluating and optimising experimental procedures. Computer simulation of spectra[21,28,35,38,39] has been used as the ultimate way of refining both chemical shifts and *J*-values, especially when the latter are required for conformational studies. For systems comprising

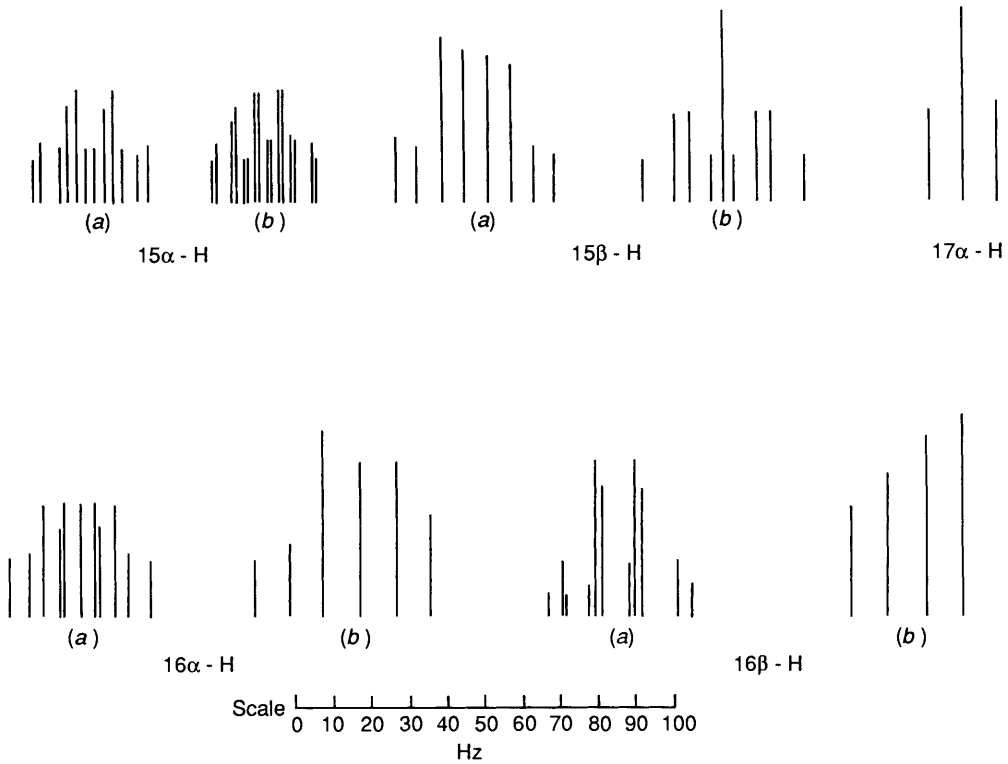


Figure 4. Templates for recognition of ^{1}H signals from their splitting patterns: Ring D. (*a*) Patterns often seen when the 17β-position is substituted (*e.g.* pregnan-20-ones, or androstan-17β-ols; C-17 tetrahedral); (*b*) alternative pattern often seen in androstan-17-ones (C-17 trigonal). For other information, see the legend to Figure 1.

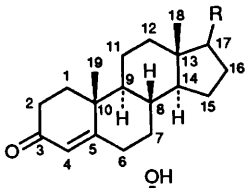
three or more spins, measurement of signal splittings may not provide accurate *J* values.[38]

Compounds Included in this Study.—Table 1 lists the 166 compounds included in this survey; data for 99 of these arose from our own work. These comprise testosterone and eleven of its monohydroxy derivatives, androst-4-ene-3,17-dione and eleven of its monohydroxy derivatives, as well as progesterone and eighteen of its monohydroxy, and six of its dihydroxy derivatives. Additionally we report data for $\Delta^{1,4}$, $\Delta^{4,6}$, and/or $\Delta^{1,4,6}$-unsaturated derivatives of these hormones. All these data except for 1-dehydrotestosterone and 11β-hydroxyprogesterone are our own. Published data for progesterone[15] agree almost exactly with ours. In order to enhance the usefulness of this compilation for predictive purposes, and for the assignments of other spectra, we have included data for a variety of other steroids mainly of the pregnane class, including the corticosteroids. Some are taken from the literature, with occasional suggestions that assignments for protons of geminal pairs require reversal (see the Discussion). Others are our own, chosen in several cases as examples to fill gaps in our knowledge of the effects of common structural features. Also included is a series of derivatives of aldosterone, which have arisen in the course of our investigations into products of aldosterone metabolism.[47–49] Available data for a few 19-nor steroids (estranes and 19-nor-17α-pregn-20-ynes, but *not* the aromatic estrogens), bile acids, and sterols are also included.

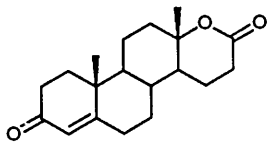
Results

Table 2 lists the ^{1}H chemical shifts (δ) and their assignments. The majority of δ values, measured directly from the one-dimensional spectra to the nearest 0.01 ppm, were determined after signals from cross-peaks in the 2D COSY or COSYDEC spectra had first been identified; some signals partially overlapped others, but could still be discerned clearly by fitting the templates, described above, to the one-dimensional spectra. The chemical shifts taken directly from 1D spectra are those in Table 2 which bear no superscript indicative of the use of some special technique. Where signals overlapped in such a way as to make the template-fitting procedure uncertain, and especially where strong second-order perturbations arose from close proximity or superimposition of multiplets arising from mutually spin-coupled protons, δ values were estimated as accurately as possible from alignments of cross-peaks in the 2D COSY or COSYDEC spectra. These δ values are appropriately superscripted in Table 2. Errors in such cases are normally considered to lie within the range ±0.02 ppm. In a very few cases we were left with uncertainties which had to be resolved by NOE measurements. Only in two key cases (androst-4-en-3-one, and aldosterone[9]) was it necessary to resort to ^{13}C and ^{1}H–^{13}C correlated spectroscopy to make full assignments. Analyses of the ^{1}H spectra of compounds with no substituents in rings A, B, or C (*e.g.* 5α,17α-pregnan-20-one and 5α-pregnan-16β-ol, each chosen as the only readily available model for its class), made use of published data for the hydrocarbon 5α-androstane.[21] Similarly, published ^{1}H spectra for 5α-androstan-3-one and the 5α-androstan-3-ols,[21] and for the series of bile acids with the 5β-configuration,[20,27] provided initial data as a basis for the evalution of chemical shifts of protons in compounds with the same features in rings A and B, and lacking unsaturation in these rings. Assignments for cholestane derivatives are based upon the few already reported in the literature,[32,33,34,36] but with some reservations (see the Discussion).

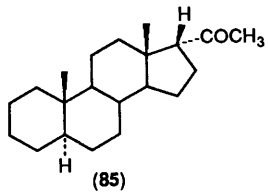
Steroids of 5β configuration present a particular difficulty in that the 9α-H multiplet, an important starting point for the location of signals from protons in the middle regions of the molecule, is strongly deshielded by ring A, and shifted into the crowded part of the spectrum around δ 1.4—1.8. The 9α-H signal



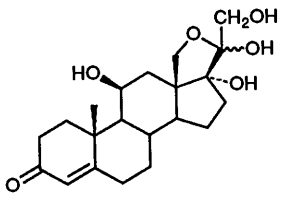
(25) R = OH, H
(39) R = O
(57) R = $COCH_3$, H



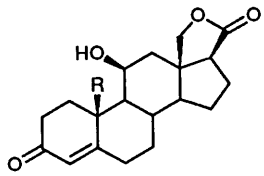
(54)



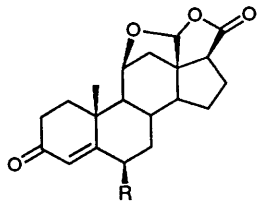
(85)



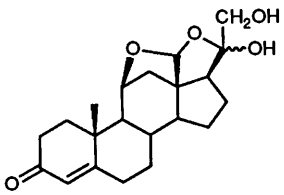
(111)



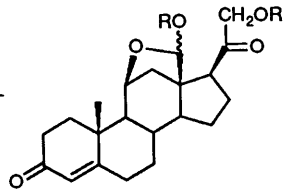
(116) R = H
(117) R = Me



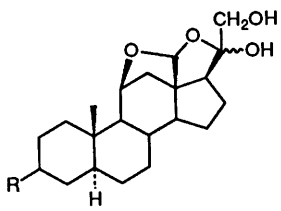
(122) R = H
(130) R = OH



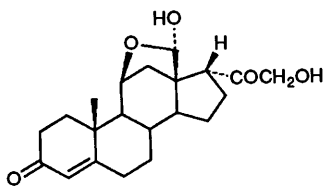
(120) (18, 20 - hemiacetal)



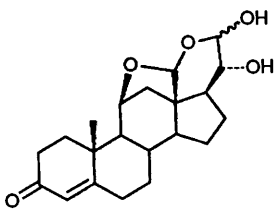
(120) (20 - oxo) R = H
(121) R = Ac



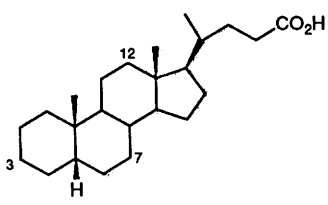
(123) R = O
(124) R = H, HO



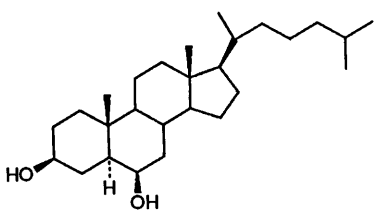
(132)



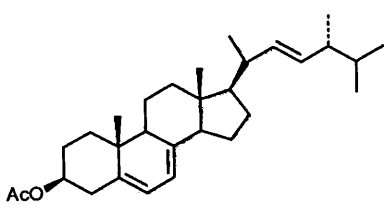
(137)



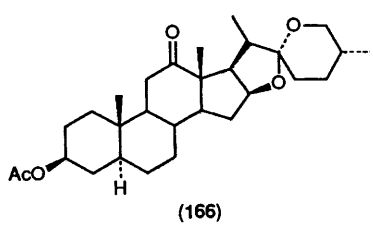
(141)



(152)



(163)



(166)

Table 1. Steroids included in this study.

		Abbreviations used in Tables 2 and 3	Reference or source*
Estranes (including 19-nor-17α-pregn-20-ynes)			
1	17α-Chloromethyl-17β-hydroxyestr-4-en-3-one	17α-CH_2Cl	40
2	17α-Azidomethyl-17β-hydroxyestr-4-en-3-one	17α-CH_2N_3	40
3	17α-Cyanomethyl-17β-hydroxyestr-4-en-3-one	17α-CH_2CN	40
4	17β-Hydroxy-19-nor-5α,17α-pregn-20-yn-3-one	17α-C≡CH, 5α-H	17
5	17β-Hydroxy-19-nor-5β,17α-pregn-20-yn-3-one	17α-C≡CH, 5β-H	17
6	5,17β-Dihydroxy-19-nor-5α,17α-pregn-20-yn-3-one	17α-C≡CH, 5α-OH	19
7	5,17β-Dihydroxy-19-nor-5β,17α-pregn-20-yn-3-one	17α-C≡CH, 5β-OH	19
Androstanes			
8	5α-Androstane	5α-An	21
9	5α-Androstan-3-one	3-one	21
10	5α-Androstan-11-one	11-one	21
11	5α-Androstan-17-one	17-one	21
12	5α-Androstan-3α-ol	3α-ol	21
13	5α-Androstan-3β-ol	3β-ol	21
14	3α-Chloro-5α-androstane	3α-Cl	21
15	3α-Fluoro-5α-androstan-17-one	3α-F-17-one	21
16	3β-Fluoro-5α-androstan-17-one	3β-F-17-one	21
17	3α-Chloro-5α-androstan-17-one	3α-Cl-17-one	21
18	3β-Chloro-5α-androstan-17-one	3β-Cl-17-one	21
19	3α-Bromo-5α-androstan-17-one	3α-Br-17-one	21
20	3β-Bromo-5α-androstan-17-one	3β-Br-17-one	21
21	3α-Iodo-5α-androstan-17-one	3α-I-17-one	21
22	3β-Iodo-5α-androstan-17-one	3β-I-17-one	21
23	Androst-5-en-17-one	Δ^5-17-one	21
24	Androst-4-en-3-one	Δ^4-3-one	
25	17β-Hydroxyandrost-4-en-3-one (testosterone)	Test (T)	
26	2α-Hydroxytestosterone	2α-OHT	
27	2β-Hydroxytestosterone	2β-OHT	
28	6α-Hydroxytestosterone	6α-OHT	
29	6β-Hydroxytestosterone	6β-OHT	
30	7α-Hydroxytestosterone	7α-OHT	
31	11α-Hydroxytestosterone	11α-OHT	
32	11β-Hydroxytestosterone	11β-OHT	
33	14-Hydroxytestosterone	14-OHT	
34	15α-Hydroxytestosterone	15α-OHT	
35	16α-Hydroxytestosterone	16α-OHT	
36	16β-Hydroxytestosterone	16β-OHT	
37	17β-Hydroxyandrosta-1,4-dien-3-one (1-dehydrotestosterone)	Δ^1-T	11
38	17β-Hydroxyandrosta-4,6-dien-3-one (6-dehydrotestosterone)	Δ^6-T	
39	Androst-4-ene-3,17-dione	3,17-Dione(A)	
40	2α-Hydroxyandrost-4-ene-3,17-dione	2α-OHA	
41	4-Hydroxyandrost-4-ene-3,17-dione	4-OHA	
42	6β-Hydroxyandrost-4-ene-3,17-dione	6β-OHA	
43	7α-Hydroxyandrost-4-ene-3,17-dione	7α-OHA	
44	7β-Hydroxyandrost-4-ene-3,17-dione	7β-OHA	
45	11α-Hydroxyandrost-4-ene-3,17-dione	11α-OHA	
46	11β-Hydroxyandrost-4-ene-3,17-dione	11β-OHA	
47	14-Hydroxyandrost-4-ene-3,17-dione	14-OHA	
48	15α-Hydroxyandrost-4-ene-3,17-dione	15α-OHA	(43)
49	16α-Hydroxyandrost-4-ene-3,17-dione	16α-OHA	
50	19-Hydroxyandrost-4-ene-3,17-dione	19-OHA	
51	Androsta-1,4-diene-3,17-dione	Δ^1-A	
52	Androsta-4,6-diene-3,17-dione	Δ^6-A	
53	Androsta-1,4,6-triene-3,17-dione	$\Delta^{1,6}$-A	
54	17a-Oxa-D-homoandrost-4-ene-3,17-dione (testololactone)	T-lactone	
55	Methyl 6α-fluoro-11β-hydroxy-16α-methyl-3-oxoandrost-4-ene-17β-carboxylate	Me 17-Carbox	21
56	17β-Hydroxyandrost-4-ene-3,16-dione	16-OxoT	
Pregnanes			
57	Pregn-4-ene-3,20-dione (progesterone)	Prog (P)	
58	2α-Hydroxyprogesterone	2α-OHP	
59	2β-Hydroxyprogesterone	2β-OHP	
60	4-Hydroxyprogesterone	4-OHP	
61	6α-Hydroxyprogesterone	6α-OHP	
62	6β-Hydroxyprogesterone	6β-OHP	

Table 1 (*continued*)

		Abbreviations used in Tables 2 and 3	Reference or source*
Pregnanes			
63	7α-Hydroxyprogesterone	7α-OHP	
64	7β-Hydroxyprogesterone	7β-OHP	
65	9-Hydroxyprogesterone	9-OHP	
66	11α-Hydroxyprogesterone	11α-OHP	
67	11β-Hydroxyprogesterone	11β-OHP	12
68	12α-Hydroxyprogesterone	12α-OHP	(46)
69	14-Hydroxyprogesterone	14-OHP	(44)
70	15α-Hydroxyprogesterone	15α-OHP	(42)
71	15β-Hydroxyprogesterone	15β-OHP	(42)
72	16α-Hydroxyprogesterone	16α-OHP	
73	17α-Hydroxyprogesterone	17α-OHP	
74	19-Hydroxyprogesterone	19-OHP	
75	21-Hydroxyprogesterone	21-OHP	
76	17α-Acetoxy-6α-methylprogesterone	17α-OAc-6MeP	13
77	Pregna-4,6-diene-3,20-dione	Δ^{6}-P	
78	Pregna-1,4,6-triene-3,20-dione	$\Delta^{1,6}$-P	
79	6β,9α-Dihydroxyprogesterone	6β,9α-OHP	(43)
80	6β,11α-Dihydroxyprogesterone	6β,11α-OHP	
81	7β,15β-Dihydroxyprogesterone	7β,15β-OHP	
82	12β,15α-Dihydroxyprogesterone	12β,15α-OHP	
83	16α,21-Dihydroxyprogesterone	16α,21-OHP	
84	6β,11β,21-Trihydroxyprogesterone	6β,11β,21-OHP	
85	5α,17α-Pregnan-20-one	5α,17α-20-one	
86	16β-Hydroxy-5α-pregnan-20-one	16β-OH-20-one	
87	2α,3α-Dihydroxy-5α-pregnan-20-one	2α,3α-OH-5α-20-one	(49)
88	3α,6β-Dihydroxy-5α-pregnan-20-one	3α,6β-OH-5α-20-one	
89	3β,6α-Dihydroxy-5α-pregnan-20-one	3β,6α-OH-5α-20-one	
90	3β,7β-Dihydroxy-5α-pregnan-20-one	3β,7β-OH-5α-20-one	
91	3β,12β-Dihydroxy-5α-pregnan-20-one	3β,12β-OH-5α-20-one	
92	3β,12β-Dihydroxy-5α-pregn-16-en-20-one 3-acetate	3β-OAc-12β-OH-Δ^{16}-20-one	
93	3α,6α-Dihydroxy-5β-pregnan-20-one	3α,6α-OH-5β-20-one	
94	3β-Acetoxypregn-5-en-20-one	3β-Ac-Δ^{5}-20-one	29
95	3β-Acetoxypregn-5-en-20β-ol	3β-Ac-Δ^{5}-20β-ol	29
96	3β-Hydroxypregna-5,20-diene	3β-OH-$\Delta^{5,20}$	29
97	3β-Hydroxypregna-5,16-diene	3β-OH-$\Delta^{5,16}$	29
98	16α,17-Epoxypregn-4-ene-3,20-dione	16,17-Epoxy-P	24[a]
99	16α,17-Epoxypregn-4-ene-3,11,20-trione	16,17-Epoxy-11-oxoP	24[a]
100	16α,17-Epoxy-11α-hydroxypregn-4-ene-3,20-dione	16,17-Epoxy-11α-OHP	24[a]
101	11β,17α-Dihydroxypregn-4-ene-3,20-dione	11β,17α-OHP	24[a]
102	Pregn-4-ene-3,6,20-trione	6-OxoP	
103	17α-Hydroxypregn-4-ene-3,11,20-trione	17α-OH-11-oxoP	24[a]
104	(20*S*)-20-Hydroxypregn-4-en-3-one	20*S*-OH-Δ^{4}-3-one	
105	(20*R*)-20-Hydroxypregn-4-en-3-one	20*R*-OH-Δ^{4}-3-one	
106	(20*R*)-9α,20-Dihydroxypregn-4-en-3-one	9α,20*R*-OH-Δ^{4}-3-one	
107	17α,21-Dihydroxypregn-4-ene-3,11,20-trione (cortisone)	Cortisone	
108	Cortisone acetate	CortAc	24[a]
109	11β,17α,21-Trihydroxypregn-4-ene-3,20-dione (cortisol)	Cortisol	34[b]
110	9α-Fluorocortisol	9α-F-cortisol	14
111	18-Hydroxycortisol	18-OH-cortisol	(61)
112	21-Acetoxy-11β,17α-dihydroxypregna-1,4-diene-3,20-dione (prednisolone acetate)	Pred Ac	24[a]
113	3β-Acetoxy-5α-pregn-16-en-20-one	3β-Ac-Δ^{16}20-one	24[a]
114	3β-Acetoxypregna-5,16-dien-20-one	3β-Ac-$\Delta^{5,16}$20-one	24[a]
115	16α,17α-Epoxy-3β-hydroxypregn-5-en-20-one	16,17-Epoxy-3β-OH-Δ^{5}-20-one	24[a]
116	11β-Hydroxy-3-oxoestr-4-ene-17β,18-carbolactone	18-OH-nor-lactone	26
117	11β-Hydroxy-3-oxoandrost-4-ene-17β,18-carbolactone	18-OH-lactone	26
118	16β-Bromo-17α-hydroxypregn-4-ene-3,11,20-trione	16β-Br-17α-OH-11-oxoP	24[a]
119	21-acetoxy-6α,9α-difluoro-11β,16α,17α-trihydroxypregna-1,4-diene-3,20-dione (fluocinonide)	Fluocinonide	28
Aldosterone and derivatives[c]			
120	Aldosterone (18,20-hemiacetal)	Aldo (H)	9
	Aldosterone (20-oxo)	Aldo (Oxo)	
121	Aldosterone 18,21-diacetate	Diac	
122	11β,18-Epoxy-3-oxopregn-4-ene-17β,18-carbolactone (aldosterone gamma-lactone)	Lactone	
123	11β,18; 18,20-Diepoxy-20,21-dihydroxy-5α-pregnan-3-one [5α-Dihydroaldosterone (18,20-hemiacetal)]	5α-DH (H)	

Table 1. (*continued*)

		Abbreviations used in Tables 2 and 3	Reference or source*
Aldosterone and derivatives[c]			
124	11β,18; 18,20-Diepoxy-5α-pregnane-3α,20,21-triol [3α,5α-Tetrahydroaldosterone (18,20-hemiacetal)]	3α,5α-TH (H)	
125	6α-Hydroxyaldosterone (18,20-hemiacetal)	6α-OH (H)	(48)
	6α-Hydroxyaldosterone (20-oxo)	6α-OH (Oxo)	
126	6α-Hydroxyaldosterone 18,21-diacetate	6α-OH-diac	(48)
127	6α-Hydroxy-5α-dihydroaldosterone (18,20-hemiacetal)	6α-OH-5α-DH (H)	
	6α-Hydroxy-5α-dihydroaldosterone (20-oxo)	6α-OH-5α-DH (Oxo)	
128	6β-Hydroxyaldosterone (18,20-hemiacetal)	6β-OH (OH)	(48)
	6β-Hydroxyaldosterone (20-oxo)	6β-OH) (Oxo)	
129	6β-Hydroxyaldosterone 18,21-diacetate	6β-OH-diac	(48)
130	6β-Hydroxyaldosterone γ-lactone	6β-OH-lactone	(48)
131	6β-Hydroxy-5α-dihydroaldosterone (18,20-hemiacetal)	6β-OH-5α-DH) (H)	
	6β-Hydroxy-5α-dihydroaldosterone (20-oxo)	6β-OH-5α-DH (Oxo)	
132	11β,18-Epoxy-18,21-dihydroxy-17α-pregn-4-ene-3,20-dione (17-isoaldosterone)	17-Iso	
133	5α-Dihydro-17-isoaldosterone	5α-DH-iso	
134	2α-Hydroxy-3α,5α-tetrahydro-17-isoaldosterone	2α-OH-3α,5α-TH-iso	(49)
135	6α-Hydroxy-17-isoaldosterone	6α-OH-iso	(48)
136	6β-Hydroxy-17-isoaldosterone	6β-OH-iso	(48)
137	11β,18; 18,21-Diepoxy-20,21-dihydroxypregn-4-en-3-one (apoaldosterone)	Apo	
138	5α-Dihydro-apoaldosterone	5α-DH-apo	
139	2α-Hydroxy-3α,5α-tetrahydroapoaldosterone	2α-OH-3α,5α-TH-apo	(49)
140	19-Noraldosterone γ-lactone	19-Nor-lactone	26
Bile acids			
141	5β-Cholan-24-oic acid	5β-Cholanic	20
142	3α-Hydroxy-5β-cholan-24-oic acid (lithocholic acid)	Litho	20
143	3α,7α-Dihydroxy-5β-cholan-24-oic acid (chenodeoxycholic acid)	Cheno	20
144	3α,7β-Dihydroxy-5β-cholan-24-oic acid (ursodeoxycholic acid)	Urso	20
145	3α,12α-Dihydroxy-5β-cholan-24-oic acid (deoxycholic acid)	Deoxy	20
146	Sodium deoxycholate	Na deoxy	27
147	3β,12α-Dihydroxy-5β-cholan-24-oic acid	3-Epideoxy	
148	3α,7α,12α-Trihydroxy-5β-cholan-24-oic acid (cholic acid)	Cholic	20
149	Sodium cholate	Na cholate	27
150	Methyl 3-oxo-7α,12α-dihydroxy-5β-cholan-24-oate	3-Oxo-7α,12α-OH	
151	3-Oxochola-4,6-dien-24-oic acid	$\Delta^{4,6}$-3-one	
Sterols and miscellaneous			
152	5α-Cholestane-3β,6β-diol	3β,6β-OH-C	
153	6α-Hydroxy-5α-cholestan-3-one	6α-OH-3-one	
154	6β-Hydroxy-5α-cholestan-3-one	6β-OH-3-one	
155	5-Hydroxy-5α-cholestan-6-one oxime	5α-OH-6-NOH	32
156	3β-Acetoxy-5-hydroxy-5α-cholestan-6-one oxime	3β-AcO-5α-OH-6-NOH	32
157	3β-Acetoxy-5-methoxy-5α-cholestan-6-one oxime	3β-AcO-5α-OMe-6-NOH	32
158	3β-Acetoxy-5-hydroxy-5β-cholestan-6-one oxime acetate	3β-AcO-5β-OH-6-NOAc	32
159	4,4-Dimethyl-5α-cholest-2-en-7-one	4,4-Me_2-2-en-7-one	34
160	3β-Hydroxy-4,4-dimethyl-5α-cholestan-7-one	3β-OH-4,4-Me_2-7-one	34
161	3β-Acetoxy-4,4-dimethyl-5α-cholestan-7-one	3β-OAc-4,4-Me_2-7-one	34
162	3β-Acetoxycholesta-5,7-diene (7-dehydrocholesteryl acetate)	Δ^7-Chol ac	36
163	(22*E*)-3β-Acetoxyergosta-5,7,22-triene (ergosteryl acetate)	Ergo ac	36
164	(20*E*,23*E*,25*E*)-26-Phenyl-27-norcholesta-5,20(22),22,25-tetraen-3β-ol	26-Ph-$\Delta^{20(22),23,25}$	33
165	(20*E*,23*E*)-24-Phenyl-25,26,27-trinorcholesta-5,20(22),23-trien-3β-ol	26-Ph-$\Delta^{20(22),23}$	33
166	(25*R*)-3β-Acetoxy-5α-spirostan-12-one (hecogenin acetate)	Hec Ac	

* Reference numbers in parentheses are to our own work. Where no source is indicated, materials were from the Steroid Reference Collection, or from unpublished work in our laboratories. [a] All δ values taken from ref. 24 have been increased by 0.13 ppm, by agreement with Prof. Dr. H. Duddeck (personal communication). [b] δ values in parentheses in Table 2 are in DMSO, from ref. 34. [c] Aldosterone-type compounds generally exist as equilibrating mixtures of the 18,20-hemiacetal form (abbreviated 'H') and the 20-oxo form (abbreviated 'oxo'), each exhibiting its own spectrum.

is then often close enough to those for 8β-H, 11α-H, and 11β-H for all these signals to show strong second-order effects. Accurate location of signals from these middle-ring protons without recourse to ^{13}C and heteronuclear correlated spectra is then a major problem, instead of being trivial as it normally is for 4-en-3-ones and 5α-steroids. COSYDEC spectra at 500 MHz have proved to be generally the most helpful proton technique in such cases, although even these may leave a margin of uncertainty in chemical shifts which is somewhat greater than usual.

Superscripts and footnotes in Table 2 indicate the methods which were used to determine particular chemical shifts where these could not be read directly from 1D-spectra. Signal profiles normally corresponded quite closely to the templates illustrated

(*text continued on p. 1590*)

Table 2. Chemical shifts for protons [δ(ppm from Me_4Si)].

(*a*) Estranes

	1 17α-CH_2Cl	**2** 17α-CH_2N_3	**3** 17α-CH_2CN	**4** 17α-C≡CH 5α-H	**5** 17α-C≡CH 5β-H	**6** 17α-C≡CH 5α-OH	**7** 17α-C≡CH 5β-OH
Solvent *	C	C	C	M	M	M	M
H							
1α	1.53	1.53	1.52	1.33	1.69	1.72	2.08
1β	2.25	2.25	2.30	2.38	2.32	2.15	2.28
2α	2.22	2.23	2.25	2.39	2.44	2.37	2.40
2β	2.40	2.41	2.25	2.48	2.16	2.45	2.16
3α	—	—	—	—	—	—	—
3β	—	—	—	—	—	—	—
4α	5.82	5.83	5.72	2.27	2.82	2.30	3.01
4β				2.27	2.07	2.59	2.08
5α	—	—	—	1.50	—	—	—
5β	—	—	—	—	2.26	—	—
6α	2.27	2.26	2.32	1.75	1.59	1.72	1.73
6β	2.48	2.48	2.47	1.30	1.83	1.72	1.66
7α	1.04	1.03	1.05	1.05	1.26	1.38	1.15
7β	1.85	1.84	1.87	1.79	1.59	1.56	1.73
8	1.46	1.44	1.51	1.30	1.27	1.29	1.33
9	0.83	0.82	0.87	0.79	1.52	1.21	1.42
10	2.11	2.11	2.21	1.33	1.69	1.65	1.54
11α	1.88	1.87	1.91	1.96	1.91	1.86	1.97
11β	1.32	1.31	1.36	1.31	1.29	1.31	1.33
12α	1.28	1.24	1.27	1.84	1.93	1.86	1.91
12β	1.69	1.68	1.65	1.69	1.74	1.67	1.73
14	1.24	1.20	1.34	1.66	1.78	1.70	1.73
15α	1.64	1.61	1.69	1.74	1.76	1.74	1.73
15β	1.39	1.36	1.40	1.40	1.41	1.39	1.42
16α	1.75	1.72	1.93	2.28	2.29	2.29	2.30
16β	2.14	2.92	2.03	2.01	2.02	2.01	2.04
17α	—	—	—	—	—	—	—
17β	—	—	—	—	—	—	—
18	1.01	0.96	0.99	0.94	0.94	0.94	0.94
19	—	—	—	—	—	—	—
20	—	—	—	—	—	—	—
21	—	—	—	2.94	2.96	2.93	2.96
Other	3.78, 3.61 (17α-CH_2)	3.53, 3.20 (17α-CH_2)	2.66 (17α-CH_2)	—	—	—	—

(*b*) Androstanes

	8 5α-An	**9** 3-one	**10** 11-one	**11** 17-one	**12** 3α-ol	**13** 3β-ol	**14** 3α-Cl	**15** 3α-F-17-one
Solvent	C	C	C	C	C	C	C	C
H								
1α	0.89	1.34	0.76	0.89	1.33	0.96	1.12	1.32
1β	1.66	2.01	2.40	1.67	1.48	1.73	1.89	1.53
2α	1.50	2.27	1.50	1.50	1.63	1.78	1.86	1.77
2β	1.41	2.37	1.41	1.41	1.68	1.40	1.86	1.56
3α	1.23	—	1.19	1.22	—	3.57	—	—
3β	1.67	—	1.65	1.66	4.05	—	—	4.81
4α	1.22	2.06	1.23	1.29	1.38	1.53	1.59	1.63
4β	1.22	2.24	1.23	1.29	1.52	1.26	1.73	1.41
5α	1.06	1.51	0.99	1.07	1.56	1.10	1.70	1.57
5β	—	—	—	—	—	—	—	—
6α	1.22	1.33	1.21	1.23	1.20	1.26	1.20	1.24
6β	1.22	1.33	1.21	1.25	1.20	1.26	1.20	1.16
7α	0.93	0.96	1.12	0.97	0.98	0.91	0.99	1.02
7β	1.69	1.73	1.79	1.78	1.70	1.67	1.70	1.81
8	1.29	1.34	1.65	1.55	1.30	1.27	1.29	1.56
9	0.69	0.76	1.69	0.72	0.79	0.66	1.75	0.82
10	—	—	—	—	—	—	—	—
11α	1.55	1.57		1.67	1.57	1.50	1.55	1.68
11β	1.26	1.39	—	1.27	1.28	1.28	1.25	1.29
12α	1.10	1.12	2.25	1.23	1.11	1.09	1.12	1.24
12β	1.71	1.73	2.25	1.79	1.72	1.71	1.71	1.80
14	0.90	0.92	1.54	1.27	0.92	0.89	0.92	1.30
15α	1.65	1.65	1.77	1.92	1.67	1.62	1.65	1.94
15β	1.15	1.16	1.23	1.50	1.15	1.14	1.15	1.51
16α	1.56	1.59	1.71	2.05	1.61	1.56	1.60	2.07
16β	1.56	1.59	1.71	2.45	1.61	1.56	1.60	2.42
17α	1.13	1.13	1.35	—	1.14	1.13	1.14	—
17β	1.42	1.40	1.45	—	1.43	1.41	1.43	
18	0.69	0.72	0.66	0.86	0.69	0.69	0.69	0.86
19	0.79	1.02	1.01	0.81	0.78	0.81	0.79	0.82
20	—	—	—	—	—	—	—	—
21	—	—	—	—	—	—	—	—
Other	—	—	—	—	—	—	—	—

Table 2 (*continued*)

	16 3β-F-17-one	**17** 3α-Cl-17-one	**18** 3β-Cl-17-one	**19** 3α-Br-17-one	**20** 3β-Br-17-one	**21** 3α-I-17-one	**22** 3β-I-17-one	**23** Δ^5-17-one	**24** Δ^4-3-one
Solvent	C	C	C	C	C	C	C	C	C
H									
1α	0.98	1.49	1.02	1.54	1.05	1.53	1.05	1.04	1.70[h]
1β	1.77	1.49	1.76	1.54	1.73	1.53	1.58	1.86	2.03
2α	1.93	1.88	2.03	1.95	2.15	1.93	2.14	1.54	2.31
2β	1.57	1.88	1.77	1.95	1.97	1.70	2.25	1.54	2.44
3α	4.46	—	3.85	—	4.02	—	4.15	1.22	—
3β	—	4.51	—	4.73	—	4.94	—	1.76	—
4α	1.74	1.67	1.80	1.72	1.87	1.77	2.01	2.02	} 5.73
4β	1.51	1.75	1.65	1.72	1.87	1.50	2.01	2.26	
5α	1.11	1.74	1.17	1.79	1.19	1.75	1.18	—	—
5β	—	—	—	—	—	—	—	—	—
6α	1.35	1.28	1.31	1.28	1.33	1.31	1.30	} 5.31	2.26
6β	1.35	1.28	1.31	1.28	1.33	1.31	1.30		2.41[h]
7α	0.98	1.05	0.96	1.06	0.96	1.09	0.96	1.67	1.04
7β	1.81	1.80	1.62	1.80	1.79	1.81	1.79	2.10	1.87
8	1.53	1.56	1.54	1.57	1.55	1.58	1.54	1.65	1.48[h]
9	0.68	0.87	0.69	0.90	0.70	0.90	0.69	1.07	0.95
10	—	—	—	—	—	—	—	—	—
11α	1.65	1.68	1.62	1.69	1.62	1.70	1.60	1.68	1.57[h]
11β	1.32	1.28	1.30	1.29	1.32	1.29	1.30	1.50	1.43
12α	1.23	1.24	1.22	1.27	1.23	1.27	1.21	1.30	1.14[h]
12β	1.78	1.80	1.79	1.82	1.80	1.81	1.79	1.86	1.77[h]
14	1.27	1.29	1.24	1.31	1.25	1.32	1.25	1.30	0.92
15α	1.92	1.94	1.91	1.95	1.92	1.96	1.91	1.96	1.69[h]
15β	1.48	1.51	1.49	1.50	1.50	1.51	1.49	1.56	1.21
16α	2.06	2.07	2.05	2.09	2.07	2.08	2.06	2.09	1.63[h,s]
16β	2.42	2.43	2.43	2.43	2.43	2.44	2.42	2.46	1.63[h,s]
17α	—	—	—	—	—	—	—	—	1.17[h]
17β	—	—	—	—	—	—	—	—	1.44[h]
18	0.86	0.86	0.85	0.86	0.86	0.86	0.85	0.90	0.75
19	0.86	0.81	0.86	0.82	0.88	0.83	0.88	1.03	1.19
20	—	—	—	—	—	—	—	—	—
21	—	—	—	—	—	—	—	—	—
Other	—	—	—	—	—	—	—	—	—

	25 Test	**26** 2α-OHT	**27** 2β-OHT	**28** 6α-OHT	**29** 6β-OHT	**30** 7α-OHT	**31** 11α-OHT	**32** 11β-OHT
Solvent	C	C	C	C	C	C	C	C
H								
1α	1.70	1.59[a]	2.49[a]	1.76	1.72	1.79	2.01	1.86
1β	2.03	2.38[c]	1.54[a]	2.05	2.05[c]	2.06	2.66	2.20
2α	2.35	—	4.19	2.38	2.40	2.38	2.33[c]	2.36
2β	2.42	4.27	—	2.44	2.53	2.43	2.43[c]	2.47
3α	—	—	—	—	—	—	—	—
3β	—	—	—	—	—	—	—	—
4α	} 5.73	5.80	5.81	6.18	5.84[a]	5.81	5.72	5.68
4β								
5α	—	—	—	—	—	—	—	—
5β	—	—	—	—	—	—	—	—
6α	2.29	2.34	2.26	—	4.36	2.42[a,d]	2.28	2.24
6β	2.42[d]	2.41	2.53[a]	4.34	—	2.65[a]	2.38[c]	2.47[c]
7α	1.00[d]	1.02[c]	1.01	1.05[a]	1.23[a]	—	1.04	1.03
7β	1.85[d]	1.86[c]	1.98	2.18[a]	2.01[c,s]	3.97	1.83	2.00[c,s]
8	1.57[d]	1.57[c]	1.71	1.62[c]	2.02[c,s]	1.62[d]	1.60	2.00[c,s]
9	0.93	0.95[c]	1.40	0.94	0.92	1.38[d]	1.10[c]	0.98[c]
10	—	—	—	—	—	—	—	—
11α	1.60[d]	1.60[c]	1.80	1.63[c]	1.54[c,s]	1.66[d]	—	4.40
11β	1.43	1.44	1.53[c]	1.42[c]	1.50[c,s]	1.47[d]	4.05	—
12α	1.10	1.08	1.14	1.10	1.10	1.10	1.17[a,c]	1.38
12β	1.86[d]	1.87[c]	1.89	1.88[a]	1.88	1.85	2 14[a]	1.98[a,c]
14	0.98[d]	0.97[c]	1.00[c]	1.03	0.99	1.36[d,s]	1.09[c]	0.95[c]
15α	1.62[d]	1.62[c]	1.59[c]	1.67[c]	1.63[c]	1.72	1.60[c]	1.66
15β	1.31	1.31	1.31	1.35	1.37	1.36[d,s]	1.29[c]	1.38[c]
16α	2.09[d]	2.08	2.08	2.10	2.10	2.14	2.10[c]	2.09
16β	1.48[d]	1.49[c]	1.47	1.49[c]	1.49[c]	1.50[d]	1.48[c]	1.48[c]
17α	3.65	3.65	3.67	3.67	3.67	3.71	3.70	3.62
17β	—	—	—	—	—	—	—	—
18	0.80	0.80	0.80	0.80	0.83	0.81	0.82	1.05
19	1.19	1.31	1.19	1.20	1.40	1.21	1.32	1.46
20	—	—	—	—	—	—	—	—
21	—	—	—	—	—	—	—	—
Other	—	—	—	—	—	—	—	—

Table 2 (*continued*)

	33 14-OHT	**34** 15α-OHT	**35** 16α-OHT	**36** 16β-OHT	**37** Δ^1-T	**38** Δ^6-T	**39** 3,17-Dione (A)	**40** 2α-OHA
Solvent	C	C	C	C	C	C	C	C
H								
1α	1.77	1.72	1.72	1.70	7.07	1.72[c]	1.71[c]	1.59[c]
1β	2.04	2.04	2.04	2.04		2.01	2.03	2.38[a]
2α	2.36[d]	2.33[c]	2.37[c]	2.35	6.23	2.43	2.35[c]	—
2β	2.42[d]	2.43	2.42	2.44		2.57	2.41[c]	4.27
4α	5.74	5.72	5.74	5.74	6.08	5.63	5.76	5.82
4β								
5α	—	—	—	—	—	—	—	—
5β	—	—	—	—	—	—	—	—
6α	2.33[d]	2.32	2.30	2.29	2.36	6.10	2.35[c]	2.38[c,s]
6β	2.44[d]	2.42[c]	2.41[c]	2.42[c]	2.47		2.40[c]	2.41[c,s]
7α	1.40[d]	1.21[c]	1.05	1.03	1.01	6.10	1.13	1.14
7β	1.74[d]	2.16[c]	1.84[c]	1.87	1.96		1.99[c]	1.99[c]
8	1.89[n]	1.80	1.57[c]	1.64[c]	1.67	2.25[c]	1.75[c]	1.75
9	1.50[d]	0.99[c]	0.98	0.95	1.04	1.20[c]	1.00	1.02
10	—	—	—	—	—	—	—	—
11α	1.70[d]	1.63	1.60[c]	1.62[c]	1.77	1.63[c]	1.70[c]	1.69
11β	1.39[d,n]	1.43	1.43	1.46	1.68	1.44	1.47	1.47
12α	1.72[d,s]	1.18	1.19	1.13	1.09	1.13[c]	1.28	1.28[c]
12β	1.74[d,n,s]	1.84	1.83[c]	1.91	1.87	1.90	1.86	1.88
14	—	1.00[a,c]	1.37	0.83	0.95	1.18[c]	1.31[c]	1.29[c]
15α	1.51[d]	—	1.62[c]	2.24	1.61	1.80[c]	1.98[c]	1.98[c]
15β	1.78[d,n]	4.13	1.83[c]	1.31	1.33	1.47[c]	1.59[b]	1.56[c]
16α	2.29[d]	1.97[a,c]	—	4.19	2.07	2.11[c]	2.12[b]	2.12[b]
16β	1.58[d]	2.11[a,c]	4.17	—	1.47	1.51[c]	2.48[b]	2.48[b]
17α	4.32	3.92	3.52[a]	3.40	3.64	3.68	—	—
17β	—	—	—	—	—	—	—	—
18	0.93	0.82	0.83	0.87	0.82	0.86	0.93	0.92
19	1.22	1.22	1.19	1.21	1.24	1.14	1.22	1.33
20	—	—	—	—	—	—	—	—
21	—	—	—	—	—	—	—	—
Other	—	—	—	—	—	—	—	—

	41 4-OHA	**42** 6β-OHA	**43** 7α-OHA	**44** 7β-OHA	**45** 11α-OHA	**46** 11β-OHA	**47** 14-OHA	**48** 15α-OHA
Solvent	C	C	C	C	C	C	C	C
H								
1α	1.71[c]	1.73	1.79[c]	1.65	2.04	1.86	1.77	1.73
1β	2.02[c]	2.06	2.06[c]	2.04	2.68	2.22[c]	2.05	2.05
2α	2.52[c,s]	2.41	2.37	2.34[c]	2.35[c]	2.37	2.33[c]	2.35[c]
2β	2.55[c,s]	2.52	2.44[c]	2.42[c]	2.44[c]	2.49[c,n]	2.40[c,n]	2.42[c]
4α	6.10 (OH)	5.84[a]	5.81	5.75	5.76	5.71	5.75	5.75
4β								
5α	—	—	—	—	—	—	—	—
5β	—	—	—	—	—	—	—	—
6α	3.07	4.41	2.47[c]	2.55[a]	2.35[c]	2.30[n]	2.38[c,n]	2.35[c]
6β	2.03[c]	—	2.68[a]	2.49[c]	2.42[c]	2.48[c,n]	2.47[c,n]	2.43[c]
7α	1.08	1.31[c]	—	3.56	1.16	1.14	1.43[c]	1.35[c]
7β	1.99[c]	2.14[c]	4.11	—	1.98[c]	2.12	1.86[c]	2.35[c]
8	1.70[c]	2.18	1.81[c]	1.77[a]	1.72	2.20[c,n]	1.94[a,c,n]	1.96
9	1.00	0.98	1.29	0.99	1.18[a]	1.01[a]	1.53[c]	1.03
10	—	—	—	—	—	—	—	—
11α	1.70[c]	1.70[c]	1.74[c]	1.72[c]	—	4.47	1.66	1.71[c]
11β	1.43	1.52	1.47	1.48[c]	4.08	—	1.43[c,n]	1.44[c]
12α	1.28	1.27[c]	1.23	1.24	1.34[a]	1.50[a]	1.82	1.40[c]
12β	1.87	1.89[a]	1.84	1.85	2.17[c]	1.97[a,n]	1.60[c,n]	1.80
14	1.28[c]	1.31[c]	1.74[c]	1.46[c]	1.41	1.25	—	1.35[a,c]
15α	2.02[c]	1.99	2.11	2.30[c]	1.98[c]	2.00[c]	1.97[c,s]	—
15β	1.57[b]	1.63[c]	1.60[c]	1.93[b]	1.56[b]	1.67[b]	1.97[c,n,s]	4.43
16α	2.12[b]	2.15[b]	2.14[b]	2.10[b]	2.15[c]	2.08[b]	2.37[c,s]	2.13[a]
16β	2.49[b]	2.49[c]	2.48[c]	2.45[c]	2.50	2.52[c,n]	2.45[c,n,s]	3.02[a]
17α	—	—	—	—	—	—	—	—
17β	—	—	—	—	—	—	—	—
18	0.93	0.96	0.93	0.93	0.96	1.17	1.05	0.97
19	1.21	1.42	1.22	1.22	1.34	1.48	1.23	1.23
20	—	—	—	—	—	—	—	—
21	—	—	—	—	—	—	—	—
Other	—	—	—	—	—	—	—	—

Table 2 (*continued*)

	49 16α-OHA	**50** 19-OHA	**51** Δ¹-A	**52** Δ⁶-A	**53** Δ¹·⁶-A	**54** T-Lactone	**55** Me 17-Carbox	**56** 16-OxoT
Solvent	C	C	C	C	C	C	C	C
H								
1α	1.71[c]	1.73	7.07	1.75[c]	7.08	1.74	1.95	1.73[c]
1β	2.03	2.35[c]		2.03		2.07[d]	2.20	2.06[c]
2α	2.33	2.28	6.23	2.47	6.28[c]	2.30[d]	2.40	2.35[c]
2β	2.42[c]	2.68[a]		2.58		2.43	2.47	2.40[c]
4α	5.75	5.87	6.08	5.72	6.05	5.76	6.02	5.76
4β								
5α	—	—	—	—	—	—	—	—
5β	—	—	—	—	—	—	—	—
6α	2.39[c]	2.35[c]	2.30	6.21	6.32[c]	2.34[d]	—	2.32
6β	2.41[c]	2.47	2.47[c]			2.40	5.20	2.43[c]
7α	1.11	1.05	1.12[c]	6.21	6.11[c]	1.11[d]	1.33	1.16[c]
7β	1.92[c]	1.98[c]	2.08[c]			2.05[d]	2.39	1.83
8	1.72[c]	1.83[c]	1.83[c]	2.39	2.46	1.41	2.04	1.74[c]
9	0.99[c]	1.11	1.10[c]	1.27[c]	1.34[c]	1.17[d]	1.06	1.14[c]
10	—	—	—	—	—	—	—	—
11α	1.71[c]	1.77[c]	1.88[c]	1.72[c]	1.94[c,s]	1.82	4.39	1.72[c]
11β	1.45	1.50[c]	1.70	1.47[c]	1.67	1.34	—	1.50[c]
12α	1.38[c]	1.19[c]	1.28	1.33	1.33[c]	1.68	1.56	1.46
12β	1.85	1.95[c]	1.96[c]	1.91	1.94[c,s]	2.01[d]	2.13	2.05[c]
14	1.53	1.23[c]	1.28[c]	1.51[c]	1.52	1.44[d]	1.28	1.53[c]
15α	2.02[c,s]	1.94[c]	1.98[c]	2.17[c,s]	2.14[c,s]	2.01[d]	1.35	2.38[c]
15β	1.95[c,s]	1.54[b]	1.60	1.74[c]	1.74	1.57[d]	1.74	1.89[a]
16α	—	2.06[b]	2.11[c]	2.17[c,s]	2.14[c,s]	2.59	—	—
16β	4.39	2.43[b]	2.47[c]	2.54[c]	2.55	2.70	2.65	—
17α	—	—	—	—	—	—	1.89	3.78[a]
17β	—	—	—	—	—	—	—	—
18	1.00	0.90	0.93	0.98	1.01	1.36	0.98	0.78
19	1.20	3.88, 4.02[a]	1.25	1.16	1.25	1.18	1.43	1.23
20	—	—	—		—	—	—	—
21	—	—	—	—	—	—	—	—
Other	—	—	—	—	—	—	3.70 (CO_2CH_3) 1.04 (16α-CH_3)	—

(*c*) Pregnanes

	57 Prog	**58** 2α-OHP	**59** 2β-OHP	**60** 4-OHP	**61** 6α-OHP	**62** 6β-OHP	**63** 7α-OHP	**64** 7β-OHP	**65** 9-OHP
Solvent	C	C	C	C	C	C	C	C	C
H									
1α	1.72[c]	1.58[d]	2.49	1.69	1.77	1.72	1.80[c]	1.69[c]	2.42[c]
1β	2.04	2.37[d]	1.56[c]	2.02	2.05	2.05	2.07	2.05	1.72[n]
2α	2.35	—	4.20	2.51[c,s]	2.37	2.40	2.39	2.36	2.32
2β	2.43	4.27	—	2.53[c,s]	2.44	2.53	2.44	2.44	2.43
3α	—	—	—	—	—	—	—	—	—
3β	—	—	—	—	—	—	—	—	—
4α	5.73	5.80	5.82	6.09 (OH)	6.20	5.83[a]	5.82	5.78	5.88
4β									
5α	—	—	—	—	—	—	—	—	—
5β	—	—	—	—	—	—	—	—	—
6α	2.29	2.33[d]	2.26	3.01[a]	—	4.36	2.43[c]	2.55[a,n]	2.31[n]
6β	2.40[c]	2.39[d]	2.54[c]	1.98	4.34	—	2.65[a]	2.44[c]	2.47[n]
7α	1.06	1.08	1.06	1.01	1.11[a]	1.28[a]	—	3.47	1.46
7β	1.87	1.89	2.00	1.87	2.19[c]	2.02[c,s]	4.00	—	1.65[c,n]
8	1.57	1.59[d]	1.68[c]	1.51	1.63[c]	1.99[c,s]	1.60[c]	1.60[c]	1.94[n]
9	0.99	1.00	1.45[c,s]	0.99[c]	0.99	0.97	1.47	1.00	—
10	—	—	—	—	—	—	—	—	—
11α	1.65[c]	1.65[d]	1.82	1.65[c]	1.65[c]	1.63[c]	1.69[c]	1.68[c]	1.77[c,n,s]
11β	1.46[c,s]	1.45[d,s]	1.49[c,s]	1.44[c,s]	1.46[c,s]	1.53	1.47[c,s]	1.48[s]	1.79[c,n,s]
12α	1.46[c,s]	1.45[d,s]	*ca.* 1.50[c,s]	1.44[c,s]	1.45[c,s]	1.45	1.47[c,s]	1.44[c,s]	1.75[n]
12β	2.08	2.08	2.10	2.07	2.08	2.09	2.06[c]	2.09[c]	1.88[n]
14	1.18	1.18[d]	1.19[c,s]	1.16[c]	1.22	1.17	1.56	1.32	1.68[c,s]
15α	1.72[c,s]	1.70[d,s]	1.67[c,s]	1.75[c]	1.75[c,s]	1.72[c,s]	1.83[c]	2.01[c]	1.66[c,s]
15β	1.27	1.27[d]	1.25[c,s]	1.27	1.30	1.33	1.30	1.66	1.25[n]
16α	1.68[c,s]	1.70[d,s]	1.67[c,s]	1.69[c]	1.72[c,s]	1.72[c,s]	1.74[c]	1.74[c]	1.68[c,s]
16β	2.19	2.20	2.19	2.19	2.20[c]	2.19[c]	2.22	2.21[c]	2.19[n]
17α	2.54	2.54	2.54[c]	2.50	2.54	2.54	2.59	2.49	2.61
17β	—	—	—	—	—	—	—	—	—
18	0.67	0.68	0.67	0.66	0.65	0.70	0.68	0.71	0.68
19	1.20	1.30	1.18	1.18	1.20	1.40	1.20	1.23	1.33
20	—	—	—	—	—	—	—	—	—
21	2.13	2.13	2.13	2.12	2.12	2.14	2.14	2.14	2.13
Other	—	—	3.48 (OH)	—	—	—	—	—	—

Table 2 (*continued*)

	66 11α-OHP	**67** 11β-OHP	**68** 12α-OHP	**69** 14-OHP	**70** 15α-OHP	**71** 15β-OHP	**72** 16α-OHP	**73** 17α-OHP
Solvent	C(M)	C(M)	C	C	C	C	C	C
H								
1α	2.02 (2.03)	1.84 (1.88)	1.72[c]	1.78[c]	1.73	1.72	1.72	1.71[c]
1β	2.67 (2.70)	2.18 (2.17)	1.99	2.04[c,n]	2.05	2.05	2.03[c]	2.03
2α	2.34 (2.34)[c]	2.35 (2.31)	2.29	2.35	2.31	2.32	2.35[c]	2.30
2β	2.44 (2.47)	2.47 (2.50)	2.42	2.44	2.43	2.45[c]	2.41	2.40
3α	—	—	—	—	—	—	—	—
3β	—	—	—	—	—	—	—	—
4α	} 5.74 (5.71)	5.67 (5.67)	5.75	5.75	5.75	5.74	5.75	5.74
4β								
5α	—	—	—	—	—	—	—	—
5β	—	—	—	—	—	—	—	—
6α	2.27 (2.26)[c]	2.23 (2.25)	2.35[c,s]	2.30[n]	2.35[c,s]	2.32[c]	2.30[c]	2.36[d,s]
6β	2.37 (2.46)[c]	2.48 (2.50)	2.37[c,s]	2.46[n]	2.41[c,s]	2.48[c]	2.39[c]	2.40[d,s]
7α	1.10 (1.09)	1.06 (1.08)	1.11	1.45	1.26[c]	1.15	1.10	1.12
7β	1.85 (1.89)	2.00 (2.03)[s]	1.87	1.74[c]	2.18	2.15[c]	1.83	1.87[d]
8	1.52 (1.62)	1.98 (2.01)[s]	1.58	1.91[a,c,n]	1.77	1.97	1.54	1.60[d]
9	1.16 (1.17)[a]	1.00 (1.04)	1.37	1.46[c]	1.04	1.05[c]	1.06	0.99
10	—	—	—	—	—	—	—	—
11α	—	4.40 (4.36)	1.73[c,s]	1.61[c]	1.64[c]	1.66[c]	1.65[c]	1.67[d,s]
11β	4.04 (3.97)	—	1.73[c,s]	1.48[c,n]	1.45	1.47[c,s]	1.44	1.44[d]
12α	1.52 (1.54)[a]	1.65 (1.64)[c]	—	2.05[n]	1.56[c]	1.47[c,s]	1.58[c]	1.70[d,h,s]
12β	2.33 (2.29)[c]	2.21 (2.22)[c]	4.07	1.74[c]	2.02[c]	2.07[c]	2.03	1.44[d,h,s]
14	1.25 (*ca.* 1.3)[c,s]	1.11 (1.19)	1.64[c]	—	1.20[c]	1.07[c]	1.64[c,s]	1.73[d]
15α	1.72 (1.71)[c,s]	1.75 (1.75)	1.78[c,s]	1.70[c,s]	—	4.33	1.62[c,s]	1.85[d]
15β	1.25 (1.26)[c,s]	1.33 (1.33)	1.31	1.79[c,n,s]	4.12	—	1.77[a,c]	1.37[d]
16α	1.72 (1.71)[c,s]	1.69 (1.64)[c]	1.78[c,s]	1.80[c,n]	1.56[c]	2.24[c,s]	—	1.60[d]
16β	2.18 (2.15)[c]	2.17 (2.14)[c]	2.12	2.31[c,n]	2.79[c,s]	2.24[c,s]	4.86	2.69
17α	2.57 (2.67)	2.43 (2.57)	3.10	3.23	2.81[c,s]	2.49	2.54[a]	—
17β	—	—	—	—	—	—	—	—
18	0.71 (0.71)	0.90 (0.87)	0.72	0.80	0.70	0.94	0.68	0.77
19	1.33 (1.35)	1.44 (1.47)	1.18	1.22	1.20	1.22	1.19	1.19
20	—	—	—	—	—	—	—	—
21	2.14 (2.16)	2.11 (2.12)	2.16	2.13	2.15	2.15	2.18	2.28
Other	—	—	—	—	—	—	—	—

	74 19-OHP	**75** 21-OHP	**76** 17α-OAc 6-Me-P	**77** Δ^6-P	**78** $\Delta^{1,6}$-P	**79** 6β,9α-OHP	**80** 6β,11α-OHP	**81** 7β,15β-OHP
Solvent	C	C	C(B)	C	C	C	M	C
H								
1α	1.80	1.71	1.70 (1.27)	1.74	} 7.06[a]	2.44	1.91	1.68
1β	2.42[c]	2.04	1.03 (1.50)	2.02		1.71[c]	2.81	2.07[c]
2α	2.35[c]	2.27[c]	2.35 (2.27)	2.45	} 6.25[a]	2.35	2.27	2.35
2β	2.75[a]	2.40[c]	2.43 (2.17)	2.59		2.59	2.58[a]	2.42
3α	—	—	—	—	—	—	—	—
3β	—	—	—	—	—	—	—	—
4α	} 5.97	5.72	5.80 (5.91)	5.69	6.01	5.84[a]	5.86[a]	5.79
4β								
5α	—	—	—	—	—	—	—	—
5β	—	—	—	—	—	—	—	—
6α	2.40[c,s]	2.29[c]	—	} 6.12[a]	6.26[c,s]	4.23	4.25	2.55[s]
6β	2.42[c,s]	2.40[c]	2.42 (1.82)			—	—	2.55[s]
7α	1.11[c]	1.09	0.88 (0.40)	} 6.12[a]	6.23[c,s]	1.81[c]	1.31[c]	3.65
7β	1.92	1.87	1.85 (1.34)			1.63[c]	1.95[a]	—
8	1.65	1.61[c]	1.69 (1.14)	2.23[c]	2.29	2.28[a]	2.03	2.04
9	1.10	0.98	1.01 (0.53)	1.27	1.48[c]	—	1.11	1.06
10	—	—	—	—	—	—	—	—
11α	1.75	1.62[c,s]	1.67 (1.22)	1.67	1.88[c]	1.60[c]	—	1.71[c]
11β	1.49	1.43[c]	1.42 (0.98)	1.47[c,s]	1.68[c]	1.84[c,s]	4.01	1.50
12α	1.40	1.62[c,s]	1.95 (1.75)	1.49[c,s]	1.49[c]	1.80[c,s]	1.54[a]	1.40
12β	2.06	1.92[c]	1.56 (1.29)	2.10[c]	2.14[c]	2.30[c]	2.30[a]	2.07[c]
14	1.16	1.19[c]	1.65 (1.47)	1.38[c,s]	1.42[c,s]	1.80[c]	1.33[c,s]	1.19[c]
15α	1.67[c,s]	1.77[c]	1.65 (1.40)	1.90	1.90[c]	1.70[c,s]	1.73[c,s]	4.48
15β	1.27	1.33[c]	1.29 (1.01)	1.40[c,s]	1.41[c,s]	1.29	1.30[c,s]	—
16α	1.69[c,s]	1.69[c]	1.65 (1.88)	1.73[c]	1.74[c]	1.70[c,s]	1.73[c,s]	2.30[c,s]
16β	2.18	2.21	2.93 (3.17)	2.25[c]	2.24[c]	2.16[c]	2.16	2.30[c,s]
17α	2.53	2.48	—	2.58	2.57	2.69	2.69	2.45
17β	—	—	—	—	—	—	—	—
18	0.66	0.70	0.67 (0.53)	0.72	0.75	0.68	0.70	0.97
19	3.91, 4.06	1.19	1.18 (0.67)	1.15	1.21	1.48	1.50	1.26
20	—	—	—	—	—	—	—	—
21	2.10	4.17, 4.23	2.03 (1.92)	2.14	2.14	2.13	2.14	2.16
Other	—	—	2.09 (1.64) ($OCOCH_3$) 1.07 (0.76) (6α-CH_3)	—	—	—	—	—

Table 2 (*continued*)

	82 12β,15α-OHP	**83** 16α,21-OHP	**84** 6β,11β,21-OHP	**85** 5α,17α-20-one	**86** 16β-OH-20-one	**87** 2α,3α-OH-5α-20-one	**88** 3α,6β-OH-5α-20-one	**89** 3β,6α-OH-5α-20-one	**90** 3β,7β-OH-5α-20-one
Solvent	C	C	M	C	C	C	C	C	C
H									
1α	1.71[c]	1.71	1.84	0.89	0.89[c]	1.30	1.36[c,s]	0.99[c]	0.96
1β	2.08[c]	2.07	2.25[c]	1.70[c]	1.68[c]	1.64	1.42[c,s]	1.66[c,s]	1.72
2α	2.35[c]	2.30	2.33[c]	1.52[c]	1.46[c,s]	—	1.61[c]	1.71[c,s]	1.82[c]
2β	2.58[c]	2.42[c]	2.61[a]	1.46[c]	1.46[c,s]	3.67[a]	1.73[c]	1.36[c]	1.40[c]
3α	—	—	—	1.29[c]	1.23[c,s]	—	—	3.42	3.60
3β	—	—	—	1.70[c]	1.68[c]	3.88[a]	4.18	—	—
4α	} 5.74	5.74	5.74	1.27[c,s]	1.23[c,s]	1.50[c,s]	1.42[c]	2.10[c]	1.57[c]
4β				1.27[c,s]	1.23[c,s]	1.50[c,s]	1.98	1.09[a]	1.32[c]
5α	—	—	—	1.03[c]	1.03[c]	1.52[c,s]	1.67[c]	0.94[c]	1.18[c]
5β	—	—	—	—	—	—	—	—	—
6α	2.35[c]	2.35[c]	4.25	1.27[c,s]	1.23[c,s]	1.27[c]	3.76	—	1.61[c]
6β	2.41[c]	2.40[c]	—	1.27[c,s]	1.23[c,s]	1.19[c]	—	3.28	1.34[c]
7α	1.22[c]	1.11[c]	1.30[a]	0.97[c]	0.90[c]	0.97	1.22[c]	0.83[a]	3.37
7β	2.17[c]	1.84[c]	2.12[c]	1.74[c]	1.68[c]	1.71[c]	1.82	1.91[a]	—
8	1.68[a]	1.56[c]	2.29[c]	1.39[c]	1.46[c]	1.39[c]	1.75[c]	1.43	1.40[c]
9	1.08	1.03[c]	0.99[a]	0.62	0.72	0.84[c]	0.85	0.68	0.73
10	—	—	—	—	—	—	—	—	—
11α	1.84	1.62[c]	4.34	1.60	1.63[c]	1.67[c]	1.64[c]	1.58[c]	1.65[c]
11β	1.38	1.43[c]	—	1.36[c]	1.35[c,s]	1.33[c]	1.35[c]	1.28	1.36[c,s]
12α	3.55	1.46[c]	1.58[a]	1.07	1.35[c,s]	1.46	1.42[c]	1.39	1.40[c,s]
12β	—	1.89[c]	2.12[a]	1.81[c]	1.99	2.04	2.03	1.97	2.02
14	1.07[c]	1.11[c]	1.20	1.39[c]	1.01	1.22[c,s]	*ca.* 1.17[c]	1.20[c,s]	1.30[c,s]
15α	—	1.84[c,s]	1.81	1.77[c,s]	2.25[c]	1.67[c,s]	1.67[c,s]	1.64[c,s]	1.93
15β	4.25	1.84[c,s]	1.40	1.26[c]	1.32[c]	1.20[c,s]	1.25[c]	1.18[c,s]	1.30[c,s]
16α	1.95[c]	—	1.69	1.77[c,s]	4.55	1.64[c,s]	1.65[c,s]	1.61[c,s]	1.70[c]
16β	2.60[c]	4.91	2.20	1.95[c]	—	2.11[c]	2.16	2.05[c]	2.18[c]
17α	2.73	2.49[a]	2.53	—	2.30	2.63	2.54	2.58[c]	2.48
17β	—	—	—	2.89	—	—	—	—	—
18	0.80	0.74	0.91	0.94	0.93	0.60	0.65	0.78	0.64
19	1.20	1.18	1.62	0.82	0.80	0.83	1.01	0.78	0.83
20	—	—	—	—	—	—	—	—	—
21	2.14	4.27	4.15, 4.20	2.13	2.20	2.11	2.12	2.04	2.13
Other	—	3.25 (OH)	—	—	—	—	—	—	—

	91 3β,12β-OH-5α-20-one	**92** 3β-OAc-12β-OH Δ[16]-20-one	**93** 3α,6α-OH 5β-20-one	**94** 3β-Ac-Δ[5]-20-one	**95** 3β-Ac-Δ[5]-20*R*-ol	**96** 3β-OH-Δ[5,20]	**97** 3β-OH-Δ[5,16]	**98** 16,17-epoxy-P
Solvent	C	C	C	C	C	C	C	C
H								
1α	0.98	1.04	1.80	1.16	1.15	1.07	1.08	1.76
1β	1.73	1.79[c,s]	1.08[a,n]	1.88	1.86	1.84	1.84	2.06
2α	1.80[c]	1.82[c,s]	1.35[c]	1.58	1.60	1.53	1.55	2.43
2β	1.39[c]	1.50[c]	1.72[c]	1.86	1.83	1.83	1.82	2.43
3α	3.59	4.68	—	4.60	4.62	3.53	3.53	—
3β	—	—	3.64	—	—	—	—	—
4α	1.56[c]	1.63[c]	1.42[c]	2.33	2.33	2.27	2.30	} 5.77
4β	1.28[c]	1.36[c]	1.92[c,n]	2.33	2.33	2.27	2.30	
5α	1.10[c]	1.20[c]	—	—	—	—	—	—
5β	—	—	1.63[c,n]	—	—	—	—	—
6α	1.28[c,s]	1.28[c,s]	—	} 5.37	5.37	5.36	5.36	2.34
6β	1.28[c,s]	1.28[c,s]	4.07					2.46
7α	0.87	0.96[c]	1.19	1.63	1.58	1.62	1.55	1.11
7β	1.68	1.73[c]	1.68[c]	1.96	1.93	1.96	2.00	1.83
8	1.30[c]	1.51[c]	1.46[n,s]	1.47	1.49	1.44	1.49	1.70
9	0.73	0.83	*ca.* 1.45[c,s]	1.03	0.94	0.94	0.98	1.01
10	—	—	—	—	—	—	—	—
11α	1.80[c]	1.89	1.52[c,s]	1.61[r]	1.49	1.56[r]	1.62[r]	1.69
11β	1.26[c]	1.36[c]	1.22[c]	1.39[r]	1.49	1.37[r]	1.46[r]	1.53
12α	3.42	3.65	1.42[c]	1.45	1.23	1.65	1.22	1.46
12β	—	—	2.03	2.07	2.04	1.88	1.80	2.10
14	1.01[c]	1.40[c]	*ca.* 1.27[c,d,s]	1.16	0.97	1.01	1.00	1.22
15α	1.78[c]	2.38[c]	1.69[c,s]	1.72[r]	1.62[r]	1.65[r]	1.70	2.05
15β	1.37[c]	2.17[a]	1.22[c,d,s]	1.29[r]	1.13[r]	1.17[r]	1.70	1.41
16α	1.97	} 6.97	1.69[c,s]	1.68	1.13	1.52	} 5.05	—
16β	2.16		2.18	2.20	1.62	1.75		3.76
17α	2.42	—	2.55	2.52	1.35	1.95	—	—
17β	—	—	—	—	—	—	—	—
18	0.71	0.87	0.60	0.64	0.77	0.61	0.76	1.13
19	0.81	0.87	0.92	1.03	1.03	1.02	1.03	1.25
20	—	—	—	—	3.73	5.76	2.25	—
21	2.20	2.37	2.12	2.13	1.14	4.96	1.50	2.08
Other	—	2.02 ($OCOCH_3$)	—	—	—	—	—	—

Table 2 (*continued*)

	99 16,17-Epoxy-11-oxoP	**100** 16,17-Epoxy-11α-OHP	**101** 11β,17α-OHP	**102** 6-OxoP	**103** 17α-OH-11-oxoP	**104** 20*S*-OH-Δ⁴-3-one	**105** 20*R*-OH-Δ⁴-3-one	**106** 9α,20*R*-OH-Δ⁴-3-one
Solvent	C	C	C	C	C	C	C	C
H								
1α	2.50	2.11	1.99	1.91[c]	2.54	1.70	1.70	2.43[c,s]
1β	2.33	2.66	2.28	2.16[c]	2.36	2.02	2.03	1.70[c]
2α	2.83	2.38	2.46	2.45	2.83	2.34	2.34	2.40[c,s]
2β	1.66	2.47	2.55	2.52	1.71	2.42	2.42	2.45[c,s]
3α	—	—	—	—	—	—	—	—
3β	—	—	—	—	—	—	—	—
4α	} 5.75	5.79	5.78	6.16	5.80	5.73	5.72	5.86
4β								
5α	—	—	—	—	—	—	—	—
5β	—	—	—	—	—	—	—	—
6α	2.33	2.38	2.35	—	2.36	2.28[c]	2.27	2.30
6β	2.46	2.47	2.58	—	2.53	2.40[c]	2.40[c]	2.45[c]
7α	1.30	1.18	1.24	2.06[a]	1.38	1.05	1.04[c]	1.46[c]
7β	1.96	1.84	2.12	2.68[a]	2.05	1.85	1.84	1.61[c]
8	1.99	1.71	2.12	1.92[c]	2.00	1.55[c,n]	1.56[c]	1.94
9	1.86	1.19	1.13	1.41	2.00	0.94	0.95	—
10	—	—	—	—	—	—	—	—
11α	—	—	4.57	1.73[c]	—	1.54[c]	1.52[c]	1.76[c,s]
11β	—	4.13	—	1.50[c,s]	—	1.42[n]	1.45	1.79[c,s]
12α	2.49	1.52	1.62	1.50[c,s]	2.91	1.17[c]	1.24[c]	1.49[c]
12β	2.76	2.47	2.13	2.13	2.17	1.91[c,n]	2.13	1.99[c]
14	1.81	1.35	1.81	1.31[c,s]	2.47	1.05[c]	1.04[c]	1.51[c,s]
15α	2.20	2.04	1.97	1.72[c,s]	2.05	1.69[c]	1.67[c,s]	1.61[c,s]
15β	1.53	1.41	1.56	1.27[c,s]	1.53	1.18[c,n]	1.17[c,s]	1.17[c,s]
16α	—	—	1.70	1.72[c,s]	1.81	1.59[c]	1.17[c,s]	1.19[c,s]
16β	3.89	3.80	1.81	2.19	2.83	1.91[c]	1.67[c,s]	1.70[c]
17α	—	—	—	2.54	—	1.34[a]	1.34[a]	1.40[a]
17β	—	—	—	—	—	—	—	—
18	1.06	1.16	1.12	0.67	0.78	0.70	0.80	0.81
19	1.44	1.38	1.54	1.16	1.48	1.19	1.19	1.33
20	—	—	—	—	—	3.72	3.73	3.72
21	2.06	2.09	2.39	2.13	2.32	1.22	1.15	1.16
Other	—	1.9 (OH)	1.10 (OH)	—	3.48 (OH)	—	—	—

	107 Cortisone	**108** Cort-Ac	**109** Cortisol	**110** 9α-F-Cortisol	**111** 18-OH	**112** Pred-Ac 20-one	**114** 3β-Ac-Δ¹⁶-20-one	**115** 3β-Ac-Δ⁵,¹⁶-20-one
Solvent	M	C	M (D)	C	M	C/P	C	C
H								
1α	1.72[c]	2.56	1.88 (1.78)	1.40	1.84	} 7.42	1.06	1.21
1β	2.70[c]	2.37	2.22 (2.08)	1.72	2.18[c]		1.77	1.95
2α	2.23	2.83	2.31 (2.18)	2.22	2.33[c]	} 6.28	1.86	1.95
2β	2.51[c]	1.72	2.49 (2.38)	2.42	2.48[c]		1.60	1.66
3α	—	—	— —	—	—		4.72	4.68
3β	—	—	— —	—	—		—	—
4α	} 5.72	5.81	5.65 (5.56)	5.67	5.67	6.03	1.63	2.42
4β							1.44	2.42
5α	—	—	— —	—	—	—	1.24	—
5β	—	—	— —	—	—	—	—	—
6α	2.33	2.36	2.27[c] (2.18)	2.24	2.26[c]	2.36	1.35	} 5.47
6β	2.53[c]	2.54	2.56[a] (2.45)	2.56	2.55[c]	2.61	1.35	
7α	1.32	1.38	1.11 (0.99)	2.25	1.12	1.15	1.03	1.75
7β	2.03[c,s]	2.06	2.04[c,s] (1.87)	1.97	2.11[c]	2.12	1.73	2.10
8	2.01[c,s]	2.03	2.06[c,s] (1.86)	2.29	2.00	2.14	1.63	1.77
9	2.11[a]	2.03	0.99[a] (0.85)	—	0.99[a]	1.07	0.77	1.12
10	—	—	— —	—	—	—	—	—
11α	—	—	4.40 (4.25)	4.13	4.40	4.47	1.63	1.66
11β	—	—	— —	—	—	—	1.44	1.66
12α	2.96[a]	3.00	2.02[a,c] (1.83)	1.45	1.62[a]	1.77	1.35	1.42
12β	2.05[a]	2.36	1.61[a] (1.53)	2.15	2.15[c]	2.05	2.39	2.48
14	2.45[c]	2.49	1.76[c,s] (1.65)	2.11	1.29[c,s]	1.73	1.46	1.51
15α	1.92	2.03	1.79[c,s] (1.65)	1.62	1.73	1.81	2.33	2.38
15β	1.46	1.53	1.39[c,s] (1.28)	1.27	1.23[c,s]	1.47	2.04	2.14
16α	1.69[c]	1.78[c,s]	1.48[c,s] (1.40)	1.44	1.40[c]	1.49	} 6.74	6.80
16β	2.73[c]	2.83	2.72 (2.56)	2.58	2.08[c]	2.61		
17α	—	—	— —	—	—	—	—	—
17β	—	—	— —	—	—	—	—	—
18	0.61	0.74	0.88 (0.75)	0.75	4.32, 3.77	0.94	0.92	1.01
19	1.43	1.49	1.47 (1.36)	1.48	1.45	1.5	0.90	1.00
20	—	—	— —	—	—	—	—	—
21	4.22, 4.58	5.19, 4.78	4.62, 4.26 (4.50, 4.07)	4.10, 4.52	3.70, 3.65	4.98, 4.95	2.30	2.35
Other	—	3.70 (OH) 2.25 ($OCOCH_3$)	(4.29, 11β-OH); (5.19, 17α-OH)	—	—	3.46 (OH) 2.21 ($OCOCH_3$)	2.06 ($OCOCH_3$)	2.11 ($OCOCH_3$)

Table 2 (*continued*)

	115 16,17-epoxy-3β-OH-Δ^5-20-one	**116** 18-OH-nor lactone	**117** 18-OH lactone	**118** 16β-Br-17α-OH-11-oxoP	**119** Fluocinonide
Solvent	C	B	B	C	D
H					
1α	1.15	1.17	1.44	2.48	7.24
1β	1.91	1.75	1.64	2.36	
2α	1.91	2.45	2.43	2.79	6.27
2β	1.61	2.16	2.43	1.67	
3α	3.60	—	—	—	—
3β	—	—	—	—	—
4α	1.91	6.07	5.92	5.76	6.11
4β	2.36				
5α	—	—	—	—	—
5β	—	—	—	—	—
6α	5.42	2.07	1.84	2.33	—
6β		1.80	2.03	2.52	5.58
7α	2.31	0.68	0.61	1.33	1.46
7β	2.01	1.43	1.47	1.96	2.25
8	1.65	1.07	1.40	2.11	2.58
9	1.05	0.38	0.39	1.98	—
10	—	2.21	—	—	—
11α	1.66	3.45	3.60	—	4.20
11β	1.66	—	—	—	—
12α	1.50	0.79	0.77	2.61	2.04
12β	1.68	1.79	1.58	2.38	1.71
14	1.25	0.63	0.58	2.37	2.00
15α	2.04	1.32	1.35	2.82	1.59
15β	1.41	1.03	1.02	1.99	1.54
16α	—	1.79	1.77	4.14	—
16β	3.76	1.91	1.93	—	4.87
17α	—	2.19	2.21	—	—
17β	—	—	—	—	—
18	1.14	4.83, 3.76	4.86, 3.76	1.31	0.81
19	1.11	—	1.13	1.47	1.47
20	—	—	—	—	—
21	2.12	—	—	2.35	5.11, 4.73
		—	—		
Other	—	—	—	3.12 (OH)	2.09 ($OCOCH_3$) 1.12, 1.33 [$C(CH_3)_2$]

(*d*) Aldosterone and derivatives (H, 18,20-hemiacetal; oxo, 20-oxo form)

	120 Aldo		**121** Diac	**122** Lactone	**123** 5α-DH (H)	**124** 3α,5α-TH (H)	**125** 6α-OH	
	(H)	(oxo)					(H)	(oxo)
Solvent	M	M	C	C	M	M	M	M
H								
1α	1.74	1.72	1.68	1.73	1.38[c]	1.35[c]	1.60[c]	1.60[c]
1β	2.22	2.20	2.13	2.22	2.17[c]	1.59[c,s]	2.18	2.18
2α	2.36	2.36	2.36[c]	2.30[c]	2.24	1.62[c,s]	2.30[c]	2.30[c]
2β	2.55	2.55	2.49	2.53	2.56[c]	1.72[c]	2.54	2.54
3α	—	—	—	—	—	—	—	—
3β	—	—	—	—	—	3.96	—	—
4α	5.71	5.71	5.74	5.69	1.98[c]	1.34[c]	6.16	6.16
4β					1.31[c]	1.49[c]		
5α	—	—	—	—	1.52[c]	1.60[c]	—	—
5β	—	—	—	—	—	—	—	—
6α	2.36	2.36	2.28[c]	2.30[c]	1.38[c,s]	1.26[c,s]	—	—
6β	2.55	2.55	2.43[c]	2.44[c]	1.38[c,s]	1.26[c,s]	4.34	4.34
7α	1.26	1.18	1.15	1.28[c]	1.18[c]	1.19[c]	1.23[c]	1.23[c]
7β	2.06	1.98	1.98[c]	2.03	1.90[c]	1.87[c]	2.27[c]	2.27[c]
8	1.82	1.75	1.82[c]	1.70[c]	1.66[c]	1.52[c]	1.90[c]	1.77[c]
9	1.15	1.07	1.04[a]	1.17[a]	0.97	0.90[c]	1.14	1.06
10	—	—	—	—	—	—	—	—
11α	4.81	4.56	4.65[a]	4.88[a]	4.81	4.80	4.79	4.54
11β	—	—	—	—	—	—	—	—
12α	1.49	1.60	1.63[a]	1.61[a]	1.46	1.45[c]	1.48	1.58
12β	2.36	2.67	2.67[a]	2.27[a]	2.32[c]	2.24[a]	2.36	2.67
14	1.54	1.56	1.58[c]	1.76[c]	1.54[c]	1.48[c]	1.63	1.53[c,s]
15α	1.91	1.96	1.99[c]	2.18[c]	1.88[c]	1.80[c]	1.90	1.90
15β	1.45	1.49	1.50[c]	1.54[c]	1.38[c]	1.25[c]	1.48[c]	1.48[c,s]
16α	1.61	1.87	1.85[c]	2.05[c]	1.65[c]	1.54[c]	1.76[c]	1.90[c]
16β	2.16	2.32	2.25[c]	2.26[c]	2.15[c]	2.13[c]	2.33[c]	2.29[c]
17α	2.59	2.93	2.97[c]	2.91	2.57	2.61[c]	2.58[c]	2.92
17β	—	—	—	—	—	—	—	—
18	5.40	5.00	5.97	5.50	5.35	5.30	5.43	5.00
19	1.33	1.29	1.26	1.31	1.17	1.02	1.31	1.27
20	—	—	—	—	—	—	—	—
21	3.47, 3.40	4.42, 4.24	4.77	—	3.44, 3.39	3.66, 3.35	3.46, 3.40	4.41, 4.22
Other	—	—	2.17 (21-$OCOCH_3$) 1.97 (18-$OCOCH_3$)	—	—	—	—	—

Table 2 (*continued*)

	126 6α-OH diac	**127** 6α-OH-5α-DH (H)	**127** 6α-OH-5α-DH (oxo)	**128** 6β-OH (H)	**128** 6β-OH (oxo)	**129** 6β-OH diac	**130** 6β-OH lactone	**131** 6β-OH-5α-OH (H)	**131** 6β-OH-5α-OH (oxo)
Solvent	C	M	M	M	M	C	M	M	M
H									
1α	1.74	1.38[c]	1.38[c]	1.73	1.73	1.69	1.76	1.30[c]	1.30[c]
1β	2.13	2.11[c]	2.11[c]	2.16[c]	2.16[c]	2.10[c]	2.21	2.03[c]	2.03[c]
2α	2.37	2.24[c]	2.24[c]	2.34[c]	2.34[c]	2.38	2.35	2.24[c]	2.24[c]
2β	2.50	2.54[c]	2.54[c]	2.63[c]	2.63[c]	2.57	2.64	2.54[c]	2.54[c]
3α	—	—	—	—	—	—	—	—	—
3β	—	—	—	—	—	—	—	—	—
4α	} 6.28	2.59[c]	2.59[c]	} 5.78	5.78	5.82	5.79	1.98[c]	1.98[c]
4β		2.22[c]	2.22[c]					2.80	2.80
5α	—	1.33[c]	1.33[c]	—	—	—	—	1.52[c]	1.52[c]
5β	—	—	—	—	—	—	—	—	—
6α	—	—	—	4.27	4.27	4.36	4.27	3.70	3.70
6β	4.38	3.41	3.41	—	—	—	—	—	—
7α	1.24[a]	1.10[c]	1.01[c]	1.45[c]	1.38[c]	1.37[a]	1.53[a]	1.38[c]	1.30[c]
7β	2.29[a]	2.16[c]	2.07[c]	2.11[c]	2.05[c]	2.13[c]	2.09[a]	1.96[c,s]	1.87[c,s]
8	1.87[c]	1.72[c]	1.65[c]	2.22[c]	2.14[c]	2.31[c]	2.19[c]	2.02[c,s]	1.95[c,s]
9	1.05	0.97	0.88	1.14	1.06	1.03[a]	1.25	0.98	0.89
10	—	—	—	—	—	—	—	—	—
11α	4.63	4.79	4.54	4.79	4.54	4.63	4.90	4.79	4.55
11β	—	—	—	—	—	—	—	—	—
12α	1.64[a]	1.47[c]	1.56[c]	1.48[c]	1.58	1.63[a]	1.72	1.47[c]	1.60[c]
12β	2.66[a]	2.32[c]	2.63[c]	2.36[c]	2.61[c]	2.67[a]	2.16	2.32[c]	2.65[c]
14	1.64[c]	1.52[c]	1.50[c]	1.61[c]	1.52[c]	1.58[c]	1.84	1.50[c]	1.54[c]
15α	1.98	1.89[c]	1.92[c]	1.95[c]	1.95[c,s]	1.98[c]	2.14[c]	1.85[c]	1.91[c]
15β	1.51	1.40[c]	1.42[c]	1.50[c]	1.50[c]	1.58[c]	1.64	1.40[c]	1.40[c]
16α	1.87[c]	1.58[c]	1.86[c]	1.73	1.91[c,s]	1.86	2.02	1.57[c]	1.84[c]
16β	2.27[c]	2.14[c]	2.25[c]	2.35[c]	2.29[c]	2.25[c]	2.29[c]	2.12[c]	2.24[c]
17	2.97[a]	2.55[c]	2.90[c]	2.60[c]	2.91	2.97	2.95	2.55[c]	2.89
18	5.95	5.34	5.43	5.45	5.04	6.03	5.66	5.39	4.98
19	1.26	1.14	1.10	1.47	1.43	1.47	1.48	1.29	1.25
20	—	—	—	—	—	—	—	—	—
21	4.76[a]	3.43, 3.38	4.39, 4.20	3.45, 3.39	4.41, 4.22	4.76	—	3.44, 3.38	4.40, 4.21
Other	2.15 ($21\text{-}OCOCH_3$) 1.95 ($18\text{-}OCOCH_3$)	—	—	—	—	2.16 ($21\text{-}OCOCH_3$) 1.94 ($18\text{-}OCOCH_3$)	—	—	—

	132 17-Iso	**133** 5α-DH-iso	**134** 2α-OH-3α,5α-TH-iso	**135** 6α-OH-iso	**136** 6β-OH-iso	**137** Apo
Solvent	M(P)	M	M	M	M	M
H						
1α	1.69 (1.48)	1.33[c]	1.27[c]	1.73	1.71	1.72
1β	2.17[c] (1.95)	2.11	1.71[c]	2.16	2.16[c]	2.20[n]
2α	2.43[c] (2.35)	2.24	—	2.30	2.33	2.31[c]
2β	2.55[c] (2.45)	2.53[a]	3.74	2.62	2.62	2.55[c,n]
3α	—	—	—	—	—	—
3β	—	—	3.88[a]	—	—	—
4α	} 5.70 (5.82)	2.00[a]	1.47[c,s]	} 6.12	5.78	5.71
4β		2.32[a]	1.47[c,s]			
5α	—	1.50[c]	1.49[c,s]	—	—	—
5β	—	—	—	—	—	—
6α	2.44 (2.08)[c]	1.38[c,s]	1.27[c,s]	—	4.27	2.30[c]
6β	2.52 (2.25)[c]	1.38[c,s]	1.27[c,s]	4.31	—	2.52[c,n]
7α	1.18 (0.98)	1.10[c]	1.08[c]	1.19[a]	1.41[c]	1.19
7β	2.02[c] (1.76[c,s])	1.89[c]	1.85[c]	2.24[c]	2.13[c,s]	2.00[c]
8	1.76 (1.71[c,s])	1.60[c]	1.50[c]	1.82	2.13[c,s]	1.79[n]
9	0.98 (0.74)	0.78[a]	0.78	0.97	0.97	1.12[a]
10	—	—	—	—	—	—
11α	4.52 (4.51)	4.53[a]	4.52	4.51	4.52	4.62[a]
11β	—	—	—	—	—	—
12α	1.28 (1.32)	1.27[a]	1.24[c]	1.30	1.30	1.38[a]
12β	2.20 (2.55)	2.18[a]	2.17	2.20	2.21	2.46[a]
14	1.59 (1.69[c,s])	1.58[c]	1.27[c]	1.63	1.61	1.53[c,s]
15α	2.01 (1.96[c])	1.99[c]	1.92[c]	2.21[c]	2.00	1.96
15β	1.37 (1.37[c])	1.30[c]	1.36[c]	1.40	1.41[c]	1.45[c,n,s]
16α	1.87[s] (1.87)[c]	1.88[c,s]	1.85[c,s]	1.89[c,s]	1.90[c,s]	1.88[c]
16β	1.87[s] (2.09)[c]	1.89[c,s]	1.85[c,s]	1.89[c,s]	1.90[c,s]	2.53[c,n]
17	3.30[c] (3.83)	3.28[a]	3.25	3.30[c]	3.30[c]	2.54[c]
18	4.90 (5.31)	4.85	?	4.90	4.90	4.98
19	1.29 (1.23)	1.11	0.90	1.28	1.45	1.30
20	—	—	—	—	—	3.59[a]
21	4.32 (4.78) 4.19 (4.57)	4.32, 4.18	4.33, 4.18	4.31, 4.18	4.33, 4.20	4.72[a]
Other	—	—	—	—	—	—

Table 2 (*continued*)

	138 5α-DH-apo	**139** 2α-OH-3α,5α-TH-apo	**140** 19-Nor-lactone
Solvent	M	M	B
H			
1α	1.36[c]	1.27[c]	1.02
1β	2.13	1.71[c]	1.84
2α	2.25	—	2.38
2β	2.54[c]	3.74[a]	2.07
3α	—	—	—
3β	—	3.88[a]	—
4α	2.00[a]	1.47[c,s]	6.01
4β	2.33[a]	1.47[c,s]	
5α	1.50[c]	1.49	—
5β	—	—	—
6α	1.37[c,s]	1.27[c,s]	2.04
6β	1.37[c,s]	1.27[c,s]	1.80
7α	1.09[c]	1.08[c]	0.73
7β	1.85[c]	1.85[c]	1.34
8	1.62	1.52[c]	0.80
9	0.93[a]	0.91[c]	0.34
10	—	—	1.99
11α	4.61[a]	4.60	4.31
11β	—	—	—
12α	1.34[c]	1.32[c]	0.81
12β	2.43[a]	2.41	1.81
14	1.50[c,s]	1.52[c]	1.80
15α	1.93[c]	?	1.44
15β	1.40[c,s]	?	0.83
16α	1.87[c]	?	1.80
16β	2.53[c,s]	?	0.89
17	2.53[c,s]	2.52	2.53
18	—	?	5.19
19	1.12	0.90	—
20	3.56[a]	3.56	—
21	4.70[a]	4.69	—
Other	—	—	—

(*e*) Bile Acids

	141 5β-Cholanic	**142** Litho	**143** Cheno	**144** Urso	**145** Deoxy	**146** Na deoxy
Solvent	C	C/D	M	M	M	W
H						
1α	1.74	1.75	1.83	1.81	1.77	1.78
1β	0.88	0.94	0.99	1.03	0.98	0.98
2α	1.34	1.29	1.36	1.28	1.44	1.37
2β	1.34	1.60	1.59	1.62	1.59	1.63
3α	1.74	—	—	—	—	—
3β	1.18	3.51	3.37	3.47	3.54	3.61
4α	1.72	1.71	2.25	1.81	1.79	1.80
4β	1.23	1.45	1.66	1.55	1.48	1.51
5α	—	—	—	—	—	—
5β	1.27	1.35	1.36	1.47	1.39	1.42
6α	1.20	1.23	1.52	1.60	1.26	1.19
6β	1.86	1.83	1.98	1.60	1.89	1.43
7α	1.08	1.09	—	3.49	1.19	1.30
7β	1.37	1.39	3.80	—	1.42	1.82
8	1.39	1.38	1.50	1.45	1.46	1.42
9	1.39	1.41	1.87	1.48	1.89	1.82
10	—	—	—	—	—	—
11α	1.39	1.38	1.48	1.47	1.53	1.55
11β	1.24	1.23	1.35	1.34	1.53	1.49
12α	1.12	1.14	1.21	1.19	—	—
12β	1.92	1.96	2.00	2.03	3.98	4.02
14	1.07	1.05	1.48	1.09	1.62	1.57
15α	1.02[q]	1.04[q]	1.09[q]	1.46[q]	1.09[q]	1.03[q]
15β	1.59[q]	1.56[q]	1.74[q]	1.90[q]	1.62[q]	1.63[q]
16α	1.88[q]	1.85[q]	1.90[q]	1.86[q]	1.87[q]	1.91[q]
16β	1.29[q]	1.27[q]	1.32[q]	1.30[q]	1.29[q]	1.24[q]
17	1.10	1.10	1.18	1.25	1.83	1.72
18	0.65	0.64	0.69	0.71	0.71	0.70
19	0.91	0.91	0.93	0.94	0.93	0.90
20	1.43	1.41	1.45	1.44	1.42	1.37
21	0.95	0.92	0.96	0.96	1.01	0.96
22	1.79, 1.34	1.75, 1.29	1.79, 1.31	1.80, 1.32	1.78, 1.35	1.37, 1.67
23	2.38, 2.24	2.32, 2.12	2.31, 2.24	2.35, 2.21	2.38, 2.23	2.05, 2.22
24	—	—	—	—	—	—
25	—	—	—	—	—	—
26, 27	—	—	—	—	—	—
Other	—	—	—	—	—	—

Table 2 (*continued*)

	147 3-Epi-deoxy	**148** Cholic	**149** Na Cholate	**150** 3-Oxo-7α,12α-OH	**151** $\Delta^{4,6}$-3-one
Solvent	C/D	M	W	C	C
H					
1α	*ca.* 1.31[d,h,s]	1.81	1.85	1.97	1.71
1β	*ca.* 1.31[d,h,s]	0.99	1.04	1.40	2.00
2α	1.47[c]	1.45	1.45	2.43	2.45
2β	1.32[c]	1.59	1.68	2.13	2.58
3α	3.93	—	—	—	—
3β	—	3.37	3.49	—	—
4α	1.86	2.29	2.14	3.40	} 5.68
4β	1.17[c]	1.66	1.72	2.20	
5α	—	—	—	—	—
5β	1.61[c]	1.38	1.44	1.81	—
6α	1.02	1.53	1.63	1.57	} 6.15
6β	1.73[c]	1.95	1.94	1.92	
7α	0.93	—	—	—	} 6.10
7β	1.26[c]	3.80	3.90	3.93	
8	1.30[h,n]	1.55	1.53	1.72	2.19
9	1.64[c,h]	2.25	2.21	2.35	1.22
10	—	—	—	—	—
11α	*ca.* 1.37[d,h,s]	1.58	1.66	1.68	1.54
11β	*ca.* 1.37[d,h,s]	1.58	1.54	1.62	1.43
12α	—	—	—	—	1.23
12β	3.83	3.97	4.06	4.04	2.05
14	1.43[c,s]	2.00	1.90	1.94	1.21
15α	1.43[c,s]	1.12[q]	1.10[q]	1.27	1.28
15β	0.91[c,n]	1.76[q]	1.79[q]	1.67	1.80
16α	1.71[c]	1.90[q]	2.01[q]	1.90[q]	1.94[q]
16β	1.12[c,n]	1.32[q]	1.31[q]	1.33[q]	1.39[q]
17	1.63[d,h]	1.86	1.77	1.77	1.16
18	0.55	0.72	0.73	0.72	0.76
19	0.80	0.92	0.93	1.00	1.11
20	1.27[c]	1.43	1.43	1.42	1.48
21	0.86	1.02	1.01	0.99	0.95
22	1.21[c], 1.65[c]	1.79, 1.35	1.39, 1.74	1.36, 1.82	1.83, 1.35
23	2.04, 2.19	2.37, 2.21	2.11, 2.28	2.25, 2.38	2.42, 2.28
24	—	—	—	—	—
25	—	—	—	—	—
26, 27	—	—	—	—	—
Other	—	—	—	3.28 (CO_2CH_3)	—

(*f*) Sterols and miscellaneous

	152 3β,6β-OHC	**153** 6α-OH-3-one	**154** 6β-OH-3-one	**155** 5α-OH-6-NOH	**156** 3β-AcO-5α-OH-6-NOH	**157** 3β-AcO-5α-OMe-6-NOH	**158** 3β-AcO-5β-OH-6-NOAc
Solvent	C	C	C	C	C	C	C
H							
1α	0.96[c]	1.38[c]	1.30[c]	1.43	1.67	1.66	1.90
1β	1.65[c]	2.00[c]	1.95[a]	1.37	1.50	1.45	1.43
2α	1.82[c]	2.32	2.31	1.40	1.78	1.80	1.67
2β	1.43[c]	2.40	2.43[a]	1.40	1.60	1.53	1.67
3α	3.65	—	—	1.40	5.02	4.85	5.05
3β	—	—	—	1.40	—	—	—
4α	1.62[c]	2.73	2.10[a]	1.89	2.20	1.58	1.90
4β	1.71[c]	2.22	2.80[a]	1.50	1.74	1.43	2.16
5α	1.15[c]	1.41[c]	1.56[c]	—	—	—	—
5β	—	—	—	—	—	—	—
6α	3.80	—	3.77	—	—	—	—
6β	—	3.47	—	—	—	—	—
7α	1.11[c]	0.89	1.23[c]	1.82	1.74	1.43	1.52
7α	1.80[c]	2.02[c]	1.83[c,s]	3.10	3.02	3.10	3.13
8	1.71[c]	1.47[c]	1.78[c,s]	1.47	1.43	1.46	1.52
9	0.67	0.76	0.77	1.66	1.72	1.72	1.40
10	—	—	—	—	—	—	—
11α	1.58[c]	1.54[c]	1.54[c]	} 1.15, 1.28	1.35, ?	1.25, 1.36	1.42, 2.02
11β	1.36[c]	1.36[c]	1.46[c]				
12α	1.10[c]	1.16[c]	1.15[c]	1.17	1.19	1.19	1.16
12β	1.98	2.01[c]	2.02	1.98	1.96	1.96	2.01
14	1.10[c,s]	1.07[c,s]	1.04[c,s]	1.18	1.22	1.22	1.13
15α	1.56	1.58[c]	1.58[c]	1.62	1.65	1.62	1.62
15β	1.07[c,s]	1.10[c,s]	1.10[c,s]	1.10	1.10	1.10	1.12
16α	1.24[c,q]	1.18[c,q]	1.27[c,q]	} 1.22, 1.88	1.25, 1.83	1.25, 1.84	1.28, 1.85
16β	1.81[q]	1.83[q]	1.83[c,q]				
17	*ca.* 1.13[c]	*ca.* 1.13[c]	*ca.* 1.1[c]	1.07	1.13	1.12	1.12
18	0.69	0.68	0.72	0.62	0.62	0.62	0.63
19	1.03	1.02	1.21	0.81	0.80	0.83	0.83
20	1.36[c]	1.37[c]	1.37[c]	1.31	1.32	1.32	1.37
21	0.90	0.91	0.91	0.88	0.88	0.87	0.88
22	1.32, 0.98[c]	1.33, 0.98[c]	1.33, 0.98[c]	0.97, 1.33	0.97, 1.32	0.97, 1.32	0.98, 1.33
23	1.56, 1.10[c]	1.55, 1.10[c]	1.56, 1.10[c]	1.11, 1.60	1.11, ?	1.10, 1.32	1.12, 1.58
24	*ca.* 1.1[c]	*ca.* 1.1[c]	*ca.* 1.1[c]	*ca.* 1.1	*ca.* 1.1	*ca.* 1.1	*ca.* 1.07
25	1.50[c]	1.51[c]	1.50[c]	1.45	1.47	1.49	1.47
26, 27	0.87, 0.86	0.87, 0.87	0.87, 0.87	0.84, 0.84	0.84, 0.83	0.84, 0.83	0.84, 0.84
Other	—	—	—	9.2 (NOH)	9.4 (NOH) 2.89 (OH) 2.03 ($COCH_3$)	9.5 (NOH) 3.07 (OCH_3) 2.0 ($OCOCH_3$)	3.63 (OH) 2.03 ($OCOCH_3$)

Table 2 (*continued*)

	159 4,4-Me_2-2-en-7-one	**160** 3β-OH-4,4-Me_2-7-one	**161** 3β-OAc-4,4-Me_2-7-one	**162** Δ^7-Chol Ac	**163** Ergo Ac	**164** 26-Ph-$\Delta^{20(22),23,25}$	**165** 24-Ph-$\Delta^{20(22),23}$	**166** Hec Ac
Solvent	C?	C?	C?	C(B)	C(B)	C	C	C
H								
1α	1.70	1.07	1.13	1.30 (1.18)	1.35 (1.15)	1.09	1.10	1.03
1β	1.98	1.75	1.75	1.79 (1.66)	1.87 (1.62)	1.86	1.85	1.59[c]
2α	5.49	1.72	1.75	1.89 (1.83)	1.90 (1.92)	1.85	1.85	1.83[c]
2β		1.65	1.66	1.53 (1.50)	1.58 (1.55)	1.52	1.52	1.50[c]
3α	5.41	3.24	4.47	4.62 (4.86)	4.68 (4.84)	3.53	3.53	4.68
3β		—	—	— —	— —	—	—	—
4α	—	—	—	2.43 (2.60)	2.50 (2.62)	2.30	2.31	1.67[c]
4β	—	—	—	2.28 (2.40)	2.35 (2.40)	2.24	2.24	1.37[c]
5α	1.62	1.24	1.31	— —	— —	—	—	1.19[c]
5β				— —	— —	—	—	—
6α	2.27	2.31	2.29	5.48 (5.57)	5.54 (5.59)	5.36	5.36	1.33[c,s]
6β	2.42	2.40	2.39					1.33[c,s]
7α	—	—	—	5.31 (5.45)	5.35 (5.46)	1.57	1.56	0.95
7β	—	—	—			2.00	2.00	1.78[c]
8	2.35	2.27	2.27	— —	— —	1.47	1.48	1.91
9	1.08	0.98	1.01	1.93 (1.87)	2.02 (1.93)	0.98	0.98	1.13[c]
11α	1.57	1.50	1.50	1.60 (1.61)	1.68 (1.60)	1.57	1.57	2.23
11β	1.53	1.50	1.50	1.49 (1.39)	1.58 (1.40)	1.45	1.46	2.40
12α	1.09	1.04	1.05	1.13 (1.11)	1.23 (1.15)	1.23	1.24	—
12β	2.00	1.98	1.98	2.00 (2.01)	2.08 (1.98)	1.84	1.84	—
14	1.40	1.35	1.36	1.83 (1.83)	1.88 (1.85)	1.12	1.13	1.44[c,s]
15α	2.15	2.18	2.19	1.63 (1.70)	1.60 (1.63)	1.71	1.70	2.11
15β	0.94	0.92	0.93	1.33 (1.47)	1.37 (1.42)	1.24	1.24	1.45[c,s]
16α	1.90[q]	1.89[q]	1.89[q]	1.29 (1.50)[q]	1.24 (1.37)[q]	1.69[q]	1.70[q]	4.32
16β	1.25[q]	1.24[q]	1.24[q]	1.91 (1.86)[q]	1.74 (1.79)[q]	1.89[q]	1.90[q]	—
17	1.11	1.07	1.10	1.09 (1.13)	1.31 (1.21)	2.14	2.15	2.50
18	0.65	0.63	0.63	0.54 (0.64)	0.62 (0.68)	0.59	0.60	1.00
19	1.12	1.12	1.14	0.86 (0.90)	0.95 (0.92)	1.01	1.01	0.88
20	1.34	1.35	1.35	1.31 (1.42)	2.03 (2.05)	—	—	1.74
21	0.91	0.90	0.90	0.87 (1.00)	1.02 (1.11)	1.85	1.90	1.06
22, 22	?	?	?	1.04 (1.33)	5.18 (5.22)	6.01	6.07	—
				0.95 (1.06)				
23,23	?	?	?	1.28 (1.45)	5.21 (5.26)	6.64	7.08	1.58, 1.68?[c]
				1.03 (1.22)				
24, 24	?	?	?	1.00 (1.20)	1.84 (1.90)	6.32	6.47	1.56, 1.42?[c]
25	1.52	1.50	1.50	1.45 (1.56)	1.48 (1.50)	6.88	—	1.62[c]
26, 27	0.86	0.86, 0.85	0.86, 0.85	0.79 (0.91)	0.81 (0.91)	6.51	—	3.35 (26-ax),
				0.80 (0.92)	0.81 (0.91)			3.49 (26-eq)
Other	0.94, 0.92 ($4,4\text{-}Me_2$)	0.96, 0.84 ($4,4\text{-}Me_2$)	0.92, 0.85 ($4,4\text{-}Me_2$)	—	—	—	—	0.80 (27)
				—	—			2.11 (OAc)

Solvents: C, $CDCl_3$; M, CD_3OD; B, C_6D_6; P, C_5D_5N; D, $(CD_3)_2SO$; W, D_2O. [a] Abnormal signal profile: signal clearly visible in the 1D spectrum, but not conforming to templates illustrated in Figures 1–4: see Table 3 for further details. [b] Signal with a distinctive 'type (*b*)' profile—see the Figures. [c] Located from COSY spectrum; likely error +0.02 ppm. [d] Located from COSYDEC spectrum: likely error +0.02 ppm. [h] Located by two-dimensional ^1H–^{13}C heteronuclear correlation spectroscopy. [n] Located or confirmed by nuclear Overhauser effect—see the text. [q] Reported assignments, or our own, for a geminal pair, which seem questionable in view of general trends (see the Discussion). [r] Reversal of reported assignments for a geminal pair, to bring δ values into line with general trends (see the Discussion). [s] Signal profile strongly perturbed by second-order effects resulting from proximity of strongly spin-coupled protons.

Table 3. ^{1}H NMR signals with abnormal or distinctive profiles.

No.	Compound	H	Multiplicity, J values[a]
	Androstanes		
26	2α-OHT	1α	t, $J_{1\alpha.2\beta} \approx J_{gem} \approx 13$ Hz (overlapping 11α-H signal)
27	2β-OHT	1α	dd, J_{gem} 13.5, $J_{1\alpha.2\alpha}$ 5.5 Hz
	(inverted chair conformation in ring A)	1β	t, $J_{gem} \approx J_{1\beta.2\alpha} \approx 13.5$ Hz
		6β	tdd, $J_{gem} \approx J_{6\beta.7\alpha} \approx 12$, $J_{6\beta.7\beta}$ 5, $J_{4.6\beta}$ 1 Hz
28	6α-OHT	7α	q, $J_{gem} \approx J_{6\beta.7\alpha} \approx J_{7\alpha.8} \approx 11.5$ Hz
		7β	ddd, J_{gem} 11.5; $J_{6\beta.7\beta}$ 5.5, $J_{7\beta.8}$ 3.5 Hz
		12β	ddd, J_{gem} 12.5; $J_{11\alpha.12\beta}$, $J_{11\beta.12\beta}$, 4 and 2.5 Hz
29	6β-OHT	4	s
		7α	td, poorly resolved, $w_{\frac{1}{2}}$ 30 Hz
30	7α-OHT	6α	dd, J_{gem} 14.5, $J_{6\alpha.7\beta}$ 3 Hz
		6β	ddd, J_{gem} 14.5, $J_{6\beta.7\beta}$ 3, $J_{4.6\beta}$ 1.5 Hz
31	11α-OHT	12α	t, $J_{gem} \approx J_{11\beta.12\alpha} \approx$ 11.5 Hz
		12β	dd, J_{gem} 11.5, $J_{11\beta.12\beta}$ 4.5 Hz
32	11β-OHT	9	dd, $J_{8.9}$ 11, $J_{9.11\alpha}$ 3 Hz
		12α	dd, J_{gem} 14, $J_{11\alpha.12\alpha}$ 3 Hz
		12β	dd, J_{gem} 14, $J_{11\alpha.12\beta}$ 3 Hz
33	14-OHT	8	td, $J_{7\alpha.8} \approx J_{8.9} \approx 11$, $J_{7\beta.8}$ 3.5 Hz
34	15α-OHT	14	dd, $J_{8.14}$ 10.5, $J_{14.15\beta}$ 9 Hz
		16α	dt, J_{gem} 14, $J_{15\beta.16\alpha} \approx J_{16\alpha.17} \approx$ 9 Hz
		16β	ddd, J_{gem} 14, $J_{16\beta.17}$ 9, $J_{15\beta.16\beta}$ 3 Hz
35	16α-OHT	17	d, $J_{16\beta.17}$ 5.7 Hz
36	16β-OHT	15β	td, $J_{gem} \approx J_{14.15\beta} \approx 13$, $J_{15\beta.16\alpha}$ 5 Hz
		16α	td, $J_{16.\alpha.17} \approx J_{15.\alpha.16\alpha} \approx 7.5$, $J_{15\beta.16\alpha}$ 5 Hz
		17	d, $J_{16\alpha.17}$ 7.5 Hz
38	Δ^6-T	6,7	s (2 H)
40	2α-OHA	1β	dd, J_{gem} 13.5, $J_{1\beta.2\beta}$ 6 Hz
		2β	dd, $J_{1\alpha.2\beta}$ 14, $J_{1\beta.2\beta}$ 6 Hz
41	4-OHA	6α	complex m, $w_{\frac{1}{2}}$ 23 Hz
42	6β-OHA	4	s
		12β	ddd, J_{gem} 12.5, $J_{11\alpha.12\beta}$, $J_{11\beta.12\beta}$ 4 and 2.5 Hz
43	7α-OHA	6β	ddd, J_{gem} 14.5, $J_{6\beta.7\beta}$ 3, $J_{4.6\beta}$ 2 Hz
44	7β-OHA	6α	dd, J_{gem} 14, $J_{6\alpha.7\alpha}$ 5 Hz
		8	q, $J_{7\alpha.8} \approx J_{8.9} \approx J_{8.14} \approx 10$ Hz
45	11α-OHA	9	t, $J_{8.9} \approx J_{9.11\beta} \approx 10$ Hz
		12α	t, $J_{11.\beta.12\alpha} \approx J_{gem} \approx 11.5$ Hz
46	11β-OHA	9	dd, $J_{8.9}$ 11, $J_{9.11\alpha}$ 3 Hz
		12α	dd, J_{gem} 14, $J_{11\alpha.12\alpha}$ 3 Hz (partly obscured by 19-H_3)
		12β	dd, J_{gem} 14, $J_{11\alpha.12\beta}$ 2.5 Hz
47	14-OHA	8	td, $J_{7\alpha.8} \approx J_{8.9} \approx 12$, $J_{7\beta.8}$ 3 Hz
48	15α-OHA	14	t, $J_{8.14} \approx J_{14.15\beta} \approx 10$ Hz
		16α	dd, J_{gem} 19, $J_{15\beta.16\alpha}$ 6.5 Hz
		16β	dd, J_{gem} 19, $J_{15\beta.16\beta}$ 8 Hz
50	19-OHA	2β	symmetrical ddd, J_{gem} 17, $J_{1\alpha.2\beta}$ 14, $J_{1\beta.2\beta}$ 5 Hz
		19,19	dd, J 11 Hz
52	Δ^6-A	6,7	s (2 H)
		8	dd or t, J 11 and 10 Hz
56	16-OxOT	15β	dd, J_{gem} 18.5, $J_{14.15\beta}$ 12 Hz
	Pregnanes		
59	2β-OHP	1α	dd, J_{gem} 14, $J_{1\alpha.2\alpha}$ 5.5 Hz
		2α	ddd, $J_{1\beta.2\alpha}$ 14, $J_{1\alpha.2\alpha}$ 5.5, $J_{2\alpha.OH}$ 1.5 Hz
61	6α-OHP	7α	q, $J_{6\beta.7\alpha} \approx J_{gem} \approx J_{7\alpha.8} \approx 11.5$ Hz
62	6β-OHP	4	s
		7α	ddd, J_{gem} 14.5, $J_{7\alpha.8}$ 12.5, $J_{6\alpha.7\alpha}$ 3 Hz
64	7β-OHP	6α	dd, J_{gem} 13.5, $J_{6\alpha.7\alpha}$ 5 Hz
66	11α-OHP	9α	t, $J_{8.9} \approx J_{9.11\beta} \approx 10$ Hz
		12α	t, $J_{gem} \approx J_{11\beta.12\alpha} \approx 11$ Hz
		12β	dd, J_{gem} 11, $J_{11\beta.12\beta}$ 5 Hz
69	14-OHP	8β	td, $J_{8.9} \approx J_{7\alpha.8} \approx 11.5$ Hz, $J_{7\beta.8}$ 3 Hz
72	16α-OHP	15β	m, J 14, 11, and 9 Hz
		17	d, $J_{16\beta.17}$ 6.5 Hz
74	19-OHP	2β	symmetrical ddd, J_{gem} 17.5, $J_{1\alpha.1\beta}$ 13.5, $J_{1\beta.2\beta}$ 5 Hz
		19,19	dd, J 10.5 Hz, (low-field d broadened by coupling to 1α-H; J 0.5–1 Hz)
77	Δ^6-P	6,7	s (2 H)
78	$\Delta^{1,6}$-P	1	d, $J_{1.2}$ 10 Hz
		2	dd, $J_{1.2}$ 10 Hz, $J_{2.4}$ 2 Hz

Table 3 (*continued*)

Pregnanes			
79	6β,9α-OHP	4	s
		8	td, $J_{7\alpha.8} \approx J_{8.14} \approx 12$, $J_{7\beta.8}$ 4 Hz
80	6β,11α-$(OH)_2$P	2β	as for 19-OHP
		4	s
		7β	dt, J_{gem} 13.5, $J_{6\alpha.7\beta} \approx J_{7\beta.8} \approx 3$ Hz
		12α	t, $J_{gem} \approx J_{11\beta.12\alpha} \approx 11.5$ Hz
		12β	dd, $J_{gem} \approx 11.5$, $J_{11\beta.12\beta}$ 4.5 Hz
83	16α,21-OHP	17	d, $J_{16\beta.17}$ 7 Hz
84	6β,11β,21-OHP	2β	symmetrical ddd, J_{gem} 17, $J_{1\alpha.2\beta}$ 15, $J_{1\beta.2\beta}$ 5 Hz
		7α	ddd, J_{gem} 14, $J_{7\alpha.8}$ 11.5, $J_{6\alpha.7\alpha}$ 4 Hz
		9	dd, $J_{8.9}$ 11, $J_{9.11\alpha}$ 3.5 Hz
		12α	dd, J_{gem} 13.5, $J_{11\alpha.12\alpha}$ 3.5 Hz
		12β	dd, J_{gem} 13.5, $J_{11\alpha.12\beta}$ 2.5 Hz
85	5α,17α-P-20-one	17	dd, J 8 and 3 Hz
86	16β-OH	17	d, J 2 Hz
87	2α,3α-OH-5α-20-one	1α	t, $J_{gem} \approx J_{1\alpha.2\beta} \approx 12$ Hz
		1β	dd, J_{gem} 12, $J_{1\beta.2\beta}$ 4.5 Hz
		2β	dt or dd, $J_{1\alpha.2\beta}$ 12, $J_{1\beta.2\beta} \approx J_{2\beta.3\beta} \approx 3.5$ Hz
		3β	narrow m, $w_{\frac{1}{2}}$ 8.5 Hz
89	3β,6α-OH-5α-20-one	4β	*ca.* q, $J_{3\alpha.4\beta} \approx J_{gem} \approx J_{4\beta.5} \approx 12$ Hz
		7α	*ca.* q, $J_{6\beta.7\alpha} \approx J_{gem} \approx J_{7\alpha.8} \approx 12$ Hz
		7β	dt, J_{gem} 12, $J_{6\beta.7\beta} \approx J_{7\beta.8} \approx 4$ Hz
92	3β-OAc-12β-OH-Δ^{16}-20-one	15β	ddd, J_{gem} 17, $J_{14.15\beta}$ 11, $J_{15\beta.16}$ 2 Hz
93	3α,6α-OH-5β-20-one	1β	td, $J_{gem} \approx J_{1\beta.2\alpha} \approx 14$, $J_{1\beta.2\beta}$ 3 Hz
		4α	dm, $w_{\frac{1}{2}}$ 23 Hz
102	6-Oxo-P	7α	dd, J_{gem} 16, $J_{7\alpha.8}$ 12 Hz
		7β	dd, J_{gem} 16, $J_{7\beta.8}$ 4 Hz
104	20*S*-OH-Δ^4-3-one	17	q, $J_{16\alpha.17} \approx J_{16\beta.17} \approx J_{17.20} \approx 9$ Hz
		20	*ca.* quintet, J 6.5 Hz
105	20*R*-OH-Δ^4-3-one	17	q, $J_{16\alpha.17} \approx J_{16\beta.17} \approx J_{17.20} \approx 9$ Hz *ca.* sextet, $w_{\frac{1}{2}}$ 27.5 Hz
106	9α,20*R*-OH-Δ^4-3-one	17	q, $J_{16\alpha.17} \approx J_{16\beta.17} \approx J_{17.20} \approx 9.5$ Hz
		20	dq, $J_{17.20}$ 9.5, $J_{20.21}$ 6 Hz
107	Cortisone	9	d, $J_{8.9}$ 11 Hz
		12α	d, J_{gem} 12.5 Hz
		12β	d, J_{gem} 12.5 Hz
109	Cortisol	6β	symmetrical tdd, $J_{gem} \approx J_{6\beta.7\alpha} \approx 14$, $J_{6\beta.7\beta}$ 5.5, $J_{4.6\beta}$ 1.5 Hz
		9	dd, $J_{8.9}$ 11, $J_{9.11\alpha}$ 3.5 Hz
		12α	dd, J_{gem} 13.5, $J_{11\alpha.12\alpha}$ 3 Hz
		12β	dd, J_{gem} 13.5, $J_{11\alpha.12\beta}$ 2.5 Hz
111	18-OH Cortisol	9	dd, $J_{8.9}$ 11, $J_{9.11\alpha}$ 3.5 Hz
		12α	dd, J_{gem} 13, $J_{11\alpha.12\alpha}$ 3 Hz
		18,18	dd, J 10 Hz
Aldosterone derivatives[b]			
121	Diac	17	dd, J 10 and 8 Hz
		21,21	s (2 H)
122	Lactone	9	d, $J_{8.9}$ 8.5 Hz
		12α	d, J_{gem} 8.5 Hz
		12β	dd, J_{gem} 8.5, $J_{11\alpha.12\beta}$ 6.5 Hz
124	3α,5α-TH (H)	17	d, J 10 Hz
126	6α-OH diac	7α	q, $J_{6\beta.7\alpha} \approx J_{gem} \approx J_{7\alpha.8} \approx 12$ Hz
		7β	ddd, J_{gem} 12, $J_{6\beta.7\beta}$, $J_{7\beta.8}$ 5.5 and 3 Hz
		17	dd, J 10 and 9 Hz
		21,21	s (2 H)
129	6β-OH diac	4	s
		7β	td, $J_{gem} \approx J_{7\alpha.8} \approx 13$, $J_{6\alpha.7\alpha}$ 3 Hz
130	6β-OH lactone	4	s
		7α	ddd, J_{gem} 14, $J_{7\alpha.8}$ 11.5, $J_{6\alpha.7\alpha}$ 3 Hz
		7β	dt, J_{gem} 14, $J_{6\alpha.7\beta} \approx J_{7\beta.8} \approx 2.5$ Hz
		16α	complex m, $w_{\frac{1}{2}}$ 30 Hz
		17	dd, J 12 and 4.5 Hz
132	17-Iso (in C_5D_5N)	17	dd, J 8.4 and 4 Hz
133	5α-DH-iso	2β	td, $J_{1\alpha.2\beta} \approx J_{gem} \approx 18$, $J_{1\beta.2\beta}$ 8 Hz
		4α	dm, J_{gem} 18, $J_{2\alpha.4\alpha} + J_{4\alpha.5} \approx 7$ Hz
		4β	t, $J_{gem} \approx J_{4\beta.5} \approx 18$ Hz
		17	dd, J 10.5 and 6 Hz
134	2α,3α-OH-5α-TH-iso	2β	ddd, $J_{1\alpha.2\beta}$ 12, $J_{1\beta.2\beta}$, $J_{2\beta.3\beta}$ 4.5 and 3 Hz
		3β	narrow m, $w_{\frac{1}{2}}$ 9 Hz
135	6α-OH 17-iso	7α	q, $J_{6\beta.7\alpha} \approx J_{gem} \approx J_{7\alpha.8} \approx 12$ Hz
136	6β-OH 17-iso	4	s

Table 3 (*continued*)

Aldosterone derivatives[b]			
137	Apo	20	dd, $J_{20.21}$ 8, $J_{17.20}$ 6.5 Hz
		21	d, $J_{20.21}$ 8 Hz
138	5α-DH-apo	4α	ddd, J_{gem} 16, $J_{4\alpha.5}$ 4, $J_{2\alpha.4\alpha}$ 2.5 Hz
		4β	t, $J_{gem} \approx J_{4\beta.5} \approx 16$ Hz
		20,21	as for apo
139	2α-OH-3α,5α-TH-apo	2β,3β	as for 2α,3α-OH-5α-TH-iso
		20,21	as for apo
Sterols *etc.*			
	6β-OH-5α-CH-3-one	1β	ddd, J_{gem} 13, $J_{1\beta.2\beta}$ 6, $J_{1\beta.2\alpha}$ 2 Hz
		2β	td, $J_{gem} \approx J_{1\alpha.2\beta} \approx 15$, $J_{1\beta.2\beta}$ 6 Hz
		4α	ddd, J_{gem} 15, $J_{4\alpha.5}$ 3.5, $J_{2\alpha.4\alpha}$ 2 Hz
		4β	t, $J_{gem} \approx J_{4\beta.5} \approx 15$ Hz

[a] J values estimated from measurements of signal splittings to nearest 0.5 Hz (J_{gem} is actually negative). [b] Unless otherwise indicated, all aldosterone derivatives with the 11β,18-epoxy bridge show the following features: 9-H, d, $J_{8.9}$ 10–12 Hz; 11α-H, d, $J_{11\alpha.12\beta}$ 6–7 Hz; 12α-H, d, J_{gem} 10–13 Hz; 12β-H, dd, 10–13, $J_{11\alpha.12\beta}$ 6–7 Hz.

in the Figures. Signals clearly discerned as abnormal, *i.e.* not conforming to the normal template patterns, are indicated by a superscript *a* in Table 2. Their observed profiles are listed in Table 3; they are, in the great majority of cases, a consequence of a reduced number of vicinal protons by virtue of substitution.

Inspection of the tabulated data showed that chemical shifts for protons at particular sites in the steroid molecule are liable to be changed very significantly by the introduction of hydroxy or other substituents at locations up to three C–C bonds away, especially where there is strong through-space (Van der Waals) interaction with a neighbouring polar group. Small substituent effects (mainly <0.1 ppm) may be observed over longer distances. These are regarded as significant only where they are reliably supported by data for several compounds. Table 4 presents the mean substituent increments found among the present compounds for hydroxy groups and a few other substitution types, including increments associated with an aldosterone-like structure bridged by oxygen between the 11β- and 18-positions. Other useful substituent increments may be derived from data for appropriate pairs of compounds by subtraction. Use of these increments permits estimates to be made of ^{1}H chemical shifts for many compounds not yet studied, in much the same way as for the angular methyl protons by use of Zürcher's data.[52–54,56] Additivity of increments is found generally to be good, except where conformational differences are likely, or where two or more polar substituents are so close as to interact strongly.

Inspection of substituent increments has revealed a number of regularities in relation to structure, and particularly in relation to the bonding and geometric relationship between the substituent and the protons affected. Some of these findings have been foreshadowed by earlier work, but a much more extensive analysis is now possible.

Discussion

^{1}H *Chemical Shifts in Steroids.*—Axial protons are well known to resonate at higher field than equatorial protons in cyclohexanes,[56] except in the vicinity of substituents. The same is generally true for protons on the steroid ring system, where the axial proton signals (in $CDCl_3$ as the solvent) are commonly found in the range δ 0.7–1.5, and equatorial protons resonate in the range δ 1.4–2.1. This generalisation can be used, with caution, for assigning the individual chemical shifts of a geminal pair located from a COSY cross-peak or a ^{1}H–^{13}C heteronuclear correlation spectrum. However, the relative shifts are usually reversed at positions α to carbonyl (*e.g.* at C-2 in 3-oxo steroids), or at the γ position in an α,β-unsaturated ketone (*e.g.* C-6 in 4-en-3-ones), although in the strongly associating solvent deuteriobenzene, the normal order of chemical shifts (eq. > ax.) may be preserved even α to carbonyl (see the data for compound **76**). The relative chemical shifts of geminal pairs may also be marginally reversed, or approximately equalised, in the vicinity of substituents, or when the axial proton of the geminal pair is under steric compression, as for example in a 1,3-relationship to one or both of the angular methyl groups: this commonly occurs for the 2β- and 6β-protons in 5α-steroids (*e.g.* for compounds **8**, **10**, **85**, and **90**), and occasionally for the 11β-proton (*e.g.* compounds **65**, **68**, and **115**).

While the axial/equatorial distinction is blurred in the five-membered and conformationally mobile[60] ring D, the quasi-axial 15β-H usually resonates at higher field than the quasi-equatorial 15α-H. Our observations (NOESY) for one bile acid (**147**) agree with this generalisation, although the reverse assignments have been suggested for some other bile acids. Similarly, for androstanes substituted only in ring A, the quasi-axial 17α-H resonates at higher field than the quasi-equatorial 17β-H.

No such distinction is seen at C-16, where both 16α-H and 16β-H are of intermediate conformational character, especially when ring D approximates to the twist conformation about an axis through C-16 and the mid-point of the 13,14-bond. The chemical shifts of the 16α/16β pair of protons are generally strongly controlled by the nature of any substituent at C-17, 16β-H being the more deshielded in androstan-17-ones and pregnan-20-ones, in contrast with 16α-H being the more deshielded in androstan-17β-ols. There has been uncertainty concerning the 16α/β assignments for bile acids (cholane derivatives) and sterols. Reported ^{1}H spectra of bile acids[20,27] and for one group of cholestane derivatives[34] list 16α-H as having a larger chemical shift than 16β-H, as for androstan-17β-ols, whereas the reverse assignments are proposed for the 16-geminal pair in some other sterols.[33,36] One report[32] leaves this pair of signals unallocated. It seems unlikely that the relative shifts at C-16 differ markedly between the cholane and cholestane series; further study is needed to establish which is correct.

The various assignments discussed above rest largely upon the results of selective NOE difference experiments, in which the C-18 and C-19 methyl groups of a number of steroids studied by us and by others have been irradiated to highlight particularly the neighbouring protons on the β-face of the molecule. The widths in the ω_1 and ω_2 dimensions of COSY cross peaks for geminal pairs, where these cross peaks are not so over-

lapped by others as to be indistinct, provide the best method for distinguishing between resonances of axial or equatorial protons, but give little help for the protons of ring D, where cross peaks for geminal-pair interactions are normally of similar width in each dimension.

We draw attention to these points, and the derived generalisation concerning the relative chemical shifts of axial *vs.* equatorial protons of geminal pairs, because in a few cases of spectra reported in the literature the assignments for such pairs appear to require reversal if they are to conform to the normal pattern. It has generally not been possible for us to confirm the reversals experimentally, but we consider that the regularities noted above provide reasonable justification for some interchanges of published geminal-pair assignments, especially at C-15 and in a few cases at C-11. We have accordingly reversed these chemical shifts in Table 2, and indicated this by a superscript (*r*).

In a few other cases, where we feel that there is reason to question the published assignments, but uncertainties remain because of the neighbouring pattern of substitution, chemical shifts are listed as reported, but are superscripted (*q*) to indicate that we consider further confirmation necessary. Some of the 16α/β pairs mentioned above come into this category. Finally, the signals from protons comprising geminal pairs in the flexible side chains of bile acids and sterols have not yet been individually determined either by us or by other workers; they present a significant challenge.

Effects Due to Hydroxy Substituents.—The ^{1}H chemical shift increments due to hydroxylation have been reported for 5α-androstan-3α- and 3β-ols, and for *cis*- and *trans*-4-t-butylcyclohexanol.[21] Our data for hydroxylated steroids are broadly consistent with those increments but show wider variations and a few quite dramatic exceptions, which have no obvious explanation. Our results also extend to structural relationships not previously covered.

α-*Effects.* The observed carbinol proton chemical-shift increments cover a wide range, from 2.84 ppm for 15α-H in 15β-ols to *ca.* 1.85 ppm for 2-H in 2-ols. There is no obvious rationale, although we note that all the smaller increments (<2.1) are those for α-protons where the hydroxy group is immediately adjacent to the 4-en-3-one system (at C-2 and C-6).

β-*Effects.* Protons at β-carbon atoms (vicinal to hydroxy groups) show shift increments which depend both upon their conformational relationship to the hydroxy group and upon the secondary or tertiary character of the hydroxy site and of the β-carbon position. The largest increments (*ca.* 0.25 ± 0.05) are normally observed when the hydroxy group and the β-proton are either both axial or both equatorial (*trans*). There are, however, a few marked exceptions where the β-proton is at a tertiary site [*e.g.* 8β-H (7α-OH) or 9α-H (11β-OH)], where the increment is quite small. Small increments, generally within the range 0.1 ± 0.05, are observed in the majority of cases where the hydroxy group and the β-proton are *cis* related (axial/equatorial or *vice versa*). Again there are exceptions, however, including a few where the increment has a small negative value [*e.g.* the sterically compressed 2α- and 4α-H in 3α-hydroxy-5β-cholan-24-oic acid (**142**), and 2β-H in 5α-androstan-3β-ol (**13**)]. One factor in deciding the magnitude of these, and indeed of *all* hydroxylation increments, may be the rotamer population about the C–O bond for the particular compound, and perhaps also the consequent time-averaged disposition of the solvent cage in the vicinity of the hydroxy group.

γ-*Effects.* Axial hydroxy groups, as would be expected, invariably introduce large increments for γ-axial protons, by virtue of spatial proximity and Van der Waals compression. Positive increments in the range 0.4 ± 0.1 ppm are typical.

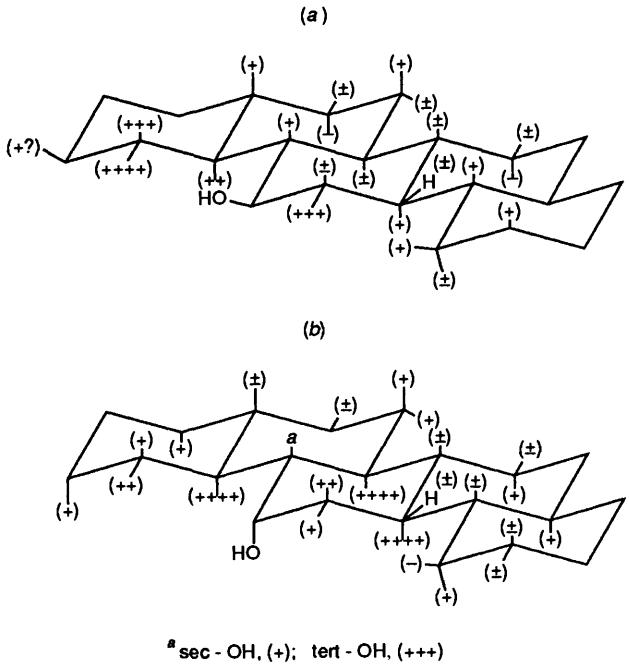


Figure 5. ^{1}H Chemical-shift increments due to hydroxy substituents: (*a*) equatorial OH; (*b*) axial OH. Ranges within which increments are normally found are given by the following scale (ppm): (+ + + + +) +0.4 to +0.6; (+ + + +) +0.2 to +0.4; (+ + +) +0.1 to +0.25; (+ +) +0.02 to +0.15; (±) −0.1 to +0.1 (variable sign); (−) −0.15 to −0.02.

Similar effects operating across the five-membered ring D have been noted[43] in the very large 17α-H shift (*ca.* 0.68) caused by a 14α-hydroxy substituent, and are seen operating in the reverse situation, when 14α-H is shifted strongly downfield by a 17α-hydroxy or -acetoxy group.

There are few instances involving γ-equatorial protons. Whether the hydroxy group is axial or equatorial, γ-equatorial proton increments are relatively small, and in one case[21] reported to be negative. Axial protons are likewise only slightly affected by γ-equatorial hydroxy groups, with observed increments in the range from +0.08 to an exceptional −0.13 (9α-H, 12β-OH).

δ (1,4)-*Effects across six-membered rings.* These are small, and may be of either sign (normally to within 0.1 ppm).

δ (1,4)-*Effects involving adjoining rings.* When the hydroxy group is at a location corresponding to that in an all-*trans* perhydrophenanthren-1-ol, it has a significant deshielding effect on spatially adjacent protons in the third ring (specifically, 11-H in 1-ols, 1-H in 11-ols, and the corresponding locations when one of the rings is five-membered, *i.e.* 15-H in 7-ols, and 7-H in 15-ols). With the hydroxy group equatorial, increments for δ-axial or quasi-axial protons lie in the range 0.2–0.4 ppm: for δ-equatorial protons, which are spatially even nearer, the range is from 0.3 to 0.65 ppm. For axial-OH, increments are less pronounced (*e.g.* for equatorial or quasi-equatorial-H, 0.1 to 0.3; for axial or quasi-axial-H, 0.03 to 0.25), consistent with somewhat greater spatial separation.

Remote effects. Although longer-range effects than those discussed above are relatively small, some occur fairly regularly and are not negligible. We note especially that axial hydroxy groups tend to cause downfield shifts for remote axial protons by up to 0.1 ppm, especially but not exclusively when both the hydroxy group and the remote axial proton are on the same face of the molecule (*e.g.* 2β-H and 11β-H in the presence of 6β-OH).

The main effects of hydroxy substituents on the chemical

Table 4. Mean substituent increments in chemical shift (δ) (for steroidal 4-en-3-ones unless otherwise indicated).

H	2α-OH	2β-OH[a]	4-OH	6α-OH	6β-OH	7α-OH	7β-OH	9-OH	11α-OH	11β-OH	12α-OH[b]	12β-OH[c]	14-OH	15α-OH
1α	−0.12	0.79	−0.01	0.06	0.01	0.08	0.05	0.71	0.31	0.14	0	−0.02	0.06	0.02
1β	0.34	−0.49	−0.02	0.01	0.02	0.03	0.01	−0.32	0.63	0.16	−0.06	0.03	0.01	0.01
2α	—	1.84	0.17	0.03	0.06	0.03	0.01	0.01	−0.01	0.01	−0.07	0.04	0	−0.01
2β	1.85	—	0.12	0.01	0.10	0.01	0.01	0.02	0.01	0.05	−0.02	0.15	0	0
4	0.07	0.08	—	0.46	0.10	0.07	0.02	0.15	0	−0.05	0.02	−0.01	0.01	0
6α	0.04	−0.03	0.73	—	2.07	0.14	0.24	0.02	−0.01	−0.05	0.07	0	0.03	0.03
6β	−0.01	0.11	0.40	1.93	—	0.25	0.06	0.06	−0.02	0.07	−0.04	0	0.05	0.01
7α	0.01	0.01	−0.05	0.05	0.21	—	2.42	0.40	0.03	0.01	0.04	−0.04	0.36	0.21
7β	0.01	0.13	0	0.32	0.15	2.13	—	−0.23	−0.02	0.14	0	−0.01	0.12	0.33
8	0.01	0.14	−0.06	0.06	0.43	0.05	0.03	−0.38	−0.02	0.43	0.01	−0.09	0.29	0.21
9	0.02	0.47	0	0.01	−0.02	0.41	0	—	0.17	0.02	0.38	0.04	0.52	0.05
11α	0	0.20	0	0.02	−0.03	0.05	0.03	0.18	—	2.77	0.08	0.20	0	0.01
11β	0	0.10	−0.03	−0.01	0.06	0.01	0.02	0.34	2.60	—	0.27	−0.07	−0.02	−0.01
12α	−0.01	0.04	−0.01	−0.01	−0.01	−0.01	−0.03	0.27	0.06	0.23	—	1.99	0.58	0.10
12β	0.01	0.03	0	0.01	0.02	−0.02	0	−0.17	0.28	0.12	1.99	—	0.30	−0.03
14	−0.01	0.02	−0.03	0.05	0	0.40	0.15	0.49	0.09	−0.05	0.46	−0.13	—	0.03
15α	−0.01	−0.03	0.04	0.04	0.01	0.11	0.31	−0.06	−0.01	0.03	0.06	–	−0.04	—
15β	−0.01	0	−0.01	0.04	0.05	0.03	0.37	−0.01	−0.02	0.07	0.04	0.13	0.43	2.84
16α	0	−0.01	0.01	0.03	0.03	0.04	0.02	0.01	0.03	−0.01	0.10	0.39	0.19	−0.12[g]
16β	0.01	−0.01	0.01	0.01	0.01	0.02	0	0.02	0	0.01	−0.07	−0.19	0.06	0.62[h]
17α	0	0.02	−0.05	0	0	0.05	−0.04	0.07	0.03	−0.05	0.55	−0.08	0.68	0.27
18	0	0	−0.01	−0.01	0.03	0.01	0.02	0.01	0.03	0.24	0.05	0.10	0.13	0.03
19	0.11	0	−0.02	0.01	0.20	0.01	0.02	0.14	0.13	0.26	−0.02	0	0.02	0.01
21	0	0	−0.01	−0.01	0	0.01	0.01	0	0.01	−0.02	0.03	−0.01	0	0.02

[a] 2β-Hydroxy steroidal 4-en-3-ones have an inverted chair conformation in ring A (R. D. Burnett and D. N. Kirk, *J. Chem. Soc., Perkin Trans. 1*, 1973, 1830; see also ref. 60). This accounts for the exceptionally large and atypical shift increments. [b] Data for one compound only. [c] From comparison of 12β,15α-dihydroxy- and 15α-hydroxy-progesterones. [d] From comparison of testosterone with androst-4-en-3-one. [e] From comparison of progesterone with androst-4-en-3-one. [f] Increments associated with the doubly bridged 11β,18;18,20-diepoxy-20-hydroxy ('hemiacetal') and the singly bridged

shifts of neighbouring and remote protons are illustrated in Figure 5. Although only semiquantitative, in view of the numerical ranges covered by the observed increments, these indications should have some value in future analyses or prediction of features of the ^{1}H spectra of steroids not included in this survey.

Experimental

^{1}H NMR spectra were recorded on a Bruker WH-400 spectrometer [University of London Intercollegiate Research Service (ULIRS) at Queen Mary and Westfield College], or on a Bruker AM-500 or AM-400 at NIMR, Mill Hill, London, or on a Jeol GSX-500 (ULIRS, at Birkbeck College, London), or in a few cases on a Bruker AM-250 spectrometer at Queen Mary and Westfield College. Some of the data reported here were obtained by use of more than one of these spectrometers; chemical shifts corresponded well, so the particular instruments used for each compound are not indicated.

Spectra are with reference to Me_4Si as an internal standard, except in some cases where the solvent was CD_3OD, and the signal at δ 3.30 due to residual CHD_2OD was used as the standard. Wherever the available quantity of steroid was sufficient, spectra were recorded for solutions at a concentration of *ca.* 20 mg cm^{-3}. Spectra were obtained at a uniform temperature of 303 K. $CDCl_3$ was 99.8% D and CD_3OD was 99.96% D, both from Goss Scientific Instruments Ltd., Ingatestone, Essex.

Proton Homonuclear Correlation Spectroscopy (COSY and COSYDEC).—Pulse sequences with N-type coherence transfer pathway selection were used, the data being processed to give absolute value presentation [a π/3 mixing pulse was used for both COSY and COSYDEC experiments and the duration of the mixing time for COSYDEC was 0.2 s]. 2K data points were collected for t_2; the number of scans per increment and the sweep width varied depending on the sample. Not more than 512 points were collected for t_1, and zero-filling was performed to give a symmetrical matrix after 2D Fourier transformation. Sine-bell window functions were used in both dimensions.

Carbon–Proton Correlation.—The pulse sequence of Bax and Morris[62] was used, assuming a value of 135 Hz for $J_{C,H}$ to calculate the delays in the pulse sequence. 2K data points were collected for t_2 (^{13}C) and 256 points for t_1 (^{1}H). Sweep widths and the number of scans per increment were set depending on the sample. A sine-bell window function was used in both dimensions and the data were presented in absolute value mode.

NOE Difference (NOEDS).—Irradiation power was adjusted to the minimum necessary to saturate the appropriate signal. An irradiation time of 1 s was used with a 5 s relaxation delay. Where multiplets were irradiated, the frequency was switched rapidly between all the lines of the multiplet to eliminate selective population transfer (SPT) effects; a 90° read pulse was also used for this reason. Irradiation was cycled between on-resonance lines and a control frequency (at one end of the spectrum) every 16 scans. 32 K points were acquired, and the subtraction to obtain a difference spectrum was performed in the time domain.

Table 4 (*continued*)

15β-OH[b]	16α-OH	16β-OH[b]	17α-OH	17β-OH[d]	19-OH	21-OH	Δ[1]	Δ[6]	17-Oxo	Δ[4] *vs.* 5α-H (3-oxo)	17β-COMe[e]	Aldosterone[f] Hemi-acetal	Aldosterone[f] 20-Oxo form
0	0.01	0	−0.01	0	0.02	−0.01	—	0.03	0	0.36	0.02	0.03	0.01
0	0	0.01	−0.02	0	0.32	−0.01	—	−0.02	0	0.02	0.01	0.18	0.16
−0.02	0.01	0	−0.04	0.04	−0.07	−0.07	—	0.10	0.03	0.04	0.04	0.09	0.09
0.01	0	0.02	−0.02	−0.02	0.27	−0.04	—	0.16	−0.02	0.07	−0.01	0.15	0.15
0.02	0.01	0.01	0.01	0	0.11	−0.01	0.34	−0.06	0.03	—	0	−0.01	−0.01
0.04	0.02	0	0.08	0.03	0	−0.01	0.06	—	0.07	0.93	0.03	0.07	0.07
0.07	−0.01	0	−0.01	0.01	0.07	−0.01	0.06	—	0	1.08	−0.01	0.15	0.15
0.08	0.02	0.03	0.05	−0.04	−0.06	0.03	0	—	0.08	0.11	0.02	0.17	0.09
0.28	0.04	0.02	0	−0.02	−0.01	0	0.10	—	0.12	0.18	0	0.19	0.11
0.40	0.02	0.07	0.03	0.09	0.08	0.04	0.09	0.66	0.27	0.19	0.09	0.21	0.14
0.06	0.03	0.02	0	−0.02	0.11	−0.01	0.11	0.27	0.05	0.19	0.04	0.17	0.09
0.01	0	0.02	0.02	0.03	0.07	−0.03	0.18	0.02	0.13	0	0.08	3.19	2.94
0.01	−0.01	0.03	−0.04	0	0.03	−0.03	0.24	0.01	0.04	0.04	0.03	—	—
0.01	0.10	0.03	0.24	−0.04	−0.09	0.16	0	0.04	0.14	0.02	0.32	−0.13	−0.02
−0.01	−0.03	0.05	−0.64	0.09	0.09	−0.16	0.06	0.03	0.09	0.04	0.31	0.44	0.75
−0.11	0.36	−0.15	0.55	0.06	−0.08	0.02	−0.03	0.20	0.39	0	0.26	0.35	0.37
2.61	−0.02	0.62	0.13	−0.07	−0.04	0.05	0	0.18	0.29	0.04	0.03	0.14	0.19
—	0.46	0	0.10	0.10	−0.05	0.08	0.02	0.15	0.38	0.05	0.06	0.12	0.16
0.56	—	2.10	−0.08	0.46	−0.06	0.01	−0.02	0.04	0.49	0.04	0.05	−0.08	0.18
0.05	2.68[j]	—	0.50	−0.15	−0.05	0.02	−0.01	0.05	0.86	0.04	0.56	−0.05	0.11
−0.06	−0.12	−0.25	—	—	0	−0.07	0.07	0.07	—	0.04	1.37	0.11	0.45
0.28	0.04	0.07	0.10	0.05	−0.03	0.03	0.02	0.05	0.18	0.03	−0.08	4.70	4.30
0.02	−0.01	0.02	−0.02	0	2.67, 2.80	−0.01	0.04	−0.05	0.03	0.17	0.01	0.14	0.10
0.02	0.03		0.15	—	−0.01	—	0	0.01	—	—	—	−0.76, −0.77	0.19, 0.01

11β,18-epoxy-18-hydroxy('20-oxo') forms of aldosterone, each compared with 21-hydroxypregn-4-ene-3,20-dione. [g] 16α-H increment is exceptionally zero in 15α-hydroxyandrost-4-ene-3,17-dione. [h] 16β-H increment is exceptionally 0.54 in 15α-hydroxyandrost-4-ene-3,17-dione. [j] 16β-H increment is exceptionally 1.91 in 16α-hydroxyandrost-4-ene-3,17-dione.

Acknowledgements

We are grateful to the UK Medical Research Council (MRC) and the US National Institutes of Health for funding (to D. N. K.) in support of the Steroid Reference Collection, to the MRC for use of NMR facilities at the National Institute for Medical Research, Mill Hill, London, and for a grant (to D. N. K.) for the study of aldosterone metabolites, to the Wellcome Trust for a Grant for microbiological hydroxylation of steroids (to D. N. K. and K. E. S.), and to the many individual scientists, and especially to Professor Sir Ewart Jones, FRS, for donating steroids to the Steroid Reference Collection.

References

1 J. W. Blunt and J. B. Stothers, *Org. Magn. Reson.*, 1977, **9**, 439.
2 W. B. Smith, *Annu. Rev. NMR Spectrosc.*, 1978, **8**, 199.
3 See refs. cited in 'Terpenoids and Steroids,' ed. J. R. Hanson (Specialist Periodical Reports), The Chemical Society, London, 1979, vol. 9, p. 258; Royal Society of Chemistry, London, 1981, vol. 10, p. 202; 1982, vol. 11, p. 174; 1983, vol. 12, p. 274.
4 D. N. Kirk, *Nat. Prod. Rep.*, 1984, **1**, 209; 1986, **3**, 505; 1989, **6**, 393, and refs. therein.
5 A. Bax, R. Freeman, T. A. Frenkiel, and M. H. Levitt, *J. Magn. Reson.*, 1981, **43**, 478.
6 R. Freeman, T. A. Frenkiel, and M. B. Rubin, *J. Am. Chem. Soc.*, 1982, **104**, 5545.
7 R. Jacquesy, C. Narbonne, W. E. Hull, A. Neszmelyi, and G. Lukacs, *J. Chem. Soc., Chem. Commun.*, 1982, 409.
8 A. Neszmelyi, W. E. Hull, G. Lukacs, and W. Voelter, *Z. Naturforsch., Teil B*, 1986, **41**, 1178.
9 B. G. Carter, D. N. Kirk, and P. J. Burke, *J. Chem. Soc., Perkin Trans. 2*, 1987, 1247.
10 D. H. Williams and I. Fleming, 'Spectroscopic Methods in Organic Chemistry,' 4th edn., McGraw-Hill, London, 1987, pp. 126–134.
11 L. D. Hall and J. K. M. Sanders, *J. Am. Chem. Soc.*, 1980, **102**, 5703.
12 L. D. Hall and J. K. M. Sanders, *J. Org. Chem.*, 1981, **46**, 1132.
13 M. W. Barrett, R. D. Farrant, D. N. Kirk, J. D. Mersh, J. K. M. Sanders, and W. L. Duax, *J. Chem. Soc., Perkin Trans. 2*, 1982, 105.
14 T. C. Wong, V. Rutar, and J.-S. Wang, *J. Am. Chem. Soc.*, 1984, **106**, 7046.
15 T. C. Wong and V. Rutar, *J. Am. Chem. Soc.*, 1984, **106**, 7380.
16 A. G. J. Sedee, G. M. J. Beijersbergen van Henegouwen, W. Guijt, and C. A. G. Haasnoot, *J. Chem. Soc., Perkin Trans. 2*, 1984, 1755.
17 A. G. J. Sedee, G. M. J. Beijersbergen van Henegouwen, W. Guijt, and C. A. G. Haasnoot, *J. Org. Chem.*, 1985, **50**, 4182.
18 A. G. J. Sedee, G. M. J. Beijersbergen van Henegouwen, M. E. de Vries, and C. Erkelens, *Steroids*, 1985, **45**, 101.
19 A. G. J. Sedee, G. M. J. Beijersbergen van Henegouwen, W. Guijt, and C. A. G. Haasnoot, *Pharm. Weekblad. Sci. Ed.*, 1985, **7**, 202.
20 D. V. Waterhous, S. Barnes, and D. D. Muccio, *J. Lipid Res.*, 1985, **26**, 1068.
21 H. J. Schneider, U. Buchheit, N. Becker, G. Schmidt, and U. Siehl, *J. Am. Chem. Soc.*, 1985, **107**, 7027.
22 S. Top, G. Jaouen, A. Vessieres, J.-P. Abjean, D. Davoust, C. A. Rodger, B. G. Sayer, and M. J. McGlinchey, *Organometallics*, 1985, **4**, 2143.
23 M. Savignac, G. Jaouen, C. A. Rodger, R. E. Perrier, B. G. Sayer, and M. J. McGlinchey, *J. Org. Chem.*, 1986, **51**, 2328.
24 H. Duddeck, D. Rosenbaum, M. Hani, A. Elgamal, and M. B. E. Fayez, *Magn. Reson. Chem.*, 1986, **24**, 999.
25 S. A. Campbell, T. A. Crabb, and R. O. Williams, *Magn. Reson. Chem.*, 1986, **24**, 803.
26 M. Harnik, Y. Kashman, S. Carmely, M. Cojocaru, S. L. Dale, M. M. Holbrook, and J. C. Melby, *Steroids*, 1986, **47**, 67.
27 M. Campredon, V. Quiroa, A. Thevand, A. Allouche, and G. Pouzard, *Magn. Reson. Chem.*, 1986, **24**, 624.
28 V. J. Robinson, A. D. Bain, and C. A. Rodger, *Steroids*, 1986, **48**, 267.
29 R. D. Dawe and J. L. C. Wright, *Can. J. Chem.*, 1987, **65**, 666.
30 W. R. Croasmun and R. M. K. Carlson, *Methods Stereochem. Anal.*, 1987, **9** (Two-dimensional NMR Spectroscopy), 387.
31 A. E. Derome, *Nat. Prod. Rep.*, 1989, **6**, 111.

32 H. Duddeck, J. Frelek, W. J. Szczepek, and W. J. Rodewald, *Bull. Chem. Soc. Ethiop.*, 1987, **1**, 18.
33 J. Drew, J.-R. Brisson, P. Morand, and A. G. Szabo, *Can. J. Chem.*, 1987, **65**, 1784.
34 N. Platzer, N. Goasdoue, and D. Davoust, *Magn. Reson. Chem.*, 1987, **25**, 311.
35 K. Bischofberger, J. R. Bull, and A. A. Chalmers, *Magn. Reson. Chem.*, 1987, **25**, 780.
36 R. E. Perrier and M. J. McGlinchey, *Can. J. Chem.*, 1988, **66**, 3003.
37 T. C. Wong and G. R. Clark, *J. Chem. Soc., Chem. Commun.*, 1984, 1518.
38 K. Marat, J. F. Templeton, and V. P. S. Kumar, *Magn. Reson. Chem.*, 1987, **25**, 25.
39 K. Marat, J. F. Templeton, R. K. Gupta, and V. P. S. Kumar, *Magn. Reson. Chem.*, 1987, **25**, 730.
40 T. C. Wong, W. Guo, M. Bohl, M. Hubner, G. Luck, T. Steiger, and G. Reck, *J. Chem. Soc., Perkin Trans. 1*, 1988, 765.
41 W. F. Reynolds, S. McLean, J. Poplawski, R. G. Enriquez, L. I. Escobar, and I. Leon, *Tetrahedron*, 1986, **42**, 3419.
42 D. W. Hughes, *Magn. Reson. Chem.*, 1988, **26**, 214.
43 K. E. Smith, S. Latif, D. N. Kirk, and K. A. White, *J. Steroid Biochem.*, 1988, **31**, 83.
44 K. E. Smith, S. Latif, and D. N. Kirk, *J. Steroid Biochem.*, 1989, **32**, 445.
45 K. E. Smith, K. A. White, and D. N. Kirk, *J. Steroid Biochem.*, 1989, **33**, 81.
46 K. E. Smith, S. Latif, D. N. Kirk, and K. A. White, *J. Steroid Biochem.*, 1989, **33**, 271.
47 D. N. Kirk, P. J. Burke, H. C. Toms, S. A. Latif, and D. J. Morris, *Steroids*, 1989, **54**, 169.
48 D. N. Kirk, B. W. Miller, G. Cooley, S. A. Latif, and D. J. Morris, *J. Chem. Res.*, 1989, (*S*) 164; (*M*) 1274.
49 S. A. Latif, D. J. Morris, L. Wei, D. N. Kirk, P. J. Burke, H. C. Toms, and C. H. L. Shackleton, *J. Steroid Biochem.*, 1989, **33**, 1119.
50 K. D. R. Setchell, M. Axelson, J. Sjovall, D. N. Kirk, and R. E. Morgan, *FEBS Lett.*, 1978, **88**, 215.
51 R. Das and D. N. Kirk, *J. Chem. Soc., Perkin Trans. 1*, 1984, 1821.
52 R. F. Zücher, *Helv. Chim. Acta*, 1961, **44**, 1380.
53 R. F. Zücher, *Helv. Chim. Acta*, 1963, **46**, 2054.
54 J. E. Bridgeman, P. C. Cherry, A. S. Clegg, J. M. Evans, Sir Ewart R. H. Jones, V. Kumar, D. G. Meakins, Y. Morisawa, and E. E. Richards, *J. Chem. Soc. C*, 1970, 250.
55 M. Karplus, *J. Am. Chem. Soc.*, 1963, **85**, 2870.
56 N. S. Bhacca and D. H. Williams, 'Applications of NMR Spectroscopy in Organic Chemistry,' Holden-Day, San Francisco, 1964.
57 J. K. M. Sanders and B. K. Hunter, 'Modern Methods in NMR Spectroscopy,' Oxford University Press, 1987.
58 G. Cooley, D. N. Kirk, R. E. Morgan, and M. L. Sá e Melo, *J. Chem. Soc., Perkin Trans. 1*, 1977, 1390, and refs. therein.
59 D. N. Kirk and H. C. Toms, *Steroids*, in press.
60 'Atlas of Steroid Structure,' vol. 1, eds. W. L. Duax and D. A. Norton, Plenum, New York, 1975; vol. 2, eds. J. F. Griffin, W. L. Duax, and C. M. Weeks, Plenum, New York, 1984.
61 C. E. Gomez-Sanchez, D. N. Kirk, R. D. Farrant, and L. Milewich, *J. Steroid Biochem.*, 1985, **22**, 141.
62 A. Bax and G. Morris, *J. Magn. Reson.*, 1981, **42**, 501.

Paper 0/00483I
Received 1*st February* 1990
Accepted 9*th March* 1990