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**Supplementary Material Available:** Structure factors and positional coordinates for $(Ph_4P)_2[Fe(WS_4)_2(HCON(CH_3)_2)_2]$ (22 pages). Ordering information is given on any current masthead page.

## Editing of $^{13}C$ NMR Spectra. A Pulse Sequence for the Generation of Subspectra

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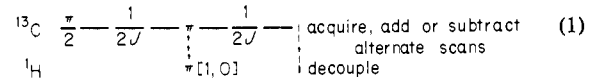
In this article we describe a simple multinuclear pulse sequence, sequence 1, which enables the acquisition of $^{13}C$ spectra containing just $CH_3$ and CH resonances or just $CH_2$ and quaternary carbon resonances. The sequence has the advantage of accurate cancellation of the unwanted resonances.




(1)

The key to the mechanism of this sequence, illustrated in Figure 1, is the judicious use of the $\pi$[H;1,0] refocusing pulse, [1,0], signifying that the pulse is applied for alternate scans only. Figure 1d,i illustrates the outcome of the sequence for a CH and $CH_2$ group, respectively, at the point at which the decoupling field is introduced, for scans in which the $\pi$[H] pulse is omitted, and Figure 1e,j illustrates the outcome for scans in which a $\pi$[H] pulse is used. For a $CH_3$ group (not illustrated[ it can be easily shown that the various carbon vectors are refocused along the $y$ or $-y$ axis as for a CH group in Figure 1d,e. Assuming proton coupling is small, quaternary carbons are unaffected by the sequence except that precession due to chemical shift and field inhomogeneity is refocused back to the $y$ axis as for a $CH_2$ group in Figure 1i,j. From Figure 1d,e,i,j it is clear that alternate use of the $\pi$[H] pulse and addition of alternate scans produces a spectrum containing only $CH_2$ and quaternary carbon resonances, and subtraction of alternate scans produces a spectrum containing only CH and $CH_3$ carbon resonances. Spectra of cholesterol, obtained in this manner, are shown in Figure 2. As often occurs in $^{13}C$ spectra, several of the cholesterol CH and $CH_2$ resonances are close together. Cancellation of signals, rather than inversion of some signals relative to others, is obviously preferable in such instances and is necessary for quantitative studies.

Spectral editing of this sort has been recently achieved by using the INEPT sequence.[1,2] However, sequence 1 has clear advantages over the INEPT sequence. Single-bond CH coupling constants vary somewhat; so an average $J$ value must be used in setting the free precession periods in sequence 1 and the INEPT sequence. Divergence from this average $J$ value leads to residual carbon signals instead of exact cancellation, but in general the cancellation is more exact for sequence 1 than for INEPT. For example, by using the INEPT sequence $CH_2$ and $CH_3$ signals may be cancelled after a total free precession period for the carbon vectors of $(2J)^{-1}$ s.[1] Although the INEPT sequence is marginally less sensitive to error in $J$ for the cancellation of $CH_3$ signals than is sequence 1, it is straightforward to show that a 5 error in $J$ leads to a 15.6% residual $CH_2$ signal for INEPT, whereas for sequence

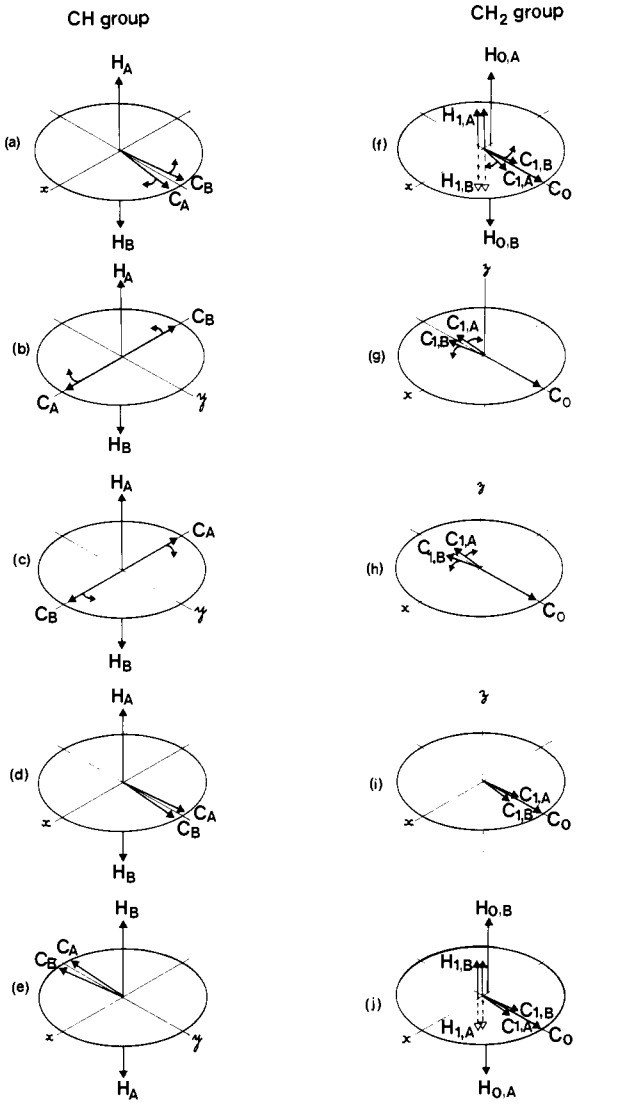



**Figure 1.** Because precession in the rotating frame due to chemical shift and field inhomogeneity is refocused at the end of the free precession period by the $\pi$[C] pulse, precession due only to proton coupling is shown. (a) After a $(\pi/2)$[c,x] pulse, the magnetization vector of $^{13}C$ nuclei coupled to protons, which is initially along the $y$ axis of the rotating frame, splits into a clockwise rotating vector ($C_A$) and an anticlockwise rotating vector ($C_B$), corresponding to whether the protons are in the $+z$ ($H_A$) or $-z$ eigenstate ($H_B$), respectively. (b) After the first period of $(2J)^{-1}$ s, where $J$ is the single-bond coupling constant, $C_A$ and $C_B$ have precessed 90°. (c) A $\pi$[C] pulse along the $y$ axis, say, swaps $C_A$ and $C_B$. (d) After the second period of $(2J)^{-1}$ s, $C_A$ and $C_B$ are refocused along the $y$ axis. (e) If after the first period of $(2J)^{-1}$ s, a $\pi$[H] pulse is introduced, the precessional direction of the $C_A$ and $C_B$ vectors are reversed and refocused along the $-y$ axis after the second period of $(2J)^{-1}$ s. (f)–(j) Vector positions for a $CH_2$ group at the same stages during the sequence as shown for a CH group in (a)–(e), respectively. The carbon magnetization vector splits into three vectors $C_{1,A}$, $C_{1,B}$, and $C_0$ corresponding to whether the attached protons are both in the $+z$ eigenstate ($H_{1,A}$), both in the $-z$ eigenstate ($H_{1,B}$), or are opposed ($H_{0,A}$ and $H_{0,B}$).

1 the residual signal would be only 1.2% of the total. Another advantage is that, unlike INEPT, the CH/$CH_3$ and $CH_2$/quaternary subspectra can be compared directly with a normal spectrum obtained with sequence 1 but without using the $\pi$[H] pulse. In fact, if the alternate scans are averaged into two different memory blocks, the three spectra, as in Figure 2, are available from the one experiment. Again, unlike INEPT, the same spectral simplifications are obtained by using off-resonance decoupling during acquisition, and the subspectra may be obtained with or without nuclear Overhauser enhancements. Although the INEPT sequence provides a one-third theoretical advantage in sensitivity over spectra obtained with the full nuclear Overhauser en-

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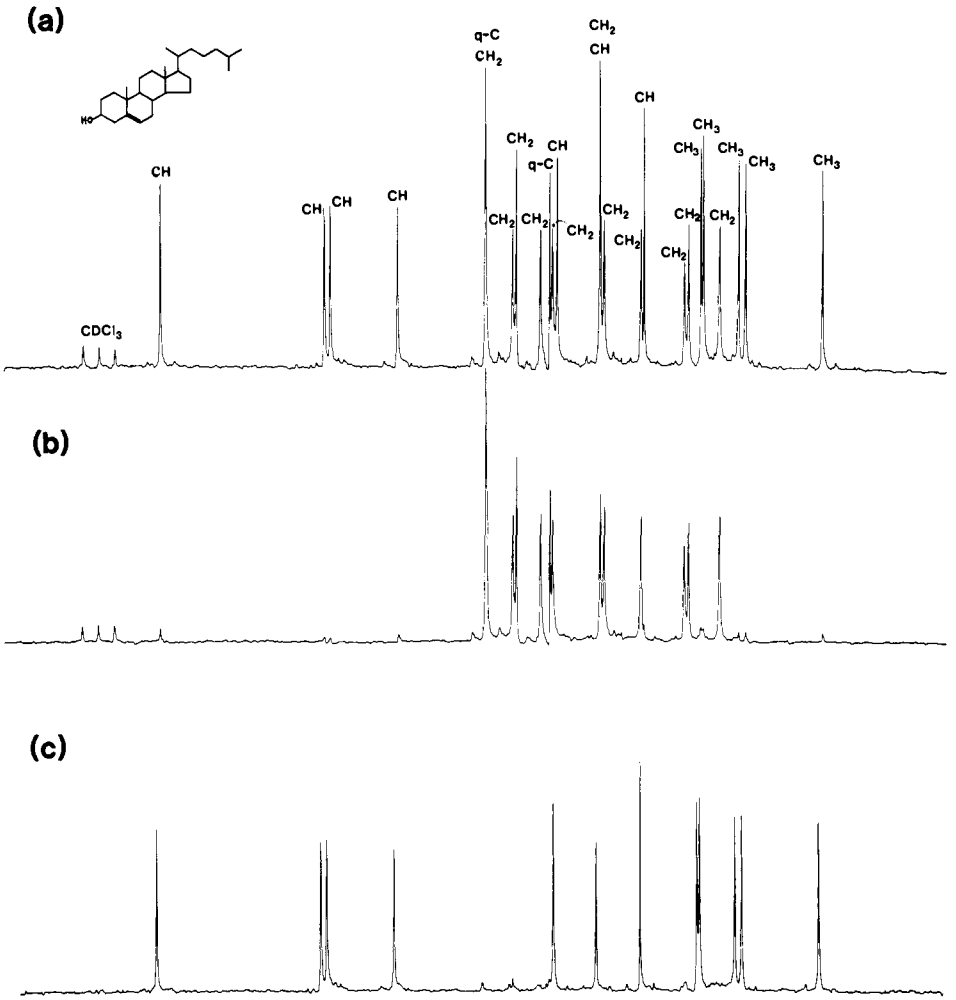
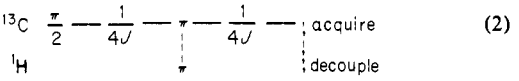



**Figure 2.** $^{13}C$ spectra[6] of cholesterol obtained by using sequence 1. (a) Without the application of the $\pi$[H] pulse, (b) with the addition of alternate scans, and (c) with the subtraction of alternate scans.

hancement, this advantage is difficult to realize in full experimentally because of pulse imperfections in the complete seven-pulse INEPT sequence.[2]

A major use of the sequence will be in the assignment of $^{13}C$ spectra. Where there is confusion between CH and $CH_3$ resonances in the $CH/CH_3$ subspectrum, resonances can be assigned by obtaining a CH spectrum using INEPT or by using off-resonance decoupling during acquisition with sequence 1. Aromatic quaternary carbon resonances and aromatic CH resonances are completely separated by using the technique. Aliphatic quaternary carbons can be assigned in the $CH_2$/quaternary subspectrum by using off-resonance decoupling or a recently published variation of off-resonance decoupling.[3] Alternatively, CH, $CH_2$, and $CH_3$ resonances may be cancelled by application of sequence 2. This




(2)

corresponds to application of the decoupling field when equivalent carbon vectors are 180° out of phase as in Figure 1b,g (equivalent $CH_3$ carbon vectors are also 180° out of phase after a total free precession time of $(2J)^{-1}$ s). Although sequence 2 requires both $\pi$[H] and $\pi$[C] pulses to be homogeneous[6] for good cancellation, and so may not be competitive with off-resonance decoupling for assignment purposes, we have found it useful for the measurement of $T_1$'s of quaternary carbons which overlap with $CH_2$ resonances in the normal spectrum by preceding sequence 2 with an inversion–recovery sequence.

A major application of sequence 1 will be in the quantitative analysis of complex mixtures such as coal liquefaction products. Present results indicate that the sequence will be accurate to better than 5% for such studies. The sequence may be considered to be a variation of the proton-flip method developed for two-dimensional heteronuclear $J$ spectroscopy[4] and could, in fact, be used to provide two-dimensional subspectra. Sequence 1 is the inverse of a recently published sequence.[5]

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(6) Spectra were obtained at 33 °C with a near-saturated solution of cholesterol in $CDCl_3$ and using a Bruker HX-90 spectrometer upgraded with an Aspect-2000 computer, associated CXP series pulse modulation electronics, and a second pule modulator to provide the four phases for proton pulses; 2000 scans were obtained for each spectrum. The spectral width was 2000 Hz (the olefinic carbon resonances are not shown), and a recycle time of 5 s was used. A standard 10 mm insert was employed, proton pulsing and decoupling being achieved with the proton decoupling coil. For $^1H$ and $^{13}C$ spectra, 90° pulse times were 27 and 8.4 $\mu$s, respectively. The 90° pulse time for $^1H$ spectra was determined as previously described.[2] The free precession time $(2J)^{-1}$ s was set by assuming an average coupling constant of 132 Hz. Accurate cancellation of resonances using sequence 1 requires a homogeneous $\pi$[H] pulse. Because of the large size of the standard proton decoupling saddle coil (diameter 21 mm, length 42 mm) compared to the sample size which is determined by the dimensions of the $^{13}C$ solenoid coil (diameter 12 mm, length 10 mm), the rf homogeneity of the $^1H$ pulses was very good as evidenced by the good cancellation obtained. Nevertheless, as a further precaution, a composite $\pi$[H] pulse $((\pi/2)[x],\pi[y],(\pi/2)[x])$ was used. Radio frequency inhomogeneity in the $\pi$[C] pulse does not affect the cancellation of resonances using sequence 1 but does introduce phase errors in the spectra. Small phase errors can be seen, for example, for the resonances close to the upfield quaternary resonance. If required, the $^{13}C$ pulse homogeneity may be improved by using a sample tube having a reduced sample size (e.g., Wilmad cat. no. 529-E-10).

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## Novel Addition Reaction of Thebaine with Acetylenic Dienophiles: Construction of a New Morphine Skeleton

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*Received April 14, 1981*

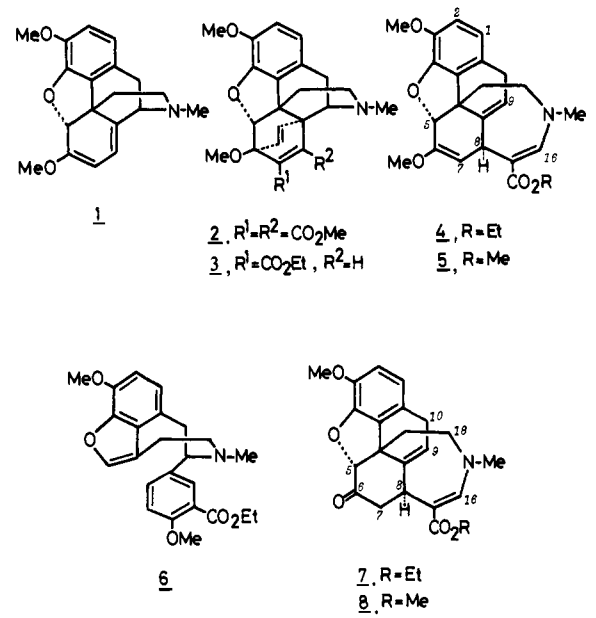
Thebaine (**1**), a unique morphine alkaloid, is too toxic to be used as an analgesic.[1] Owing to its diene structure, however, the Diels–Alder reactions of **1** with various dienophiles and chemical transformations of the resulting adducts have been extensively investigated.[2-9] Many of the compounds derived from **1** in this way show high analgesic activity.[3] During the course of our studies on chemical modifications of **1**, we have found that **1** undergoes abnormal addition reactions with acetylenic dienophiles in polar solvents, providing in high yields novel adducts derived from the morphine skeleton.

Rapoport and Sheldrick[10] reported that **1** and dimethyl acetylenedicarboxylate react smoothly in benzene at 50 °C to give the Diels–Alder adduct **2** in high yield, while the similar reaction of ethyl propiolate (EP) gives the adduct **3** only in very poor yield. In the latter case, the low reactivity was attributed to rapid polymerization of EP under the reaction conditions employed.[10] Therefore, we reexamined the same reaction under milder conditions by using various solvents. To our surprise, **1** was found to react very readily with EP in polar solvents even at room temperature. Thus, treatment of **1** (Chart I) with 1.5 equiv of EP in acetonitrile at room temperature (30 min) followed by evaporation in vacuo gave a quantitative yield of the cyrstalline adduct **4**, mp 168–170 °C (ethyl acetate).[11] The product **4** was also obtained in 64% yield by using $CH_2Cl_2$ as a solvent, although the similar reaction in benzene resulted in the formation of several minor products including **4** along with the recovery of large amounts of unreacted thebaine (**1**). The adduct **4** was totally different from the reported Diels–Alder adduct **3** (mp 130–131 °C).[10] While **3** is known to easily undergo the retro-Diels–Alder reaction at 140 °C to give **6**,[10] compound **4** is stable under the identical thermolytic conditions.

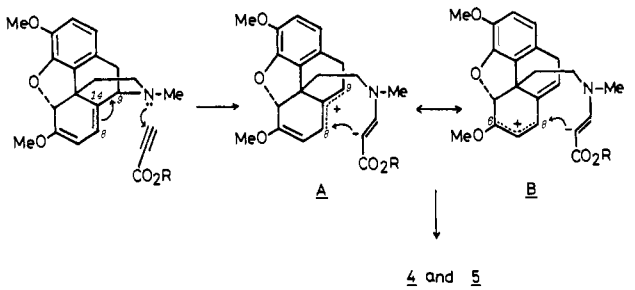
The structure of **4** was determined on the basis of its spectroscopic data and chemical conversions. Its nature as a 1:1 adduct was apparent from the elemental analysis and mass spectrum ($M^+$, $m/e$ 409). The IR (Nujol) spectrum showed a characteristic absorption at 1680 $cm^{-1}$ for a >NC=CCOOEt moiety. The $^1H$ NMR ($CDCl_3$) spectrum exhibited signals of the ethyl group at $\delta$ 1.28 (t, $J$ = 6.8 Hz, 3 H) and 4.14 (q, $J$ = 6.8 Hz, 2 H), three methyl groups at $\delta$ 2.91 (s, 3 H), 3.55 (s, 3 H), and 3.82 (s, 3 H), two methine protons at $\delta$ 4.50 (br d, $J$ = 5.2 Hz, H-8) and 4.97 (d, J = 1.2 Hz, H-5), three olefinic protons at $\delta$ 5.25 (dd, $J$ = 5.2, 1.2 Hz, H-7), 5.93 (dd, $J$ = 5.4, 2.7 Hz, H-9), and 7.33 (s, H-16), and two aromatic protons at $\delta$ 6.65 (s, 2 H). The assignments were confirmed by the double-resonance decoupling experiments. The $^{13}C$ NMR ($CDCl_3$) spectrum showed signals of an ester carbonyl [$\delta$169.3 (s)], 12 $sp^2$ carbons [$\delta$150.5 (s), 150.5 (d), 144.5 (s), 142.3 (s), 141.0 (s), 133.7 (s), 128.3 (s), 124.5 (d), 118.6 (d), 111.8 (d), 104.5 (s), and 102.2 (d)], three methine carbons [$\delta$86.1 (d), 38.4 (d), and 37.9 (s)], three methylene carbons [$\delta$ 59.5 (t), 54.4 (t), and 53.3 (t)], and four methyl carbons [$\delta$56.2 (q), 50.2 (q), 44.2 (q), and 14.5 (q)]. From these data, **4** was concluded to be the novel 1:1 adduct derived from a morphine skeleton. The similar reaction of **1** with methyl propiolate (MP) in acetonitrile or methanol afforded the corresponding adduct **5**[11,12] in a quantitative yield.

Structure of these adducts was further confirmed by the following chemical conversions. While **4** (or **5**) was recovered unchanged from the catalytic hydrogenation ($H_2$, 5% Pd–C, ethyl acetate) or reductive treatment ($LiAlH_4$, THF, reflux), the enol ether functionality in **4** (or **5**) was exposed on mild acid hydrolysis (concentrated HCl–THF 20:80, 20 h, 25 °C) to give the ketone **7** (60%) [or **8**[13] (56%)], mp 170–172 °C (ethyl acetate):[11] MS, $m/e$ 395 ($M^+$); IR (Nujol) 1735 and 1680 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) $\delta$ 1.27 (t, $J$ = 6.9 Hz, 3 H), 1.68–2.00 (m, 2 H), 2.51

Chart I




Scheme I

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(11) Satisfactory combustion analyses were obtained for all new compounds.
(12) Compound **5**: mp 160–162 °C (ethyl acetate); *MS*, $m/e$ 395 ($M^+$); IR (Nujol) 1680 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) $\delta$ 1.86–2.40 (m, 2 H), 2.91 (s, 3 H), 3.15–3.24 (m, 2 H), 3.55 (s, 3 H), 3.72 (s, 3 H), 3.82 (s, 3 H), 4.50 (br d, $J$ = 5.2 Hz, H-8), 4.97 (d, $J$ = 1.2 Hz, H-5), 5.25 (dd, $J$ = 5.2, 1.2 Hz, H-7), 5.93 (dd, $J$ = 5.4, 2.7 Hz, H-9), 6.65 (s, H-1 and H-2), and 7.33 (s, H-16); $^{13}C$ NMR ($CDCl_3$) $\delta$29.4 (t), 37.9 (s), 38.4 (d), 44.3 (q), 50.2 (q), 51.0 (q), 53.1 (t), 54.4 (t), 56.2 (q), 86.1 (d), 102.2 (d), 104.4 (s), 111.8 (d), 118.6 (d), 124.5 (d), 128.3 (s), 133.6 (s), 140.9 (s), 142.3 (s), 144.6 (s), 150.5 (s), 150.7 (d), and 169.7 (s).

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