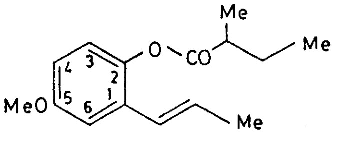
Indirect ^{13}C–^{1}H Coupling in Asymmetrically Trisubstituted Benzenes: a Carbon-13 Nuclear Magnetic Resonance Study

By **Friedrich von Massow,*** Botanisches Institut der Universität Karlsruhe (TH), Lehrstuhl 1, 75 Karlsruhe, Kaiserstraße 2, W. Germany
Martin A. R. Smith,* Bruker-Physik AG, 7512 Rheinstetten-Fo, Silberstreifen, W. Germany

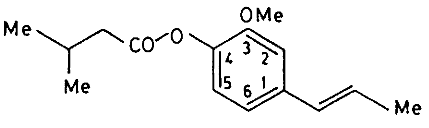
Undecoupled ^{13}C n.m.r. spectra of a series of asymmetrically trisubstituted benzenes have been obtained by proton ' gated '-decoupling, and show invariably a characteristic sharp doublet in the aromatic region. The origin of this phenomenon is discussed in terms of the indirect ^{13}C–^{1}H coupling pathways available within the ring as dictated by the positions of the substituents. It is shown that a doublet without fine structure arises from the carbon atom having no protons *meta,* that it is a generally predictable facet of these systems and as such a valuable aid to assignment.

DURING the course of ^{13}C n.m.r. investigations into the structure of a previously unknown component (1) of essential oils of *Pimpinella anisum* L[1], we noted a proton gated-decoupling spectrum (see Experimental section) which contained a strong doublet ($J = 162$ Hz, from direct ^{13}C–^{1}H coupling) without the fine structure one would expect from indirect coupling. On the basis of a comparison of observed and calculated chemical shifts [2] we were able to assign this resonance to C-3. A similar conclusion applied to the observation of an identical doublet in the gated spectrum of (2) except that in this instance it arose from C-5.

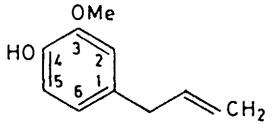
In order to throw further light on this phenomenon and in the interest of promoting a better understanding of the ^{13}C–^{1}H multiplets to be expected from the unsubstituted ring carbons in trisubstituted benzenes of



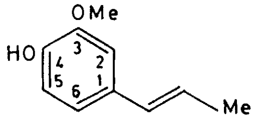
(1)



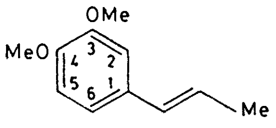
(2)



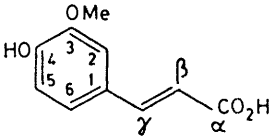
(3)



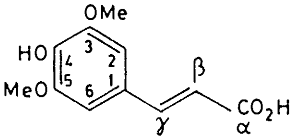
(4)



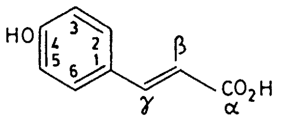
(5)



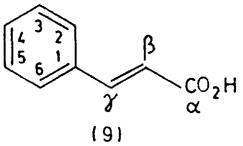
(6)



(7)



(8)



(9)

---

[1] K. H. Kubeczka, F. v. Massow, V. Fomacek, and M. A. R. Smith, *Z. Naturforsch.* 1976, **316**, 283.

[2] (*a*) J. B. Stothers, 'Carbon-13 N.M.R. Spectroscopy,' Academic Press, New York and London, 1972, p. 197; (*b*) substituent effect data for $-CH=CH-CH_3$ taken from an anisole spectrum in $CDCl_3$; C-1 + 11.1 p.p.m.; $o = -1.6$ p.p.m.; $m = +0.8$ p.p.m., $p = 0.0$ p.p.m;. (*c*) no substituent data for $-CH=CH-CO_2H$ or allyl was available. We based the substituent effects of both groups, therefore, on $-CH=CH_2$ (see ref. 2*a*).

this type, we have extended our investigations to include a wider range of similar compounds. These are: eugenol (3), isoeugenol (4), 4-methoxyisoeugenol (5), and ferulic acid (6).

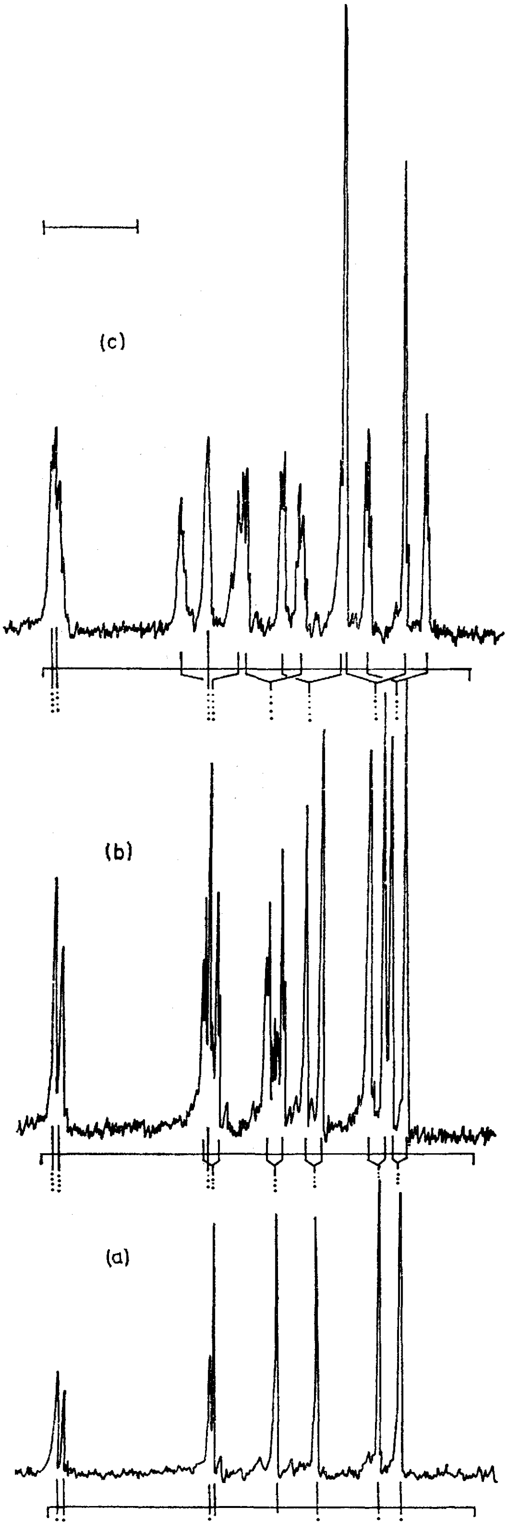
Our results show that under normal experimental conditions of 6 kHz sweep widths such a sharp doublet ($W_{1/2}$ *ca.* 1 Hz) is to be expected from those carbons having no proton on the *meta*-carbon atoms. We regard this observation as a valuable aid to assignment.

EXPERIMENTAL

Compound (1) was obtained as previously described.[1] Compounds (2) and (5) are specially synthesised for us by Dr. K. H. Kubeczka who also donated (3) and (4). The remaining compounds were obtained commercially from EGA Chemie AG and used as received. ^{13}C Fourier transform n.m.r. spectra were measured in $CDCl_3$ [compounds (1)—(5)] or [$^2H_6$]acetone [compounds (6)—(9)] solution using $SiMe_4$ as internal reference. Control experiments between the two solvents showed no significant solvent effects. Spectra were obtained on a Bruker WH-90 instrument. Typically pulse widths were 2.5 µs (22° dip angle), sweep widths 6 kHz and each transient comprised 8 k, or if time permitted, 16 k data points. Gated decoupling involves the application of a strong modulated proton decoupling pulse which is switched off immediately prior to the measuring pulse and the beginning of data acquisition. After the pulse the receiver samples the state of the magnetisation in a plane orthogonal to the field direction (in which Overhauser enhancement has accrued). In consequence the carbon lines retain both nuclear Overhauser enhancement and proton coupling since the latter appears instantaneously. The technique, therefore, enables considerable time saving during the accumulation of proton-coupled ^{13}C spectra. Proton decoupling times were usually 2 s and were repeated 0.2 s after storage of each transient.

RESULTS AND DISCUSSION

The chemical shifts of all ring carbons, together with their calculated positions [1,2] are summarised in Table 1. With the exception of the C-4 of ferulic acid the observed values are all in very good agreement with the theory. This applies especially to those atoms (C-3 or C-5) * for which we observe a sharp doublet in the gated-decoupling spectrum. The isolated, unsubstituted carbon (C-6 or C-2) shows a coupled spectrum which consists of a doublet (from direct coupling) with fine structure approximating doublets or triplets. With the exception of the ether (2) the apparent coupling constants lay between 5.5—6 Hz. The third unsubstituted carbon (C-4 or C-6) showed variable fine structure of the basic doublet and an apparent indirect coupling constant of from 5.5 to 7.4 Hz. Real and apparent coupling constant data are summarised in Table 1. The observations are illustrated in the case of compound (5) in the Figure.



(a) Broad band, (b) off-resonance, and (c) gated-decoupling spectra of 4-methoxyisoeugenol from 150 to 100 p.p.m. Vertical pecked-lines below each spectrum denote the ring carbons. The inserts shown in the gated spectrum is 250 Hz

In the case of ferulic acid (6) we found coincident chemical shifts for C-5 and the olefinic side-chain β-carbon.† Furthermore, the combined signal gave only a sharp doublet in the gated decoupling spectrum. This

---

* Throughout this section the carbons referred to are in compound (1) or (2)—(6) respectively.

† I.U.P.A.C. convention is used throughout. Thus the carboxy-carbon is designated α.

observation seemed to warrant further investigation and we accordingly examined a series of similar acids in which the interfering ring carbon (*a*) would not be expected to show a sharp doublet (*vide infra*) and (*b*) would be expected to have a different chemical shift compared to ferulic acid. Thus, in synapic acid (7) and *p*-cumaric acid (8) as well as in ferulic acid, a strong doublet without fine structure was always found at *ca.* 116 p.p.m. in the gated spectrum (Table 2). The appropriate signal for *trans*-cinnamic acid (9) similarly is not significantly shifted at 119.1 p.p.m. The origin of this signal is, therefore, the olefinic β-carbon. The additional ring, olefinic, and carboxylic carbons of these compounds could be assigned by off-resonance and gated decoupling experiments and, in the case of the ring carbons, the chemical shifts are in agreement with the theory. Table 2 summarises the data for the side-chain carbons.

TABLE 1

Observed and calculated [1,2] ring carbon chemical shifts [a] and coupling constants

	Compound (1) [b,c]			Compound (2) [b,c,d]			Compound (3) [e]		
Carbon	δ [f]	$J(^{13}CH)$	J_{Fine} [g]	δ	$J(^{13}CH)$	J_{Fine}	δ	$J(^{13}CH)$	J_{Fine}
C-1	131.4 (133.4)			138.5 (137.3)			131.9 (130.3)		
C-2	141.6 (141.2)			108.9 (112.9)	157	4	111.5 (113.0)	156	5.9
C-3	123.3 (123.1)	162	0	151.7 (153.3)			146.8 (146.5)		
C-4	113.3 (114.5)	162	6.4	137.3 (136.2)			144.1 (139.6)		
C-5	157.3 (157.4)			122.8 (123.1)	162	0	114.7 (116.3)	157	0
C-6	111.1 (112.9)	169	*h*	118.1 (119.5)	171	*h*	121.3 (119.6)	159	7.3

	Compound (4) [e]			Compound (5) [c]			Compound (6) [e]		
	δ	$J(^{13}CH)$	J_{Fine}	δ	$J(^{13}CH)$	J_{Fine}	δ	$J(^{13}CH)$	J_{Fine}
C-1	130.3 (131.9)			130.7 (130.9)			125.8 (130.3)		
C-2	108.0 (113.4)	155	5.9	108.7 (111.6)	145	5.5	111.3 (113.0)	155	5.9
C-3	146.3 (147.1)			148.7 (144.2)			148.0 (146.5)		
C-4	144.4 (140.1)			148.0 (143.4)			149.2 (139.6)		
C-5	114.3 (116.9)	158	0	111.2 (114.0)	157	0	115.6 (116.3)	159	0
C-6	118.9 (120.0)	167	5.9	118.4 (118.2)	167	5.8	122.7 (119.6)	156	*h*

[a] P.p.m. downfield of internal $SiMe_4$. [b] Ref. 1. [c] Ref. 2*a* and *b*. [d] Chemical shift taken from mean of broad-band-, off-resonance-, and gated-decoupling spectra. [e] Ref. 2*a* and *c*. [f] Calculated values in parentheses. [g] Apparent indirect $^{13}C-^{1}H$ coupling, see text. [h] Not resolved or too complex.

TABLE 2

^{13}C Chemical shift [a] and coupling-constant data for the side-chain carbons of compounds (6)—(9)

	C-α(CO_2H)			C-β			C-γ		
Compound	δ	$J(^{13}CO_2H)$	$J(COH)$	δ	$J(^{13}CH)$	J_{Fine} [b]	δ	$J(^{13}CH)$	J_{Fine} [b]
(6)	167.9	7.2	3.2	115.6	159	0	144.5	153	4.5
(7)	169.7	6.3	2.8	116.3	159	0	146.6	154	4.5
(8)	168.8	7.1	2.8	115.7	159	0	145.9	152	4
(9)	167.7	7.2	3.1	119.1	161	0	145.1	153	4

[a] P.p.m. downfield of internal $SiMe_4$. [b] Footnote *g* Table 1.

Examination of indirect $^{13}C-^{1}H$ couplings in benzene[3] has shown the following inter-ring couplings (Hz): $J(^{13}CH) = 157.5$, $J(^{13}CCH) = +1.0$, $J(^{13}CCCH) = +7.4$, and $J(^{13}CCCCH) = -1.1$. Values for 1,3,5-trichlorobenzene are not substantially different.[4] It is important to note the relatively large 3-bond coupling. Given the situation in which differences in carbon chemical-shifts are substantial we, therefore, ascribe the origin of a sharp doublet in undecoupled ^{13}C n.m.r. spectra of substituted benzenes to (*a*) direct $^{13}C-^{1}H$ coupling and (*b*) a combination of coupling to *ortho*- and *para*-protons in the absence of *meta*-coupling, *i.e.* when the remaining indirect couplings are less than (8 k interferogram) or of the order of (16 k interferogram) the theoretical resolution. Such an observation is generally predictable and in our examples this applies successfully to C-3 [compound (1)] or C-5 [compounds (2)—(6)]. Further application of these rules to the other unsubstituted carbons predicts the observation of fine structure since *meta*-protons are now present and the coupling is much greater than the theoretical resolution. It was not our purpose to undertake a rigorous analysis of the splitting patterns observed for the latter, although it is evident from the apparent coupling constants observed (Table 1) that indirect coupling is dominated by the *meta*-proton now present. If the rationale above is extended further to the couplings observed in the olefinic side-chain of the acids (6)—(9), a very small indirect coupling between each carbon and the vicinal proton $J(^{13}CCH)$ is predicted. Additionally however, C-γ is placed in the favourable position 3 bonds away from the

---

[3] F. J. Weigert and J. D. Roberts, *J. Amer. Chem. Soc.*, 1967, **89**, 2967.

[4] R. Freeman, *J. Chem. Phys.*, 1965, **43**, 3087.

protons on C-2 and C-6 and always shows a doublet (J = 152—154 Hz) of apparent triplets (J = 4—5 Hz). We consider this treatment justified, particularly since proton–carbon couplings in olefinic systems have been used as models for benzene.[3,5] We should also add that the carboxy-carbon (C-α) shows always a clear first-order doublet of doublets (Table 2), the larger coupling varying from 6.3 to 7.2 Hz. This is in excellent agreement with the expected three-bond coupling of *ca.* 7 Hz to the proton on C-γ. Since C-β shows no indirect coupling the smaller coupling of 2.8—3.2 Hz probably derives from the carboxy-proton, although we note that such values appear to be somewhat hard to find in the literature.[6,7]

We find that the basic doublet structure in the coupled spectra of C-β in compounds (1), (2), (4), and (5) unlike that in compounds (6)—(9) is supplemented by fine structure. We tentatively ascribe this interaction to the methyl protons. In this respect our observations above, as well as those from earlier work,[3,4] applied to indirect ^{13}C–^{1}H coupling transmitted between exclusively sp^2 carbons. If, as expected, the magnitude of such couplings is dominated by the Fermi contact term, participation of an sp^3 carbon should predict an even smaller two-bond coupling than expected for vicinal ^{13}C–^{1}H coupling in the corresponding acid compounds. However, the presence of both couplings might be expected to provide for the effects observed. Further work on this problem is in progress.

Conclusion.—We have shown, in accordance with earlier observations and theory, that in undecoupled ^{13}C n.m.r. spectra of asymmetrically trisubstituted benzenes, the C-5 carbon will show only direct proton coupling. In addition, though in a less precise fashion, the splitting patterns for the other unsubstituted carbons can be predicted. It is our opinion that, given the rules we propose, routine gated decoupling experiments such as those we have described, provide a convenient and far less amgibuous means of assignment compared, in particular, to off-resonance decoupling.

We offer our sincere thanks to Dr. K. H. Kubeczka for the gift of many of the compounds used (see Experimental section), and to Mr. V. Formacek for valuable discussions.

[5/1599 *Received*, *7th August*, 1975]

---

[5] G. J. Karabatsos, J. D. Graham, and F. M. Vane, *J. Amer. Chem. Soc.*, 1962, **84**, 37.

[6] G. A. Olah and A. M. White, *J. Amer. Chem. Soc.*, 1969, **91**, 5801.

[7] G. A. Olah and A. M. White, *J. Amer. Chem. Soc.*, 1967, **89**, 7072.