Monatshefte für Chemie 125, 1101–1111 (1994)

**Monatshefte für Chemie**
**Chemical Monthly**


# NMR Spectroscopy of Organophosphorus Compounds II [1]: Stereochemistry of [1-(2*H*-Azirin-2-yl)alkyl]phosphonates#

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**Summary.** The conformation and relative configuration of [1-(2*H*-azirin-2-yl)alkyl]phosphonates (**2**) has been established by thorough investigation of some characteristic representatives of the series by $^{1}H$, $^{13}C$, $^{15}N$, and $^{31}P$ NMR spectroscopy. It is shown that the chemical shift of the proton located $\alpha$ to the phosphonate group can be used as a criterion for the discrimination and stereochemical assignment of diastereoisomers. NMR spectroscopic features of the compounds are discussed in terms of structural relationships.

**Keywords.** [1-(2*H*-Azirin-2-yl)alkyl]phosphonates; Configuration; Conformation; Diastereotopy; NMR.

**NMR-Spektroskopie von phosphororganischen Verbindungen, 2. Mitt. [1]: Stereochemie von [1-(2*H*-Azirin-2-yl)alkyl]phosphonaten**

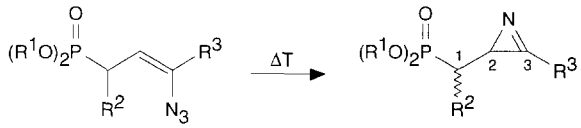
**Zusammenfassung.** Die detaillierte NMR-spektroskopische Untersuchung ($^{1}H$, $^{13}C$, $^{15}N$, $^{31}P$) einiger charakteristischer Vertreter von [1-(2*H*-Azirin-2-yl)alkyl]phosphonaten erlaubte es, Konformation und relative Konfiguration der betreffenden Verbindungen zu bestimmen. Die chemische Verschiebung des bezüglich des Phosphonatrests $\alpha$-ständigen Protons kann als Kriterium zur Unterscheidung und stereochemischen Zuordnung von Diastereomeren herangezogen werden. Die Phänomenologie der NMR-Spektren wird im Zusammenhang mit strukturellen Parametern diskutiert.

## Introduction

In the course of a synthetic project aiming at a diastereoselective approach to substituted [(aziridin-2-yl)alkyl]phosphonates, various [1-(2*H*-azirin-2-yl)alkyl]-phosphonates have been prepared as intermediate products [2]. Starting from allylic $\alpha$- or $\gamma$-hydroxyphosphonates which are transformed to the corresponding azido-phosphonates, the reaction finally involves a ring closure of phosphonate substituted vinylazides (**1**) to 2*H*-azirines (**2**; Scheme 1). Thermolysis of vinylazides **1** with $R^2$ different from H afforded two diastereomeric cyclization products **2**. In the context

# Dedicated to Univ.-Prof. Dr. *K. Schlögl* with the best wishes to his 70th birthday

of a further synthetic utilization of the 2*H*-azirines, the necessity of an easy, fast, and reliable method for their stereochemical assignment became evident. In this paper, we report a multinuclear NMR spectroscopic investigation of model compounds **2a–c** whose conformation in solution and relative configuration have been established by means of NOE data and homo- and heteronuclear coupling constants.




1 2

| | $R^1$ | $R^2$ | $R^3$ |
|---|---|---|---|
| **2a** | Et | H | Ph |
| **2b** | $^i$Pr | *R*-Me | Ph |
| **2c** | $^i$Pr | *S*-Me | Ph |

**Scheme 1.** The stereochemical descriptors *R* and *S* refer to a configuration at C(2) arbitrarily assumed to be *R*

The labelling of carbons as given in Scheme 1 and the naming of compounds **2a–c** in the title and throughout the text has been chosen for convenience. According to IUPAC nomenclature, compounds **2a–c** have to be designated as follows: **2a**, phosphonic acid, [(3′-phenyl-2′*H*-azirin-2′-yl)methyl], diethyl ester; **2b**: phosphonic acid, [(1*RS*,2′*RS*)-1-(3′-phenyl-2′*H*-azirin-2′-yl)ethyl], diisopropyl ester; **2c**: phosphonic acid, [(1*SR*,2′*RS*)-1-(3′-phenyl-2′*H*-azirin-2′-yl)ethyl], diisopropyl ester.

## Results and Discussion

For the interpretation of NMR data related to structural features like coupling constants and NOE enhancements, first of all an unambiguous NMR spectroscopic assignment of the substances under investigation has to be established. For compounds **2a–c**, although of rather low molecular weight, this task can be accomplished only in part directly from chemical shift and coupling arguments. The large number of transitions arising from the diastereotopy of the phosphonate residues (and, of course, the protons at C(1) in the case of **2a**) and from phosphorus-proton coupling leads to severe signal overlap. Moreover, H–C(2) and one of the protons at C(1) are perfectly isochronous in $CDCl_3$ solution (cf. Table 1), giving rise to higher order spectra with nontrivial coupling patterns and missing coupling constants. We therefore started our evaluation from a sample of **2a** in $C_6D_6$ where solvent anisotropy causes the degenerate chemical shifts mentioned above to separate. The approximate chemical shifts and coupling constants derived from a $^{31}P$ decoupled proton NMR spectrum of **2a** in $C_6D_6$ were submitted to an iterative spin system calculation giving the exact values for the three-spin system *pro-R*–H–C(1)/*pro-S*–H–C(1)/H–C(2). These in turn served as input for the computation of the

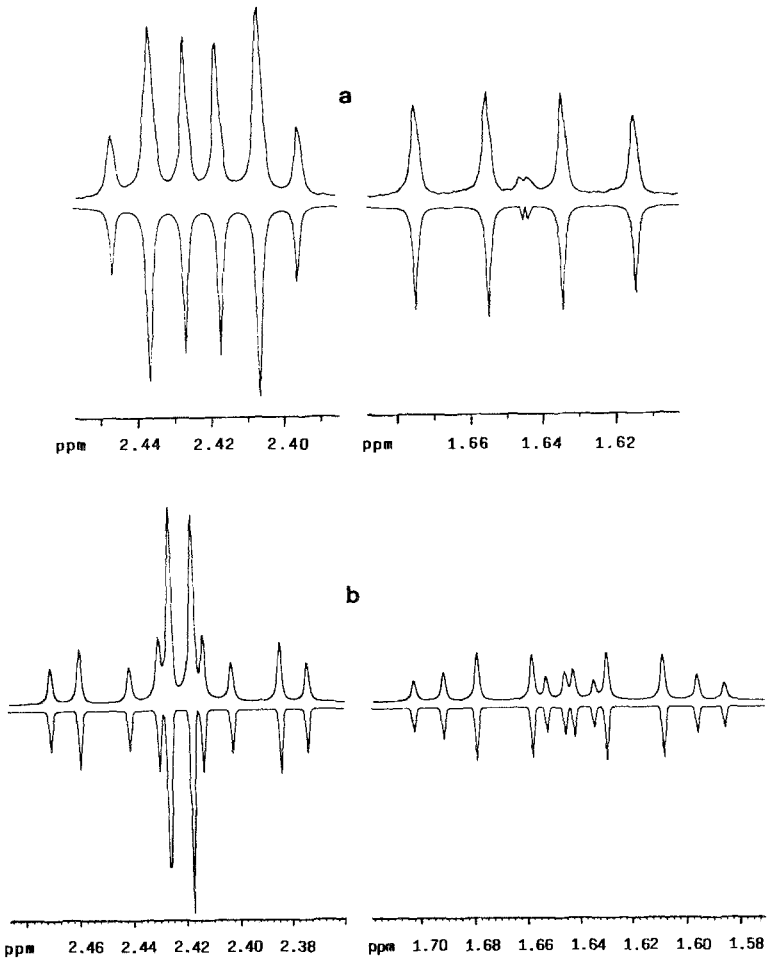



**Fig. 1.** Experimental (upper trace) and calculated (lower trace) $^1$H NMR spectra of the spin system *pro-R*-H–C(1)/*pro-S*-H–C(1)/H–C(2) of compound **2a** in $CDCl_3$; a: $^{31}$P decoupled; b: fully coupled; for chemical shifts and coupling constants, see Tables 1, 4, and 5

corresponding parameters of **2a** in $CDCl_3$ in an analogous way. Having achieved a satisfactory agreement between experimental and calculated data, the same procedure was applied to phosphorus coupled spectra, yielding in addition phosphorus-proton coupling constants (Fig. 1). With this information at hand, the proton NMR spectra of **2b** and **2c** could be assigned straightforwardly (Tables 1, 4, and 5). It should be noted, however, that the chemical shifts of the diastereotopic protons at C(1) have still to be regarded as interchangeable at this stage of investigation.

Connectivities within the phosphonate residues were established by $^{31}$P decoupled H,H-COSY experiments. As an example for the complexity of the spectra in the alkoxy regions even if phosphorus couplings are eliminated, the relevant section of the $\{^{31}P\}$H,H-COSY spectrum of **2b** is shown in Fig. 2. The assignment of the $^{13}$C NMR spectra of **2a–c** was performed *via* HMQC experiments, yielding $^{13}$C chemical shifts and – more important in the context of spatial structure determination – $^{31}$P, $^{13}$C coupling constants. As a result of the above assignment

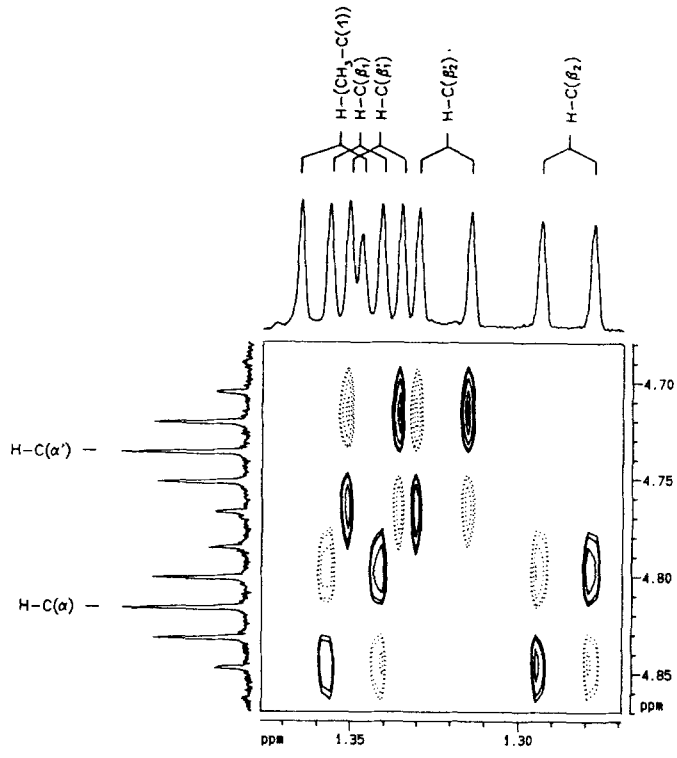



**Fig. 2.** Section plot of the $\{^{31}P\}$DQF-H,H-COSY spectrum of **2b** (solid lines: positive levels; dotted lines: negative levels; for lettering, see legend of Table 1); all methyl groups are contained within a region of 0.1 ppm; isopropyl and methyl protons of the alkoxy residues are unequivocally connected and may not be interchanged arbitrarily

strategy, consistent sets of $^{1}H$ and $^{13}C$ NMR data for the phosphonate residues were obtained. Consequently, the usual interchangeability of chemical shifts and coupling constants among equal substituents at a specific site is restricted to an exchange of the alkoxy assignment as a whole for compounds **2a–c** (see also legend of Table 1).

For details of the $^{15}N$ and $^{31}P$ NMR experiments, see Experimental. No interpretable $^{17}O$ NMR spectrum could be obtained from any of the compounds due to the extreme line widths of the oxygen resonances of **2a–c** [3]. All shift and coupling data are presented in Tables 1–6.

The most striking fact regarding the $^{1}H$ NMR spectrum of **2a** is the large chemical shift difference (0.77 and 0.82 ppm in $CDCl_3$ and $C_6D_6$, respectively) of the diastereotopic protons at C(1). This effect can only be rationalized assuming a highly restricted mobility about the C(1)–C(2) bond and, as a consequence thereof, a rather different chemical environment of *pro-R*–H–C(1) and *pro-S*–H–C(1) within the molecule. Making use of the available vicinal coupling information ($^{3}J_{H,H}$, $^{3}J_{P,H}$, and $^{3}J_{P,C}$) and the classical *Karplus* dependence of coupling constants on the dihedral angle [4–8], a preferred conformation can be derived which is depicted in Fig. 3 as *Newman* projection along the axis C(1) → C(2)*.

The tendency of **2a** to adopt a conformation with the phosphonate residue oriented opposite to the phenyl ring may well be understood taking into account the steric demand of the bulky phosphonate group. Molecular model considerations clearly demonstrated that the spatial structure derived from

* Bond lengths and bond angles of the azirine ring have been taken from Refs. [9, 10]

**Table 1.** $^1$H chemical shifts of compounds **2a–c** ($CDCl_3$ unless stated otherwise; ppm; relative to internal *TMS*); greek letters denote the positions in the alkoxy groups of the phosphonate residues relative to the ester oxygen atom (for **2a**, replace $\beta_1$ by $\beta$ and $\beta'_1$ by $\beta'$); italics refer to the aromatic substituent in the usual manner; [1]in $C_6D_6$; [2]calculated values (see text); [3]experimental and calculated values are identical; [a–j]chemical shifts marked with the same superscript may be interchanged provided the assignment of the alkoxy residues as a whole ($^1$H, $^{13}$C, coupling constants) remains consistent

| | **2a** | **2a**[1] | **2b** | **2c** |
|---|---|---|---|---|
| H–C(1) | 2.42[2]/1.65[2] (*pro-R*/*pro-S*) | 2.34[3]/1.52[3] (*pro-R*/*pro-S*) | 1.55 | 2.36 |
| H–($CH_3$–C(1)) | – | – | 1.36 | 0.74 |
| H–C(2) | 2.42[3] | 2.46[3] | 2.33 | 2.52 |
| H–C($\alpha$) | 4.14[a] | 3.94[c] | 4.82[e] | 4.76[h] |
| H–C($\beta_1$) | 1.30[b] | 1.02[d] | 1.35[f] | 1.32[i] |
| H–C($\beta_2$) | – | – | 1.29[f] | 1.26[i] |
| H–C($\alpha'$) | 4.09[a] | 3.83[c] | 4.74[e] | 4.70[h] |
| H–C($\beta'_1$) | 1.27[b] | 0.96[d] | 1.34[g] | 1.29[j] |
| H–C($\beta'_2$) | – | – | 1.32[g] | 1.29[j] |
| H–C(*o*) | 7.98 | 8.07 | 8.08 | 7.98 |
| H–C(*m*) | 7.52 | 7.07 | 7.55 | 7.47 |
| H–C(*p*) | 7.55 | 7.07 | 7.56 | 7.48 |

**Table 2.** $^{13}$C chemical shifts of compounds **2a–c** ($CDCl_3$ unless stated otherwise; ppm; relative to internal *TMS*); for greek letters and italics, refer to Table 1; for **2a**, replace $\beta_1$ by $\beta$ and $\beta'_1$ by $\beta'$; [1]in $C_6D_6$; [a–j]chemical shifts marked with the same superscript may be interchanged provided the assignment of the alkoxy residues as a whole ($^1$H, $^{13}$C, coupling constants) remains consistent

| | **2a** | **2a**[1] | **2b** | **2c** |
|---|---|---|---|---|
| C(1) | 31.24 | 31.99 | 37.38 | 33.69 |
| $CH_3$–C(1) | – | – | 12.69 | 10.12 |
| C(2) | 26.02 | 26.53 | 32.93 | 31.57 |
| C(3) | 170.33 | 170.58 | 170.80 | 169.78 |
| C($\alpha$) | 61.86[a] | 61.51[c] | 70.31[e] | 70.18[h] |
| C($\beta_1$) | 16.40[b] | 16.48[d] | 24.11[f] | 24.09[i] |
| C($\beta_2$) | – | – | 24.07[f] | 23.97[i] |
| C($\alpha'$) | 61.66[a] | 61.30[c] | 70.09[e] | 70.16[h] |
| C($\beta'_1$) | 16.30[b] | 16.34[d] | 24.12[g] | 24.06[j] |
| C($\beta'_2$) | – | – | 24.04[g] | 23.98[j] |
| C(*i*) | 124.81 | 125.82 | 125.41 | 125.76 |
| C(*o*) | 129.79 | 130.04 | 129.87 | 129.62 |
| C(*m*) | 128.99 | 129.08 | 128.92 | 128.82 |
| C(*p*) | 133.12 | 132.79 | 132.95 | 132.85 |

**Table 3.** $^{15}N$ and $^{31}P$ chemical shifts of compounds **2a–c** ($CDCl_3$; ppm; $^{15}N$: relative to external nitromethane; $^{31}P$: relative to external 85% phosphoric acid)

| | **2a** | **2b** | **2c** |
|---|---|---|---|
| $^{15}N$ | −103.96 | −105.62 | −106.90 |
| $^{31}P$ | 28.71 | 29.35 | 29.95 |

**Table 4.** $^1H,^1H$ coupling constants of compounds **2a–c** (Hz); for greek letters, refer to Table 1

| | **2a** ($CDCl_3$, calc.) | **2a** ($C_6D_6$, exp.) | **2a** ($C_6D_6$, calc.) |
|---|---|---|---|
| *pro-R*–H–C(1), *pro-S*–H–C(1) | −15.5 | −15.1 | −15.3 |
| *pro-R*–H–C(1), H–C(2) | 4.3 | 4.1 | 4.0 |
| *pro-S*–H–C(1), H–C(2) | 7.1 | 7.4 | 7.3 |
| H–C(α; α′), H–C(β; β′) | 7.2 | 7.2 | – |
| | **2b** | **2c** | |
| H–C(1), H–C(2) | 6.9 | 3.3 | |
| H–C(1), H–($CH_3$–C(1)) | 7.4 | 7.3 | |
| H–C(α, α′), H–C($\beta_1, \beta_2$; $\beta'_1, \beta'_2$) | 6.3 | 6.2 | |

**Table 5.** $^{31}P,^1H$ coupling constants of compounds **2a–c** (Hz); [1]experimental values; [a,b]values with the same superscript may be interchanged (see, however, legend of Table 1); for greek letters, refer to Table 1

| | **2a** ($CDCl_3$, calc.) | **2a** ($C_6D_6$, exp.) | **2a** ($C_6C_6$, calc.) |
|---|---|---|---|
| P, *pro-R*–H–C(1) | −18.6 | −18.7 | −18.7 |
| P, *pro-S*–H–C(1) | −19.8 | −19.8 | −19.6 |
| P, H–C(2) | 3.4 | 3.3 | 3.4 |
| P, H–C(α) | $8.5^{1,a}$ | $8.9^b$ | – |
| P, H–C(α′) | $8.0^{1,a}$ | $8.3^b$ | – |
| | **2b** | **2c** | |
| P, H–C(1) | −20.6 | −20.8 | |
| P, H–($CH_3$–C(1)) | 18.2 | 18.8 | |
| P, H–C(2) | 2.6 | 3.2 | |
| P, H–C(α, α′) | 7.7 | 7.7 | |

**Table 6.** $^{31}P$, $^{13}C$ coupling constants of compounds **2a–c** (Hz, absolute values); [a–j]values with the same superscript may be interchanged (see, however, legend of Table 1); for greek letters and italics, refer to Table 1; for **2a**, replace $\beta_1$ by $\beta$ and $\beta'_1$ by $\beta'$

| | **2a** | **2a**[1] | **2b** | **2c** |
|---|---|---|---|---|
| P, C(1) | 138.1 | 136.6 | 140.1 | 141.3 |
| P, $CH_3$–C(1) | – | – | 4.7 | 5.6 |
| P, C(2) | 2.9 | 2.9 | 0.0 | 0.0 |
| P, C(3) | 4.4 | 4.4 | 3.1 | 2.9 |
| P, C($\alpha$) | 6.5[a] | 5.2[e] | 7.1[e] | 7.1[h] |
| P, C($\beta_2$) | 7.3[b] | 5.8[d] | 3.6[f] | 3.6[i] |
| P, C($\beta_2$) | – | – | 4.7[f] | 4.7[i] |
| P, C($\alpha'$) | 6.5[a] | 5.5[e] | 7.1[e] | 7.1[h] |
| P, C($\beta'_1$) | 7.3[b] | 5.8[d] | 3.8[g] | 3.8[j] |
| P, C($\beta'_2$) | – | – | 4.7[g] | 4.9[j] |
| P, C(*i*) | 2.2 | 2.9 | 2.5 | 2.5 |

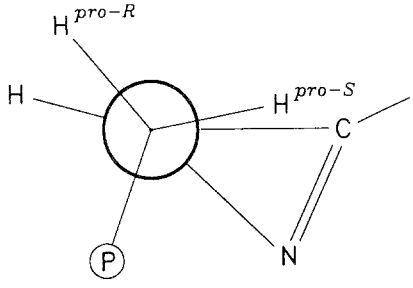



**Fig. 3.** *Newman* projection of the preferred conformation of compound **2a** in solution with respect to the C(1)–C(2) bond as derived from $^3J_{H,H}$, $^3J_{P,H}$, and $^3J_{P,C}$

NMR spectroscopy fulfills the condition of least steric strain. As there is no indication for some kind of residual mobility about the C(1)–C(2) bond in the NMR spectrum of any of the observed nuclei at room temperature, the rotational barrier must be supposed to be rather high. However, no attempts have been made to determine the thermodynamic parameters of the system during the present investigation.

Having achieved a sensible conception of the molecular structure of **2a** in solution, NOE difference spectra were recorded to get a cross-check of the data accumulated so far and an unambiguous assignment of *pro-R*–H–C(1) and *pro-S*–H–C(1). Because of the above mentioned accidental isochrony of H–C(2) and one of the protons at C(1) in $CDCl_3$, these experiments were performed in $C_6D_6$ solution. Dipolar interactions between H–C(*o*) and H–C(2) confirmed the correct assignment of the aromatic protons and the azirine proton. In addition, the C(1) proton at $\delta = 1.52$ ppm experiences an NOE effect upon irradiation of H–C(*o*). Taking into account the previously derived conformation of **2a**, this shift value has to be assigned to *pro-S*–H–C(1) (cf. Fig. 3), whose distance to H–C(*o*) – as can easily be verified with the help of a *Dreiding* molecular model – is only slightly larger than the distance of two *ortho* protons within an aromatic ring. As a consequence, the signal at 2.34 ppm must be ascribed to *pro-R*–H–C(1), thus completing the NMR spectroscopic assignment of **2a** in $C_6D_6$. Regarding the very similar patterns of the spin

system *pro-R*–H–C(1)/*pro-S*–H–C(1)/H–C(2) in both $C_6D_6$ and $CDCl_3$, the assignment of **2a** in chloroform solution has been accomplished by analogy (Table 1). Looking for an explanation of the unusually large $\Delta\delta$ of the diastereotopic protons, their chemical environment was screened for structural elements of potential influence on their chemical shift values. However, the geometry of **2a** is such that neither the phenyl ring nor the C=N bond can be held responsible for the observed effects: the aromatic moiety is too far away to exert a noticeable influence on any of the protons in question, and as to the azirine double bond, *pro-S*–H–C(1) is located almost exactly on the equishielding suface of its anisotropy cone whereas *pro-R*–H–C(1) is again too far apart to permit an explanation of its chemical shift solely by the anisotropy effect of the C=N bond. These structure derived considerations are corroborated experimentally by the observation that the effect also occurs when $R^3$ is different from phenyl and – although less pronounced – with the corresponding aziridines [2]. Major contributions from the heteroatoms nitrogen and phosphorus can also be excluded on the basis of the NMR spectroscopic behaviour of **2b** and **2c** as will be seen later.

As a final resort, the anisotropy of the C(2)–C(3) single bond was taken into consideration, being the only environmental factor differing strongly for *pro-R*–H–C(1) and *pro-S*–H–C(1) (Fig. 3). In the chemistry of six-membered cyclic compounds, it is a well known fact that the difference in chemical shifts between equatorial and axial protons can be explained by this phenomenon [11] which has been investigated theoretically in the early days of NMR spectroscopy [12, 13] and can be summoned in the *McConnell* equation given below ($\Delta\sigma$: shielding contribution; $\Delta\chi$: magnetic anisotropy; $r$: distance from center of bond; $\theta$: angle between bond and distance vector).

$$\Delta\sigma = \Delta\chi \frac{(1 - 3\cos^2\theta)}{12\pi r^3}$$

Values for $\theta$ and $r$ for *pro-R*–H–C(1) and *pro-S*–H–C(1) with respect to the center of the C(2)–C(3) single bond were derived independently from a *Dreiding* molecular model, a geometric drawing, and a PC based molecular modelling algorithm [14]. All methods yielded virtually identical results. Inserting these parameters in the *McConnell* equation demonstrates that the shielding contributions resulting from the anisotropy of the C(2)–C(3) bond amount to −0.28 ppm for *pro-R*–H–C(1) and to +0.26 ppm for *pro-S*–H–C(1), giving rise to a chemical shift difference of 0.54 ppm for the diastereotopic protons (Table 7). Furthermore, the calculation confirms their assignment derived from coupling information and NOE data, taking into account that shielding and chemical shift are of opposite sign.

Bearing in mind that considerations as given above have to be looked at cautiously due to imperfections in the determination of molecular geometry and to literature values for $\Delta\chi$ which mostly are more or less rough estimations derived from model compounds or semiempirical calculations [11], the coincidence between calculated (0.54 ppm) and observed (0.77 and 0.82 ppm in $CDCl_3$ and $C_6D_6$, respectively) $\Delta\delta$ values has to be regarded as rather satisfactory. However, the theoretical model might fit still better to the experimental data taking into account effects caused by the C(2)–N single and the C(3)–N double bond. As mentioned earlier, *pro-S*–H–C(3) is suspected to experience no or almost no effect due to its

**Table 7.** Chemical shielding contributions $\Delta\sigma$ (ppm) as calculated from the *McConnell* equation assuming $\Delta\chi_{C-C} = 140 \cdot 10^{-36}$ m$^3$/molecule [11]; $r$ (pm): distance from the center of the C(2)–C(3) bond; $\theta$ (degrees): angle between distance vector and C(2)–C(3) bond; note that the contribution to the chemical shift value has the opposite sign of $\Delta\sigma$

| | *pro-R*–H–C(1) | *pro-S*–H–C(1) |
|---|---|---|
| $r$ | 270 | 210 |
| $\theta$ | 25 | 70 |
| $\Delta\sigma$ | −0.28 | +0.26 |

location on the equishielding surface of the C=N anisotropy cone. The same is true with respect to the C(2)–N single bond. The remaining $\Delta\delta$ of approximately 0.25 ppm should therefore result from contributions to the deshielding of *pro-R*–H–C(1) only. No literature values are available for $\Delta\chi_{C-N}$ and $\Delta\chi_{C=N}$, and the effects exerted upon *pro-R*–H–C(1) by both C(3)=N and C(2)–N cannot be separated. Therefore, the respective contributions to its chemical shift could not be estimated. However, as $\Delta\delta$ values for azirine derivatives are considerable larger than those for the corresponding aziridines (*vide supra*) [2], the only structural difference being the replacement of a double by a single bond in the latter case, we suppose that the main contribution to the additional deshielding of *pro-R*–H–C(1) originates from C(3)=N. An evaluation of $\Delta\chi_{C=N}$ *via* the *McConnell* equation using $\Delta\sigma = -0.25$ ppm, $r = 340$ pm and $\theta = 21$ degrees yields a value of approximately $230 \cdot 10^{-36}$ m$^3$/molecule, which fits well between literature data for C–C single and triple bonds both in sign and magnitude [11].

When looking at the chemical shift of H–C(1) in the diastereomeric compounds **2b** and **2c**, one immediately recognizes the coincidence of the $\delta$ values with those of one of the diastereotopic protons at C(1) in **2a** in each case (Table 1). It has therefore to be assumed that the chemical environment of H–C(1) in **2b** equals that of *pro-S*–H–C(1) and the surroundings of H–C(1) in **2c** are similar to those of *pro-R*–H–C(1) in **2a**. This in turn leads to the conclusion that the conformational behaviour of **2b** and **2c** is governed exclusively by the steric demand of the phosphonate residue, whereas the methyl group is of no noticeable influence.

The correctness of the above argumentation has been proved by NOE experiments rendering connectivities between H–C(*o*) and H–C(1) in **2b** and H–C(*o*) and H–($CH_3$–C(1)) in **2c**. Moreover, as can also be seen from Table 1, the methyl groups at C(1) in compounds **2b** and **2c** exhibit a $\Delta\delta$ of 0.62 ppm which is comparable to the $\Delta\delta$ values found for *pro-R*–H–C(1) and *pro-S*–H–C(1) in **2a**. The reasons for this behaviour are obviously the same as those discussed earlier for the respective protons. As expected, the methyl group of **2b**, which is turned away from the azirine ring, is shifted to lower field, whereas the methyl group of **2c**, located above the C(2)–C(3) single bond, experiences an upfield shift. The $^{13}$C chemical shifts of $CH_3$–C(1) in **2b** and **2c** show an identical attitude: the shift difference amounts to 2.57 ppm (Table 2), again resulting from a lowfield shift in **2b** and a highfield shift in **2c**.

To make sure that no significant contribution to the shift characteristics of compounds **2a–c** has been overlooked, their $^{15}N$ and $^{31}P$ NMR spectra have been recorded (Table 3). The chemical shifts of these nuclei are very similar for all compounds under investigation. This is not surprising in the case of $^{31}P$; however, if there were any interaction between $CH_3$–C(1) in **2c** and the nitrogen atom, this ought to manifest itself in a difference in $\delta(^{15}N)$ for compounds **2b** and **2c**. This is obviously not the case, again demonstrating the neglegible influence of the methyl group on the conformations of **2b** and **2c**.

Taking into account all infromation derived from the evaluation of the NMR spectra of compounds **2a–c**, the results can be summarized as follows:

(1) The solution conformation of [1-(2*H*-azirin-2-yl)alkyl]phosphonates and [(aziridin-2-yl)alkyl]phosphonates is governed by the tendency of the phosphonate group to adopt a position nearly opposite to substituents at C(3).
(2) The rotational barrier about the C(1)–C(2) bond seems to be rather high; no conformational interchangement can be observed at room temperature.
(3) The chemical shifts of protons (and methyl substituents) at C(1) are controlled mainly by the anisotropy of the C(2)–C(3) single bond and can serve as an indicator of stereochemistry.
(4) The relative configurations of compounds **2b** and **2c** are (1*RS*,2*RS*) and (1*SR*,2*RS*), respectively, in terms of the carbon labelling used throughout this paper. For systematic nomenclature, see introduction.
(5) Generally, the relative configurations of substituted [1-(2*H*-azirin-2-yl)alkyl] phosphonates and [(aziridin-2-alkyl]phosphonates can be derived from the resonance position of H–C(1) in the proton NMR spectrum which is always shifted to higher field for the isomer with H–C(1) located above the C(2)–C(3) single bond. The effect is more pronounced fo azirine derivatives, probably due to an additional influence of the C=N bond, and allows a definitive stereochemical assignment for this class of compounds even if only one diastereomer is available.

## Experimental

The synthesis of compounds **2a–c** has been described elsewhere [2]. All NMR spectra were recorded at 300 K on a Bruker AM 400 WB NMR spectrometer operating at 9.395 T ($^1H$, 400.13 MHz; $^{13}C$, 100.62 MHz; $^{31}P$, 161.98 MHz; $^{15}N$, 40.56 MHz) using a dual probe ($^1H/^{13}C$, 5 mm) for phosphorus coupled proton and carbon experiments, a triple resonance probe ($^1H/^{13}C/^{31}P$, 10 mm) for the generation of phosphorus decoupled $^1H$ and $^{13}C$ spectra, and an inverse probe (5 mm) with tunable heteronucleus coil for $^{15}N$ and $^{31}P$ measurements. For solvents and reference substances, see Tables 1–3. Samples were degassed by a stream of argon prior to the acquisition of NOE difference spectra. $^{31}P$ decoupling was performed in the CW mode (B-SV 3 BX frequency generator), whereas $^{13}C$ decoupling (HMQC spectra) was effected by a GARP1 sequence [15] and a BFX-5 amplifier. Exclusively original software supplied by the spectrometer manufacturer [16] was used (NOE difference, multiple irradiation [17, 18]; $^{13}C$, SEFT [19]; $^{15}N$, inverse gated (pulse angle 30°, relaxation delay 5 s, CPD decoupling); $^{31}P$, CPD decoupling; 2D, DQF-COSY [20, 21] and HMQC [22] (both experiments with and without $^{31}P$ coupling)). Data were processed on a UNIX workstation (Aspect X32) using the UXNMR software package [23]. Spin systems were calculated and iterated on the spectrometer computer (Aspect 3000) by the PANIC algorithm [24].

## Acknowledgements

The authors express their gratitude to the *Hochschuljubiläumsstiftung der Stadt Wien* and to the *Fonds zur Förderung der wissenschaftlichen Forschung in Österreich* (Project No. P 6537 C) for financial support.

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*Received May 13, 1994. Accepted May 27, 1994*