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Rearrangement

Stereoselective Cyclopropanation as a Way to 1-Aminocyclopropane-1-phosphonic Acids: Rationale for Phosphoryl Group Migration

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Abstract: Asymmetric cyclopropanation of vinylphosphonates by using (*S*)-dimethylsulfonium(*p*-tolylsulfinyl)methylide and subsequent highly stereoselective methylation provided substituted cyclopropylphosphonates, which are useful intermediates in the synthesis of rigid aminophosphonic acids. However, in some examples desulfinylation by *i*PrMgCl led to 1,2-migration of the phosphoryl group. The scope of this transformation was investigated by changing the temperature, electronegativity of the substituent α to phosphoryl group, and the configuration of the cyclopropylphosphonates. It was found that a *cis* relationship between the phosphoryl and sulfinyl groups led exclusively to the product of migration. It was proposed that the rearrangement occurred as an internal process in a concerted manner. The feasibility of an intramolecular mechanism was supported by DFT calculations. The products of desulfinylation with retained structure were used for the synthesis of enantiomerically pure 1-aminocyclopropane-1-phosphonic acids.

Introduction

The extraordinary richness of organophosphorus compounds, their tremendous structural and electronic diversity, as well as their specific chemical behavior make them versatile reagents that play a very important role in modern synthetic organic chemistry. Bioisosteric phosphonic acid analogues of important compounds such as amino acids are finding increased interest. This is associated, among other issues, with their tetrahedral structure and thereby their related possible action as a "transition-state analogue".[1] Restriction of conformational flexibility has also proven effective in drug design to improve various properties of biologically active substances.[2] In particular, introduction of the cyclopropane ring into amino acids leads to structures selective in binding with different subtypes of receptors. This is why aminocyclopropanephosphonic acids have become a subject of intense investigation.[3]

It is well known that the biological activity of amino acids and derivatives depends on the absolute configuration, so to find an efficient way of controlling the stereochemistry around the cyclopropane ring remains an important goal. In our recent work, we concentrated on the synthesis of cyclopropanes in enantiomerically pure form and their conversion into particular amino acids. Enantiopure sulfoxides have become an important class of chiral auxiliaries owing to their ease of preparation and the high level of asymmetric induction exerted by the chiral sulfinyl group. Moreover, chiral sulfur groupings that can induce asymmetry in the reaction can usually be removed easily from the molecule under mild conditions.[4] Recently, we designed a new type of chiral sulfur ylide as a single enantiomer containing a sulfinyl group bonded to the ylidic carbon atom.[5] Cyclopropanation of activated vinylic phosphonates by using this ylide was an effective way to prepare appropriate phosphonocyclopropyl sulfoxides, which became, according to our concept, convenient intermediates in the synthesis of conformationally constrained analogues of aminophosphonic acids.

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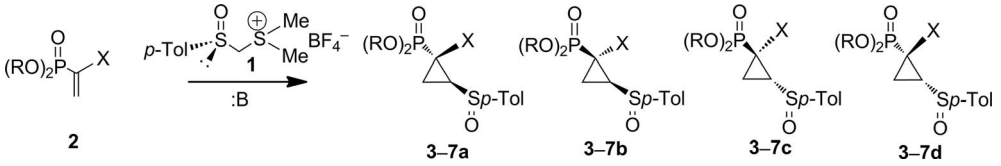
Results and Discussion

Cyclopropanation

(*S*)-Dimethylsulfonium(*p*-tolylsulfinyl)methylide (**1**) was shown to be an effective reagent for cyclopropane formation in a Michael-initiated ring closure (MIRC)-type reaction.[6] Cyclopropanation was performed with different vinylic phosphonates, additionally activated by a second electron-withdrawing substituent. The ylide was generated with NaH as a base prior to the reaction and was also formed in situ by reaction of **1** in the presence of potassium carbonate or 1,8-diazabicyclo-[5.4.0]undec-7-ene (DBU) as a base (Table 1).

Stereoselectivity was found to depend on the structure of the Michael acceptor and slightly on the reaction conditions. The relative configuration was determined by ^{1}H NMR spectro-

Table 1. Cyclopropanation of vinylic phosphonates with ylide **1**.



Entry	R	X	Reaction conditions	Cyclo-propane	Total yield [%]	Ratio of **a**/**b**/**c**/**d**[a]	Ratio *trans*/*cis*[b]	Facial selectivity
1.	Me	CO_2tBu	NaH/MeCN, 0 °C, 2 h	**3**	80	62:28:10:–	72:28	90:10
2.	Me	CO_2tBu	K_2CO_3/CH_2Cl_2, r.t., overnight	**3**	95	65:21:14:–	79:21	86:14
3.	Me/D[c]	CO_2tBu	NaH/MeCN, 0 °C, 2 h	*d*-**3**	76	62:28:10:–	72:28	90:10
4.	Et	CO_2Et	NaH/THF, 0 °C, 2 h	**4**	75	70.5:13:15:1.5	85.5:14.5	83.5:16.5
5.	Et	CO_2Et	NaH/MeCN, 0–20 °C	**4**	80	64:23:13:–	77:23	87:13
6.	Et	CO_2Et	NaH/MeCN, 0 °C	**4**	76	68:27:5:–	73:27	95:5
7	Et	CO_2Et	K_2CO_3/CH_2Cl_2, r.t., overnight	**4**	84	62:26:12:–	74:26	88:12
8.	Et/D[c]	CO_2Et	NaH/MeCN, –10 °C	*d*-**4**	78	64:23:13:–	77:23	87:13
9.	Et	CN	DBU/CH_2Cl_2, overnight	**5**	89	80:5:15:–	95:5	85:15
10.	Et	CN	K_2CO_3/CH_2Cl_2, r.t.	**5**	93	84:3.5:12.5:–	96.5:3.5	87.5:12.5
11.	Et	S*p*Tol	K_2CO_3/CH_2Cl_2, r.t., overnight	**6**	85	52:38:10:–	62:38	90:10
12.	Et	SO*p*Tol[d]	K_2CO_3/CH_2Cl_2, r.t., overnight	**7**	83	–:95:–:5	–:100	95:5
13.	Et	SO*p*Tol[d]	NaH/MeCN, 0 °C	**7**	74	–:95:–:5	–:100	95:5

[a] Ratio of diastereomers was established by analysis of the crude reaction mixture by ^{31}P NMR spectroscopy. [b] Relative to phosphonate group. [c] Me/D, Et/D = cyclopropane with CD_2 in the cyclopropane ring. [d] Enantiomerically pure (*S*)-(+)-(1-diethoxyphosphoryl)vinyl *p*-tolyl sulfoxide was used as the Michael acceptor.

scopy, for which the coupling constant values, $^3J_{HP}$, were usually conclusive for the assignment of the *cis* (J_{PH} ≈ 9.0 Hz) or *trans* (J_{PH} ≈ 15.0 Hz) geometry in substituted cyclopropylphosphonates. For convenience and clarity, we give the *cis*–*trans* description relative to the phosphonate group, even if it is not in accordance with the priority of substituents. Generally, steric congestion causes the phosphonate moiety to be considered as a *trans*-directing group,[7] and this was also the case in our reactions. The ratio of *trans* versus *cis* diastereomers depended on the relative sizes of both geminal substituents in the Michael acceptor. The best results were observed for a relatively small CN group; for sulfenyl and alkoxycarbonyl substituents, the diastereoselectivity was rather moderate, although for all substrates the *trans* isomers dominated. The only exception was cyclopropane **7** (Table 1, entries 12 and 13), which was formed against the phosphonate *trans*-directing-group rule, because full *cis* diastereoselectivity was established. We explained this result by dipole–dipole interaction between both polar sulfinyl substituents during cyclopropanation. Cyclopropane **7** should be treated as a special case, as its formation occurred under control of two sulfinyl auxiliaries. On the basis of the stereochemical pathways of cyclopropanations occurring under control of each sulfinyl group, the configuration of obtained product **7** was assigned tentatively.[8]

Facial selectivity for all performed experiments varied from 83.5:16.5 to 95:5 depending on the structure of the Michael acceptor. The highest ratio was observed for cyclopropane **7**, for which each of the two sulfinyl auxiliaries led to the same major isomer.[8]

DFT calculations performed earlier to understand the stereochemistry of epoxidation[9] indicate that the starting ylide is not planar, which implies diastereomerism of the reactant. It exists in a pyramidal form and the ylide carbon atom has a configuration close to sp^3 with the C-ylide and S-sulfoxide lone pairs of electrons in a *gauche* position. Although relatively low inversion barriers indicate that rapid inversion may take place in solution, conformation **B** seems to be more favorable than **A** owing to steric reasons. According to this assumption, approach of the ylide should lead to formation of a product with the 1*R* and 2*S* configurations on the newly formed stereogenic centers (Figure 1).

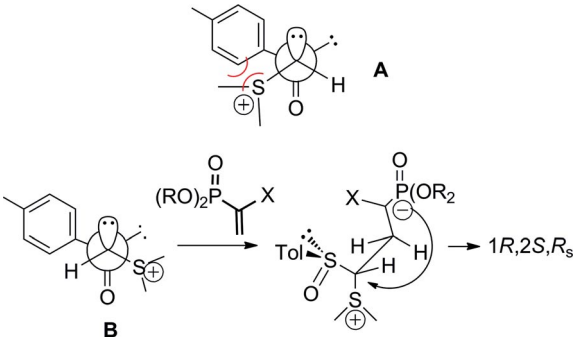


Figure 1. Preferential conformation **B** of ylide **1** and preferred intermediate leading to the major isomers.

Conclusive results were obtained from single-crystal X-ray diffraction analysis of *tert*-butyl 1-dimethylphosphono-2-*p*-tolylsulfinyl cyclopropanecarboxylate (**3a**, Figure 2), which confirmed our earlier speculations. The configuration of the major diastereomer was established unambiguously by using the Bijvoet method to be (1*R*,2*S*,R_S).[10]

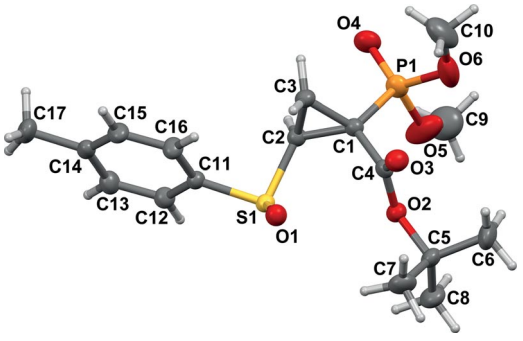
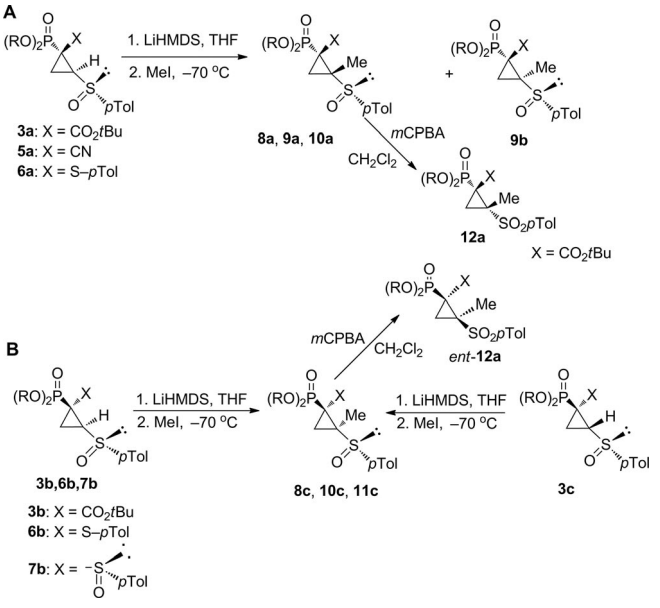


Figure 2. Single-crystal X-ray structure of **3a**. Displacement ellipsoids are drawn at the 50 % probability level.



Scheme 1. Methylation of cyclopropyl sulfoxides. *m*CPBA = *meta*-chloroperoxybenzoic acid.

Methylation

To introduce an additional substituent onto the cyclopropane ring, substitution at the α-carbon atom to the sulfinyl group was performed. The corresponding carbanion was formed by using lithium hexamethyldisilazane (LiHMDS) as the base, and the carbanion was then quenched with a methylating agent (Scheme 1).

In general, the reaction was stereoselective and only a single diastereomer of cyclopropanes **8a**, **10a**, in the approach presented in part A of Scheme 1 and **8c**, **10c**, **11c** (in part B) were formed (see also Table 2). The relative configurations of the obtained methylated cyclopropanes were determined by NOESY experiments: the H-*cis* and H-*trans* protons were easily assigned according to the P–H coupling constants. For products **8a**, **10a**, and **11c**, we observed interaction between the methyl group and the H-*trans* proton, which supports the *cis* configuration (i.e., phosphoryl group and β-sulfinyl substituent on the same side of the ring) of all structures mentioned above (see the Supporting Information).

We determined the crystal and molecular structures of cyclopropane **8a** by X-ray diffraction (Figure 3). This unequivocally confirmed that the absolute configuration of the chiral center formed at the α-carbon atom to the sulfinyl group was *R*; thus, the absolute configuration of **8a** is (+)-(1*R*,2*R*,*S*$_s$). Oxidation of **8a** and **8c** gave the corresponding sulfones; the sulfones showed the same chemical shift in the ^{31}P NMR spectrum (δ = 20.2 ppm) contrary to the sulfoxides, owing to the loss of chirality at sulfur. It additionally confirmed the same relative configuration of both products. On the basis of our earlier established relations, configurational assignment was extended to all investigated structures.

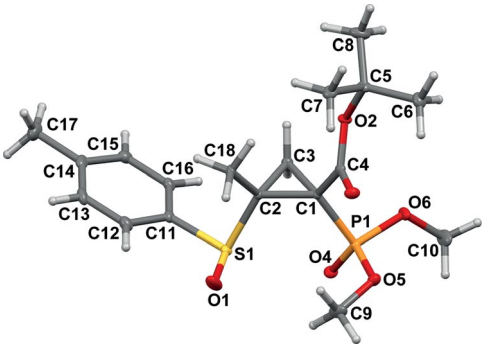


Figure 3. Single-crystal X-ray structure of **8a**. Displacement ellipsoids are drawn at the 25 % probability level.

Only for the case in which a CN group was used as an electron-withdrawing substituent was a much different steric

Table 2. Methylation of cyclopropyl sulfoxides.

Entry	Cyclopropane	X	Conditions	Product(s)	Total yield [%]	Relative configuration [P/SOTol *cis*]/[P/SOTol *trans*]	Steric course
1	**3a**	CO_2tBu	MeI	**8a**	93	>98:–	inversion
2	**3b**	CO_2tBu	MeI	**8c**	75	>98:–	retention
3	**3c**	CO_2tBu	MeI	**8c**	86	>98:–	inversion
4	**3a**	CO_2tBu	$(MeO)_2SO_2$	**8a**	81	>98:–	inversion
5	**5a**	CN	MeI	**9a**/**9b**	88	50:50	retention/inversion
6	**5a**	CN	$(MeO)_2SO_2$	**9a**/**9b**	90	22:78	retention/inversion
7	**6a**	S*p*Tol	MeI	**10a**	86	>98:–	inversion
8	**6a**	S*p*Tol	$(MeO)_2SO_2$	**10a**	78	>98:–	inversion
9	**6b**	S*p*Tol	MeI	**10c**	81	>98:–	retention
10	**6b**	S*p*Tol	$(MeO)_2SO_2$	**10c**	77	>98:–	retention
11	**7b**	S(O)*p*Tol	MeI	**11c**	72	>98:–	retention

course of methylation observed. First, the reaction was not stereoselective with the use of methyl iodide (Table 2, entry 5), contrary to the other cyclopropylphosphonates, and two products of methylation were formed. Moreover, it was the only example for which we observed the influence of the character of the methylating agent; the use of dimethyl sulfate increased the stereoselectivity to 22:78 (Table 2, entry 6). For the major diastereomer formed in that case (i.e., compound **9b**), an NOE interaction of the methyl group with the H-*cis* proton was observed, which evidenced that the methyl group and the phosphoryl substituent were on the same side of the cyclopropane ring (see the Supporting Information).

The stereochemical result of the reaction of sulfoxide-stabilized carbanions with electrophiles depends on (1) the stereochemistry of the carbanion initially formed, (2) the configurational interconversion of the carbanion during the reaction, and (3) the mode in which the electrophile attacks the carbanion.[11]

In the presented case, the introduction of a methyl group in the *trans* position (relative to the phosphonate group) can be the effect of inversion, assuming formation of a lithium derivative *trans* to the phosphoryl group (structure **C**) and subsequent retention of configuration in the alkylation step. However, stronger carbanion stabilization and the absence of an unfavorable interaction between the two bulky substituents make structure **D** more favorable than structure **C** (Figure 4). This proposition was supported by preliminary PM3 calculations.

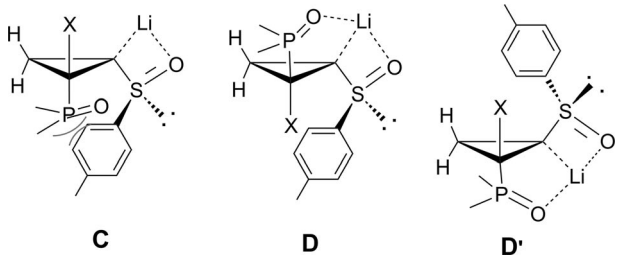


Figure 4. Lithium derivatives with *trans* and *cis* structures.

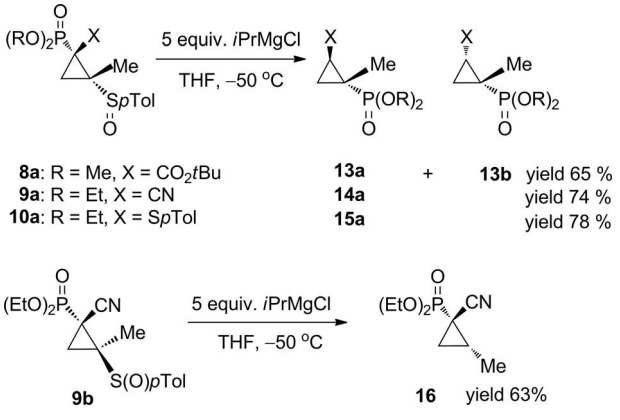
In this way, according to our hypothesis, for all cases, regardless of configuration of the starting cyclopropane, a *trans* carbanion (phosphoryl group and β-sulfinyl substituent on the same side of the ring) was formed. Thus, *trans* lithium derivatives **D** should be formed by retention of configuration from *trans* cyclopropyl sulfoxides **3a**, **4a**, **6a**, and *trans* **D′** should be formed by retention of configuration from **3c** and inversion from *cis* cyclopropanes **3b**, **6b**, and **7b**. Owing to steric reasons, the approach of the methylating agent should occur only from the back side (inversion), which explains the high selectivity of this step. This can be considered as common behavior of carbanions, as inversion of configuration is established as a typical mode in the stereochemistry of electrophilic reactions in which α-sulfinyl carbanions are not stabilized by intramolecular chelation.[11–13]

Low selectivity during the formation of cyclopropane **9** evidenced that the approach of methyl iodide can occur from both sides with about the same probability. A possible explanation could be connected with the small size of the nitrile substituent and strong repulsion between the CN and SO dipoles,[14] which could change the conformation and configuration of the sulfinyl carbanion. Precoordination of the nitrile function, as postulated by the Knochel group,[15] can increase participation of structure **C**, which would result in the lack of selectivity observed in this case. Improved stereoselectivity of methylation by using dimethyl sulfate is the result of attack from the lithium side caused by chelation between the metal and the electrophile.[16]

1,2-Migration

To remove the sulfinyl chiral auxiliary, a metal-exchange reaction was applied by using a Grignard reagent.[17,18] Our last experience showed this method to be less polluting to the environment and in some cases more selective than the classical method for which amalgam or Raney nickel is used.[17c]

However, in recent experiments we found that the reaction of phosphonocyclopropyl sulfoxides **8a**, **9a**, and **10a** with *i*PrMgCl led to unprecedented 1,2-migration of the phosphoryl group[19] (Scheme 2). To the best of our knowledge, migration of the phosphoryl group in a cyclopropane ring has not been previously reported. This phenomenon was observed by us for the first time in the case of phosphonocyclopropanecarboxylates and led to different products than expected. It was reasonable to investigate the influence of the structure of the cyclopropylphosphonate and the reaction conditions on the behavior of the carbanion formed after sulfinyl–metal exchange to determine the scope and limitations of the discovered rearrangement.



Scheme 2. The reaction of phosphonocyclopropyl sulfoxides with *i*PrMgCl.

It was established that the reaction of a Grignard reagent with cyclopropane **3a**, unsubstituted in the α position to the sulfinyl group, could be controlled by temperature. At low temperatures (–50 °C), the desulfinylated cyclopropane was observed as the only product, whereas increasing the temperature and extending the reaction time caused the formation of a regioisomer of the rearranged structure.[19] Unfortunately, the same relation did not work for methylated cyclopropyl sulfoxides. Lowering the temperature stopped the reaction, and only starting materials were isolated.

According to our hypothesis, the driving force causing 1,2-migration of the phosphoryl group is the instability of the carbanion formed after removing the sulfinyl group, whereas there are two stabilizing substituents present at the adjacent carbon atom. For this reason, the phosphoryl group relocates to quench the initial carbanion, whereas the new carbanion is still stabilized by the remaining X substituent. We selected cyclopropylphosphonates that were subjected to the sulfinyl–metal exchange reaction, with X substituents presenting diminishing electron-withdrawing character (CO_2R > CN > SAr). In this way, the newly created carbanion would be stabilized more or less effectively after rearrangement. Evidently, even the relatively weak sulfenyl group was sufficient, because the 1,2-migration of the phosphoryl group took place for all the used cyclopropylphosphonates.

Another factor that should have an influence on the rearrangement is the configuration of the phosphonocyclopropyl sulfoxides. Indeed, for all the obtained methylation products with *cis* configuration (i.e., compounds **8a**, **9a**, and **10a**), the 1,2-migration took place exclusively. The only example for which we were able to avoid rearrangement of the α phosphoryl group on a cyclopropane ring was **9b** (phosphoryl and sulfinyl groups in *trans* relation), and it afforded unsulfinylated product of retained structure **16**[20] (Scheme 2). The last observations suggest that rearrangement occurs as an internal process in a concerted manner. Given that during the sulfinyl–magnesium exchange a carbanion is formed with retention of configuration,[21] for *cis* isomers the phosphoryl group is "ready" to migrate as it is on the same side of the cyclopropane; for the *trans* structures, inversion of the magnesium derivative is required. Additional rationale for the intramolecular character of the phosphoryl group migration is the optical activity of the rearranged products.

The feasibility of an intramolecular isomerization mechanism was confirmed by DFT calculations. Calculations were performed by using a derivative of **9a**, the simplest structure among the cyclopropyl sulfoxides investigated by us, for which the sulfinyl group was replaced by magnesium chloride and the ethoxy functions at the phosphorus center were changed to methoxy groups to save computing time (Scheme 3). The results suggest that the reaction involves coordination of the phosphoryl oxygen atom to magnesium [i.e., structure **9a**(Mg)-1] followed by attack of the transient carbanion on the phosphorus atom with the formation of a bicyclic structure similar to **9a**(Mg)_ts1 (Scheme 3). The reaction pathway involves two transition states, **9a**(Mg)_ts1 and **9a**(Mg)_ts2 (Scheme 3), which result from rotation of the phosphoryl substituents around the phosphorus atom with an overall free-energy barrier of 28 kcal mol^{-1} in the gas phase. The first transition state involves breaking of the C2–Mg bond; the second transition state corresponds to formation of the C1–Mg bond. The driving force for the isomerization is the higher thermodynamic stability of the structure with a negatively charged carbon atom substituted by a more electron-withdrawing group (nitrile in this case). The resulting product, that is, **14a**(Mg)-1, is more stable than starting isomer **9a**(Mg)-1 by about 7 kcal mol^{-1}. SCRF calculations performed by assuming THF as the solvent provided an analogous picture, with a total free-energy barrier of 30 kcal mol^{-1} and a net free-energy gain of –11 kcal mol^{-1}. The free-energy profiles of the reaction in the gas phase and in THF are compared in Figure 5. The calculated free-energy barrier for isomerization seems to be too high if taking into account that the reaction proceeds smoothly at temperatures as low as 0 °C. We believe that this is the result of specific solvation effects that are very significant for organic magnesium compounds in ether

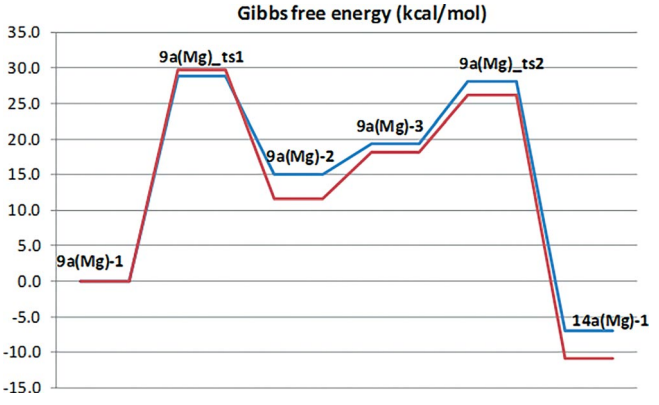
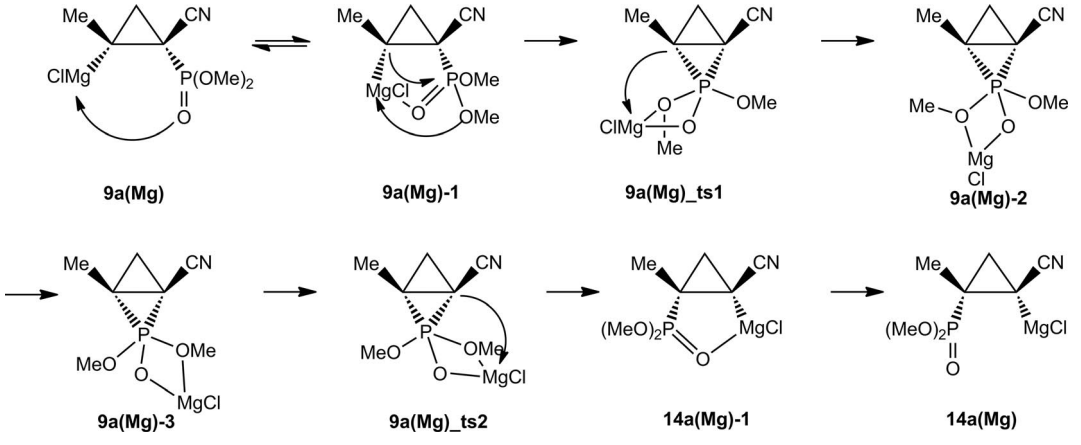
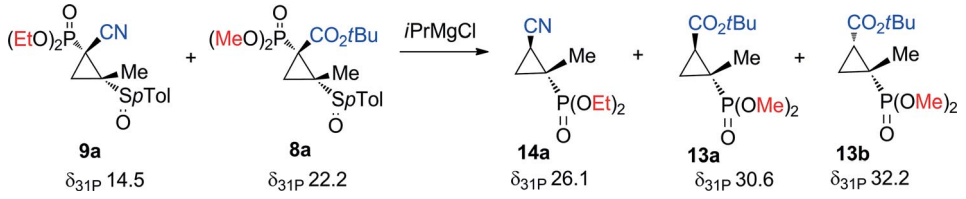


Figure 5. Gibbs free-energy profile for the isomerization of phosphonocyclopropyl sulfoxide (Scheme 3) in the gas phase (blue line) and in THF (red line).



Scheme 3. Mechanism of isomerization (migration of the phosphonate group) according to DFT calculations.



Scheme 4. Crossover experiment.

solutions. These effects were not considered in the calculations owing to high computational costs.

Alternatively, one can consider a bimolecular exchange mechanism (Figure 6). To establish whether the presented migration reaction was occurring by an intra- or intermolecular mode (Figure 6) with participation of two molecules, a crossover experiment involving two different phosphonates was devised. Thus, a 1:1 mixture of phosphonocyclopropyl sulfoxides **8a** and **9a** was treated with *i*PrMgCl (5 equiv.) at 0 °C for 30 min. The only observed products in the crude reaction mixture were rearranged phosphonates **13a**, **13b**, and **14a** (Scheme 4). The lack of crossover products indicates that the reaction proceeds in an intramolecular fashion.

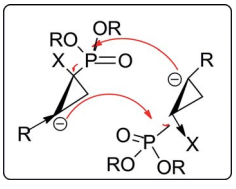


Figure 6. Hypothetical intermolecular mode of isomerization.

Conversion into 1-Aminocyclopropane-1-phosphonic Acids

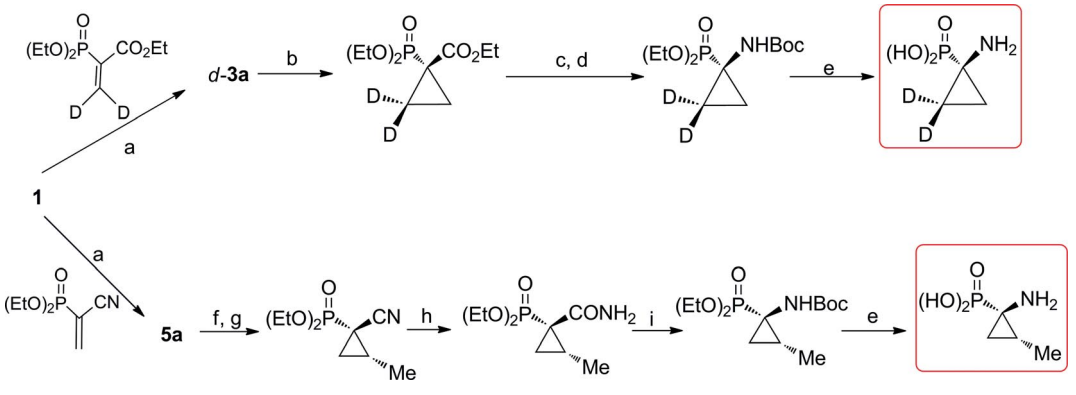
Elaborated procedures of desulfinylation in two cases allowed us to avoid 1,2-migration of the α phosphoryl group on the cyclopropane ring either by lowering the temperature or by changing the configuration of the dominating diastereomer of phosphonocyclopropyl sulfoxide. The cyclopropylphosphonates with a retained structure and configuration were used in the synthesis of enantiopure (+)-(1*R*)-1-amino-2,2-dideuteriocyclopropanephosphonic acid,[22] which is the first approach to this deuterium-labeled analogue, and a phosphonic analogue of norcoronamic acid[20] (Scheme 5).

In the synthesis of enantiopure (+)-(1*R*)-1-amino-2,2-dideuteriocyclopropanephosphonic acid, Curtius rearrangement was used to convert the ester group into an amino group. A procedure involving the use of diphenylphosphoryl azide gave the best results. In the synthesis of a phosphonic analogue of (–)-norcoronamic acid, enantiopure (–)-(1*S*,2*R*)-2-methyl-1-diethylphosphonocyclopropanenitrile was converted into the appropriate amide, which was then subjected to lead tetraacetate mediated oxidative Hoffmann rearrangement.

Conclusion

It was established that the stereoselective synthesis of substituted cyclopropylphosphonates by asymmetric cyclopropanation of vinylphosphonates with dimethylsulfonium(*p*-methylsulfinyl)methylide occurs with high facial selectivity and good to moderate diastereoselectivity. Methylation of cyclopropylphosphonates, the basic structures in the performed synthesis, occurred exclusively with the formation of diastereomers for which the phosphoryl group and 2-sulfinyl substituent were on the same side of the ring. Owing to the high stereoselectivity and the presence of substituents that could be easily converted into amino groups, such as CO_2R and CN, this approach was considered as a general method for the formation of aminocyclopropane-1-phosphonic acids.

However, during desulfinylation of the investigated cyclopropylphosphonates by their reaction with *i*PrMgCl, 1,2-migration of the phosphoryl group was discovered. This phenomenon can



Scheme 5. Synthesis of (+)-(1*R*)-[2,2-$^2H_2$]-1-aminocyclopropane-1-phosphonic acid and (–)-(1*S*,2*R*)-1-amino-2-methylcyclopropanephosphonic acid. Reagents and conditions: (a) separation of diastereomers; (b) *i*PrMgCl (5 equiv.), THF, –50 °C, 1 h, 83 %; (c) LiOH (aq.), 96 %; (d) $(PhO)_2P(O)N_3$, Et_3N *t*BuOH, 88 %; (e) 6 N HCl, propylene epoxide; (f) LiHMDS, $(MeO)_2SO_2$, 63 % (g) *i*PrMgCl, THF, –30 °C; (h) H_2O_2, K_2CO_3, MeOH, 70 °C, 12 h, 90 %; (i) $Pb(OAc)_4$, *t*BuOH, 85 °C, 5 h, 76 %.

be compared to the base-induced migration of a phosphoryl group between a heteroatom and a carbon atom,[23,24] but for cyclopropanes, it was here observed for the first time.[19] Some factors describing the scope and limitations of this transformation were found. One, the influence of temperature: cyclopropane unsubstituted in the α-position to the sulfinyl group can be controlled by temperature; two, the influence of configuration of the cyclopropylphosphonate: a *cis* relationship between the phosphoryl and sulfinyl groups leads to the product of migration, but a *trans* relationship affords the product of desulfinylation with the retained structure; three, the influence of X substituents with decreasing electronegativities (X: CO_2R > CN > SAr): even the relatively weak sulfenyl group is not sufficient to avoid rearrangement.

The possibility of an intramolecular isomerization mechanism was verified by DFT calculations. Nevertheless, some products of desulfinylation with retained structures were obtained by fixing the temperature and by exploiting the different behavior of cyclopropanenitrile; these substrates were used for the synthesis of enantiomerically pure 1-aminocyclopropane-1-phosphonic acids.

Experimental Section

General: Unless stated otherwise, all air- and water-sensitive reactions were performed under an argon atmosphere by using freshly distilled dry solvents. Glassware was dried prior to use by heating under vacuum. Commercial-grade reagents and solvents were used without further purification except as indicated below. THF and diethyl ether were distilled from Na/benzophenone prior to use. Thin-layer chromatography (TLC) was conducted on Silica Gel 60 F254 TLC purchased from Merck. Column chromatography was performed by using Merck silica gel (70–230 mesh). NMR spectra were recorded with a Bruker AV 200, Bruker DRX 500, or Bruker Avance III 600 spectrometer. ^{1}H, ^{13}C, and ^{31}P chemical shifts are reported relative to the residual proton resonance in the deuterated solvents or referred to an 85 % aqueous solution of H_3PO_4. Microanalyses were performed with an Elemental Analyzer EA 1108. HRMS were recorded with a Finnigan MAT 95 apparatus. Optical rotations were measured by using a Perkin–Elmer MC 241 photopolarimeter.

Cyclopropanation

Procedure 1: NaH (0.11 g, 2.2 mmol) was added to a solution of (*S*)-dimethylsulfonium(*p*-tolylsulfinyl)methyl tetrafluoroborate (0.6 g, 2 mmol) in dry MeCN (8–10 mL) at room temperature under an argon atmosphere. The resulting mixture was stirred for 30 min. Then, the precipitate was filtered off and a solution of *tert*-butyl 1-dimethylphosphonoacrylate (0.44 g, 2 mmol) in dry MeCN (5 mL) was added. After stirring at room temperature for 2 h, the reaction was quenched with aq. NH_4Cl solution (20 mL), extracted with hexane (4 × 5 mL), and dried with $MgSO_4$. After filtration, the solvent was evaporated under reduced pressure to afford **3** in 80 % yield as a mixture of diastereomers. Separation of the diastereomers was achieved by chromatography on silica (hexane/acetone, 2:1).

Procedure 2: A round-bottomed flask equipped with a magnetic stir bar was charged with *tert*-butyl 1-dimethylphosphonoacrylate (0.44 g, 2 mmol), (*S*)-dimethyl sulfonium(*p*-tolylsulfinyl)methyl tetrafluoroborate (0.6 g, 2 mmol), and CH_2Cl_2 (20 mL). K_2CO_3 (0.3 g) was added to this suspension, and the mixture was stirred vigorously overnight. Filtration and evaporation of the solvent afforded a mixture of diastereomers in 95 % yield. Separation of the diastereomers was achieved by chromatography on silica (hexane/acetone, 2:1).

***tert*-Butyl (+)-(1*R*,2*S*,R_S)-1-Dimethylphosphono-2-*p*-tolylsulfinylcyclopropanecarboxylate (3a):** White solid; m.p. 93–94 °C, yield 0.4 g (55 %). $[\alpha]_D^{20}$ = +109.5 (*c* = 6.8, acetone) ^{1}H NMR (600 MHz, $CDCl_3$): δ = 1.50 [s, 9 H, COC(CH_3)$_3$], 1.71 (ddd, J_{HH} = 5.6, 8.5 Hz, J_{PH} = 14.4 Hz, 1 H), 2.25 (ddd, J_{HH} = 5.6, 6.6 Hz, J_{PH} = 11.2 Hz, 1 H), 2.39 (s, 3 H, $C_6H_4CH_3$), 2.85 [ddd, J_{HH} = 6.6, 8.5 Hz, J_{PH} = 15.2 Hz, 1 H, C*H*S(O)], 3.62 and 3.75 (2 d, J_{PH} = 11.0 Hz, 6 H, POCH_3), 7.31 and 7.59 (A_2B_2, 4 H, $C_6H_4CH_3$) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 12.6 (d, J_{CP} = 2.2 Hz, CH_2C), 21.4 ($C_6H_4CH_3$), 27.9 [COC(CH_3)$_3$], 28.1 (d, J_{CP} = 179.8 Hz), 44.4 (d, J_{CP} = 3.2 Hz, CHSO), 53.7 (d, J_{CP} = 6.1 Hz), 53.8 (d, J_{CP} = 5.9 Hz), 83.7 [*C*OC(CH_3)$_3$], 124.1, 130.1, 140.9, 142.0, 164.3 (d, J_{CP} = 4.7 Hz) ppm. ^{31}P NMR (81 MHz, $CDCl_3$): δ = 22.5 ppm. MS (CI): *m*/*z* = 389 [M + H]$^+$. $C_{17}H_{25}O_6PS$ (388.41): calcd. C 52.57, H 6.49; found C 52.43, H 6.38.

***tert*-Butyl (–)-(1*S*,2*S*,R_S)-1-Dimethylphosphono-2-*p*-tolylsulfinylcyclopropanecarboxylate (3b):** Pale-yellow oil, yield 0.12 g (16 %). $[\alpha]_D^{20}$ = –25.4 (*c* = 3.2, acetone) ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.40 [s, 9 H, COC(CH_3)$_3$], 1.99 (ddd, J_{HH} = 5.6, 8.9 Hz, J_{PH} = 9.0 Hz, 1 H), 2.25 (ddd, J_{HH} = 5.6, 6.8 Hz, J_{PH} = 12.5 Hz, 1 H), 2.39 (s, 3 H, $C_6H_4CH_3$), 2.95 [ddd, J_{HH} = 6.8, 8.9 Hz, J_{PH} = 9.0 Hz, 1 H, C*H*S(O)], 3.81 and 3.83 (2 d, J_{PH} = 11.0 Hz, 6 H, POCH_3), 7.33 and 7.77 (A_2B_2, 4 H, $C_6H_4CH_3$) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 18.0 (d, J_{CP} = 3.7 Hz, CH_2C), 21.4 ($C_6H_4CH_3$), 27.8 [COC(CH_3)$_3$], 29.2 (d, J_{CP} = 195.6 Hz), 49.2 (d, J_{CP} = 2.7 Hz, CHSO), 53.1 (d, J_{CP} = 6.2 Hz), 53.7 (d, J_{CP} = 6.2 Hz, $POCH_3$), 83.6 [*C*OC(CH_3)$_3$], 124.4, 129.9, 141.6, 141.8, 166.1 (d, J_{CP} = 7.2 Hz) ppm. ^{31}P NMR (81 MHz, $CDCl_3$): δ = 20.6 ppm. MS (CI): *m*/*z* = 389 [M + H]$^+$. HRMS (EI): calcd. for $C_{17}H_{25}O_6PS$ [M]$^+$ 388.1109; found 388.1096.

***tert*-Butyl (+)-(1*R*,2*S*,R_S)-1-Dimethylphosphono-2-*p*-tolylsulfinyl-3,3-$^2H_2$-cyclopropanecarboxylate (*d*-3a):** White solid; m.p. 92–94 °C, yield 0.3 g (50 %). $[\alpha]_D^{20}$ = +86.8 (*c* = 1.0, acetone). ^{1}H NMR (200 MHz, $CDCl_3$): δ = 1.46 [s, 9 H, COC(CH_3)$_3$], 2.35 (s, 3 H, $C_6H_4CH_3$), 2.81 [d, J_{PH} = 15.4 Hz, 1 H, C*H*S(O)], 3.57 and 3.70 (2 d, J_{PH} = 11.1 Hz, 6 H, $POCH_3$), 7.27 and 7.75 (AB, J_{HH} = 8.1 Hz, 4 H, $C_6H_4CH_3$) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 12.1 (quint, J_{CD} = 25.5 Hz, CD_2), 21.2 ($C_6H_4CH_3$), 27.6 [(CH_3)$_3$C], 27.7 (d, J_{CP} = 180.4 Hz), 44.0 (d, J_{CP} = 3.2 Hz, *C*HS), 53.3 (d, J_{CP} = 6.0 Hz), 53.5 (d, J_{CP} = 6.0 Hz), 83.6 [(CH_3)$_3$*C*], 124.1, 129.9, 140.6, 141.8, 164.0 (d, J_{CP} = 4.8 Hz, C=O) ppm. ^{31}P NMR (81 MHz, $CDCl_3$): δ = 22.5 ppm. MS (CI): *m*/*z* = 391 [M + H]$^+$. HRMS (FAB): calcd. for $C_{17}{}^1H_{23}{}^2H_2O_6PS$ [M]$^+$ 390.1235; found 390.1239.

***tert*-Butyl (–)-(1*S*,2*S*,R_S)-1-Dimethylphosphono-2-*p*-tolylsulfinyl-3,3-$^2H_2$-cyclopropanecarboxylate (*d*-3b):** Yellowish oil, yield 0.09 g (15 %). $[\alpha]_D^{20}$ = –38.7 (*c* = 3.1, acetone). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.33 [s, 9 H, COC(CH_3)$_3$], 2.35 (s, 3 H, $C_6H_4CH_3$), 2.88 [d, J_{HH} = 9.4 Hz, 1 H, C*H*S(O)], 3.73–3.79 (2 d, J_{HH} = 11.1 Hz, 6 H, $POCH_3$), 7.27 and 7.70 (A_2B_2, J_{HH} = 8.1 Hz, 4 H, $C_6H_4CH_3$) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 17.1 (quint, J_{CD} = 25.5 Hz), 21.2, 27.6, 28.9 (d, J_{CP} = 196.0 Hz), 48.8 (d, J_{CP} = 3.2 Hz), 53.0 (d, J_{CP} = 6.1 Hz), 53.5 (d, J_{CP} = 6.9 Hz), 83.45, 124.2, 129.8, 141.3, 141.4, 165.8 (d, J_{CP} = 6.8 Hz) ppm. ^{31}P NMR (81 MHz, $CDCl_3$): δ = 20.6 ppm. MS (CI): *m*/*z* = 391 [M + H]$^+$. HRMS (FAB): calcd. for $C_{17}{}^1H_{23}{}^2H_2O_6PS$ [M]$^+$ 390.1235; found 390.1230.

Ethyl (+)-(1*R*,2*S*,R_S)-1-Diethylphosphono-2-*p*-tolylsulfinyl-3-cyclopropanecarboxylate (4a): Yellowish oil, yield 0.46 g (60 %). $[\alpha]_D^{20}$ = +78.9 (*c* = 1.2, acetone). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.23 (t, J_{HH} = 7.0 Hz, 3 H, $POCH_2CH_3$), 1.28 (t, J_{HH} = 7.0 Hz, 3 H, $POCH_2CH_3$), 1.32 (t, J_{HH} = 7.1 Hz, 3 H, $COCH_2CH_3$), 1.75 (ddd, J_{HH} = 5.7, 8.5, J_{PH} = 15.2 Hz, 1 H), 2.28 (ddd, J_{HH} = 5.6, 6.4, J_{PH} = 12.1 Hz,

1 H), 2.42 (s, 3 H, $C_6H_4CH_3$), 2.88 [ddd, J_{HH} = 6.4, 8.5, J_{PH} = 15.1 Hz, 1 H, C*H*S(O)], 3.89–3.94 (m, 1 H, POC*H*HCH$_3$), 4.0–4.03 (m, 1 H, POC*H*HCH$_3$), 4.07–4.14 (m, 2 H, POCH_2CH$_3$), 4.26 (q, 2 H, COCH_2CH$_3$, J_{HH} = 7.1 Hz), 7.32 and 7.58 (A_2B_2, 4 H, $C_6H_4CH_3$) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 12.7 (m, *C*D$_2$), 14.1 (*C*H$_3$CH$_2$OC), 16.3 (m, *C*H$_3$CH$_2$OP), 21.5 ($C_6H_4CH_3$), 27.5 (d, J_{CP} = 181.0 Hz, *C*P), 44.6 (*C*HSO), 62.5 (CH$_3$*C*H$_2$OC), 63.1 (d, J_{CP} = 6.0 Hz, CH$_3$*C*H$_2$OP), 63.4 (d, J_{CP} = 6.7 Hz, CH$_3$*C*H$_2$OP), 124.3, 130.0, 140.8, 142.1, 165.7 (d, J_{CP} = 7.7 Hz) ppm. ^{31}P NMR (81 MHz, $CDCl_3$): δ = 18.8 ppm. MS (CI): *m*/*z* = 389 [M + H]$^+$.

Ethyl (+)-(1*S*,2*S*,*R*$_S$)-1-Diethylphosphono-2-*p*-tolylsulfinyl-3-cyclopropanecarboxylate (4b): Yellowish oil, yield 0.06 g (8 %). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.20 (t, J_{HH} = 7.2 Hz, 3 H, POCH$_2$C*H*$_3$), 1.31 (t, J_{HH} = 7.0 Hz, 3 H, POCH$_2$C*H*$_3$), 1.34 (t, J_{HH} = 7.0 Hz, 3 H, COCH$_2$C*H*$_3$), 2.04 (ddd, J_{HH} = 5.6, 8.5, J_{PH} = 9.0 Hz, 1 H), 2.28 (ddd, J_{HH} = 5.6, 7.0, J_{PH} = 12.6 Hz, 1 H), 2.38 (s, 3 H, $C_6H_4CH_3$), 3.00 [ddd, J_{HH} = 5.6, 8.5, J_{PH} = 9.0 Hz, 1 H, C*H*S(O)], 4.09–4.26 (m, 6 H, OCH_2CH$_3$), 7.29 and 7.74 (A_2B_2 aromatic) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 13.8 (*C*H$_3$CH$_2$OC), 16.3 (m, *C*H$_3$CH$_2$OP), 18.1 (m, *C*D$_2$), 21.3 ($C_6H_4CH_3$), 27.6 (d, J_{CP} = 195.7 Hz), 49.7 (*C*HSO), 62.4 (CH$_3$*C*H$_2$OC), 62.9 (d, J_{CP} = 6.2 Hz, CH$_3$*C*H$_2$OP), 63.4 (d, J_{CP} = 6.5 Hz, CH$_3$*C*H$_2$OP), 124.5, 129.9, 141.6, 142.1, 167.5 (d, J_{CP} = 7.7 Hz) ppm. ^{31}P NMR (81 MHz, $CDCl_3$): δ = 17.3 ppm. MS (CI): *m*/*z* = 389 [M + H]$^+$.

Ethyl (+)-(1*R*,2*S*,*R*$_S$)-1-Diethylphosphono-2-*p*-tolylsulfinyl-3,3-$^2H_2$-cyclopropanecarboxylate (*d*-4a): Yellowish oil, yield 0.41 g (53 %). $[\alpha]_D^{20}$ = +79 (*c* = 3.6, acetone). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.23 (t, J_{HH} = 7.0 Hz, 3 H, POCH$_2$C*H*$_3$), 1.28 (t, J_{HH} = 7.0 Hz, 3 H, POCH$_2$C*H*$_3$), 1.32 (t, J_{HH} = 7.1 Hz, 3 H, COCH$_2$C*H*$_3$), 2.42 (s, 3 H, $C_6H_4CH_3$), 2.90 [d, J_{PH} = 15.2 Hz, 1 H, C*H*S(O)], 3.89–3.94 (m, 1 H, POC*H*HCH$_3$), 4.0–4.03 (m, 1 H, POC*H*HCH$_3$), 4.07–4.14 (m, 2 H, POCH_2CH$_3$), 4.26 (q, J_{HH} = 7.1 Hz, 2 H, COCH_2CH$_3$), 7.32 and 7.58 (A_2B_2, 4 H, $C_6H_4CH_3$) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 12.8 (m, *C*D$_2$), 14.1 (*C*H$_3$CH$_2$OC), 16.3 (m, *C*H$_3$CH$_2$OP), 21.5 ($C_6H_4CH_3$), 27.5 (d, J_{CP} = 180.2 Hz), 44.6 (*C*HSO), 62.5 (CH$_3$*C*H$_2$OC), 63.1 (d, J_{CP} = 6.0 Hz, CH$_3$*C*H$_2$OP), 63.4 (d, J_{CP} = 6.7 Hz, CH$_3$*C*H$_2$OP), 124.3, 130.0, 140.8, 142.1, 165.7 (d, J_{CP} = 7.7 Hz) ppm. ^{31}P NMR (81 MHz, $CDCl_3$): δ = 18.7 ppm. MS (CI): *m*/*z* = 391 [M + H]$^+$. HRMS (ES): calcd. for $C_{17}{}^1H_{23}{}^2H_2O_6NaPS$ [M + Na]$^+$ 413.1133; found 413.1128.

Ethyl (–)-(1*S*,2*S*,*R*$_S$)-1-Diethylphosphono-2-*p*-tolylsulfinyl-3,3-$^2H_2$-cyclopropanecarboxylate (*d*-4b): Yellowish oil, yield 0.15 g (20 %). $[\alpha]_D^{20}$ = –32 (*c* = 7.4, acetone). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.23 (t, J_{HH} = 7.2 Hz, 3 H, POCH$_2$C*H*$_3$), 1.34 (t, J_{HH} = 7.0 Hz, 3 H, POCH$_2$C*H*$_3$), 1.37 (t, J_{HH} = 7.0 Hz, 3 H, COCH$_2$C*H*$_3$), 2.41 (s, 3 H, $C_6H_4CH_3$), 3.02 (d, J_{PH} = 9.0 Hz, 1 H, SC*H*), 4.09–4.32 (m, 6 H, OCH_2CH$_3$), 7.32 and 7.77 (A_2B_2 aromatic) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 14.0 (m, *C*H$_3$CH$_2$OC), 16.3 (*C*H$_3$CH$_2$OP), 18.1 (m, *C*D$_2$), 21.5 ($C_6H_4CH_3$), 29.1 (d, J_{CP} = 158.0 Hz), 49.7 (*C*HSO), 62.5 (CH$_3$*C*H$_2$OC), 63.0 (CH$_3$*C*H$_2$OP), 63.5 (d, J_{CP} = 6.7 Hz, CH$_3$*C*H$_2$OP), 124.5, 129.9, 141.6, 142.1, 167.5 (d, J_{CP} = 7.7 Hz) ppm. ^{31}P NMR (81 MHz, $CDCl_3$): δ = 17.3 ppm. MS (CI): *m*/*z* = 391 [M + H]$^+$.

Ethyl (+)-(1*S*,2*R*,*S*$_S$)-1-Diethylphosphono-2-*p*-tolylsulfinyl-3,3-$^2H_2$-cyclopropanecarboxylate (*d*-4c): Yellowish oil, yield 0.055 (8 %). $[\alpha]_D^{20}$ = +120 (*c* = 10.1, acetone). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.33 (t, J_{HH} = 7.0 Hz, 3 H, POCH$_2$C*H*$_3$), 1.34 (t, J_{HH} = 7.0 Hz, 3 H, POCH$_2$C*H*$_3$), 1.37 (t, J_{HH} = 7.1 Hz, 3 H, COCH$_2$C*H*$_3$), 2.43 (s, 3 H, $C_6H_4CH_3$), 3.08 [d, J_{PH} = 13.9 Hz, 1 H, C*H*S(O)], 4.11–4.21 (m, 4 H, POCH_2CH$_3$), 4.26–4.42 (m, 2 H, COCH_2CH$_3$), 7.33 and 7.58 (A_2B_2, 4 H, $C_6H_4CH_3$) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 14.0 (*C*H$_3$CH$_2$OC), 14.9 (m, *C*D$_2$), 16.3 (d, J_{CP} = 5.8 Hz, *C*H$_3$CH$_2$OP); 16.4 (d, J_{CP} = 6.7 Hz, *C*H$_3$CH$_2$OP), 21.4 ($C_6H_4CH_3$), 27.0 (d, J_{CP} = 181.9 Hz), 48.0 (*C*HSO), 62.7 (CH$_3$*C*H$_2$OC), 63.4 (m, CH$_3$*C*H$_2$OP), 124.2, 130.1, 140.8, 142.0, 166.2 (d, J_{CP} = 5.2 Hz) ppm. ^{31}P NMR (81 MHz, $CDCl_3$): δ = 18.8 ppm. MS (CI): *m*/*z* = 391 [M + H]$^+$. HRMS (ES): calcd. for $C_{17}H_{23}H_2O_6NaPS$ [M + Na]$^+$ 413.1133; found 413.1135.

(+)-(1*R*,2*S*,*R*$_S$)-1-Diethylphosphono-2-*p*-tolylsulfinylcyclopropanenitrile (5a): Yellowish oil, yield 0.172 g (53 %). $[\alpha]_D^{20}$ = +57.8 (*c* = 3.2, acetone). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.02 [t, J_{HH} = 7.0 Hz, 3 H, (C*H*$_3$CH$_2$O)P], 1.15 [t, J_{HH} = 7.0 Hz, 3 H, (C*H*$_3$CH$_2$O)P], 1.98 (ddd, J_{HH} = 5.8, 8.3 Hz, J_{PH} = 14.1 Hz, 1 H), 2.30 (ddd, J_{HH} = 5.8, 6.6 Hz, J_{PH} = 10.4 Hz, 1 H), 2.41 (s, 3 H, $C_6H_4CH_3$), 2.98 [ddd, J_{HH} = 6.6, 8.3 Hz, J_{PH} = 15.2 Hz, 1 H, C*H*S(O)], 3.71 and 3.94 (2 m, 2 H, POCH_2CH$_3$), 4.13–4.20 (m, 2 H, POCH_2CH$_3$), 7.35 and 7.69 (A_2B_2, 4 H, $C_6H_4CH_3$) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 10.5 (d, J_{CP} = 191.1 Hz, *C*PCN), 16.0 and 16.1 [2 d, J_{CP} = 6.2 Hz, (*C*H$_3$CH$_2$O)P], 21.4 ($C_6H_4CH_3$), 44.0 (d, J_{CP} = 1.9 Hz, *C*H$_2$), 53.3 (*C*HSO), 64.0 (d, J_{CP} = 6.5 Hz, CH$_3$*C*H$_2$OP), 64.4 (d, J_{CP} = 6.5 Hz, CH$_3$*C*H$_2$OP), 115.0 (*C*N), 124.4, 130.4, 139.8, 143.1 ppm. ^{31}P NMR (81 MHz, $CDCl_3$): δ = 14.7 ppm. MS (CI): *m*/*z* = 342 [M + H]$^+$. HRMS (EI): calcd. for $C_{15}H_{20}NO_4PS$ [M]$^+$ 341.0851; found 341.0848.

(–)-(1*R*,2*S*,*R*$_S$)-1-Diethylphosphono-2-*p*-tolylsulfinylcyclopropyl *p*-Tolyl Sulfide (6a): Oil, yield 0.175 g (42 %). $[\alpha]_D^{20}$ = –33.3 (*c* = 1.8, acetone). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.16 [t, J_{HH} = 7.1 Hz, 3 H, (C*H*$_3$CH$_2$O)P], 1.20 [t, J_{HH} = 7.0 Hz, 3 H, (C*H*$_3$CH$_2$O)P], 1.84–1.90 (m, 2 H, CH$_2$), 2.33 (s, 3 H, SC$_6$H$_4$C*H*$_3$), 2.40 [s, 3 H, S(O)C$_6$H$_4$C*H*$_3$], 3.08 [ddd, J_{HH} = 6.7, 8.3 Hz, J_{PH} = 12.2 Hz, 1 H, C*H*S(O)], 3.77–3.83 (m, 1 H, POC*H*HCH$_3$), 3.91–3.99 (m, 2 H, POCH_2CH$_3$), 4.00–4.07 (m, 1 H, POC*H*HCH$_3$), 7.14 and 7.52 (A_2B_2, 4 H, $C_6H_4CH_3$), 7.32 and 7.68 (A_2B_2, 4 H, $C_6H_4CH_3$) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 16.3 [(d, J_{CP} = 2.4 Hz, *C*H$_3$CH$_2$O)P], 16.8, (CH$_2$), 21.2 ($C_6H_4CH_3$), 21.5 ($C_6H_4CH_3$), 26.8 (d, J_{CP} = 197.7 Hz, *C*PS), 49.7 (*C*HSO), 63.1 (d, J_{CP} = 6.5 Hz), 63.4 (d, J_{CP} = 6.5 Hz), 124.7, 129.1, 129.5, 129.8, 133.3, 138.8, 141.4, 141.9 ppm. ^{31}P NMR (81 MHz, $CDCl_3$): δ = 21.0 ppm. MS (CI): *m*/*z* = 439 [M + H]$^+$. HRMS (ES+): calcd. for $C_{21}H_{27}O_4NaPS_2$ [M]$^+$ 461.0986; found 461.0989.

(–)-(1*S*,2*S*,*R*$_S$)-1-Diethylphosphono-2-*p*-tolylsulfinylcyclopropyl *p*-Tolyl Sulfide (6b): Oil, yield 0.125 g (30 %). $[\alpha]_D^{20}$ = –20.5 (*c* = 1.3, acetone). ^{1}H NMR (600 MHz, $CDCl_3$): δ = 1.28 [t, J_{HH} = 7.0 Hz, 3 H, (C*H*$_3$CH$_2$O)P], 1.33 [t, J_{HH} = 7.0 Hz, 3 H, (C*H*$_3$CH$_2$O)P], 1.76–1.79 (m, *C*HH), 2.27 (s, 3 H, SC$_6$H$_4$C*H*$_3$), 2.32–2.36 (m, 1 H, *C*HH), 2.39 [s, 3 H, S(O)C$_6$H$_4$C*H*$_3$], 2.85–2.89 [m, 1 H, C*H*S(O)], 4.12–4.21 (m, 4 H, POCH_2CH$_3$), 6.85 and 7.13 (A_2B_2, 4 H, $C_6H_4CH_3$), 7.12 and 7.52 (A_2B_2, 4 H, $C_6H_4CH_3$) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 16.3 [(d, J_{CP} = 2.4 Hz, *C*H$_3$CH$_2$O)P], 16.4, [(*C*H$_3$CH$_2$O)P], 21.1 ($C_6H_4CH_3$), 21.5 ($C_6H_4CH_3$), 22.2 (CH$_2$), 28.5 (d, J_{CP} = 200.4 Hz, *C*PS), 52.3 (*C*HSO), 63.0 (d, J_{CP} = 5.5 Hz), 63.8 (d, J_{CP} = 6.0 Hz), 124.6, 128.7, 129.5, 129.7, 133.3, 138.4, 141.2, 141.4 ppm. ^{31}P NMR (81 MHz, $CDCl_3$): δ = 19.9 ppm. MS (CI): *m*/*z* = 439 [M + H]$^+$. HRMS (EI): calcd. for $C_{21}H_{27}O_4PS_2$ [M]$^+$ 438.1078; found 438.1088.

(+)-(1*S*,2*S*,*Ss*,*R*$_S$)-1-Diethylphosphono-2-*p*-tolylsulfinylcyclopropyl *p*-Tolyl Sulfoxide (7b): Oil, yield 0.39 g (90 %). $[\alpha]_D^{20}$ = +170.7 (*c* = 0.9, acetone). ^{1}H NMR (600 MHz, $CDCl_3$): δ = 1.01 [t, J_{HH} = 7.1 Hz, 3 H, (C*H*$_3$CH$_2$O)P], 1.18 [t, J_{HH} = 7.0 Hz, 3 H, (C*H*$_3$CH$_2$O)P], 1.94 (ddd, J_{HH} = 6.2, 8.8 Hz, J_{PH} = 14.8 Hz, 1 H, C*H*H), 2.23–2.27 (m, 1 H, C*H*H), 2.41 [s, 3 H, S(O)C$_6$H$_4$C*H*$_3$], 2.42 [s, 3 H, S(O)C$_6$H$_4$C*H*$_3$], 3.29 [ddd, 1 H, J_{HH} = 6.7, 8.8 Hz, J_{PH} = 13.0 Hz, C*H*S(O)], 3.78–3.85 (m, 2 H, POCH_2CH$_3$), 3.91–3.99 (m, 1 H, POC*H*CH$_3$), 4.00–4.025 (m, 1 H, POC*H*CH$_3$), 7.32 and 7.62 (A_2B_2, 4 H, $C_6H_4CH_3$), 7.35 and 7.88 (A_2B_2, 4 H, $C_6H_4CH_3$) ppm, ^{13}C NMR (150 MHz, $CDCl_3$): δ = 12.7 (CH$_2$), 15.8 [d, J_{CP} = 7.4 Hz, *C*H$_3$CH$_2$O)P], 16.0, [(CH$_3$CH$_2$O)P], 21.5 ($C_6H_4CH_3$), 21.55 ($C_6H_4CH_3$), 29.7 (d, J_{CP} = 166.0 Hz, *C*PS), 49.0 (*C*HSO), 63.2 (d, J_{CP} = 6.0 Hz), 63.6 (d, J_{CP} = 5.5 Hz), 124.1, 125.8, 129.3, 130.3, 138.0, 141.0, 141.2, 142.3 ppm.

^{31}P NMR (81 MHz, $CDCl_3$): δ = 17.3 ppm. MS (CI): m/z = 455 $[M + H]^+$. HRMS (ES+): calcd. for $C_{21}H_{27}O_5PS_2$ $[M]^+$ 454.1038; found 454.1031.

Methylation: LiHMDS (prepared by adding 0.55 mL of 2 M BuLi in hexane to 0.25 mL of HMDS) was added to a solution of cyclopropyl sulfoxide **3a** (0.39 mg, 1 mmol) in 10 mL of THF at –70 °C. The mixture was stirred for 15 min and then MeI (1.2 mmol) was added at –70 °C. The mixture was warmed slowly to 0 °C. After quenching with NH_4Cl, the water phase was extracted with CH_2Cl_2 (3×), and the combined organic phase was dried with $MgSO_4$, filtered, and concentrated. Crude product **8a** was purified by recrystallization (Et_2O).

***tert*-Butyl (+)-(1*R*,2*R*,S_S)-1-Dimethylphosphono-2-*p*-tolylsulfinyl-2-methylcyclopropanecarboxylate (8a):** White solid; m.p. 133–135 °C, yield 0.37 g (93 %). $[\alpha]_D^{20}$ = +28.8 (*c* = 3.9, acetone). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.17 [s, 3 H, CH_3-C(SO)], 1.45 [s, 9 H, $COC(CH_3)_3$], 1.63 (dd, J_{HH} = 6.2 Hz, J_{PH} = 9.1 Hz, 1 H), 1.93 (dd, J_{HH} = 6.2 Hz, J_{PH} = 16.6 Hz, 1 H), 2.39 (s, 3 H, $C_6H_4CH_3$), 3.84 (d, J_{PH} = 11.2 Hz, 3 H, $POCH_3$), 3.96 (d, J_{PH} = 11.4 Hz, 3 H, $POCH_3$), 7.29 and 7.50 (A_2B_2, 4 H, $C_6H_4CH_3$) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): 9.15 (d, J_{CP} = 1.4 Hz), 20.1 (d, J_{CP} = 3.0 Hz), 21.3, 27.7, 35.7 (d, J_{CP} = 179.7 Hz), 47.8 (d, J_{CP} = 4.4 Hz), 53.4 (d, J_{CP} = 5.9 Hz), 53.8 (d, J_{CP} = 6.4 Hz), 83.2, 124.7, 129.6, 138.5, 141.6, 165.2 (d, J_{CP} = 4.3 Hz) ppm. ^{31}P NMR (81 MHz, $CDCl_3$): δ = 22.2 ppm. MS (CI): m/z = 403 $[M + H]^+$. $C_{18}H_{27}O_6PS$ (402.44): calcd. C 53.72, H 6.76; found C 53.84, H 6.87.

***tert*-Butyl (–)-(1*S*,2*S*,S_S)-1-Dimethylphosphono-2-*p*-tolylsulfinyl-2-methylcyclopropanecarboxylate (8c):** Pale-yellow oil. $[\alpha]_D^{20}$ = –36.4 (*c* = 0.8, acetone). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.96 [s, 3 H, CH_3-C(SO)], 1.44 [s, 9 H, $COC(CH_3)_3$], 1.78 (dd, 1 H, *J* = 6.3, 9.5 Hz), 2.27 (dd, 1 H, *J* = 6.2, 17.0 Hz), 2.40 (s, 3 H, $C_6H_4CH_3$), 3.82 (d, 6 H, $POCH_3$, *J* = 10.9 Hz), 7.32 and 7.89 (A_2B_2, 4 H, $C_6H_4CH_3$) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 9.15 (d, J_{CP} = 1.4 Hz), 21.3, 22.7 (d, J_{CP} = 3.8 Hz), 27.7, 35.9 (d, J_{CP} = 185.7 Hz), 46.6 (d, J_{CP} = 4.3 Hz), 53.5 (d, J_{CP} = 6.1 Hz), 53.6 (d, J_{CP} = 6.4 Hz), 83.2, 125.4, 129.5, 137.9, 140.9, 164.5 (d, J_{CP} = 4.5 Hz) ppm. ^{31}P NMR (81 MHz, $CDCl_3$): δ = 20.7 ppm. MS (CI): m/z = 403 $[M + H]^+$. HRMS (FAB): calcd. for $C_{18}H_{27}O_6PS$ $[M + H]^+$ 403.1344; found 403.1352.

(+)-(1*R*,2*R*,S_S)-1-Diethylphosphono-2-*p*-tolylsulfinyl-2-methylcyclopropanenitrile (9a): Yellowish oil, yield 0.1 g (28 %) [when $(MeO)_2SO_2$ was used]. $[\alpha]_D^{20}$ = +22.1 (*c* = 0.7, acetone). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.46 [t, J_{HH} = 7.0 Hz, 3 H, $(CH_3CH_2O)P$], 1.48 [t, J_{HH} = 7.0 Hz, 3 H, $(CH_3CH_2O)P$], 1.49 (s, 3 H, CH_3), 1.66 (dd, J_{HH} = 6.1 Hz, J_{PH} = 7.7 Hz, 1 H, CH_{cis}), 2.25 (dd, J_{HH} = 6.1 Hz, J_{PH} = 16.1 Hz, 1 H, CH_{trans}), 2.43 (s, 3 H, $C_6H_4CH_3$), 4.29–4.40 [m, 2 H, $(CH_3CH_2O)P$], 4.41–4.44 [m, 2 H, $(CH_3CH_2O)P$], 7.32 and 7.51 (A_2B_2, 4 H, $C_6H_4CH_3$) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 11.9 (CH_3), 16.3 [$(CH_3CH_2O)P$], 20.0 [d, J_{CP} = 190.4 Hz, *C*P(O)], 21.4 ($C_6H_4CH_3$), 24.1, 50.0 (*C*HSO), 64.2 [d, J_{CP} = 6.2 Hz, $(CH_3CH_2O)P$], 64.9 [d, J_{CP} = 6.5 Hz, $(CH_3CH_2O)P$], 116.5 (*C*N), 124.5, 129.9, 138.0, 142.2 ppm. ^{31}P NMR (81 MHz, $CDCl_3$): δ = 14.0 ppm. MS (CI): m/z = 356 $[M + H]^+$. HRMS (EI): calcd. for $C_{16}H_{22}NPSO_4$ $[M]^+$ 355.1007; found 355.1005.

(+)-(1*R*,2*S*,S_S)-1-Diethylphosphono-2-*p*-tolylsulfinyl-2-methylcyclopropanenitrile (9b): Yellowish oil, yield 0.22 g (63 %) [when $(MeO)_2SO_2$ was used]. $[\alpha]_D^{20}$ = + 52.5, (*c* = 0.9, acetone). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.17 [t, J_{HH} = 7.0 Hz, 3 H, $(CH_3CH_2O)P$], 1.38 (s, 3 H, CH_3), 1.42 [t, J_{HH} = 7.0 Hz, 3 H, $(CH_3CH_2O)P$], 2.06 (dd, J_{HH} = 5.8 Hz, J_{PH} = 14.0 Hz, 1 H, CH_{cis}), 2.40 [dd, J_{HH} = 5.8 Hz, J_{PH} = 8.9 Hz, 1 H, CH_{trans} *C*HS(O)], 2.43 (s, 3 H, $C_6H_4CH_3$), 3.96–3.99 [m, 1 H, $(CH_3CH_2O)P$], 4.01–4.05 [m, 1 H, $(CH_3CH_2O)P$], 4.23–4.27 [m, 2 H, $(CH_3CH_2O)P$], 7.36 and 7.73 (A_2B_2, 4 H, $C_6H_4CH_3$) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 9.1 (CH_2), 14.5 (d, J_{CP} = 180.3 Hz), 16.1 [$(CH_3CH_2O)P$], 16.2 (d, J_{CP} = 6.0 Hz, CH_3CH_2OP), 21.5 ($C_6H_4CH_3$), 25.6, 47.8 (*C*HSO), 63.7 [d, J_{CP} = 6.5, $(CH_3CH_2O)P$], 64.4 [d, J_{CP} = 6.1 Hz, $(CH_3CH_2O)P$], 116.6 (*C*N), 124.9, 129.8, 136.9, 142.4 ppm. ^{31}P NMR (81 MHz, $CDCl_3$): δ = 13.8 ppm. MS (CI): m/z = 356 $[M + H]^+$. HRMS (CI): calcd. for $C_{16}H_{23}NO_4PS$ $[M + H]^+$ 356.1083; found 356.1085.

(+)-(1*S*,2*R*,S_S)-1-Diethylphosphono-2-*p*-tolylsulfinyl-2-methylcyclopropyl *p*-Tolyl Sulfide (10a): Viscous oil, yield 0.39 g (86 %). $[\alpha]_D^{20}$ = –33.3 (*c* = 1.3, acetone). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.14 (dd, J_{HH} = 7.0 Hz, J_{PH} = 7.6 Hz, 1 H), 1.25 [t, J_{HH} = 7.0 Hz, 3 H, $(CH_3CH_2O)P$], 1.33 [t, J_{HH} = 7.0 Hz, 3 H, $(CH_3CH_2O)P$], 1.48 [s, 3 H, CH_3-C(SO)], 2.23 (dd, J_{HH} = 7.0 Hz, J_{PH} = 18.6 Hz, 1 H), 2.28 (s, 3 H, $SC_6H_4CH_3$), 2.38 [s, 3 H, $S(O)C_6H_4CH_3$], 4.15–4.21 (m, 4 H, $POCH_2$), 7.09 and 7.32 (A_2B_2, 4 H, $C_6H_4CH_3$), 7.29 and 7.51 (A_2B_2, 4 H, $C_6H_4CH_3$) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 10.5, 16.2 (d, J_{CP} = 6.5 Hz), 16.4 (d, J_{CP} = 6.2 Hz), 21.0, 21.4, 24.2, 32.7 (d, J_{CP} = 190.1 Hz), 52.1, 63.3 (d, J_{CP} = 6.5 Hz), 63.4 (d, J_{CP} = 6.6 Hz), 124.7, 129.2, 129.5, 129.6, 130.3, 136.7, 139.6, 141.3 ppm. ^{31}P NMR (81 MHz, $CDCl_3$): δ = 21.9 ppm. MS (EI): m/z = 452 $[M]^+$. HRMS (EI): calcd. for $C_{22}H_{29}PS_2O_4$ $[M]^+$ 452.1245; found 452.1244.

(+)-(1*R*,2*S*,S_S)-1-Diethylphosphono-2-*p*-tolylsulfinyl-2-methylcyclopropyl *p*-Tolyl Sulfide (10c): Oil. $[\alpha]_D^{20}$ = –20.6 (*c* = 0.85, acetone). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.28 [t, J_{HH} = 7.0 Hz, 3 H, $(CH_3CH_2O)P$], 1.31 [s, 3 H, CH_3-C(SO)], 1.34 (dd, J_{HH} = 6.4 Hz, J_{PH} = 7.8 Hz, 1 H), 1.38 [t, J_{HH} = 7.0 Hz, 3 H, $(CH_3CH_2O)P$], 2.29 (s, 3 H, $SC_6H_4CH_3$), 2.43 [s, 3 H, $S(O)C_6H_4CH_3$], 2.52 (dd, J_{HH} = 6.4 Hz, J_{PH} = 17.3 Hz, 1 H), 4.18–4.28 (m, 4 H, $POCH_2$), 6.96 and 7.20 (A_2B_2, 4 H, $C_6H_4CH_3$), 7.30 and 7.82 (A_2B_2, 4 H, $C_6H_4CH_3$) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 13.0, 16.4, 21.1, 21.4, 27.0, 33.7 (d, J_{CP} = 197.4 Hz), 52.8, 63.0 (d, J_{CP} = 6.5 Hz), 63.3, 125.6, 129.4, 129.9, 130.4, 137.2, 137.9, 141.1 ppm. ^{31}P NMR (81 MHz, $CDCl_3$): δ = 19.9 ppm. MS (EI): m/z = 452 $[M]^+$. HRMS (EI): calcd. for $C_{22}H_{29}NPS_2O_4$ $[M]^+$ 452.1245; found 452.1241.

(+)-(1*S*,2*R*,*Ss*,S_S)-1-Diethylphosphono-2-*p*-tolylsulfinyl-2-methylcyclopropyl *p*-Tolyl Sulfoxide (11c): Viscous oil, yield 0.34 g (72 %). $[\alpha]_D^{20}$ = –114.2 (*c* = 0.99, acetone). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.11 [t, J_{HH} = 7.0 Hz, 3 H, $(CH_3CH_2O)P$], 1.36 [t, J_{HH} = 7.0 Hz, 3 H, $(CH_3CH_2O)P$], 1.48 [s, 3 H, CH_3-C(SO)], 2.13 (dd, J_{HH} = 6.8 Hz, J_{PH} = 8.8 Hz, 1 H), 2.46 (s, 3 H, $SC_6H_4CH_3$), 2.47 [s, 3 H, $S(O)C_6H_4CH_3$], 2.76 (dd, J_{HH} = 6.8 Hz, J_{PH} = 17.3 Hz, 1 H), 3.85–3.95 (m, 2 H, $POCH_2$), 4.17–4.21 (m, 2 H, $POCH_2$), 7.29 and 7.34 (A_2B_2, 4 H, $C_6H_4CH_3$), 7.30 and 7.74 (A_2B_2, 4 H, $C_6H_4CH_3$) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 14.0, 15.8 (d, J_{CP} = 6.7 Hz, CH_3CH_2OP), 16.2 (d, J_{CP} = 6.7 Hz, CH_3CH_2OP), 21.5 ($C_6H_4CH_3$), 24.8, 47.9 (d, J_{CP} = 169.6 Hz, *C*P), 49.9 (*C*HSO), 63.1 (d, J_{CP} = 6.6 Hz, CH_3CH_2OP), 63.8 (d, J_{CP} = 5.8 Hz, CH_3CH_2OP), 125.4, 125.6, 129.2, 129.5, 137.5, 137.8, 141.5, 141.7 ppm. ^{31}P NMR (81 MHz, $CDCl_3$): δ = 15.3 ppm. HRMS (FAB): calcd. for $C_{22}H_{30}PS_2O_5$ $[M + 1]^+$ 469.1260; found 469.1272.

Oxidation to Sulfone: Oxidation was performed by adding *meta*-chloroperbenzoic acid (0.46 g, 0.26 mmol) to a solution of sulfoxide **8a** or **8c** (0.8 g, 0.2 mmol) in CH_2Cl_2 (10 mL). The mixture was stirred vigorously overnight. Then, the mixture was washed with a saturated aqueous solution of $NaHCO_3$, and the organic solvent was evaporated. The crude product was purified on silica gel (acetone/diethyl ether).

***tert*-Butyl (+)-(1*R*,2*R*)-1-Dimethylphosphono-2-*p*-tolylsulfonyl-2-methylcyclopropanecarboxylate (12a):** Oil. $[\alpha]_D^{20}$ = +12.3 (*c* = 2.1, acetone), yield 0.8 g (95 %). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.25 [s, 3 H, CH_3-C(SO)], 1.44 [s, 9 H, $COC(CH_3)_3$], 1.71 (dd, J_{HH} = 5.5 Hz, J_{PH} = 9.5 Hz, 1 H), 2.35 (dd, J_{HH} = 5.5 Hz, J_{PH} = 18.0 Hz, 1 H), 2.44 (s, 3 H, $C_6H_4CH_3$), 3.84 (d, J_{PH} = 11.0 Hz, 3 H, $POCH_3$), 3.88 (d, J_{PH} = 11.5 Hz, 3 H, $POCH_3$), 7.36 and 8.04 (A_2B_2, 4 H, $C_6H_4CH_3$) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 17.3, 21.7, 21.8, 27.7, 37.9 (d, J_{CP} =

183.7 Hz), 47.8 (d, J_{CP} = 5.5 Hz), 53.8 (d, J_{CP} = 7.0 Hz), 54.5 (d, J_{CP} = 6.2 Hz), 85.1, 129.3, 129.8, 134.9, 144.8, 165.1 (d, J_{CP} = 3.4 Hz) ppm. ^{31}P NMR (81 MHz, $CDCl_3$): δ = 20.2 ppm. MS (EI): *m/z* = 418 $[M]^+$. HRMS (FAB): calcd. for $C_{18}H_{28}O_7PS$ $[M + 1]^+$ 419.1295; found 419.1293.

Metal–Sulfinyl Exchange: *i*PrMgCl (2.0 M in THF, 1 mmol, 0.5 mL) was added to a stirred solution of diethyl 1-cyano-2-*p*-tolylsulfinyl-2-methylcyclopropylphoshonate (**9**, 0.2 mmol) in anhydrous THF (5.0 mL) at –50 °C, and the mixture was stirred at this temperature for 1 h. The reaction was quenched by adding NH_4Cl, and the mixture was extracted with chloroform (5 × 5 mL). The combined extract was dried with anhydrous $MgSO_4$, filtered, and concentrated. Purification was performed by plate chromatography (hexane/acetone, 4:1).

***tert*-Butyl (+)-(1*S*,2*R*)-2-Methyl-2-dimethylphosphonocyclopropanecarboxylate (13a):** Oil. $[\alpha]_D^{20}$ = +19.4 (*c* = 1.2, acetone). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.94 (ddd, *J* = 4.5, 7.75 Hz, J_{PH} = 9.37 Hz, 1 H), 1.30 (d, J_{PH} = 12.45 Hz, 3 H, CH_3-CP), 1.47 [s, 9 H, $COC(CH_3)_3$], 1.67 (ddd, J_{HH} = 4.5, 6.6 Hz, J_{PH} = 16.75 Hz, 1 H), 1.72 (ddd, J_{HH} = 6.6, 7.75 Hz, J_{PH} = 9.33 Hz, 1 H), 3.74 (d, *J* = 10.7 Hz, 3 H, $POCH_3$), 3.76 (d, J_{PH} = 10.7 Hz, 3 H, $POCH_3$) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 18.3 (CH_2C), 19.0 (d, J_{CP} = 194.0 Hz, CP), 21.8 (d, J_{CP} = 4.7 Hz), 27.9 [$COC(CH_3)_3$], 29.4 (d, J_{CP} = 2.9 Hz), 52.5 (d, J_{CP} = 6.3 Hz), 52.9 (d, J_{CP} = 6.2 Hz, $POCH_3$), 81.0 [$COC(CH_3)_3$], 168.4 (d, J_{CP} = 7.1 Hz) ppm. ^{31}P NMR (81 MHz, $CDCl_3$): δ = 30.6 ppm. MS (CI): *m/z* = 265 $[M + H]^+$. HRMS (FAB): calcd. for $C_{11}H_{22}O_5P$ $[M + H]^+$ 265.1205; found 265.1211.

(+)-(1*S*,2*R*)-2-Methyl-2-diethylphosphonocyclopropanenitrile (14a): Oil, yield 0.032 g (74 %). $[\alpha]_D^{20}$ = –38.8 (*c* = 0.25, acetone). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.11 (ddd, J_{HH} = 5.0, 5.5, J_{PH} = 13.5 Hz, 1 H), 1.39 (t, J_{HH} = 7.0 Hz, 3 H), 1.40 (t, J_{HH} = 7.0 Hz, 3 H), 1.47 (d, J_{PH} = 13.0 Hz, 3 H, CH_3-CP), 1.62 (ddd, J_{HH} = 5.0, 9.0 Hz, J_{PH} = 14.0 Hz, 1 H), 2.04 (ddd, J_{HH} = 5.5, 9.0 Hz, J_{PH} = 14.3 Hz, 1 H), 4.13 (m, 4 H, $POCH_2$) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 15.9 (CH_2), 16.4 (d, J_{CP} = 5.7 Hz), 17.1 (d, J_{CP} = 194.0 Hz, CP), 18.2, 29.7 (d, J_{CP} = 2.9 Hz), 62.8 (d, J_{CP} = 6.2 Hz, $POCH_2$), 127.1 (CN) ppm. ^{31}P NMR (81 MHz, $CDCl_3$): δ = 26.1 ppm. MS (CI): *m/z* = 218 $[M + H]^+$. HRMS (FAB): calcd. for $C_9H_{16}NPO_3[M]^+$ 217.0872; found 217.0868.

***p*-Tolyl (+)-(1*R*,2*R*)-2-Methyl-2-diethylphosphonocyclopropyl Sulfide (15a):** Oil, yield 0.26 g (78 %). $[\alpha]_D^{20}$ = +62.6 (*c* = 0.8, acetone). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.71 (ddd, J_{HH} = 5.2, 5.5 Hz, J_{PH} = 12.9 Hz, 1 H), 1.31 (t, J_{HH} = 7.0 Hz, 3 H), 1.35 (t, J_{HH} = 7.0 Hz, 3 H), 1.37 (d, J_{PH} = 13.6 Hz, 3 H, CH_3-CP),1.62 (ddd, J_{HH} = 5.0, 9.0 Hz, J_{PH} = 14.0 Hz, 1 H), 1.64 (ddd, J_{HH} = 5.2, 8.9 Hz, J_{PH} = 16.8 Hz, 1 H), 2.31, 2.86 (ddd, J_{HH} = 5.5, 8.9 Hz, J_{PH} = 13.9 Hz, 1 H), 4.03–4.15 (m, 4 H, $POCH_2$), 7.09 and 7.30 (A_2B_2, 4 H, $C_6H_4CH_3$) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 13.2 (CH_3), 16.4 (d, J_{CP} = 4.5 Hz), 16.5 (d, J_{CP} = 6.0 Hz), 17.8 (CH_2), 17.9 (d, J_{CP} = 186.5 Hz, CP), 21.0, 24.4, 62.0 (d, J_{CP} = 6.1 Hz, $POCH_2$), 62.2 (d, J_{CP} = 6.0 Hz, $POCH_2$), 127.7, 129.6, 133.2, 135.5 ppm. ^{31}P NMR (81 MHz, $CDCl_3$): δ = 26.1 ppm. MS (CI): *m/z* = 315 $[M + H]^+$. HRMS (FAB): calcd. for $C_{15}H_{23}PSO_3$ $[M]^+$ 314.1105; found 314.1111.

(–)-(1*S*,2*R*)-2-Methyl-1-diethylphosphonocyclopropanenitrile (16): Yellowish oil, yield 0.137 g (63 %). $[\alpha]_D^{20}$ = –14.3 (*c* = 6.7, acetone). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.40 [t, J_{HH} = 7.0 Hz, 3 H, $(CH_3CH_2O)P$], 1.42 [t, J_{HH} = 7.0 Hz, 3 H, $(CH_3CH_2O)P$], 1.44 (d, J_{HH} = 6.7 Hz, 3 H, CH_3) 1.55 (ddd, J_{HH} = 4.8, 7.1 Hz, J_{PH} = 14.2 Hz, 1 H, CH_{cis}), 1.70 (ddd, J_{HH} = 4.8, 8.9 Hz, J_{PH} = 7.3 Hz, 1 H, CH_{trans}), 1.90 (m, CH-CH_3), 4.24 [m, 4 H, $(CH_3CH_2O)P$] ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 8.6 (d, J_{CP} = 198.8 Hz, C1), 13.0 (d, J_{CP} = 3.4 Hz, CH_3) 16.3 [d, J_{CP} = 6.0 Hz, $(CH_3CH_2O)P$], 16.4 [$(CH_3CH_2O)P$], 21.9, 24.4, 63.3 [d, J_{CP} = 6.5 Hz, $(CH_3CH_2O)P$], 63.6 [d, J_{CP} = 6.0 Hz, $(CH_3CH_2O)P$], 119.9 (CN) ppm. ^{31}P NMR (81 MHz, $CDCl_3$): δ = 18.0 ppm. MS (CI): *m/z* = 218 $[M + H]^+$. HRMS (CI): calcd. for $C_9H_{17}NPO_3$ $[M + H]^+$ 218.0950; found 218.0946.

Computational Methods: Calculations were performed with the Gaussian 09 package[25] by using density functional theory (DFT) methods, namely, the B3LYP hybrid functional with the 6-31+G(d) basis set, which combines high accuracy with moderate computational cost. The B3LYP functional has proven its applicability in a wide range of chemical problems. All stationary points were identified by vibrational analysis, which also provided thermochemical corrections to the electronic energy. Thermochemical corrections were scaled by a factor of 0.98.[26] Final electronic accurate energies on the B3LYP/6-31+G(d) optimized geometries were calculated by using the wB97XD functional including empirical dispersion and long-range corrections[27] with triple-ζ 6-311+G(2d,p) basis set. Calculations in solution were performed by using the default SCRF-PCM continuum solvation model in Gaussian with an UFF cavity definition by assuming THF as the implicit solvent. Ultrafine integration grid was applied for PCM calculations.

X-ray Diffraction: X-ray diffraction data were collected for compound **3a** at room temperature and for compound **8a** at 100 K by the ω-scan technique by using a Bruker AXS Smart APEX-II CCD[28] diffractometer with MonoCap capillary and 30W Incoatec Microfocus Source IμS with Montel optics and Cu-K_α radiation (λ = 1.54178 Å). The crystal structure was solved by using a direct method with the SHELXS-2013 program. Atomic scattering factors were taken from the International Tables for X-ray Crystallography. Positional parameters of non-hydrogen atoms were refined by a full-matrix least-squares method with anisotropic thermal parameters by using the SHELXL-2014/7 program.[29] The crystal and structure refinement data are summarized in Table S1 (Supporting Information).

CCDC 1433286 (for **3a**) and 1433185 (for **8a**) contain the supplementary crystallographic data for this paper. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre.

Supporting Information (see footnote on the first page of this article)**:** Experimental and computational details as well as spectroscopic and analytical data for new compounds.

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