Oxepines from Pyrylium Salts and Diazo Esters. Cycloaddition Behavior toward 4-Phenyl-1,2,4-triazoline-3,5-dione[1]

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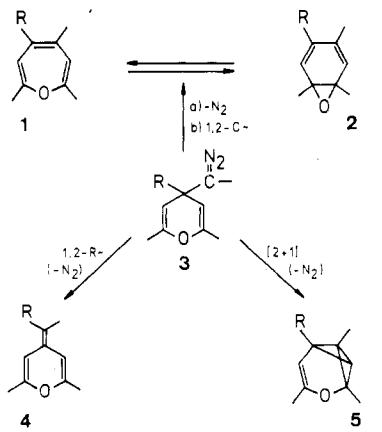
Electrophilic diazoalkane substitution of the diazo esters **7a** and **b** with 2,4,6-trimethylpyrylium tetrafluoroborate (**6a**) results in the formation of the 4-(diazomethyl)-4*H*-pyrans **8a** and **b** as well as the 1*H*-1,2-diazepines **13a** and **b**. The latter are formed by a spontaneous isomerization of the primarily produced 2-(diazomethyl)-2*H*-pyrans **9a** and **b**. In contrast, analogous reactions of 4-methyl-2,6-diphenylpyrylium tetrafluoroborate (**6b**) with **7a** and **b** only furnish the diazo compounds **8c** and **d**. Allylpalladium chloride catalyzed decomposition of **8a–d** in benzene at room temperature leads to the oxepines **14a–d** (92–98% yield). When **14a** and **b** are subjected to chromatography on Kieselgel, both oxepines isomerize to cyclohexadienones **18a** and **b** and phenols **19a** and **b**. The oxepines **14a–d** react with the triazolinedione **23** to form the Diels–Alder adducts **25a–d**, which are derived from the valence tautomeric benzene oxides **15a–d**. Only in the case of the reaction of **14c** with **23** does the oxepine form itself undergo [4 + 2] cycloaddition to give **26c**, which subsequently isomerizes in a hetero Cope rearrangement to **27c**.

The valence tautomeric system oxepine/benzene oxide (**1** ⇄ **2**) plays a significant role in the understanding of electrocyclic reactions and has been studied intensively.[2] With the metal-catalyzed decomposition of 4-(diazomethyl)-4*H*-pyrans **3**,[3] we have found a new access to this system and have used it for the synthesis of 2,7-di-*tert*-butyl-substituted oxepines.[1] The reaction **3** → **1** ⇄ **2** proceeds smoothly only when R = alkyl; when R = H, a rapid 1,2 H shift (**3** → **4**)[4] completely suppresses the ring-expansion reaction. Intramolecular cyclopropanation (**3** → **5**), which also takes place at the expense of the oxepine formation, has been observed in the case of benzocondensed (diazomethyl)pyrans[5] (Scheme I).

In the present investigations, we were interested in the question of whether pyrylium salts with less sterically demanding substituents (**6**; R^1 = Me, Ph in place of *t*-Bu) could be converted via (diazomethyl)pyrans into the corresponding oxepine/benzene oxide systems.

Scheme I

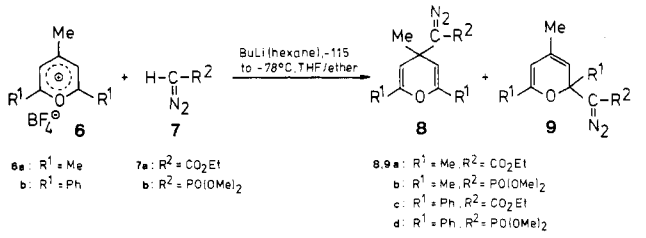


Results

4-(Diazomethyl)-4-methyl-4*H*-pyrans 8. The pyrylium salt **6a** required for the electrophilic diazoalkane substitution[6] was prepared by reported methods; we have prepared the compound **6b** in high yield (85%) by the reaction of 2,6-diphenylpyrylium perchlorate with methylmagnesium iodide in ether followed by hydride cleavage using triphenylcarbenium tetrafluoroborate in acetonitrile.

Since the diazo esters **7a** and **b** did not react with the pyrylium salts **6a** and **b** in the presence of triethylamine (pyrylium salts without substituents in the 4-position are readily susceptible to the electrophilic diazoalkane substitution under these conditions[4]), they were first metalated in 1/1 tetrahydrofuran/diethyl ether at −115 °C (**7a**) or −78 °C (**7b**) by butyllithium in hexane (Scheme II).

Scheme II



Subsequent reactions with **6a** and **b** then gave the 4-(diazomethyl)-4-methyl-4*H*-pyrans as yellow to orange oils (**8a,c,d**) or yellow crystals (**8b**) after chromatographic workup. In the reactions of **6a** with the diazo esters **7a** and **b**, the 4-methyl-1*H*-1,2-diazepines **13a** and **b** were isolated also. These products are derived from the 2-diazomethyl isomers **9a** and **9b** (see the following section).

The diazo compounds **8a–d** are characterized by diazo vibrations in the IR spectra at 2075–2080 cm^{-1}, which are shifted to lower wavenumbers as compared with those of **7a** and **b** (2092 or 2113 cm^{-1}). The compounds can be unequivocally differentiated from the possible constitutional isomers **9a–d** by ^1H NMR spectroscopy. The two hydrogen atoms in positions 3 and 5 of **8a–d** each exhibit the same chemical shifts (δ 4.62, 4.54, 5.50, 5.45). The same is true for the methyl groups in the 2- and 6-positions of **8a** and **b** (δ 1.81 and 1.83).

4-Methyl-1*H*-1,2-diazepines 13. As already mentioned, the 2-diazomethyl isomers **9a** and **b**, produced in

(1) Carbenes. 31. Part 30: Hoffmann, K.-L.; Regitz, M. *Chem. Ber.* **1985**, *118*, 3700.
(2) Reviews: Vogel, E.; Günther, H. *Angew, Chem.* **1967**, *79*, 429; *Angew. Chem., Int. Ed. Engl.* **1967**, *6*, 385. Jerina, D. M.; Yagi, H.; Daly, J. W. *Heterocycles* **19733**, *1*, 267. Boyd, D. R. In *Comprehensive Heterocyclic Chemistry*; Katritzky, A. R., Rees, C. W., Pergamon: New York, 1984; Vol. 7, p 547 ff. Boyd, D. R.; Jerina, D. M. In *Heterocyclic Compounds*; Hassner, A. Ed.; Wiley: New York, 1985; Vol. 42, Part 3, p 197 ff.
(3) Hoffmann, K.-L.; Regitz, M. *Tetrahedron Lett.* **1983**, *24*, 5355.
(4) Regitz, M.; Khbeis, S. *Chem. Ber.* **1984**, *117*, 2233.
(5) Facklam, T.; Hoffmann, K.-L.; Regitz, M. *Chem. Ber.*, in press.
(6) Review: Fink, J.; Regitz, M. *Synthesis* **1985**, 569.

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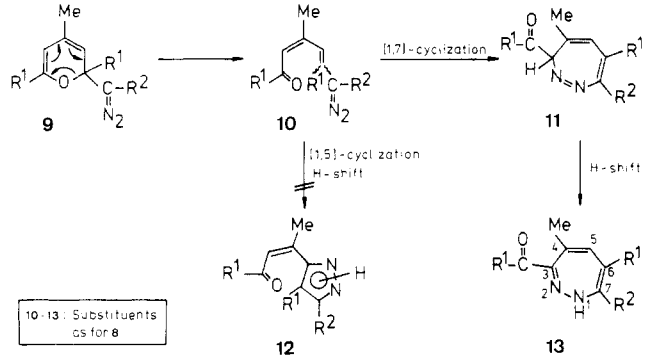
Scheme III



addition to **8a** and **b** in the reactions of **6a** with **7a** and **b**, isomerize to the 1*H*-1,2-diazepines **13a** and **b**. We have no evidence for the formation of **13c** and **d** in the electrophilic diazoalkane substitution[6] of **6b** with **7a** and **b** (Scheme III).

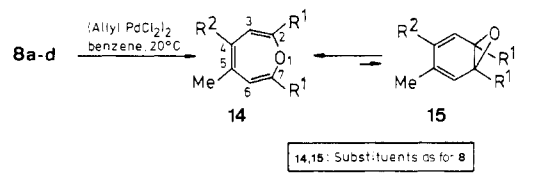
The constitutions of the diazepines **13a** and **b**, which gave correct microanalyses, were deduced from spectroscopic studies. The absorptions for the diazo groups in the IR spectra are missing; instead, strong NH bands in the region 3275–3330 cm^{-1} are observed. Signals for the NH protons are also present in the ^1H NMR spectra (δ 7.25, 6.76). In the case of **13b**, we assume that this hydrogen is at N-1 from the vicinal phosphorus coupling ($^3J_{H,P}$ = 12.1 Hz). In addition to this proton, the ring skeleton of **13b** possesses only the hydrogen at position 5, which exhibits a complicated but interpretable coupling pattern. The double quartet for **13a** (δ 6.31) with $^4J_{H,H}$ couplings of 1.6 and 0.6 Hz resulting from the methyl groups in the 4- and 6-positions is split further in **13b** by the phosphorus nucleus of the 7-dimethoxyphosphoryl group (δ 6.31 also, $^4J_{H,H(4\text{-}Me)}$ = 1.6 Hz, $^4J_{H,H(6\text{-}Me)}$ = 0.5 Hz, $^4J_{H,P}$ = 1.3 Hz). The magnitudes and assignments of all coupling constants were confirmed by double-resonance experiments.

In the ^{13}C NMR spectra of **13a** and **b**, all the resonances for the ring substituents are found directly. The carbonyl carbon atom of the acetyl group in position 3 has the greatest diagnostic significance (δ 198.4, 197.9). The occurrence of these signals impressively confirms the ring-opening step **9** → **10**. Of the ring carbon atoms, the azomethine carbon atoms C-3 resonate at the lowest field (δ 162.5, 162.0). The fact that this signal in the spectrum of **13b** is not split by coupling with phosphorus was used for its assignment. The resonance for C-5 was unambiguously recognized in the proton-coupled ^{13}C NMR spectrum; in the case of **13b**, a $^3J_{C,P}$ coupling of 15.4 Hz results in further splitting. That the resonance of C-7 occurs at the highest field (δ 133.3, 131.9) is as expected and is unequivocally confirmed by the large coupling with phosphorus in **13b** (184.3 Hz). The magnitudes of the phosphorus–carbon couplings (2.5, 21.2 Hz) in the phosphoryl-substituted diazepine **13b** also give decisive evidence for the assignments of the remaining ring carbon atoms C-4 and C-6. A comparison of the chemical shifts of **13b** with those of **13a** also permits assignment of the carbon atoms 4 and 6 in the latter product (see the Experimental Section).

In a mechanistic sense, the previously unknown 2-(diazomethyl)-2*H*-pyran/1*H*-1,2-diazepine rearrangement **9** → **13** may be interpreted in the following way. Initially, an electrocyclic ring opening occurs to give the butadienyldiazo compound **10**, a well-known step for 2*H*-pyrans.[7]

(7) See, e.g.: Balaban, A. T.; Nenitzcescu, C. *Justus Liebigs Ann. Chem.* **1959**, *625*, 74. Dimroth, K. *Angew. Chem.* **1960**, *72*, 331.

Scheme IV



The diazo isomers **10** are not isolated, presumably because they undergo a rapid [1,7] cyclization to give the 3*H*-1,2-diazepines **11**. The final step in the reaction sequence is an H shift to afford **13**. Literature precedents for the [1,7] ring closure of the butadienyldiazo compounds are known.[8] In principle, a [1,5] ring closure starting from **10** to give the vinylpyrazoles **12** must also be discussed. In general, such reactions are observed when diazo compounds of the type **10** possess a sterically demanding group at the carbonyl carbon atom.[1,9]

With the exception of methyl 1*H*-1,2-benzodiazepine-3-carboxylate,[10] the compounds **13a** and **b** are, to the best of our knowledge, the first representatives of noncondensed 1*H*-1,2-diazepines that are unsubstituted in the 1-position.[11] Compounds of the same structural type with acyl substituents at N-1 are stable, those with the alkyl groups in the same position are rather unstable;[12] in principle this could also be expected for **13a** and **b**. 1*H*-Azepines, the parent compound of which undergoes ready tautomerization to 3*H*-azepine,[13] are now stabilized by hydrogen-bond formation with the acyl groups in the 2-positions.[14] When this is applied to the 1*H*-1,2-diazepines **13a** and **b**, the substituents R^2 [CO_2Et, $PO(OMe)_2$] should exhibit the same effect; furthermore, the acceptor character of the acetyl groups in position 3 should also have a positive influence on the stability of the heterocycles.

Oxepines 14. Even at room temperature in benzene, the 4-(diazomethyl)-4-methyl-4*H*-pyrans **8a–d** can be converted by treatment with allylpalladium chloride (dimer) to the oxepines **14a–d** (92–98%) (Scheme IV). The reaction proceeds with elimination of nitrogen and [1,2] C shift. The products are obtained in the form of yellow to orange-red oils (**14a–c**) or orange crystals (**14d**). The oxepines **14c** and **d** are purified by column chromatography on Kieselgel; however, this method is not suitable for **14a** (chromatographic purification on basic aluminum oxide) and **14b** (purification with active charcoal). The latter two oxepines undergo acid-catalyzed isomerizations to give cyclohexadienones and phenols (**14** → **18** + **19**) on Kieselgel. This reaction will be discussed in the next section.

The IR and ^1H and ^{13}C NMR spectra of the oxepines **14a–d** (see the Experimental Section) confirm the configurations proposed and require no interpretation. They are to a large extent in accord with those of the 4-accep-

(8) See: Robertson, J. R.; Sharp, J. T. *Tetrahedron* **1984**, *40*, 3095. Further references to earlier publications are given therein.

(9) Anderson, C. D.; Sharp, J. T.; Strathdee, R. S. *J. Chem. Soc., Perkin Trans. 1* **1979**, 2209. Robertson, J. R.; Sharp, J. T. *J. Chem. Soc., Chem. Commun.* **1983**, 1003. Theis, W.; Regitz, M. *Tetrahedron* **1985**, *41*, 2625.

(10) Padwa, A.; Nahm, S. *J. Org. Chem.* **1981**, *46*, 1402.

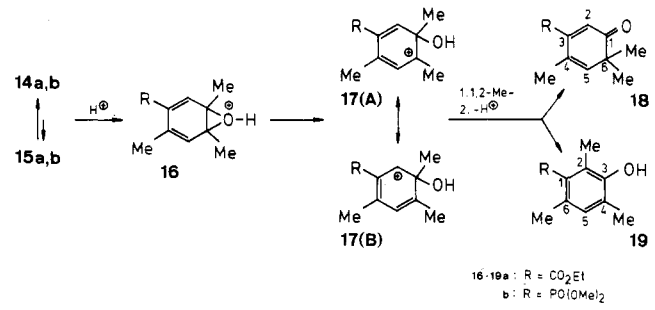
(11) Review: Sharp, J. T. In *Comprehensive Heterocyclic Chemistry*; Katritzky, A. R., Rees, C. W., Eds.; Pergamon: New York, 1984; Vol. 7, p 595 ff.

(12) Harris, D. J.; Snieckus, V. *J. Chem. Soc., Chem. Commun.* **1976**, 844.

(13) Vogel, E.; Altenbach, H.-J.; Drossard, J.-M.; Schmickler, H.; Stegelmeier, H. *Angew. Chem.* **1980**, *92*, 1053; *Angew. Chem., Int. Ed. Engl.* **1980**, *19*, 1016.

(14) Ayanger, N. R.; Purohit, A. K.; Tilak, B. D. *J. Chem. Soc., Chem. Commun.* **1981**, 399.

Scheme V



tor-substituted 2,7-di-*tert*-butyl-5-methyloxepines.[1]

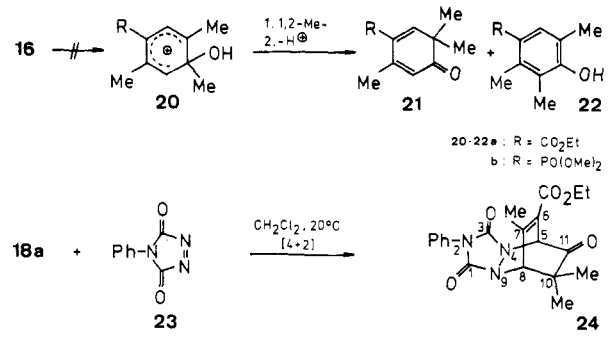
Cyclohexadienones 18 and Phenols 19. As mentioned above, the 2,7-dimethyl-substituted oxepines **14a** and **b**, in contrast to the phenyl-substituted members of the same series, **14c** and **d**, cannot be purified by chromatography on (acidic) Kieselgel with ethyl acetate. As shown by experiments under the same reaction conditions, these two products each isomerize to give 2/1 mixtures of **18** and **19** in high yields. These mixtures can be cleanly separated by column chromatography (**18a/19a**) or by fractional crystallization (**18b/19b**) (Scheme V).

The phenols **19a** and **b** are easily identifiable on account of the intense OH absorptions (3480, 3220 cm^{-1}). Decisive for the structural assignment of **19** (and thus the certain differentiation from the also feasible structure **22**) is the magnitude of the coupling of the aromatic 5-hydrogen atom with phosphorus in the case of **19b** (δ 6.85, $^4J_{H,P}$ = 6.2 Hz), which indicates the meta orientation of the two coupling nuclei.[15] That the 2- and 2′-positions relative to the phosphoryl-substituted carbon atom are occupied by two methyl groups is shown by the equal couplings with phosphorus (δ 2.48, 2.50, $^4J_{H,P}$ = 1.8 Hz); this observation is also not in accord with the structure **22b**.

In the ^{13}C NMR spectra of both **19a** and **b**, resonances for six aromatic carbon atoms are seen and all can be assigned; in the case of the phosphoryl-substituted phenol **19b**, the magnitude of the phosphorus coupling plays a decisive role in the assignments (see the Experimental Section).

First indications for the cyclohexadienone structures of **18a** and **b** are given by the occurrence of CO absorptions (1662, 1665 cm^{-1}) in the IR spectra. In the ^1H NMR spectra of the two unsaturated ketones, the hydrogen atoms 2-H resonate, as to be expected, at the lowest field (δ 6.36, 6.59). In the case of **18a**, a long-range coupling with 4-methyl and 5-H protons is apparent as a broadening of the signal, whereas in **18b** a pseudoquintet, resulting from the overlapping of two quartets, is observed. The proximity of the dimethoxyphosphoryl group in **18b** makes itself noticeable by a typical cis $^3J_{H,P}$ coupling of 20.3 Hz.[16,17] The 5-hydrogen atoms of both cyclohexadienones resonate at δ 6.04 and 6.05, respectively, and exhibit the $^5J_{H,H}$ coupling (0.7, 0.8 Hz) characteristic for this system,[18,19] as well as an allylic coupling of 1.5 Hz with the 4-methyl protons. In the case of **18b**, this signal has a ddd structure as a result of the above-mentioned and the additional coupling with phosphorus (0.6 Hz).

Scheme VI



Resonances at δ 206.4 and 205.5 in the ^{13}C NMR spectra of **18a** and **b** immediately signal the presence of CO functions. The magnitude of the coupling with phosphorus in the case of **18b** (^3J = 19.9 Hz) definitively excludes the alternative structure **21b**. The five further ring carbon atoms absorb in the expected regions (see the Experimental Section); only the low-field positions of the C-3 resonances (δ 146.2, 142.8) that are typical for α,β-unsaturated ketones need be emphasized.

The interpretation of the acid-catalyzed isomerization reaction is based on the assumption that small equilibrium amounts of the arene oxide, which, however, cannot be detected by NMR spectrometry, are present in the system **14** ⇄ **15** and are initially protonated to give the oxonium ion **16**. Subsequent opening of the hetero three-membered ring proceeds specifically and leads exclusively to the cation **17(A)** ↔ **17(B)**. A following 1,2 methyl shift to both ends of the pentadienyl system and deprotonation are then responsible for the formation of **18** and **19**. Arene oxide isomerization reactions of this type are known.[2]

Whether or not oxepines undergo acid-catalyzed (in this case Kieselgel) isomerization to cyclohexadienones and phenols seems to depend on whether or not a sufficient equilibrium concentration of the benzene oxide tautomer is present. This is apparently the case for the system **14a,b/15a,b** but no longer so for **14c,d/15c,d**. The phenyl groups in the 2- and 7-positions stabilize the monocyclic form to such an extent that the bicyclic tautomer, from which the isomerization starts, has no chance of existence. The fact that 4-acceptor-substituted 2,7-di-*tert*-butyloxepines also remain unchanged in the presence of Kieselgel[1] may be attributable to the same reason. In this case, however, it is the enormous steric effect of the two *tert*-butyl groups that prevents the formation of the benzene oxide tautomer.

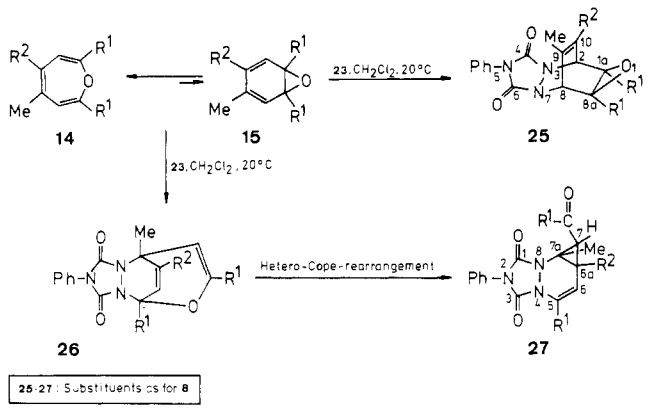
A ring-opening reaction to form cation **20**, which also starts from **16**, does not take place, at least within the limits of detection by NMR; **21** and **22** cannot be detected in the crude products. This is presumably because the cation **17**, as can be estimated qualitatively, is thermodynamically more stable than the isomer **20** and thus governs the product distribution[20] (Scheme VI).

The presence of the 1,3-diene moiety in **18a** was confirmed chemically by a Diels–Alder reaction with the triazolinedione **23** to furnish the triazolopyridazine **24** (see the Experimental Section for spectroscopic data).

Triazolinedione Adducts 25 and 27. It is known from the cycloheptatrienes that they form cycloadducts derived from the valency tautomeric norcaradiene with dienophiles such as the triazolinedione **23** even when the diene is no longer detectable by spectroscopy as an equilibrium

(15) Pretsch, E.; Clerc, T.; Seibel, J.; Simon, W. *Tabellen zur Strukturaufklärung Organischem Verbindungen*; Springer Verlag: Berlin, 1976; p H360.
(16) Cf. ref 15.
(17) Williams, D. H.; Fleming, I. *Spektroskopische Methoden zur Strukturaufklärung*, 4th ed.; Thieme Verlag: Stuttgart, 1979; p 145.
(18) Jackman, L. M.; Sternhell, S. *Applications of Nuclear Magnetic Resonance Spectroscopy in Organic Chemistry*, 2nd ed.; Pergamon: Oxford, 1969; p 342.
(19) Günther, H. *NMR-Spektroskopie*; Thieme Verlag: Stuttgart, 1973; p 360.
(20) Jerina, D. M.; Daly, J. W.; Witkop, B. *J. Am. Chem. Soc.* **1968**, *90*, 6523.

Scheme VII



partner.[21] This is also true for the oxepines **14a**, **b**, and **d**, which react smoothly with **23** in dichloromethane at room temperature to give the 1/1 adducts **25a**, **b**, and **d** in 83–89% yields. These represent the Diels–Alder adducts of the bicyclic isomers **15a**, **b**, and **d**. The corresponding reaction of **14c** with **23** under otherwise identical conditions proceeds differently in that an isomer with the structure **27c** (66%) is formed together with **25c** (23%). The two urazoles can be separated by fractional crystallization. In this context, it should be mentioned that 4-acceptor-substituted 2,7-di-*tert*-butyloxepines react with **23** to give exclusively products corresponding to **27**[1] (Scheme VII).

The structural confirmation of **27c** is relatively simple. The ^1H and ^{13}C NMR spectroscopic data agree very well with those of an already known tricyclic compound with a slightly different substitution pattern [**27**; R^1 = *t*-Bu, R^2 = PO(OMe)Ph]. The latter was obtained in the same manner from 2,7-di-*tert*-butyl-4-(methoxyphenylphosphoryl)-5-methyloxepine [**14**; R^1 = *t*-Bu, R^2 = PO(OMe)Ph] and **23**, and its structure was confirmed by an X-ray crystallographic analysis.[1] An interesting phenomenon in the ^1H NMR spectrum of **27c** should be mentioned: as a result of the chiral carbon atoms of the three-membered ring, the two ethyl hydrogen atoms of the ester group are diastereotopic and appear as the AB part (16 lines) of an ABX_3 system (see the Experimental Section).

The structural assignment of the Diels–Alder adducts **25a–d** is based mainly on the ^{13}C NMR resonances of the skeletal carbon atoms: C-1/C-3, δ 156.0–156.5; C-9, δ 146.9–153.1; C-10, δ 118.4–122.8; C-2, δ 64.8–66.3; C-8, δ 60.5–62.4; C-1a, δ 54.1–59.7; C-8a, δ 52.3–58.3.

Last doubts on the structures of the Diels–Alder adducts **25** were eliminated by an X-ray structural analysis of **25d** (see Figure 1 (supplementary material)). Bond lengths and angles are normal and require no interpretation.

The varying reaction behaviors of the oxepines **14** with the triazolinedione **23** (formation of **25** and/or **27**) depend on the substituents whereby two extreme situations have to be differentiated.

(a) R^1 = Me: In this case apparently only small amounts of the benzene oxide are in equilibrium with the oxepine, and these react with the strong dienophile **23** to form **25** and are rapidly replaced.

(b) R^1 = *t*-Bu: For steric reasons (see the preceding section), an equilibrium concentration of the benzene oxide is not achieved so that the monocycle undergoes the [4 + 2] cycloaddition with **23**. The formation of **26** is followed by a rapid hetero Cope rearrangement with formation of **27**. Only few reactions of this type are known.[1,22–24]

Finally, in the case of R = Ph, a situation is reached in which both possibilities can compete with each other (formation of **25** and **27**).

Experimental Section

Melting points are uncorrected and were determined with a Mettler FP 61 apparatus (heating rate 3 °C/min). Microanalyses were obtained on a Perkin-Elmer Analyzer 240. IR spectra were recorded with a Perkin-Elmer 397 spectrophotometer. ^1H NMR spectra were obtained on Varian EM 390 and Bruker WP 200 spectrometers with tetramethysilane as internal standard. ^{13}C NMR spectra were recorded on a Bruker WP 200 spectrometer also with tetramethylsilane as internal standard. Column chromatography was performed on Kieselgel (Macherey and Nagel, 0.05–0.2 mm) or aluminum oxide (basic, Macherey and Nagel, deactivated with 5% water). The separations were monitored by TLC on DC-Fertigplatten Polygram Sil G/UV_{254} or Alugram Sil G/UV_{254} using the same eluent systems as for the column chromatography. Reactions with lithiated diazo esters were carried out under an argon atmosphere. All solvents employed were anhydrous and were distilled before use.

4-Methyl-2,6-diphenylpyrylium Tetrafluoroborate (6b). To a suspension of 16.6 g (49.9 mmol) of 2,6-diphenylpyrylium perchlorate[4] in 150 mL of ether was added dropwise under nitrogen a solution of 12.5 g (75.2 mmol) of methylmagnesium iodide in 100 mL of ether, and the mixture was stirred for 2 h at room temperature. Washing with 50 mL of saturated aqueous ammonium chloride solution and with 100 mL of water, drying with magnesium sulfate, and evaporation at 30 °C (15 Torr) gave 11.6 g (94%) of 4-methyl-2,6-diphenyl-4*H*-pyran, which was used in the next step without further purification.

A solution of 10.0 g (40.3 mmol) of the 4*H*-pyran in 50 mL of acetonitrile was treated with 13.3 g (40.3 mmol) of triphenylcarbenium tetrafluoroborate, and the mixture was stirred at room temperature for 3 h. Evaporation at 30 °C (15 Torr), taking up of the residue in about 5 mL of acetone, and addition of 200 mL of ether yielded 11.9 g (89%) of **6b** as a red-brown, crystalline powder, mp 234 °C dec (lit.[25] mp 236–240 °C).

Reaction of 2,4,6-Trimethylpyrylium Tetrafluoroborate (6a) with Ethyl Diazoacetate (7a). To a solution of 1.14 g (10.0 mmol) of the diazoacetate **7a**[26] in 200 mL of tetrahydrofuran/ether (1/1) cooled to −115 °C was added dropwise with stirring within 30 min 6.3 mL (10.1 mmol) of a 1.6 N *n*-butyllithium solution in hexane,[27] previously cooled to −78 °C. Over the next 30 min, 2.10 g (10.0 mmol) of the pyrylium salt **6a**[28] was added in portions. The mixture was allowed to warm to −78 °C and was stirred for 4 h. It was then allowed to warm to room temperature and 100 mL of dichloromethane added. The mixture was washed twice with 50-mL portions of saturated, aqueous sodium hydrogen carbonate solution and once with 50 mL of water and then dried over magnesium sulfate. Concentration at 30 °C (15 Torr) gave 2.10 g of a red oil, which was chromatographed on 220 g of Kieselgel with ethyl acetate/hexane (1/1) to give the following in succession.

(a) Ethyl diazo(2,4,6-trimethyl-4*H*-pyran-4-yl)acetate (**8a**): 0.48 g (20%); yellow oil; IR (film) 2075 (C=N_2), 1695 cm^{-1} (br, C=O/C=C); ^1H NMR ($CDCl_3$) δ 1.25 (3 H, t, *J* = 7.1 Hz, CH_3-ethyl), 1.42 (3 H, s, 4-CH_3), 1.81 (6 H, s, 2,6-CH_3), 4.18 (2 H, q, *J* = 7.1 Hz, CH_2-ethyl), 4.62 (2 H, s, 3,5-H). Anal. Calcd for $C_{12}H_{16}N_2O_3$: C, 61.00; H, 6.83; N, 11.86. Found: C, 60.8; H, 6.83; N, 11.7.

(b) Ethyl 3-acetyl-4,6-dimethyl-1*H*-1,2-diazepine-7-carboxylate (**13a**): 0.45 g (19%); orange oil, obtained in analytical purity by

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(23) Boyd, D. R.; Berchtold, G. A. *J. Org. Chem.* **1979**, *44*, 468. VanEpp, J. E.; Boyd, D. R.; Berchtold, G. A. *J. Org. Chem.* **1981**, *46*, 1817.
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(26) Searle, N. E. *Organic Syntheses*; Wiley: New York, 1963; Collect. Vol. IV, p 424.
(27) Commercial product from Jansen, B-2340 Beerse, Belgium.
(28) Balaban, A. T.; Boulton, G. A. *J. Organic Syntheses*; Wiley: New York, 1973; Collect. Vol. V, p 1112.

further chromatography on 50 g of Kieselgel eluting with ethyl acetate/hexane (1/2); IR (film) 3330 (NH), 1715, 1690 (C=O), 1615 cm^{-1} (C=C); ^1H NMR ($CDCl_3$) δ 1.35 (3 H, t, J = 7.2 Hz, CH_3-ethyl), 1.99 (3 H, d, J = 1.6 Hz, 4-CH_3), 2.09 (3 H, d, J = 0.6 Hz, 6-CH_3), 2.38 (3 H, s, CH_3-acetyl), 4.29 (2 H, q, J = 7.2 Hz, CH_2-ethyl), 6.31 (1 H, qq, J = 1.6, 0.6 Hz, 5-H), 7.25 (1 H, s, NH); ^{13}C NMR ($CDCl_3$) δ 14.3 (CH_3-ethyl), 18.7 (6-CH_3), 21.6 (4-CH_3), 27.3 (CH_3-acetyl), 61.9 (CH_2-ethyl), 133.3 (C-7), 138.2 (C-6), 141.5 (C-5), 142.6 (C-4), 162.5 (C-3), 163.6 (CO-ester), 198.4 (CO-acetyl). Anal. Calcd for $C_{12}H_{16}N_2O_3$: C, 61.00; H, 6.83; N, 11.86. Found: C, 60.8; H, 6.76; N, 11.7.

Reaction of 2,4,6-Trimethylpyrylium Tetrafluoroborate (6a) with Dimethyl Diazomethanephosphonate (7b). Diazo ester **7b**[29] (1.50 g, 10.0 mmol) in 200 mL of tetrahydrofuran/ether (1/1) was reacted at −78 °C with 6.3 mL (10.1 mmol) of 1.6 N *n*-butyllithium solution in hexane[27] and 2.10 g (10.0 mmol) of pyrylium salt **6a**[28] and worked up as described above for the reaction **6a** + **7a**. A red-brown oil (2.20 g) was obtained and chromatographed on 800 g of basic aluminum oxide with ethyl acetate as eluent to give the following successively.

(a) A decomposition product (0.5 g) of **6a**, which was not studied further.

(b) Dimethyl diazo(2,4,6-trimethyl-4*H*-pyran-4-yl)methanephosphonate (**8b**): 0.59 g (22%); yellow crystals; mp 51 °C (from pentane); IR (KBr) 2075 (C=N_2), 1700 (C=C), 1245 (P=O), 1020 cm^{-1} (POC); ^1H NMR ($CDCl_3$) δ 1.30 (3 H, s, 4-CH_3), 1.83 (6 H, s, 2,6-CH_3), 3.75 (6 H, d, $J_{H,P}$ = 11.7 Hz, $POCH_3$), 4.54 (2 H, s, 3,5-H). Anal. Calcd for $C_{11}H_{17}N_2O_4P$: C, 48.53; H, 6.29; N, 10.29. Found: C, 48.7; H, 6.21; N, 10.2.

(c) Dimethyl 3-acetyl-4,6-dimethyl-1*H*-1,2-diazepine-7-phosphonate (**13b**): 0.56 g (21%); orange crystals; mp 51 °C (from ether/pentane, 1/1); IR (KBr) 3310, 3275 (NH), 1685 (C=O), 1620, 1610 (C=C), 1245 (P=O), 1040, 1010 cm^{-1} (POC); ^1H NMR (CD_2Cl_2) δ 1.91 (3 H, dd, $J_{H,P}$ = 2.8 Hz, $J_{H,H}$ = 0.5 Hz, 6-CH_3), 1.95 (3 H, dd, $J_{H,H}$ = 1.6 Hz, $J_{H,P}$ = 0.7 Hz, 4-CH_3), 2.34 (3 H, s, CH_3-acetyl), 3.71 (6 H, d, $J_{H,P}$ = 11.5 Hz, $POCH_3$), 6.31 (1 H, dqq, $J_{H,P}$ = 1.3 Hz, $J_{H,H}$ = 1.6, 0.5 Hz, 5-H), 6.76 (1 H, d, $J_{H,P}$ = 12.1 Hz, NH); ^{13}C NMR ($CDCl_3$) δ 17.5 (d, $J_{C,P}$ = 2.7 Hz, 6-CH_3), 21.6 (4-CH_3), 27.4 (CH_3-acetyl), 52.7 (d, $J_{C,P}$ = 4.6 Hz, $POCH_3$), 131.9 (d, $J_{C,P}$ = 184.3 Hz, C-7), 140.0 (d, $J_{C,P}$ = 15.4 Hz, C-5), 141.2 (d, $J_{C,P}$ = 21.2 Hz, C-6), 143.2 (d, $J_{C,P}$ = 2.5 Hz, C-4), 162.0 (C-3), 197.9 (CO). Anal. Calcd for $C_{11}H_{17}N_2O_4P$: C, 48.53; H, 6.29; N, 10.29. Found: C, 48.4; H, 6.20; N, 10.3.

Ethyl Diazo(2,6-diphenyl-4-methyl-4*H*-pyran-4-yl)acetate (8c). Diazo ester **7a**[26] (1.14 g, 10.0 mmol) in 200 mL of tetrahydrofuran/ether (1/1) at −115 °C was reacted with 6.3 mL (10.1 mmol) of a previously cooled (to −78 °C) 1.6 N solution of *n*-butyllithium in hexane[27] and 3.34 g (10.0 mmol) of pyrylium salt **6b** as described above for the reaction of **6a** + **7a**. Ether (200 mL) was added, and the mixture was worked up to give a dark red oil, which was purified by chromatography on 390 g of Kieselgel with ethyl acetate/hexane (1/9) as eluent. The eluted product was taken up in 20 mL of ether, stirred with 2 g of active charcoal, filtered, and evaporated at 30 °C (15 Torr) to give 1.41 g (39%) of **8c** as a pale yellow oil: IR (film) 2080 (C=N_2), 1685 cm^{-1} (br, C=O/C=C); ^1H NMR ($CDCl_3$) δ 1.22 (3 H, t, J = 7.1 Hz, CH_3-ethyl), 1.65 (3 H, s, 4-CH_3), 4.18 (2 H, q, J = 7.1 Hz, CH_2-ethyl), 5.50 (2 H, s, 3,5-H), 7.31 (10 H, m, H-arom). Anal. Calcd for $C_{22}H_{20}N_2O_3$: C, 73.32; H, 5.59; N, 7.77. Found: C, 73.5; H, 5.69; N, 7.6.

Dimethyl Diazo(2,6-diphenyl-4-methyl-4*H*-pyran-4-yl)-methanephosphonate (8d). Diazo ester **7b**[29] (1.50 g, 10.0 mmol) in 200 mL of tetrahydrofuran/ether (1/1) at −78 °C was reacted with 6.3 mL (10.1 mmol) of 1.6 N *n*-butyllithium solution in hexane[27] and 3.34 g (10.0 mmol) of pyrylium salt **6b**, as described for the reaction of **6a** + **7a**, and worked up after addition of 200 mL of ether. A dark red oil was obtained and was purified by chromatography on 250 g of Kieselgel with ethyl acetate as eluent. Further chromatography on 400 g of neutral aluminum oxide with the same eluent gave 0.71 g (18%) of **8d** as an orange oil: IR (film) 2075 (C=N_2), 1680 (C=C), 1260 (P=O), 1025 cm^{-1} (POC); ^1H NMR ($CDCl_3$) δ 1.56 (3 H, s, 4-CH_3), 3.77 (6 H, d, $J_{H,P}$ = 11.8 Hz, $POCH_3$), 5.45 (2 H, s, 3,5-H), 7.40–7.75 (10 H, m, H-arom). Anal. Calcd for $C_{21}H_{21}N_2O_4P$: C, 63.63; H, 5.34; N, 7.07. Found: C, 63.7; H, 5.51; N, 6.8.

Ethyl 2,5,7-Trimethyl-4-oxepinecarboxylate (14a). A solution of 0.47 g (2.0 mmol) of diazo ester **8a** in 50 mL of benzene was stirred with 15 mg of allylpalladium chloride (dimer)[30] for 2 h at room temperature, and then the mixture was evaporated. The residue was chromatographed on 80 g of basic aluminum oxide with ethyl acetate/hexane (1/2) as eluent to give 0.40 g (97%) of **14a** as a yellow oil: IR (film) 1710 (C=O), 1662, 1645, 1562 cm^{-1} (C=C); ^1H NMR ($CDCl_3$) δ 1.30 (3 H, t, J = 7.2 Hz, CH_3-ethyl), 1.92 (6 H, s, 2,7-CH_3), 2.11 (3 H, s, 5-CH_3), 4.19 (2 H, q, J = 7.2 Hz, CH_2-ethyl), 5.35 (1 H, s, 3-H); 5.78 (1 H, s, 6-H); ^{13}C NMR ($CDCl_3$) δ 14.1 (CH_3-ethyl), 20.8 (5-CH_3), 21.5, 21.6 (2,7-CH_3), 60.1 (CH_2-ethyl), 111.5 (C-3), 116.8 (C-6), 126.3 (C-4), 144.4 (C-5), 150.6 (C-2), 155.2 (C-7), 167.2 (CO). Anal. Calcd for $C_{12}H_{16}O_3$: C, 69.21; H, 7.74. Found: C, 68.9; H, 7.77.

Dimethyl 2,5,7-Trimethyl-4-oxepinephosphonate (14b). A solution of 0.54 g (2.0 mmol) of diazo ester **8b** in 50 mL of benzene was stirred at room temperature with 15 mg of allylpalladium chloride (dimer)[30] for 2 h, and then the mixture was evaporated at 30 °C (15 Torr). Dissolution of the residue in 25 mL of ether, addition of 0.5 g of active charcoal, filtration after 10 min, and renewed evaporation gave 0.45 g (92%) of **14b** as a yellow oil: IR (film) 1655, 1555 (C=C), 1250 (P=O), 1055, 1035 cm^{-1} (POC); ^1H NMR (acetone-d_6) δ 1.90, 1.92 (each 3 H, each s, 2,7-CH_3), 2.12 (3 H, d, $J_{H,P}$ = 3.2 Hz, 5-CH_3), 3.64 (6 H, d, $J_{H,P}$ = 11.2 Hz, $POCH_3$), 5.49 (1 H, d, $J_{H,P}$ = 3.3 Hz, 3-H), 5.60 (1 H, d, $J_{H,P}$ = 8.0 Hz, 6-H); ^{13}C NMR (acetone-d_6) δ 21.1, 21.6 (2,7-CH_3), 21.9 (d, $J_{C,P}$ = 6.1 Hz, 5-CH_3), 52.3 (d, $J_{C,P}$ = 5.6 Hz, $POCH_3$), 113.9 (d, $J_{C,P}$ = 11.6 Hz, C-3), 118.0 (d, $J_{C,P}$ = 20.9 Hz, C-6), 123.5 (d, $J_{C,P}$ = 181.9 Hz, C-4), 149.9 (d, $J_{C,P}$ = 10.4 Hz, C-5), 150.7 (d, $J_{C,P}$ = 13.2 Hz, C-2), 153.3 (C-7). Anal. Calcd for $C_{11}H_{17}O_4P$: C, 54.10; H, 7.02. Found: C, 54.0; H, 6.95.

Ethyl 2,7-Diphenyl-5-methyl-4-oxepinecarboxylate (14c). A solution of 0.72 g (2.0 mmol) of the diazo ester **8c** in 50 mL of benzene was stirred at room temperature with 15 mg of allylpalladium chloride (dimer)[30] for 4 h, and the mixture was then evaporated at 30 °C (15 Torr). The residue was chromatographed on 100 g of Kieselgel with ethyl acetate/hexane (1:9) as eluent to yield 0.65 g (98%) of **14c** as an orange oil: IR (film) 1708 cm^{-1} (C=O); ^1H NMR ($CDCl_3$) δ 1.33 (3 H, t, J = 7.1 Hz, CH_3-ethyl, 2.33 (3 H, s, 5-CH_3), 4.28 (2 H, q, J = 7.1 Hz, CH_2-ethyl), 6.22 (1 H, s, 3-H), 6.70 (1 H, s, 6-H), 7.26–7.73 (10 H, m, H-arom); ^{13}C NMR ($CDCl_3$) δ 14.3 (CH_3-ethyl), 22.2 (5-CH_3), 60.6 (CH_2-ethyl), 113.0 (C-3), 117.8 (C-6), (C-6), 127.8 (C-4), 126.1–135.0 (C-arom), 144.7 (C-5), 151.0 (C-2), 154.6 (C-7), 167.5(CO). Anal. Calcd for $C_{22}H_{20}O_3$: C, 79.50; H, 6.06. Found: C, 79.5; H, 6.20.

Dimethyl 2,7-Diphenyl-5-methyl-4-oxepinephosphonate (14d). A solution of 0.79 g (2.0 mmol) of the diazo ester **8d** in 50 mL of benzene was stirred at room temperature with 15 mg of allylpalladium chloride (dimer)[30] for 4 h, and the mixture was then evaporated at 30 °C (15 Torr). The residue was chromatographed on 100 g of Kieselgel with ethyl acetate as eluent to yield 0.71 g (96%) of **14d** as orange crystals: mp 94 °C; IR (KBr) 1615, 1520 (C=C), 1240 (P=O), 1055, 1020 cm^{-1} (POC); ^1H NMR ($CDCl_3$) δ 2.38 (3 H, dd, $J_{H,P}$ = 3.1 Hz, $J_{H,H}$ = 0.5 Hz, 5-CH_3), 3.79 (6 H, d, $J_{H,P}$ = 11.2 Hz, $POCH_3$), 6.24 (1 H, d, $J_{H,P}$ = 3.4 Hz, 3-H), 6.53 (1 H, dq, $J_{H,P}$ = 9.0 Hz, $J_{H,H}$ = 0.5 Hz, 6-H), 7.25–7.75 (10 H, m, H-arom); ^{13}C NMR ($CDCl_3$) δ 22.5 (d, $J_{C,P}$ = 6.0 Hz, 5-CH_3), 52.3 (d, $J_{C,P}$ = 5.2 Hz, $POCH_3$), 113.7 (d, $J_{C,P}$ = 12.2 Hz, C-3), 117.7 (d, $J_{C,P}$ = 21.1 Hz, C-6), 122.8 (d, $J_{C,P}$ = 183.6 Hz, C-4), 126.1–134.7 (C-arom), 149.8 (d, $J_{C,P}$ = 11.4 Hz, C-5), 151.2 (d, $J_{C,P}$ = 14.4 Hz, C-2), 154.8 (d, $J_{C,P}$ = 2.5 Hz, C-7). Anal. Calcd for $C_{21}H_{21}O_4P$: C, 68.47; H, 5.75. Found: C, 68.3; H, 5.81.

Kieselgel-Catalyzed Isomerization of Oxepine 14a to Ethyl 1-Oxo-4,6,6-trimethyl-2,4-cyclohexadiene-3-carboxylate (18a) and Ethyl 3-Hydroxy-2,4,6-trimethylbenzoate (19a). Oxepine **14a** (0.42 g, 2.0 mmol) was chromatographed on 200 g of Kieselgel with ethyl acetate (elution time 8 h), and 0.35 g (83%) of an oily, 2/1 mixture (by ^1H NMR spectroscopy) of **19a** and **18a** was obtained. Column chromoatography on 50 g of Kieselgel with ethyl acetate/hexane (1/9) as eluent furnished the following in succession.

(29) Seyferth, D.; Marmor, R. S.; Hilbert, P. *J. Org. Chem.* **1971**, *36*, 1379.

(30) Commercial product from EGA-Chemie, D-7924 Steinheim.

(a) Cyclohexadienone **18a**: 0.11 g (26%); colorless oil; obtained in analytical purity after Kugelrohr distillation at 90 °C (oven temperature) (0.15 Torr); IR (film) 1725, 1662 (C=O), 1640 cm^{-1} (C=C); ^1H NMR ($CDCl_3$) δ 1.20 (6 H, s, 6-CH_3), 1.36 (3 H, t, J = 7.2 Hz, CH_3-ethyl), 2.04 (3 H, dd, J = 1.5, 0.4 Hz, 4-CH_3), 4.33 (2 H, q, J = 7.2 Hz, CH_2-ethyl), 6.04 (1 H, dq, J = 1.5, 0.7 Hz, 5-H), 6.36 (1 H, s, br, 2-H); ^{13}C NMR ($CDCl_3$)·δ 14.1 (CH_3-ethyl), 19.7 (4-CH_3), 25.6 (6-CH_3), 47.1 (C-6), 61.7 (CH_2-ethyl), 124.4 (C-4), 125.7 (C-2), 145.8 (C-5), 146.2 (C-3), 166.8 (CO-ester), 206.4 (CO-ketone). Anal. Calcd for $C_{12}H_{16}O_3$: C, 69.21; H, 7.74. Found: C, 69.0; H, 7.75.

(b) Phenol **19a**: 0.23 g (55%); solidified after Kugelrohr distillation at 130 °C (oven temperature) (0.15 Torr); colorless crystals; mp 54 °C; IR (KBr) 3480 (OH), 1700 cm^{-1} (CO); ^1H NMR ($CDCl_3$) δ 1.33 (3 H, t, J = 7.1 Hz, CH_3-ethyl), 2.11, 2.12 (each 3 H, each s, 2,6-CH_3), 2.17 (3 H, s, 4-CH_3), 4.35 (2 H, q, J = 7.1 Hz, CH_2-ethyl), 5.75 (1 H, s, OH), 6.71 (1 H, s, 5-H); ^{13}C NMR ($CDCl_3$) δ 13.0 (2-CH_3), 14.3 (CH_3-ethyl), 16.0 (4-CH_3), 18.8 (6-CH_3), 61.1 (CH_2-ethyl), 120.7 (C-4), 125.0 (C-1), 126.1 (C-2), 130.0 (C-5), 132.9 (C-6), 150.3 (C-3), 170.4 (CO). Anal. Calcd for $C_{12}H_{16}O_3$: C, 69.21; H, 7.74. Found: C, 69.2; H, 7.79.

Kieselgel-Catalyzed Isomerization of Oxepine 14b to Dimethyl 1-Oxo-4,6,6-trimethyl-2,4-cyclohexadiene-3-phosphonate (18b) and Dimethyl 3-Hydroxy-2,4,6-trimethylbenzene-1-phosphonate (19b). Oxepine **14b** (0.48 g, 2.0 mmol) was chromatographed on 50 g of Kieselgel with ethyl acetate as eluent (elution time 3 H), and 0.46 g (96%) of an oily, 2/1 mixture of **18b** and **19b** (by ^1H NMR spectroscopy) was obtained.

(a) Crystallization from ether/pentane (1/1) furnished 0.30 g (62%) of phenol **19b** as colorless crystals: mp 123 °C; IR (KBr) 3220 (OH), 1600 (C=C), 1215 (P=O), 1055, 1015 cm^{-1} (POC); ^1H NMR ($CDCl_3$) δ 2.26 (3 H, s, 4-CH_3), 2.48 (3 H, d, $J_{H,P}$ = 1.8 Hz, 2-CH_3), 2.50 (3 H, d, $J_{H,P}$ = 1.8 Hz, 6-CH_3), 3.70 (6 H, d, $J_{H,P}$ = 11.5 Hz, $POCH_3$), 6.80 (1 H, s, OH), 6.85 (1 H, d, $J_{H,P}$ = 6.2 Hz, 5-H); ^{13}C NMR ($CDCl_3$) δ 14.6 (d, $J_{C,P}$ = 3.2 Hz, 2-CH_3), 16.7 (4-CH_3), 22.6 (d, $J_{C,P}$ = 2.4 Hz, 6-CH_3), 51.9 (d, $J_{C,P}$ = 5.6 Hz, $POCH_3$), 121.6 (d, $J_{C,P}$ = 182.0 Hz, C-1), 129.3 (d, $J_{C,P}$ = 2.8 Hz, C-4), 130.2 (d, $J_{P,C}$ = 13.2 Hz, C-2), 132.0 (d, $J_{C,P}$ = 19.1 Hz, C-5), 135.1 (d, $J_{C,P}$ = 11.5 Hz, C-6), 151.4 (d, $J_{C,P}$ = 20.7 Hz, C-3). Anal. Calcd for $C_{11}H_{17}O_4P$: C, 54.10; H, 7.02. Found: C, 53.9; H, 6.92.

(b) Evaporation of the ether/pentane filtrate from **19b** and Kugelrohr distillation of the residue at 130 °C (oven temperature) (0.05 Torr) yielded 0.15 g (31%) of cyclohexadienone **18b** as a yellow oil: IR (film) 1665 (C=O), 1635 (C=C), 1255 (P=O), 1055, 1035 cm^{-1} (POC); ^1H NMR ($CDCl_3$) δ 1.20 (6 H, s, CH_3), 2.12 (3 H, ddd, $J_{H,P}$ = 10 Hz, $J_{H,H}$ = 1.5, 0.6 Hz, 4-CH_3), 3.84 (6 H, d, $J_{H,P}$ = 11.1 Hz, $POCH_3$), 6.05 (1 H, ddq, $J_{H,P}$ = 7.3 Hz, $J_{H,H}$ = 1.5, 0.8 Hz, 5-H), 6.59 (1 H, ddq, $J_{H,P}$ = 20.3 Hz, $J_{H,H}$ = 0.8, 0.6 Hz, 2-H); ^{13}C NMR ($CDCl_3$) δ 20.1 (4-CH_3), 25.4 (6-CH_3), 46.9 (C-6), 53.1 (d, $J_{C,P}$ = 6.1 Hz, $POCH_3$), 124.9 (d, $J_{C,P}$ = 9.0 Hz, C-4), 132.4 (d, $J_{C,P}$ = 4.9 Hz, C-2), 142.8 (d, $J_{C,P}$ = 172.5 Hz, C-3), 145.5 (d, $J_{C,P}$ = 14.9 Hz, C-5), 205.3 (d, $J_{C,P}$ = 19.9 Hz, CO). Anal. Calcd for $C_{11}H_{17}O_4P$: C, 54.10; H, 7.02. Found: C, 53.9; 6.88.

Ethyl 2-Phenyl-7,10,10-trimethyl-1,3,11-trioxo-5,8-etheno-2,3,5,8-tetrahydro-1*H*-[1,2,4]triazolo[1,2-*a*]pyridazine-6-carboxylate (24). To a solution of 100 mg (0.48 mmol) of cyclohexadienone **18a** in 25 mL of dichloromethane was added dropwise with stirring at room temperature a solution of 84 mg (0.48 mmol) of triazolinedione **23**[31] in 25 mL of dichloromethane. The mixture lost its color and was then evaporated at 30 °C (15 Torr) [remaining traces of solvent were removed at 40 °C (10^{-3} Torr)] to give 183 mg (100%) of the adduct **24** as a colorless, crystalline powder: mp 135 °C; IR (KBr) 1770, 1740, 1715, 1700 cm^{-1} (CO); ^1H NMR ($CDCl_3$) δ 1.22, 1.40 (each 3 H, each s, 10-CH_3), 1.34 (3 H, t, J = 7.1 Hz, CH_3-ethyl), 2.49 (3 H, s, 7-CH_3), 4.27 (2 H, q, J = 7.1 Hz, CH_2-ethyl), 4.71 (1 H, s, 8-H), 5.59 (1 H, s, 5-H), 7.38–7.49 (5 H, m, H-arom); ^{13}C NMR ($CDCl_3$) δ 14.1 (CH_3-ethyl), 20.9 (7-CH_3), 22.7, 23.8 (10-CH_3), 43.7 (C-10), 61.6 (CH_2-ethyl), 61.8 (C-8), 67.0 (C-5), 121.1 (C-6), 126.3–131,3 (C-arom), 155.0, 156.0 (CO-1/CO-3), 156.3 (C-7), 162.3 (CO-ester), 202.1 (CO-11). Anal. Calcd for $C_{20}H_{21}N_3O_5$: C, 62.65; H, 5.52; N, 10.96. Found: C, 62.2; H, 5.51; N, 10.9.

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Ethyl 4,6-Dioxo-5-phenyl-1a,8a,9-trimethyl-2,8-etheno-1a,2,5,6,8,8a-hexahydro-4*H*-oxireno[*d*][1,2,4]triazolo[1,2-*a*]pyridazine-10-carboxylate (25a). To a solution of 0.21 g (1.0 mmol) of oxepine **14a** in 10 mL of dichloromethane was added dropwise with stirring at room temperature within 30 min a solution of 0.17 g (0.97 mmol) of triazolinedione **23**[31] in 15 mL of dichloromethane. After 1 h, the mixture was evaporated at 30 °C (15 Torr), and the residue was taken up in 5 mL of ether. Addition of 5 mL of pentane and cooling to −20 °C gave 0.31 g (83%) of the adduct **25a** as colorless crystals: mp 125 °C; IR (KBr) 1770, 1715 (CO), 1640 cm^{-1} (C=C); ^1H NMR ($CDCl_3$) δ 1.32 (3 H, X_3 part of an ABX_3 system, $J_{A,X}$ = 7.2 Hz, $J_{B,X}$ = 7.0 Hz, CH_3-ethyl), 1.59, 1.61 (each 3 H, each s, 1a,8a-CH_3), 2.33 (3 H, s, 9-CH_3), 4.27 (2 H, AB part of an ABX_3 system, δ_A 4.26, δ_B 4.21, $J_{A,B}$ = 10.8 Hz, $J_{A,X}$ = 7.2 Hz, $J_{B,X}$ = 7.0 Hz, CH_2-ethyl), 4.82 (1 H, s, 2-H), 5.51 (1 H, s, 8-H), 7.28–7.49 (5 H, m, H-arom); ^{13}C NMR ($CDCl_3$) δ 13.0 (8a-CH_3), 13.2 (1a-CH_3), 14.2 (CH_3-ethyl), 19.2 (9-CH_3), 53.3 (C-8a), 54.1 (C-1a), 60.5 (C-8), 61.2 (CH_2-ethyl), 65.6 (C-2), 121.9 (C-10), 125.4–131.2 (C-arom), 146.9 (C-9), 156.2, 156.4 (CO-4/CO-6), 163.2 (CO-ester). Anal. Calcd for $C_{20}H_{21}N_3O_5$: C, 62.65; H, 5.52; N, 10.96. Found: C, 62.4; H, 5.64; N, 10.9.

Dimethyl 4,6-Dioxo-5-phenyl-1a,8a,9-trimethyl-2,8-etheno-1a,2,5,6,8,8a-hexahydro-4*H*-oxireno[*d*][1,2,4]triazolo[1,2-*a*]pyridazine-10-phosphonate (25b). To a solution of 0.24 g (0.98 mmol) of the oxepine **14b** in 10 mL of dichloromethane was added dropwise with stirring at room temperature within 30 min a solution of 0.17 g (0.97 mmol) of the triazolinedione **23**[31] in 15 mL of dichloromethane. After 1 h, the mixture was evaporated at 30 °C (15 Torr), and the oily residue was chromatographed of 50 g of Kieselgel with ethyl acetate as eluent. Renewed evaporation of the eluate at 40 °C (15 Torr), dissolution of the residual oil in a little ethyl acetate, addition of pentane, and cooling to −20 °C produced 0.35 g (86%) of the adduct **25b** as colorless crystals: mp 141 °C; IR (KBr) 1775, 1720 (C=O), 1248 (P=O), 1055, 1015 cm^{-1} (POC); ^1H NMR ($CDCl_3$) δ 1.59, 1.60 (each 3 H, each s, 1a,8a-CH_3), 2.30 (3 H, d, $J_{H,P}$ = 3.4 Hz, 9-CH_3), 3.71 (3 H, d, $J_{H,P}$ = 11.4 Hz, $POCH_3$), 3.73 (3 H, d, $J_{H,P}$ = 11.3 Hz, $POCH_3$), 4.80 (1 H, d, $J_{H,P}$ = 5.2 Hz, 8-H), 5.14 (1 H, d, $J_{H,P}$ = 8.4 Hz, 2-H), 7.30–7.47 (5 H, m, H-arom); ^{13}C NMR ($CDCl_3$) δ 13.0, 13.1 (1a,8a-CH_3), 19.6 (d, $J_{C,P}$ = 4.6 Hz, 9-CH_3), 52.5, 52.7 (each d, $J_{C,P}$ = 5.6 Hz, $POCH_3$), 52.9 (d, $J_{C,P}$ = 2.2 Hz, C-8a), 54.3 (d, $J_{C,P}$ = 4.3 Hz, C-1a), 61.6 (d, $J_{C,P}$ = 12.6 Hz, C-8), 64.8 (d, $J_{C,P}$ = 15.3 Hz, C-2), 118.4 (d, $J_{C,P}$ = 190.8 Hz, C-10), 125.5–131.1 (C-arom), 151.5 (d, $J_{C,P}$ = 8.7 Hz, C-9), 156.1, 156.5 (CO-4/CO-6). Anal. Calcd for $C_{19}H_{22}N_3O_6P$: C, 54.42; H, 5.29; N, 10.02. Found: C, 54.2; H, 5.38; N, 10.0.

Reaction of Oxepine 14c with Triazolinedione 23. To a solution of 1.0 g (3.0 mmol) of oxepine **14c** in 10 mL of dichloromethane was added dropwise with stirring at room temperature within 30 min a solution of 0.52 g (3.00 mmol) of triazolidinedione **23**[31] in 45 mL of dichloromethane. After 1 h, the mixture was evaporated at 30 °C (15 Torr).

(a) By fractional crystallization of the pale yellow, oily residue from dichloromethane/ether 1.0 g (66%) of ethyl 7-*endo*-benzoyl-1,3-dioxo-2,5-diphenyl-7a-methyl-2,3,6a,7a-tetrahydro-1*H*,7*H*-cyclopropa[*c*][1,2,4]triazolo[1,2-*a*]pyridazine-6a-carboxylate (**27c**) was obtained as colorless crystals: mp 151 °C; IR (KBr) 1780, 1725 (C=O), 1657 cm^{-1} (C=C); ^1H NMR ($CDCl_3$) δ 1.35 (3 H, X_3 part of an ABX_3 system, $J_{A,X}$ = $J_{B,X}$ = 7.1 Hz, CH_3-ethyl), 2.13 (3 H, s, 7a-CH_3), 3.95 (1 H, s, 7-H), 4.35 (2 H, AB part of an ABX_3 system, δ_A 4.39, δ_B 4.32, $J_{A,B}$ = 10.5 Hz, $J_{A,X}$ = $J_{B,X}$ = 7.1 Hz, CH_2-ethyl), 5.22 (1 H, s, 6-H), 7.23–8.05 (15 H, m, H-arom); ^{13}C NMR ($CDCl_3$) δ 14.3 (CH_3-ethyl), 18.6 (7a-CH_3), 36.4 (C-7a), 43.5 (C-7), 48.7 (C-6a), 63.1 (CH_2-ethyl), 100.7 (C-6), 127.1 (C-5), 125.6–137.5 (C-arom), 147.6, 147.9 (CO-1/CO-3), 169.0 (CO-ester), 193.4 (CO-benzoyl). Anal. Calcd for $C_{30}H_{25}N_3O_5$: C, 70.99; H, 4.96; N, 8.28. Found: C, 70.7; H, 5.04; N, 8.3.

(b) By evaporation of the filtrate from **27c** at 30 °C (15 Torr), dissolution of the residue in ether/pentane (1/1), and cooling at −20 °C, 0.34 g (23%) of ethyl 4,6-dioxo-9-methyl-1a,5,8a-triphenyl-2,8-etheno-1a,2,5,6,8,8a-hexahydro-4*H*-oxireno[*d*][1,2,4]-triazolo[1,2-*a*]pyridazine-10-carboxylate (**25c**) was obtained as colorless crystals: mp 162 °C; IR (KBr) 1775, 1720 (C=O), 1695 cm^{-1} (C=C); ^1H NMR ($CDCl_3$) δ 1.30 (3 H, X_3 part of an ABX_3 system, $J_{A,X}$ = 7.3 Hz, $J_{B,X}$ = 7.0 Hz, CH_3-ethyl), 2.45 (3 H, s, 9-CH_3), 4.26 (2 H, AB part of an ABX_3 system, δ_A 4.28, δ_B 4.23,

$J_{A,B}$ = 10.9 Hz, $J_{A,X}$ = 7.3 Hz, $J_{B,X}$ = 7.0 Hz, CH_2-ethyl), 5.40 (1 H, s, 8-H), 6.07 (1 H, s, 2-H), 7.17–7.56 (15 H, m, H-arom); ^{13}C NMR ($CDCl_3$) δ 14.2 (CH_3-ethyl), 19.3 (9-CH_3), 58.3 (C-8a), 59.4 (C-1a), 61.3 (C-8), 61.5 (CH_2-ethyl), 66.3 (C-2), 122.8 (C-10), 125.5–137.5 (C-arom), 153.1 (C-9), 156.3, 156.5 (CO-4/CO-6), 163.4 (CO-ester). Anal. Calcd for $C_{30}H_{25}N_3O_5$: C, 70.99; H, 4.96; N, 8.28. Found: C, 70.7; H, 5.01; N, 8.4.

Dimethyl 4,6-Dioxo-9-methyl-1a,5,8a-triphenyl-2,8-etheno-1a,2,5,6,8,8a-hexahydro-4*H*-oxireno[*d*][1,2,4]triazolo[1,2-*a*]pyridazine-10-phosphonate (25d). To a solution of 0.74 g (2.0 mmol) of oxepine **14d** in 25 mL of dichloromethane was added dropwise with stirring at room temperature within 30 min a solution of 0.35 g (2.0 mmol) of the triazolinedione **23**[31] in 25 mL of dichloromethane. After 1 h, the mixture was evaporated at 30 °C (15 Torr), and the residue was dissolved in ether. The resultant solution was treated with pentane until a slight cloudiness was observed, and then cooled at −20 °C for 24 h. The adduct **25d** was obtained as colorless crystals: 0.89 g (82%); mp 208 °C; IR (KBr) 1775, 1725 (C=O), 1625 (C=C), 1253 (P=O), 1020 cm^{-1} (POC); ^1H NMR δ 2.42 (3 H, d, $J_{H,P}$ = 3.4 Hz, 9-CH_3), 3.76 (3 H, d, $J_{H,P}$ = 11.3 Hz, $POCH_3$), 3.77 (3 H, d, $J_{H,P}$ = 11.4 Hz, $POCH_3$), 5.38 (1 H, d, $J_{H,P}$ = 5.0 Hz, 8-H), 5.67 (1 H, d, J_{H8P} = 8.4 Hz, 2-H), 7.23–7.50 (15 H, m, H-arom); ^{13}C NMR ($CDCl_3$) δ 19.8 (d, $J_{C,P}$ = 4.2 Hz, 9-CH_3), 52.6 (d, $J_{C,P}$ = 4.8 Hz, $POCH_3$), 52.9 (d, $J_{C,P}$ = 5.9 Hz, $POCH_3$), 57.9 (C-8a), 59.7 (d, $J_{C,P}$ = 4.4 Hz, C-1a), 62.4 (d, $J_{C,P}$ = 13.1 Hz, C-8), 65.3 (d, $J_{C,P}$ = 15.1 Hz, C-2), 119.2 (d, $J_{C,P}$ = 191.2 H, C-10), 125.5–132.3 (C-arom), 152.1 (d, $J_{C,P}$ = 9.3 Hz, C-9), 156.0, 156.4 (CO-4/CO-6). Anal. Calcd for $C_{29}H_{26}N_3O_6P$: C, 64.09; H, 4.82; N, 7.73. Found: C, 63.8; H, 4.92; N, 7.7.

X-ray Analysis of 25d. Crystal data: $C_{29}H_{26}N_3O_6P$, MW 543.5; orthorhombic space group $P2_12_12_1$; a = 7.956 (3), b = 16.370 (3), c = 20.340 (3) Å; Z = 4; D_{calc} = 1.361 g cm^{-3}. Data collection: Enraf-Nonius CAD 4 diffractometer, monochromatized Mo Kα radiation; crystal size 0.55 × 0.24 × 0.24 mm, 2371 unique reflections ($2 \le \theta \le 24°$), scan width (0.90 + 0.35 tan θ)°, scan speed 1.67–5° min^{-1}. Three monitoring reflections gave no hint to systematic changes of intensity. Structure solution and refinement: solution by MULTAN 82, full-matrix least-squares refinement of 456 variables with 1965 observations ($I > 2.2\sigma(I)$, unit weights). Hydrogen atoms were refined with isotropic temperature factors (B = 5.0 Å^2 except for C28 and C29 (B = 8.0 Å^2)). Final values: R = 0.043, $R_w = (\sum\Delta^2F/\sum F_o^2)^{1/2}$ = 0.040; maximum shift/error ratio 1.88 for H atoms, 0.60 for heavy atoms. All callculations were carried out on a PDP 11/23 plus computer using the Enraf-Nonius SDP software.

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Registry No. **6a**, 773-01-3; **6b**, 2340-23-0; **8a**, 109216-89-9; **8b**, 109216-90-2; **8c**, 109216-91-3; **8d**, 109216-92-4; **13a**, 109216-93-5; **13b**, 109216-94-6; **14a**, 109216-95-7; **14b**, 109216-96-8; **14c**, 109216-97-9; **14d**, 109216-98-0; **18a**, 109216-99-1; **18b**, 109217-00-7; **19a**, 109217-01-8; **19b**, 109217-02-9; **23**, 4233-33-4; **24**, 109241-75-0; **25a**, 109217-05-2; **25b**, 109217-06-3; **25c**, 109217-03-0; **25d**, 109217-04-1; **27c**, 109217-07-4; N_2=$CHCO_2Et$, 623-73-4; N_2=$CHPO(OMe)_2$, 27491-70-9; 2,6-diphenylpyrylium perchlorate, 3558-68-7; 4-methyl-2,6-diphenyl-4*H*-pyran, 55696-71-4.

Supplementary Material Available: ORTEP drawing and tables of positional and thermal parameters, bond distances, bond angles, and general thermal factors for **25d** (8 pages). Ordering information is given on any current masthead page.

Sulfur-33 NMR of Cyclic Sulfides, Sulfoxides, and Sulfones

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Natural abundance sulfur-33 chemical shifts were measured for three-, four-, five-, and six-membered ring sulfides, sulfoxides, and sulfones and the atomic charges at sulfur calculated for all compounds. With increasing oxidation of the sulfur atom there is proportionality between the chemical shift and the atomic charge only for three-membered ring compounds. Thiirane, thiirane 1-oxide, and thiirane 1,1-dioxide are shielded by several tens of ppm with respect to larger rings or the dimethyl analogues. The results are discussed in terms of a balance between the factors contributing to the chemical shift, namely, the atomic charge, the bond-order term, and the mean excitation energy.

Sulfur-containing compounds are useful intermediates in a variety of new syntheses of biologically important products.[1] Sulfur-33 NMR could in principle have a number of chemical applications, such as the identification of conformation or structure of sulfur-containing compounds, since NMR chemical shifts are intimately related to the electronic environment of a given nucleus.[2] Unfortunately, the experimental difficulties associated with sulfur-33 NMR[3] have discouraged organic chemists from exploring this interesting field, and even the chemical shifts of the most common organosulfur compounds are still unknown.

We have now measured the sulfur-33 chemical shifts of three-, four-, five-, and six-membered ring systems containing the sulfenyl (–S–), sulfinyl (–SO–), and sulfonyl ($–SO_2–$), functional groups, i.e., compounds **1–5**. Furthermore the charges at the sulfur atom were calculated for these compounds in order to find out whether there

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