The use of 1,2-shifts in carbenes and nitrenes in the generation of novel heterocumulenes

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Abstract: Ethenedithione, $S=C=C=S$, has been generated in flash vacuum pyrolysis (FVP) reactions from isoxazolone and Meldrum's acid derivatives and characterized by IR, UV and mass spectrometry. Evidence for the existence of $HN=C=C=S$ and its isomerization to thioformyl cyanide is also presented. The preparation and characterization of iminopropadienone derivatives $RN=C=C=C=X$ (X = O, S, or NR') from a variety of isoxazole compounds is described. These highly reactive cumulenes are formed via vinylidene, vinylnitrene, and ketenimine intermediates.

INTRODUCTION

The 1,2-hydrogen shift in alkyl carbenes, giving alkenes, is known to be very facile, proceeding with activation energies of only a few kcal/mol (1,2). Other groups, especially aryl, also migrate, and the following order of migratory aptitudes has been determined: $H > Ph > CH_3$ (3,4). The activation energies for the 1,2-hydrogen shift converting vinylidenes to acetylenes has also been found by both experiment and theory to be very small (5).

In nitrenes, the 1,2-hydrogen shifts are so facile that it may be argued that *singlet* methylnitrene does not exist: there is no barrier to its isomerization to methaneimine (2,6,7).

We have exploited these facile hydrogen shifts in two syntheses of iminoacetonitrile (1), formally an HCN dimer, as shown below (8).
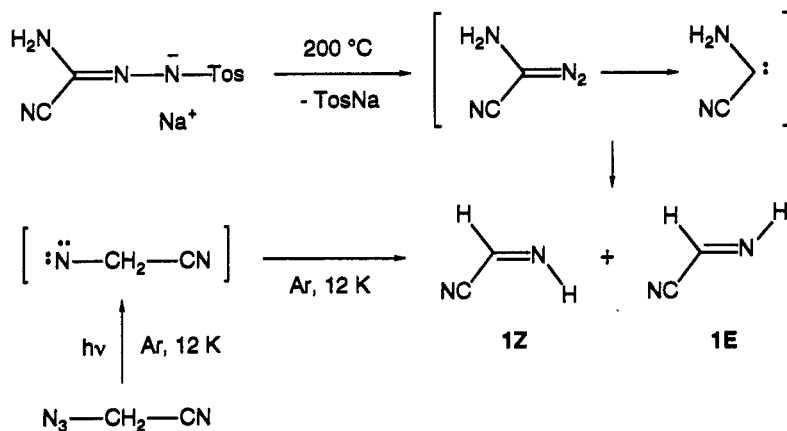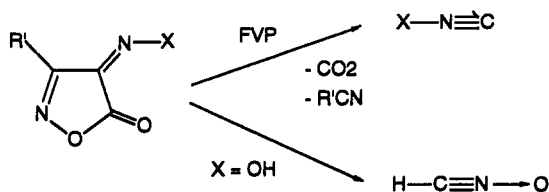

VINYLIDENES

We have used flash vacuum pyrolysis (FVP) of isoxazolones (2) as a means of generating transient vinylidenes (3) in the gas phase. The facile 1,2-hydrogen shift in the vinylidenes makes this a very useful synthesis of acetylenes (4), particularly aryl- and heteroarylacetylenes. The products are isolated in a cold trap at liquid nitrogen temperature (-196 °C), from where they can be distilled if necessary. The isolated yields of aryl- and heteroarylacetylenes are usually 70-97% (9,10). The reaction can easily be carried out on a preparative scale, and it allows the synthesis of acetylenes that are otherwise difficult or impossible to make, e.g. 2-ethynylpyrrole. Both 3-methyl- and 3-phenylisoxazolones can be employed for this purpose, but the 3-methyl derivatives are preferred since acetonitrile and CO_2 are the only byproducts.
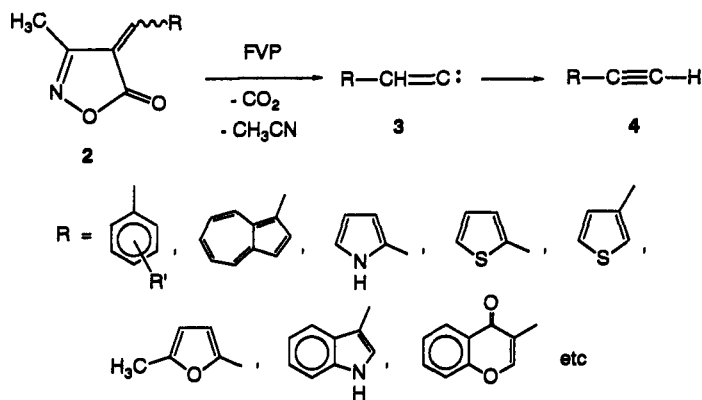
This method also gives access to secondary (11) and primary (12) aminoacetylenes. The former isomerize to ketenimines, and the latter to nitriles on warm-up.
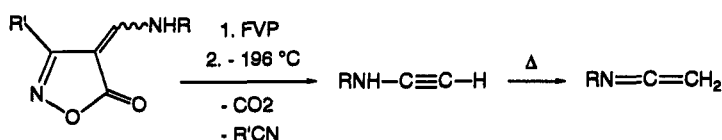

By analogy, isocyanides (RNC (13)), isocyanoamines (R-NH-NC (14)), fulminates (RO-NC (15)) and fulminic acid (HCNO (16)) can also be generated from isoxazolone precursors.


Earlier work aimed at the generation of cyclohexyne and 3-azacyclohexyne (17) led us to devise a synthesis of C_2S_2 (10) as illustrated in Scheme 1. FVP of either 3-methyl- or 3-phenylisoxazolone 5 was expected to lead to the vinylidene 8. Ring expansion would generate the dithiacyclohexyne 9, which in a retro-Diels Alder reaction fragments to ethene and $S=C=C=S$ (10) (ref. 18). In fact, C_2S_2 (10) was obtained in excellent yields on FVP of 5 at 700-900 °C (10^{-4} mbar) and identified by its collision activation mass spectrum (CAMS), its Ar matrix IR spectrum (asymmetric stretch 1180 cm^{-1}; $^{34}SCCS$ 1176 cm^{-1}, $S^{13}CCS$ 1163 cm^{-1}), and the Ar matrix UV spectrum (18). C_2S_2 has been produced in a mass spectrometer by neutralization-reionization mass spectrometry (NRMS) (19) and in Ar matrix by photolysis or pyrolysis of entirely different types of precursors (20). C_2S_2 is a highly reactive molecule. Although it can be generated in FVP reactions at temperatures up to 1000 °C as long as the pressure is low ($\leq 10^{-3}$ mbar), it polymerizes at 60 K in the condensed state. In the gas phase it breaks down to CS when the pressure (and the contact time) is increased.

Scheme 1
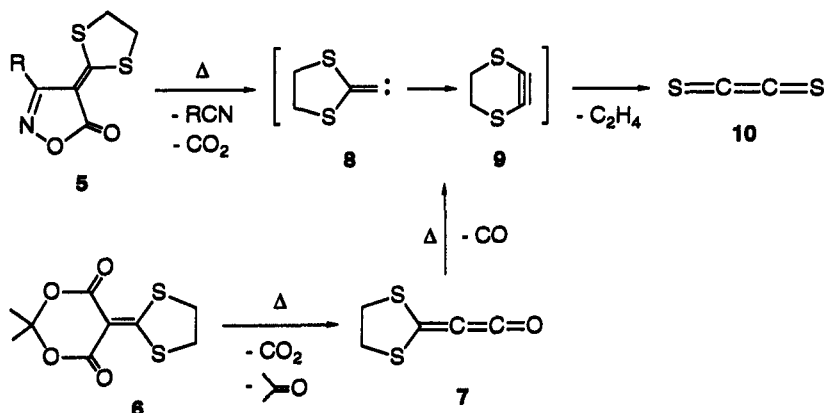
As seen in Scheme 1, the Meldrum's acid derivative **6** was also employed as an efficient precursor of C_2S_2 (**18**). In this case, the methyleneketene **7** is formed first (400 - 700 °C), and it is a relatively stable methyleneketene that can be observed in solution at ca -50 °C by IR and ^1H NMR. We have found that methyleneketenes of the general formula **11**, bearing donor substituents X and Y (especially N, and O) are highly stabilized in comparison with the all-carbon analogues. Thus, compounds **11** can be handled in solution at low temperatures and are observable by IR spectroscopy up to room temperature (21-23).
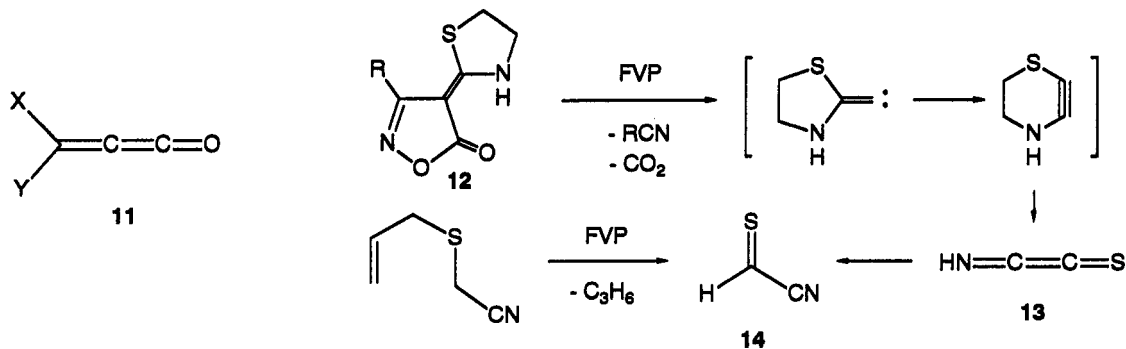

FVP of ketene **7** above 700 °C caused decarbonylation and formation of C_2S_2 (**10**), again monitored by MS, IR, and UV spectroscopy (18) (Scheme 1).

Using a similar strategy, we recently obtained NRMS evidence for the existence of HN=C=C=S (**13**), obtained by mass spectrometry of the isoxazolones **12** (24). A matrix isolation of **4** has not yet been achieved. FVP of **12** undoubtedly gives rise to **13**, but it isomerizes under the reaction conditions (intermolecularly) to give thioformyl cyanide (**14**) (24,25). Ab initio calculations demonstrate that the intramolecular 1,3-H shift (**13 → 14**) would have a large activation barrier (289 kJ/mol). Hence, **13** is expected to be stable in the dilute and wall-less gas phase and to be condensable if cooled rapidly enough.

In all the isoxazolone reactions above, we took advantage of the weak N-O bond, which predestines these molecules to eliminate CO_2 and - in the examples shown so far - a nitrile. Formally, the breaking of the N-O bond produces a vinyl nitrene, and there are many examples of these being involved in the formation of azirines, ketenimines, or in the rearrangement of isoxazoles to oxazoles (26-28). This principle has also been applied in our synthesis of iminopropadienones (**18**) from isoxazolopyrimidinones **15** (29-30) (Scheme 2). Ring opening of **15** gives formally the (singlet)

Scheme 2
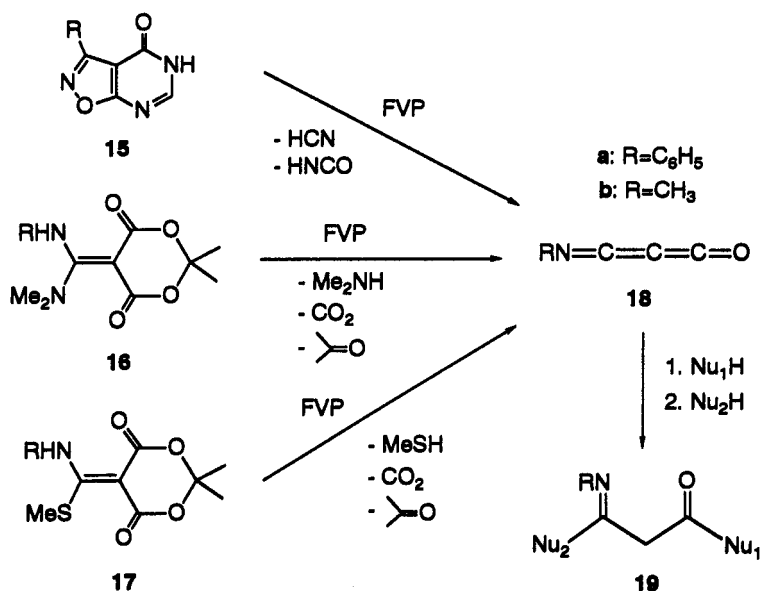
vinylnitrene **20** which, when R is an aryl group, can undergo a 1,2-shift to yield a ketenimine (**21**). A fragmentation reaction of **20** gives rise to RNC_3O (**18**). The migratory aptitude of alkyl groups in
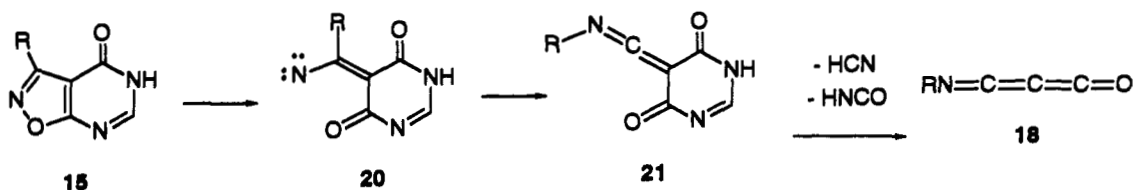

20 is far less than that of aryls, and this method is, therefore, only useful for the preparation of **18a** and analogs.

Iminopropadienones (**18**) can also be generated from Meldrum's acid derivatives **16** and **17** (Scheme 2), whereby the diamines **16** are particularly useful. The first step of the FVP of **16** is elimination of Me_2NH, giving a ketenimine (**22**), which again undergoes a fragmentation reaction.
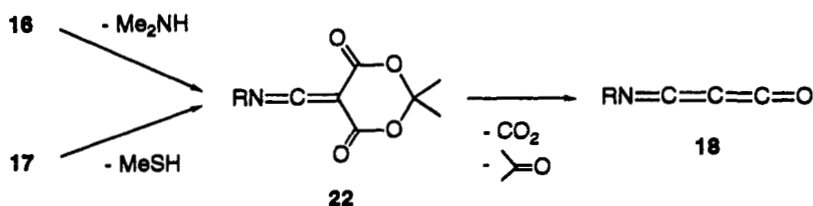
22 can be observed directly by IR and MS, but never in large amount because the fragmentation reaction occurs almost at the same temperature as the elimination ($\geq$ 300 °C) (29). Since this method does not depend on a migration of the R group, it is useful also for the synthesis of the methyl derivative **18b** (29, 31).

A detailed study of the IR spectrum of **18a**, using ^{15}N and ^{13}C isotopomers and ab initio calculations, has been reported (33).

Scheme 3
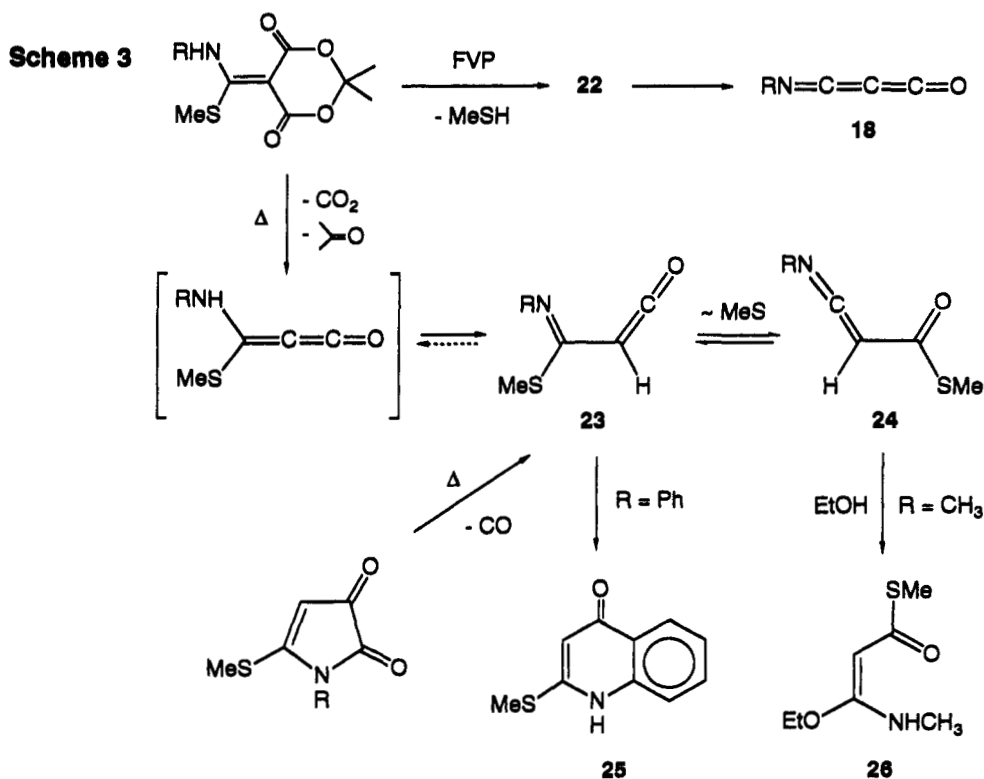
Although the odd-membered heterocumulenes X=C=C=C=Y are far more stable (thermodynamically) than the even-membered analogues, X=C=C=Y (18,19,34), and carbon suboxide is a well-known and fairly stable compound (35), the iminopropadienones 18 are highly reactive substances which require handling below ca -40 °C. Nevertheless, 18 is trappable in good yields with nucleophiles, giving malonic imide derivatives 19 (Scheme 2) (29,31).

The methylthiovinyl-Meldrum's acid derivatives 17 are less well suited for the preparation of 18 because of competing formation of imidoylketenes 23 and oxoketenimines 24 (interconverting via a 1,3-shift of SCH_3 and trappable as quinolones 25 and enaminones 26, respectively (29,32; Scheme 3)

In further work, we have generated the bisimines 28 from the molecular ions of 27 followed by NRMS (36). The thermal generation of 28 for matrix isolation IR spectroscopy is better carried out using isoxazolones 29 as the precursor (reaction via ketenimines, nitrenes, and azirines) (37).
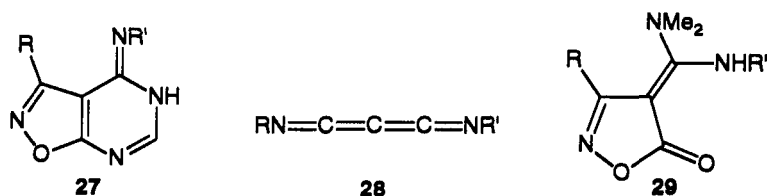
The sulfur analogue 33 was more difficult to produce. The isoxazolopyrimidinethione 30 gave a small amount of 33 (ca 5%) together with ca 95% of $PhNC_3O$; the formation of 33 could be ascertained only after this compound had been obtained by other means (vide infra). The isothiazolopyrimidinethione 31 is extremely stable towards FVP and gives only traces of 33 (38). Finally, isoxazolone chemistry via nitrene rearrangements using 32 as the precursor was successful in generating clean samples of 33, which has been identified by MS and IR spectroscopy (39).
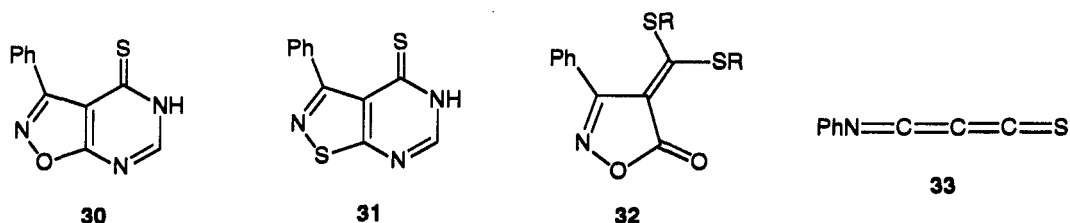
ACKNOWLEDGEMENTS

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