Valence Isomerization between Diazo Compounds and Diazirines

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Diazo compounds and diazirines have been separately studied in detail and are widely used in research and for applied purposes. Although the mutual isomerization of these compounds was discovered 50 years ago, it has still been only modestly investigated. Meanwhile, this type of mutual transformation has to be taken into account on every occasion when one of these compounds is used or investigated. This review discusses all main cases of mutual isomerization between diazo compounds and diazirines with the goal of providing an impulse for its rational application, as well as describing the isomerism.

1. Introduction

For a long time, diazo compounds of type 1 and diazirines 2 (Figure 1) served as an interesting example of a chemical misinterpretation, because chemists, while drawing the structure of one, implied the other, not knowing that both types of compounds can exist simultaneously.

After the discovery of the diazo compounds their structures became the subject of prolonged discussion. Originally cyclic structures of type 2 were attributed to diazoacetic acid derivatives by Curtius[1] and to diazomethane by Pechmann.[2] Later, Angeli,[3] Thiele,[4] and Langmuir[5] provided evidence supporting the linear form 1. As a result of the scientific discussion the two classes of compounds became connected. As was discovered later, this was not accidental.

Further investigations drew an exact line between the linear and the cyclic compounds. The linear structures of diazo compounds were confirmed in different ways: by electronic diffraction in 1934,[6] by IR spectroscopy in 1949,[7] by isotope labeling in 1957,[8] and by microwave spectroscopy in 1958.[9]

The first diazirines were synthesized in 1960–1961 by Paulsen[10] and Schmitz[11] and their cyclic structures were unambiguously confirmed in 1962 by both physical[12] and chemical methods.[13] The last point of doubt relating to the structures and the existence of these types of compounds had thus been laid to rest. It was shown that the linear isomers 1[14] and the cyclic isomers 2[15] not only differ in their physical characteristics, but also have little or nothing in common in their chemical properties, except the tendency to abstract nitrogen and mutual isomerization. The simplicity of thermal or photochemical elimination of nitrogen...
both from diazo compounds and from diazirines allows for a limited possibility of reversible valence isomerization.

2. Isomerization of Diazirines into Diazo Compounds

The chemistry of diazirines has a relatively short history. The time of their discovery coincided with the period of intensive research into carbenes, so it is not surprising that the influence of light on diazirines, with the goal of generating carbenes, was among the first topics to be studied. The presence of diazo isomers among other products after photolysis was thus established practically at once. Several processes compete with possible isomerization in the course of diazirine decay (on photo- or thermoactivation): namely, fluorescence, internal conversion, intersystem crossing, carbon–nitrogen bond cleavage followed by intramolecular processes (e.g., coupling with loss of nitrogen, formation of alkenes through 1,2-hydride migration), intermolecular reactions (e.g., with solvent or other diazirines), and simple nitrogen extrusion to generate the carbene intermediates. It has been shown that the substituents have a significant role in determining whether or not linear diazo isomers are formed.

2.1. Diazirine

Both diazirine and diazomethane are poorly stable gases under ambient conditions and are therefore used in diluted form. Explosions of sufficiently concentrated compounds on warming or on contact with metal surfaces have been repeatedly encountered.[16] Photolysis of diazirine gave rise to some diazomethane, but thermolysis has not been reported.

Primary experiments with photochemical decomposition of diazirine (3, Scheme 1) in the gas phase (in admixture with N₂, λ = 320 nm) showed that one of the initial products of the reaction is diazomethane (8, confirmed by UV absorption at 213, 217, 229, 420 nm), with a quantum yield of formation close to 0.2.[17] Its levels increased at the beginning of the reaction and decreased along with the consumption of diazirine, due to secondary photolysis. It is interesting that the nearest homologues of diazirine – methyl-, ethyl-, and dimethyl-diazzirine – do not form stable diazo compounds in the gas phase, but instead lose their excess energy through intramolecular reactions, with nitrogen elimination and rearrangements.[18] Irradiation of the same diazirines in solution resulted in the formation of diazo compounds in yields of up to 40%.

It has thus been shown that both the structure of the starting diazirine and the environment influence the stabilization of excited molecules and hence the reaction products.

Irradiation of diazirine (3) in an isotopically labeled nitrogen matrix at 20 K (Scheme 1) is a first-order reaction that leads to the formation of the diazomethanes 6–8, labeled in the cases of 6 and 7 with the nitrogen from the matrix, as shown by IR spectroscopy.[19] 15N-Labeled diazirine (5) is not formed. It was concluded that the formation of diazomethane in the matrix occurs in two steps: i. molecule excitation causes nitrogen elimination, forming carbene (4), which ii. reacts with a neighboring nitrogen molecule to afford the diazomethanes 6–8.

The photolysis of diazomethane (8) under the same conditions did not result in the formation of diazirine (5). However, upon irradiation of the 14N-labeled diazomethane 6, redistribution of the label with the formation of approximately equal amounts of the two labeled diazomethanes 6 and 7 was observed, along with the formation of unlabeled diazomethane (8), through incorporation of nitrogen from the unlabeled matrix. Such a product distribution confirms the intermediacy of carbene (4), formed in the course of the transformations of the labeled diazomethane 6 in the matrix.

Two thermal reactions could occur in the ground state (S₀) of diazirine (3): 1) isomerization to diazomethane, and 2) decomposition to give singlet carbene and molecular nitrogen. The computed barrier energy heights clearly testify that methylene formation should be the priority process with respect to isomerization,[20] however this prediction needs to be checked.

2.2. Alkyl Diazirines

The alkyl diazirines 2 (Scheme 2) are stable and readily available chemicals, whereas the isomeric diazoalkanes 1 are usually volatile and labile compounds, the occurrence of which during the courses of reactions of alkyl diazirines has thus been confirmed only by use of special methods. Spectroscopy (IR, UV) has served as a powerful method to establish the fact of isomerization during low-temperature photolysis. During thermolysis, however, no diazo compounds have been observed. Alternative trapping experi-

Scheme 1. Photolysis of labeled and unlabeled diazomethanes and diazirine in matrices.

Scheme 2. Photolysis of alkyl diazirines.
ments have been suggested and proved highly efficient in demonstrating high yields of diazo isomers both under photolysis and under thermolysis.

Photolysis of the diazirine 2a in a N₂ matrix (312 nm, 10 K, 12 h) led to the formation of the carbene 9a and insignificant quantities of the diazoalkane 1a (IR: 2020 cm⁻¹).[23] Similarly, photolysis of the diazirine 2b in an Ar matrix (λ > 200 nm, 12 K) gave the diazomethane 1b (IR: 2135 cm⁻¹), which was stable under the irradiation conditions, together with the carbene 9b as primary products.[22]

Dependence of the product distribution on the wavelength of the initiating light was observed in the case of the diazirine 2c in a N₂ matrix. Short-wavelength irradiation (334 nm, 6 K, 28 h) produced two main products: the diazoalkane 1c (IR: 2053 cm⁻¹) and the carbene 9c (IR: 802 cm⁻¹). Use of longer-wavelength irradiation (475 nm, 1 h) resulted in complete consumption of the carbene 9c and gave stable products, but the diazomethane 1c persisted under irradiation with this light. It is interesting that irradiation of the diazirine 2c in an Ar matrix – unlike in N₂ – at 20 K drove the reaction to the side of the carbene 9c only and that no diazomethane 1c was observed.[23]

Upon partial photolysis of the diazirines 2d[24] (Scheme 2) and 10a (Scheme 3, IR: 1582 cm⁻¹)[25] with long-wavelength light (350 nm, CH₂Cl₂, 30 min) an intense pink color (λmax = 500 nm) attributed to the corresponding diazo compounds 1d and 11a (IR: 2040 cm⁻¹) appeared. Qualitative treatment with acrylonitrile (0.1 m) showed that the diazoalkane 1d (half-life under ambient conditions was about 1 h) disappeared immediately on addition of the reagent. One might expect that trapping of 1d in such a way could allow estimation of the quantity present.

Photolysis of the diazirines 10c and 10d (Scheme 3) in the presence of N-phenylmaleimide resulted in the formation of the bicyclic pyrazolines 12c and 12d. The same results were obtained on thermal decomposition of the diazirines 10c and 10d.[26] The intermediacy of the diazo isomers 11c and 11d was thus revealed by means of the trap and N-phenylmaleimide appears to be a suitable partner for linkage of diazo compounds through 1,3-dipolar cycloaddition reactions.[27]

Unexpected results were obtained in attempts to design photoactivatable phospholipids to undergo cross-linking with proteins on photoexcitation.[28,29] The (fluoroalkyl)diazirines 13a-c were tested for this purpose (Scheme 4). It was proposed that the carbene intermediates could not be stabilized by intramolecular F⁻ shifts analogously with 3-(trifluoromethyl)-3-phenyldiazirine[30] and should give not olefins, as in the case of H⁺ shifts, but products of intermolecular cross-linking.

On irradiation of the diazirine 13a (IR: 1600 cm⁻¹) with short-wavelength light in solution (cyclohexane, cyclohexene, or MeOH), the isomeric diazoalkane 14a (IR: 2120 cm⁻¹) was obtained in a high yield together with products of nitrogen abstraction: the cyclopropane 15a (intramolecular C–H insertion) and the olefin 16a (radical migration).[28,29] No intermolecular carbene reactions were therefore observed. The presence of a small amount of AcOH in cyclohexene solution did not change the product yields (14a was observed to be stable in the presence of low concentrations of the acid), but in pure AcOH the diazoalkane was not detected.

Similarly, irradiation of the monosubstituted diazirine 13b (Scheme 4) gave the products both of isomerization (the diazoalkane 14b, IR: 2120 cm⁻¹) and also of nitrogen elimination (the cyclopropane 15b and the olefin 16b). The perhalodiazirine 13c isomerized into the corresponding diazoalkane 14c (IR: 2120 cm⁻¹).

It was thus established that: i. the α,α-perfluorodiazirines 13 and the diazoalkanes 14 are stable under ambient conditions, and ii. all the corresponding carbenes are stabilized with respect to intramolecular reactions (migration of a radical or insertion in β-C–H bond) in the absence of α-protons.

In the thermolysis of the vinylidiazirine 17 (Scheme 5) at 200 °C, nitrogen elimination levels of only 7% were observed, together with the formation of the pyrazole 18 (about 90%).[16c] The same pyrazole 18 was also obtained after stirring of 17 at room temperature for a week. The
vinyl diazomethane 19 was proposed as one of the possible intermediates of this reaction, because it forms the same pyrazole 18 on standing at room temperature for 2 days.

Scheme 5. Thermolysis of the vinyldiazirine 17.

2.3. Spirodiazirines

Spirodiazirines are close analogues of alkyldiazirines with very similar stabilities, availabilities, and properties. In addition, though, they also display some subtle features due to steric effects that allow them to be considered separately from the alkyldiazirine family. Like their open-chain analogues, cyclic diazoalkanes are labile and chemically active compounds. Spirodiazirines undergo isomerization to diazo compounds in moderate yields (30–60%) under photolysis or thermolysis conditions. The colors of the reaction mixtures, UV and IR spectroscopy, and chemical traps were used to visualize the formation of diazo isomers, with fullerenes serving as the most powerful agent for detection. Isomerization was not observed on photolysis of diazirines in the gas phase, nor in complexes with zeolite and cyclodextrins.

Photoactivation of the spirodiazirines 20c and 20d (Scheme 6), with attached cycles of various sizes (n = 6, 7), in the forms of liquid films resulted in a change in the initial yellow color of the films to a reddish one that remained in the forms of liquid films. IR spectra suggested the conversion of the diazirines 20a into the diazoalkanes 21c and 21d.

Scheme 6. Photolysis of spirodiazirines.

Qualitatively, the band corresponding to the diazo compound 21b disappeared within several minutes after termination of the photolysis of the diazirine 20b (n = 5). For the larger-ring compounds 20c and 20d (n = 6, 7), the lifetimes of the diazo compounds 21c and 21d were several times longer. UV spectra showed that 30–50% of the diazirines 20a–d were converted into the diazoalkanes 21a–d. Furthermore, in the course of photolysis of the diazirines 20a–d the formation of the azines 22a–d, which might be formed from the corresponding diazo compounds, was observed. In view of these two factors, the levels of conversion of the diazirines 20 into the diazoalkanes 21 are thus (approximately) 20% for 21a (n = 4), 36% for 21b (n = 5), 59% for 21c (n = 6), and 70% for 21d (n = 7).[18,31] However, there is an opinion that the formation of azines might not be due solely to diazo precursors.[33–35] It should be noted that photolysis of the diazirine 20b (n = 5) in the gas phase at pressures above 20 mm gave cyclohexene (25b) and nitrogen as main products, without the diazoalkane 21b being detected.[18]

A quantitative estimation of the isomerization process was obtained by photolysis of the diazirines 20a–d in the presence of acetic acid. It is known that diazirines are inert to acids whereas diazoalkanes react rapidly with them. The yields of the acetates 24, interaction products of the diazoalkanes 21 and AcOH, on photolysis were 40% for 24a (n = 4), 39% 24b (n = 5), 34% for 24c (n = 6), and 32% for 24d (n = 7), together with the hydrocarbons 25a–d and other products. Photolysis of the diazirine 20b (n = 5) in deuteroacetic acid showed that cyclohexene (25b 20%) with a deuterium label in the vinylic position was formed along with the acetate 24b (39%). This means that both products had their origins in the interaction between the diazoalkane 21b and AcOD. The degree of isomerization of the diazirine 20b to the diazoalkane 21b on photolysis is thus about 59%.31,33

No diazo isomers were detected in the course of photolysis of the diazirines 20c (n = 6) and 20d (n = 7), entrapped within α-, β- and γ-cyclodextrin (not shown) in the solid state, and only the formation of nitrogen elimination products (main) and azines (minor) was noted. Whereas the formation of azines was almost completely prevented in the α- and γ-cyclodextrin complexes, in β-cyclodextrin complexes they were produced in moderate yields (18–42%).[35,36] Coordination of the diazirines with the cyclodextrins thus suppresses their ability to isomerize to their diazo counterparts, with nitrogen elimination becoming the main process.

The diazo group is a classical dipole, and so Huisgen reactions (1,3-dipolar cycloadditions) have been used to demonstrate the potential for visualization of labile diazo isomers by trapping with dipolarophiles.[37] Photolysis of the diazirine 20b with dimethyl acetylenedicarboxylate in toluene solution (Scheme 7) gave the diazaspirodecadiene 26 (18–22%), provided that the photolysis of 26 itself was suppressed with a suitable optical filter, such as aq. NiCl₂.[38] If photolysis was carried out without the filter the spiro ester 27 was formed in a high yield, because 26 is
unstable under these conditions. Photoirradiation of the diazirine 20b in the presence of the spiro ester 27 in combination with the NiCl₂ filter also induced trapping of the intermediate 21b in high yield because 27 is also a good dipolarophile.

The yield of diazirine-to-diazo isomerization for 20b obtained in the cycloaddition reaction (22%) thus appeared to be considerably lower than those calculated from the reaction by IR monitoring (36%) or observed in the reaction with acetic acid as a trap (59%). The significant difference in yields between cycloaddition and AcOH decomposition is obviously the result of a high thermal instability of 21b relative to its speed of cycloaddition.

The formation of a diazo compound was not affected significantly by the introduction of a methyl group α to the diazirine moiety. Qualitatively it was demonstrated that a pentane solution of the diazirine 20e (IR: 2939 cm⁻¹) turned peach-colored during photolysis for a few hours, which was ascribed to the formation of the linear diazo compound 21e (IR: 2025 cm⁻¹).[39]

Deuterium labels are widely used for investigation of reaction mechanisms. Analysis of the distribution of labels in products obtained from the photolysis of the spirobicyclic diazirine 28a (Scheme 8) in MeOD thus identified about 23% deuteration in the nortricyclene 33.[40] This result reflects the proportion of diazoalkane participation in the formation of 33, because the carbene 30 will also form 33 by intramolecular insertion and in this case no deuterium labels will be incorporated. Protonation of the intermediate diazoalkane 29a by the solvent gave rise to diazonium ions (not shown), followed by reaction with MeOD resulting in the formation of the ethers 31 and 32 with C₁ and C₂ deuterium labels. Trapping experiments showed that the ethers were formed from the diazo compound. Addition of diethyl fumarate as a scavenger to 29a in MeOH resulted in a drop in the relative yield of 31 + 32 from 42% to 13%, whereas in the presence of fumaronitrile only traces of ethers were obtained, which unequivocally identifies their origin.

Moreover, photolysis of 28a in a MeOD/fumaronitrile mixture afforded 33 virtually free of deuterium (<0.02 D), so in this case only the carbene 30a was the precursor for 33. The azine 34 was obtained as an additional product of the photolysis. Its quantity increased (from 6% to 32%) with the concentration of 28a (from 70 to 490 mmol L⁻¹) whereas no significant changes in the product distribution of 31–33 were observed. It appears that the immediate precursors of 31–33 are not involved in the formation of 34.

As a result, these experiments testify that the unobservable diazoalkanes 29a and 29b participated in the photolysis of diazirines 28a and 28b to large extents [29a (R = H): 62%, 29b (R = Me): 80%].

A low yield of the scavenger product 37 (Scheme 9) was obtained upon irradiation of the diazirine 35 in the presence of diethyl fumarate.[41] On one hand this could point to the formation of the diazo isomer 36. On the other hand, however, the low yield of 37 could be an indication both of an insignificant isomerization step and of inefficient activity of diethyl fumarate in the diazo dipole trapping.

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\begin{align*}
\text{Scheme 8. Photolysis of spirodiazirines in methanol.}
\end{align*}
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\text{Scheme 9. Photolysis of a spirodiazirine in the presence of diethyl fumarate.}
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The initial concentration of the diazirine solution was shown to influence the product ratio.[42] Photolysis of a dilute solution of the diazirine 38 with a few laser shots (Scheme 10) gave two new absorption bands: the first one at 234 nm is due to the diazo compound 39 and the second one at 214 nm mainly due to the azine 40. In a more concentrated solution of the diazirine 38 the yield of the diazo compound 39 was unchanged, but that of the azine 40 had significantly increased. Incomplete correlation between azine formation and disappearance of diazo compound is obvious in this case and attests that the mechanism of the diazirine formation does not only involve simple dimerization of diazo molecules.[35]

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\begin{align*}
\text{Scheme 10. Laser photolysis of a spirodiazirine.}
\end{align*}
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The rearrangement of the spiro[adamantane-2,3’-diazirine] derivative 41a to the diazoadamantane 42a (Scheme 11) could be monitored by FT-IR spectroscopy both in solution (n-heptane) and in KBr (pellet).[43] After only a few seconds of photolysis (Hanovia, 450 W) at room temperature a strong band corresponding to the diazo compound 42a (IR: 2033 cm⁻¹) became observable.[44] The primary photoproducts of the diazirine 41a – diazoadamantane (42a) and 2-adamantylidene (43a) – were formed with quantum yields of about 0.5 each. It is likely that the excited singlet state of 41a, which has a lifetime of 0.24 ns, is their direct precursor.[45]
Interestingly, when the diazirine 41a was incorporated in zeolite inclusion complexes the formation of the diazo compound 42a was in several cases totally suppressed and only the azine 44a (up to 12%) could be detected upon photolysis.\textsuperscript{[46]} Nitrogen elimination had thus become the main process, as a result of coordination between the diazirine moiety and the internal surface of a zeolite hole, the same as in the case of cyclodextrins.\textsuperscript{[36]}

Fumaronitrile served as an effective scavenging agent for the intermediate diazoadamantanes 42a and 42b (\(\lambda_{\text{max}} = 330\) nm) formed on photodecomposition of the diazirines 41a and 41b (Scheme 11) in aprotic solvents, driving the reactions to the corresponding pyrazolines 45a and 45b.\textsuperscript{[47]}

The yields of the scavenging products agree well with other results of photolysis in which 60\% of the diazirine 41a reacted through the intermediacy of the diazo compound 42a and the other 40\% decomposed directly to 2-adamantanylidene (43a).\textsuperscript{[48,49]}

In contrast, a thermal experiment (140 °C, 1 h) showed the preferential decomposition of the diazirine 41a to the carbene 43a and products of its further transformations, with no diazoadamantane (42a) or trapping product 45a being detectable.\textsuperscript{[47]} Most likely this negative observation is the result of insufficient stability of both 42a and 45a under the reaction conditions.

Thermolysis of the diazirine 41a in the presence of C\(_{60}\) at 150 °C (dichlorobenzene, Pyrex tube in darkness) resulted in the formation of the corresponding adducts C\(_{60}\)Ad as a mixture of two isomers – the fulleroid 46 and the methanofullerene 47 (ratio 35:65, Scheme 12) – in 95\% yield with no azine being detectable.\textsuperscript{[50]} Irradiation of a benzene solution of 41a and C\(_{60}\) (Pyrex tube, 15 °C) gave the same adducts C\(_{60}\)Ad in 80\% yield with the ratio of the two isomers (the fulleroid 46 and the methanofullerene 47) as 51:49.\textsuperscript{[49]} This reflects the formation ratio of the diazo compound and the carbene during the reaction\textsuperscript{[51,52]} and is consistent with the results obtained under other conditions.\textsuperscript{[48,49]} Fullerene can thus serve as more powerful trap than fumaronitrile for thermolysis study.

### 2.4. Halodiazirines

Diazirines containing halogen atoms (F, Cl, Br) are reasonably stable and accessible compounds.\textsuperscript{[15m]} In contrast, \(\alpha\)-halo-substituted diazoolanes are extremely unstable even at low temperatures, which makes their detection very hard.\textsuperscript{[53]} There are only a few positive examples in which the corresponding diazo compounds have been detected either spectroscopically or chemically in the courses of photochemical reactions. Sometimes specific stabilization of diazo compounds by one particular halogen and not by the others occurs. Thermal isomerization is currently unknown.

Irradiation of the diazirine 2e (Scheme 13), matrix-isolated in argon (320–380 nm, 10 K), led to a small IR peak at 2050 cm\(^{-1}\), which might be due to chloro(phenyl)diazomethane (1e).\textsuperscript{[54]} However, generation of the \(\alpha\)-halogenediazo compounds 1f from the 3-aryl-3-halodiazirines 2f was not confirmed by kinetic measurements or trapping experiments in photolysis at room temperature,\textsuperscript{[55]} nor on thermolysis.\textsuperscript{[56,57]} Modern techniques allow the observation of the formation of short-lived molecules even under ambient conditions, so in ultrafast laser flash photolysis (UFP, 270 nm) of the diazirine 2e at room temperature in CHCl\(_3\), two broad bands in the IR spectrum were observed within a few picoseconds of the laser pulse.\textsuperscript{[58]} These did not decay within the detection window (3 ns) and were assigned to the diazomethane 1e (2040 cm\(^{-1}\)) and to the singlet carbene 9e (1583 cm\(^{-1}\)).

![Scheme 11. Photolysis of adamantane-derived diazirines.](image1)

Scheme 11. Photolysis of adamantane-derived diazirines.

![Scheme 12. Decomposition of the adamantane-derived diazirine 41a in the presence of C\(_{60}\).](image2)

Scheme 12. Decomposition of the adamantane-derived diazirine 41a in the presence of C\(_{60}\).

![Scheme 13. Reactions of halodiazirines.](image3)

Scheme 13. Reactions of halodiazirines.

Irradiation both of 3-benzyl-3-chlorodiazirine (2g) and of 3-benzyl-3-bromodiazirine (2h), matrix-isolated in argon (\(\lambda = 380\) nm, 10 K), produced traces of (benzyl)chlorodiazomethane (1g, IR: 2048 cm\(^{-1}\)) and (benzyl)bromodiazomethane (1h, IR: 2045 cm\(^{-1}\)), respectively. No diazo band for 1i (at 2100–2000 cm\(^{-1}\)) was detected on photolysis of methylchlorodiazirane (2I) in the matrix.\textsuperscript{[59]} The same is true for 3-chloro-3-methoxydiazirane (2j), which shows no absorption due to the diazo compound 1j at 1900–2300 cm\(^{-1}\) on irradiation (\(\lambda > 340\) nm, Ar, 10 K).\textsuperscript{[56]}
Laser-flash photolysis of the diazirines $2k$ and $2m$ (Scheme 13) in isooctane at 25 °C produced transient UV absorptions in the 230–250 nm range, decaying with “lifetimes” of ca. 0.5 s and assigned to the corresponding diazomethanes $1k$ and $1m$, due to their spectral similarity with the absorption of diazomethane ($8, \lambda_{\text{max}} = 220 \text{ nm}$). At lower temperature (−30 °C) the lifetimes increased to several minutes and quantum yields of formation were measured as approximately 10–13%.

The fluorodiazomethane derivative $49e$ (Scheme 14) was identified by its IR absorption (2029 cm$^{-1}$) as the primary product of photoreaction of the fluorodiazirine $48a$ in an Ar matrix.[61] Further irradiation of the matrix showed the total disappearance of diazo and azido groups and the product was identified from its IR spectrum and with the aid of calculations as the carbononitrene $50a$ in a basic triplet state. This was followed by stabilization to $51a$. It is interesting that under similar conditions the chlorodiazirine $48b$ and the bromodiazirine $48c$ showed no tendency to isomerize to linear diazo compounds of type $49$ and that the azidocarbenes $53be$ and $53ce$ were instead identified as intermediates of these reactions, followed by the carbononitrenes $50b$ and $50c$.

Scheme 14. Photolysis of halodiazirines in an Ar matrix.

Remarkably, the monosubstituted diazirine $48d$ ($X = H$) was converted under the same conditions into the carbononitrene $55$, and with further stabilization into the product $51d$. A similar pattern was observed for the $p$-isomers $52a–c$ (Scheme 14).[62] It appeared that the fluorodiazomethane derivative $49f$ (IR: 2023 cm$^{-1}$) was formed in the early stages of irradiation of the fluorodiazirine $52a$ in an Ar matrix (13 K, 1 min), followed by fast (9 min) decomposition to the diradical $54a$. In the cases of the 3-chlorodiazirine $52b$ and the 3-bromodiazirine $52c$, no diazo isomers of type $49$ were observed, but the azidocarbenes $53bf$ and $53cf$ were formed. These eliminated nitrogen and transformed into the diradicals $54b$ and $54c$ and further stable molecules.

The gas-phase thermolysis of difluorodiazirine ($56$, Scheme 15) yielded the azine $59$, tetrafluoroethylene, hexafluorocyclopropane, and other products.[13] The same azine $59$ was formed on photolysis of $56$ in an Ar matrix (4 K). It was suggested that nitrogen elimination takes place not from the diazirine $56$, but after its isomerization to difluorodiazomethane ($57$). A bimolecular reaction between the electrophilic difluorocarbene ($58$) and either difluorodiazirine ($56$) or its linear isomer $57$ formed by photoisomerization has been postulated as a possible mechanism.[63] However, no clear confirmation of the generation of the diazo product $57$ has been obtained.

Scheme 15. Thermolysis of 3,3-difluorodiazirine in the gas phase.

The chlorostyrene $63a$, formed on photolysis of the 3-chlorodiazirine $60a$ (Scheme 16), could be generated either from the intermediate carbene $62a$ or from the isomeric chlorodiazomethane $61a$.[64] On one hand, the carbene $62a$ could easily be transformed into the chlorostyrene $63a$ through an intramolecular hydride shift. On the other hand, the diazoalkane $61a$ could also form $63a$ through acid-catalyzed decomposition. To clarify whether or not the diazirine $60a$ would undergo isomerization to the diazo compound $61a$ its photolysis ($\lambda > 350 \text{ nm}$) in 3-methylpentane at −175 °C was studied. The IR spectrum of the reaction mixture indeed showed the absorption due to the diazoalkane $61a$ (2040 cm$^{-1}$). The intensity of this band essentially did not vary over several hours at −175 °C, but it was significantly weakened on heating to −70 °C. These results do not necessarily mean that the diazirine $60a$ will also photoisomerize to the diazo compound $61a$ at normal temperatures, but they do at least attest to the possibility.

Scheme 16. Photolysis of halodiazirines.

IR spectroscopy confirmed that irradiation of the halodiazirines $60a$ (Scheme 16, $^{13}$C NMR: 48.4 ppm), $60b$ ($^{13}$C NMR: 48.3 ppm), or $60c$ ($^{13}$C NMR: 39.8 ppm), matrix-isolated in argon (ca. 380 nm, 10 K), produced only traces of the benzylidiazomethanes $61a$ (IR: 2048 cm$^{-1}$), $61b$ (IR: 2047 cm$^{-1}$), or $61c$ (IR: 2045 cm$^{-1}$), in contrast with significant yields of the corresponding carbenes $62a–c$ and the styrenes $63a–c$.[59]

No isomerization of the bromodiazirine $64a$ (Scheme 17), the chlorodiazirine $64b$, or the fluorodiazirine $64c$ to the diazo isomers $65a–c$ was detected under monochromatic irradiation ($64a$: 330 nm/1 h, $64b$: 318 nm/1 h, $64c$: 316 nm/2 h) in an Ar matrix at 12 K.[65] Similarly, photolysis of the chlorodiazirine $64b$ and the fluorodiazirine $64c$ in $N_2$ matrices did not lead to the diazoalkanes $65b$ and $65c$. However, photolysis of the bromodiazirine $64a$ with monochromatic light in a $N_2$ matrix (6 h) showed the total disappearance of the diazirine $64a$ together with the detection of ab-
sorption bands corresponding to the diazoalkane 65a (IR: 2095 cm\(^{-1}\)), the carbene 66a, and the olefin 67a. Continuation of photolysis with short-wavelength light (265 nm) reduced the yield of the carbene 66a (10%) and increased those of the olefin 67a (50%) and the diazoalkane 65a (40%). Irradiation of the same mixture with long-wavelength light (460 nm) reduced the amount of the diazoalkane 65a (5%) and increased the formation of the carbene 66a (25%) and the olefin 67a (70%).[65]

Scheme 19. Photolysis of chlorodiazirines in the presence of C\(_{60}\).

Analogously, irradiation of 3-chloro-3-phenyldiazirine (2e) and C\(_{60}\) (15 °C, Pyrex tube, benzene) afforded the corresponding adduct C\(_{60}\)(CPhCl), identified as the methanofullerene 74e, in 99% yield.[49] No adduct 73e was observed, so no diazomethane 1e was formed.

2.5. Silyldiazirines

Silyldiazirines obtained from the corresponding diazo compounds have shown the capability for back-isomerization into linear partners only in some cases in Ar matrices at low temperature. No data on their thermal isomerization have yet been reported.

The first silyldiazirine, compound 75a (Scheme 20), was obtained on irradiation of the diazomethane 76a, matrix-isolated in argon at 8 K, as a component of a photostationary mixture.[68] It was later established that the diazirine is also reasonably stable at room temperature and could even be distilled. Moreover, the photochemical approach became a convenient route to 75a at room temperature.[69]

Scheme 20. Photolysis of silyldiazirines in Ar matrixes.

Short-wavelength irradiation of pure diazirine 75a caused decomposition with loss of nitrogen to give the silylene 77a very cleanly.

No diazo compound 76a was detected. The less substituted Si derivatives 75b and 75c showed similar behavior.[70]

It was mentioned in one case that 75a forms a photostationary mixture with its linear isomer 76a on irradiation in an Ar matrix (8 K), finally giving the 1,1,2-trimethylsilene 77a. Details of the experiment and product distribution were not reported, however.[68]

A tendency to isomerize was also demonstrated by the bis(diazirinyl)silane 78a (Scheme 21, IR: 1642, 1639 cm\(^{-1}\)).[71,72] Short-wavelength irradiation in an Ar matrix gave an insignificant quantity of a diazo compound, most likely 79a, together with the silirene 80a. The IR data, however, do not allow distinction between a mixture of 79a and 75a.
with the bisdiazirine $78a$ and the diazdiazirine $81a$. Two further bis(diazirines) – $78b$ and $78c$ – demonstrated similar isomerization ability.

![Scheme 21. Photolysis of bis(diazirinyl)silanes in Ar matrixes.](image)

Incorporated of silicon in a crowded unsaturated cycle and attachment to a diazirine moiety (Scheme 22) prevented its isomerization to a linear diazo structure under both photolysis and thermolysis conditions.$^{[73,74]}$ Interruption of photolysis of the silyldiazirine $82a$ (IR: 1620 cm$^{-1}$, Pyrex filter, benzene/tBuOH or benzene/MeOH, 12 h) at incomplete conversion showed only nitrogen elimination products: the silole $84$ and the 1,2-dihydrosiline $85$. No isomerization to $83a$ was observed, but a certain amount of the initial diazirine $82a$ was recovered (32%). Photolysis of $82a$ in MeOH gave similar products.

![Scheme 22. Decomposition of the (l-silacyclopentadienyldiazirine diazirine $82a$.](image)

Thermolysis of the diazirine $82a$ (benzene/tBuOH, 150 °C, 10 min) also did not lead to the formation of the diazomethane $83a$. If stable enough under the thermolysis conditions it should be detectable, if formed.$^{[73,74]}$ However, diazo-to-diazirine isomerization occurred.

2.6. Aryldiazirines

Like halodiazirines, aryldiazirines are fairly readily accessible and are therefore well studied. Their linear isomers, the corresponding aryl diazomethanes, are moderately stable and can be observed under ambient conditions. Both photolysis and thermolysis of aryldiazirines tend towards the formation of the corresponding diazomethanes at the expense of nitrogen extrusion. The more polar the solvent used for thermal isomerization, the higher is the yield of diazo compound obtained. The $C_{60}$ probe technique has been used to determine the quantitative partitioning between carbene production, diazoalkane production, and other reactions.

One of the first publications on diazirine synthesis noted that the color of colorless 3-methyl-3-phenyldiazirine turns to pink-red and shows an absorption band corresponding to the diazo group at 2042 cm$^{-1}$ in its IR spectrum on standing in sunlight for two days.$^{[75]}$ Similarly, photolysis of the diazirines $86a$ and $86b$ (Scheme 23) in hexane (Pyrex filter) showed new photosensitive products (UV: 275, 480 nm) that at first accumulated and then disappeared.$^{[55]}$

The kinetics of the disappearances of the diazirines $86a$ and $86b$ in the presence of AcOH were first order, with one of the reaction products being identified in each case as the acetate $88a$ or $88b$, the product of a reaction between acetic acid and the diazo compound $87a$ or $87b$. In the course of the photolysis of the diazirines $86a$ and $86b$ either in liquid films or in CCl$_4$ solutions the absorptions corresponding to the diazirine group at 1600 cm$^{-1}$ in the IR spectra decreased together with growth of bands corresponding to the diazo group at 2000 cm$^{-1}$. All these experiments showed that the 3-aryl-3H-diazirines $86a$ and $86b$ isomerized at least partially on photolysis to afford the linear diazomethanes $87a$ and $87b$.$^{[56]}$

![Scheme 23. Photolysis of monoaryl diazirines.](image)

Ultrafast IR spectroscopic studies of ultrafast laser flash photolysis (LFP) of the diazirine $86c$ (CHCl$_3$, room temperature) with 270 and 375 nm excitation showed the production of the transient isomeric diazo compound $87c$ (IR: 2030 cm$^{-1}$).$^{[76]}$ The development of the integrated diazo band over time reveals its formation with two time constants of 4.4 and 240 ps, with an intensity ratio of 75:25. It was concluded that the diazo compound $87c$ was formed by two pathways: a fast pathway (75%) from the $S_2$ state of the diazirine $86c$ and a slow pathway (25%) from the $S_1$ state of the diazirine. Furthermore, a short-wavelength laser pulse (270 nm) excited the diazirine to the $S_2$ electronic state, in which the direct formation of the diazo compound and the singlet carbene were so rapid that they could even compete with the internal conversion leading to the $S_1$ state. A long-wavelength laser pulse (355 nm) pumped the diazirine $86c$ only to the $S_1$ excited state. As a result, the diazirine isomerizes into the diazo compound as the major decay pathway, as well as forming the singlet carbene as a minor decay pathway.

Rearrangements of alkyl-aryldiazirines to diazo compounds appear to dominate over direct nitrogen extrusion and can take place either photochemically or thermally (Scheme 24). Interruption of the thermolysis of the diazirines $89a$ and $89b$ (DMSO, 100 °C) at incomplete conversion allowed the isolation of the corresponding diazopentane $90a$ (UV: 520 nm) and diazoethane $90b$ (IR: 2040 cm$^{-1}$), together with the azines $92a$ and $92b$, the ketones $93a$ and $93b$, and other products.$^{[77]}$ This result has shown that the mechanism of the decomposition of the diazirines $89a$ and $89b$ is not unidirectional. It was also demonstrated that the polarity of the solvent, but not its nature, would influence the product distribution. Neat decomposition of the diazir-
ines mainly produces the azines.\textsuperscript{[35]} It is interesting to note that the complex of the diazirine 89b with β-cyclodextrin produces mainly cyclopropanes or styrene on thermal and photolytic decomposition and that no diazo compound or azine are formed.\textsuperscript{[78]}

![Scheme 24](image)

Scheme 24. Reactions of alkylphenyldiazirines.

Photolysis of the diazirine 89c (Scheme 24) in the near UV (353 nm) led to the intermediate isomeric diazomethane 90c (about 35% by spectroscopy) together with the direct formation of carbene products.\textsuperscript{[30]} After total decomposition both of the diazirine 89c and of the diazomethane 90c (90 min) the yields of insertion products were 95% (insertion into the O–H bond of MeOH) or 50% (insertion into the C–H bond of cyclohexane). Moreover, the diazo product appeared to be reasonably stable and did not decompose in AcOH in cyclohexane (0.1 M) in an attempted trapping experiment.

Being themselves obtained by oxidation reactions, diazirines are generally inert to oxidizing agents. When reaction with an oxidizing agent does take place it does so with the diazirine decomposition products. Thermal oxidation of the diazirine 89a with m-chloroperoxybenzoic acid (MCPBA) showed that the oxidation proceeded to form the decomposition products of the carbenic and diazo pathways (Scheme 24).\textsuperscript{[79]} The ketone 93a could be formed as a result of oxidation of the diazopentane 90a with MCPBA whereas the cis- and trans-pentene oxides 94a are derived from the carbenic intermediate 91a, which rearranges to the cis- and trans-pentenes before oxidation.

It was shown that the decomposition of 89a in chlorobenzene proceeds 50% in carbenic fashion and 50% by the diazo process. In a more polar solvent (nitrobenzene) the decomposition occurs 75% by the diazo pathway and in an even more polar solvent (DMSO) this pathway accounts for as much as 90% of the product. The diazirine moiety is known to be less polar than the diazo group, so the more polar the solvent used for thermal isomerization, the better it stabilizes an increase in polarity in the transition state and the higher the yield of diazo compound obtained.\textsuperscript{[80]}

Both thermal and photochemical decomposition of the diazirine 89a in CD$_2$CO$_2$D (Scheme 24) gave the acetate 96 and a mixture of the cis- and trans-pentenes 97.\textsuperscript{[79b,79c]} The identical yields and product ratios in the two reactions led to the conclusion that both processes pass through the same intermediate: the diazoalkane 90a. The similarity of the results implies that both processes occur in the ground state of 90a irrespective of the activation method and the character of the initial activated state. Protonation of the diazoalkane 90a leads to the diazonium ion 95, which gives the known thermal reaction products 96 and 97. If a carbene had been the initial product an intramolecular migration of a hydride ion should have driven a reaction to afford the undeuterated olefin 97, which was not found.

An attempt to trap the diazomethane intermediate 90b in the form of a cycloadduct with a dipolarophile was not successful (Scheme 24).\textsuperscript{[81]} Photolytic decomposition of 89b in the presence of N-methylmaleimide in ethereal solution gave no [2+3] cycloaddition product 98 despite the evident formation of the diazo compound 90b (development of a red color on photolysis of the diazirine 89b in solution and a quantitative yield of an insertion product of type 88 on photolysis in the presence of acetic acid). Only the azine 92b (8%) and the cyclopropane 99 (43%) were isolated. However, the corresponding pyrazoline 98 (23%, mixture of diastereomers), the direct cycloadduct of the diazo compound and the dipolarophile, was obtained from a solvent-free photolysis, together with the azine 92b (4%) and the cyclopropane 99 (41%, mixture of diastereomers). Once again it was demonstrated that the outcome of trapping of intermediates depends, among other factors, on the nature of the reaction medium.

Thermal rearrangement of the diazirine 89a to the diazo compound 90a was also investigated in the presence of fullerene (C$_{60}$, Scheme 25).\textsuperscript{[30–52]} The fulleroid C$_{60}$CPh(nBu) (101), with the nBu group located above the five-membered ring, was confirmed by $^1$H NMR. Yields were high: 70% in an o-dichlorobenzene/C$_6$D$_6$ mixture and 76% in DMSO. In addition, the minor fulleroid 102, the methanofullerene 103, and (E)-1-phenylpent-1-ene (100) were detected. These results indicate that the major decomposition pathway for the diazirine 89a is the formation of the diazoethane 90a (about 80%) and agree with other thermal experiments carried out with the compound.\textsuperscript{[79]}

Spectral methods are a powerful tool for the detection of unstable aryldiazomethanes at low temperatures (Scheme 26). Narrow-band photolysis of the diazirine 104 (IR: 1639, 1631 cm$^{-1}$) in an Ar matrix resulted in almost quantitative isomerization to the diazoalkane 105 (IR: 2042 cm$^{-1}$, unstable under usual conditions). Further photolysis of 105 with long-wavelength light transformed it into
Isomerization between Diazo Compounds and Diazirines

The spirodiazirine 110a (Scheme 27) in fact appears to be the only stable diaryldiazirine (isolated by chromatography) currently known, and its properties have been studied to some degree.\[^{[84]}\] Thermolysis of 110a in MeOH led to its complete isomerization to the diazo compound 111a. Photolysis of the diazirine 110a in MeOH gave products of carbene reactions with the solvent, although partial formation of the diazo compound 111a was noted. From kinetic measurements the assumption was made that the formation of the carbene products 112a and 113 occurs as a result of the decomposition of the diazirine 110a and not of the intermediate diazofluorene 111a.

2.8. α-Keto-Diazirines

Even the first attempts to synthesize α-keto-diazirine showed that such compounds, unlike their linear diazo-ketone isomers, are much less stable and less accessible than aliphatic diazirines. The diazirine 20b (Scheme 28) is thus stable at room temperature\[^{[85]}\] whereas the diazirine 114 loses nitrogen with a half-life of 1 h.\[^{[86]}\] The stable bicyclic diazirines 115\[^{[87]}\] and 116a\[^{[88]}\] were identified later. Their stabilities were explained in terms of the positive influence of strained factors in the molecule skeletons, consistently with the behavior of other cyclic azo compounds.\[^{[89]}\] The perfluorinated keto-diazirine 117c also appeared to be stable, which was explained in terms of the distinctive properties of fluorine atoms.\[^{[90,91]}\] In general, data for α-keto-diazirines are fragmentary and poor. Several known examples testify that irradiation leads mainly to the nitrogen elimination products and that isomeric diazoketones are formed in minor quantities. The same is true for thermolysis.

Scheme 28. Structures and photolysis products of diazirines.

The diazirine 116a, obtained serendipitously in a synthesis of strained molecules, was the first α-keto-diazirine stable under conventional conditions.\[^{[88]}\] Photolysis of 116a led to the formation of the acid 119a and small amount of the diazoketone 118a. Because the photolysis of the diazoketone 118a also gave the isomeric diazirine 116a the assumption was made that these two compounds undergo photoreversible interconversion. Further conversion of these isomers involving Wolff rearrangements can proceed with each partner of this pair, but probably with different rates.

Scheme 27. Reactions of diaryldiazirines.
Photolysis of the diazirines 117a and 117b (Scheme 29) in an Ar matrix with short-wavelength light led to nitrogen abstraction and rearrangement to the ketene 121a (IR: 2192 cm\(^{-1}\)), but formation of the diazoketones 120a and 120b was not confirmed.\[^{[89]}\] Irradiation of a close analogue – the diazirine 117c – with long-wavelength light transformed it into the ketene 121c and the diazoketone 120c, but in this case no yields or product ratio were reported.\[^{[90]}\]

\[\text{Scheme 29. Photolysis of (perfluoroalkyl)diazirines in Ar matrixes.}\]

Thermolysis of the diazirine 117c in CCl\(_4\) (80 °C) led only to the formation of insertion products with the solvent.\[^{[90]}\] Heating in the gas phase (80 °C, 3.5 h, 300 mm, diluted with Ar) resulted in quantitative elimination of nitrogen with the formation of the ketene 121c. The isomeric diazoketone 120c is stable under these conditions, so it is assumed that thermal isomerization of the diazirine 117c does not occur and that 121c is formed from it directly without stepwise opening of the diazirine cycle.

The diazirine 115 (Scheme 30) appeared to be inert to the action of long-wavelength light (\(\lambda > 395\) nm). In the course of short-wavelength photolysis, however, it disappeared quickly, giving the intermediate diazocamphor 122 (UV: 250, 300 nm) with a quantum yield close to 0.7 and oxygenated in an Ar matrix with short-wavelength light led to nitrogen abstraction and rearrangement to the ketene 121c. The isomeric diazoketone 120c is stable under these conditions, so it is assumed that thermal isomerization of the diazirine 117c does not occur and that 121c is formed from it directly without stepwise opening of the diazirine cycle.

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\[\text{Scheme 30. Photolysis of the spiroketo-diazirine 115.}\]

The pair made up by the diazocamphor 122 and the diazirine 115 is unique because of the thermal stabilities of both cyclic and linear isomers. As a rule, only one of the two isomers displays this property.\[^{[87]}\]

\[2.9.\text{ Carbamidodiazirines}\]

The monocarbamidodiazirines 125a-c (Scheme 31) were the first diazirines with \(\alpha\)-carbonyl groups that were found to be stable under conventional conditions and could be isolated and investigated. Both the diazirines and the isomeric diazoleamide are fairly stable, although the data for them are not numerous. The formation of diazo compounds from diazirines in low yields is observed both on photolysis and on thermolysis.

\[\text{Scheme 31. Isomerization of carbamidodiazirines.}\]

Irradiation of the diazirine 125a with monochromatic light (312 nm, 1 h) led to a mixture of compounds. One was identified as the product of isomerization: the linear \(N\)-methylhexadiazocetamide 126a (IR: 2140 cm\(^{-1}\)), quite a stable compound.\[^{[92]}\] Similar irradiation of the diphenylamide 125b (334 nm, 2.25 h) also led to the formation of a complex mixture of products contained the isomeric diazomide 126b (IR: 2100 cm\(^{-1}\)). Photolysis of 125b with short-wavelength light (312 nm) no longer led to formation of the diazomide 126b, possibly because of absorption of this radiation by the diphenylamide group. Thermolysis of the diazirine 125c in boiling toluene quantitatively yielded \(N\)-methylxindole and did not show the presence of the isomeric diazomide 126c.

\[\text{Scheme 32. Reactions of spirocyclic carbamidodiazirines.}\]

Kinetic measurements showed that the half-life of the diazirine 127a was around 14 h at 18 °C and about 12 min at 50 °C and that the energy of activation for thermal isomerization to the diazoidole 128b was about 27 kcal mol\(^{-1}\).
Low stabilities of keto-diazirines had been observed earlier: 114, for example, eliminates nitrogen within an hour at room temperature.[86,94]

The bis(carbamido)diazirine 131, unlike the monocarbamidodiazirines 125a, 125b, and 127a or the dialkyl diazirine-3,3-dicarboxylates 135, 139a, and 139b, did not show a propensity to isomerize to the diazo compound 132 on photolysis (Scheme 32).[95] Only products of nitrogen abstraction – the barbituric acid 133 and the ester 134 – were identified, although no data were reported either for the diazirine 131 or for the products of photolysis (the same compounds were also obtained from photoirradiation of the isomeric diazodiamicid 132).

2.10. Diethyl Diazirine-3,3-dicarboxylate

In spite of the fact that the diazomalonic ester 136 (Scheme 33) has been known for more than 40 years[96] and that its cyclic isomer – the diazirine 135 – and analogues have been synthesized in the form of various derivatives of malonic acid,[97] data for their mutual transformation have appeared only more recently. The dependence of the isomerization yields on the wavelength of the irradiating light has been reported, although they are certainly not high. Thermolysis gave only traces of diazo compound, together with formation of other products.

Irradiation of the diazirine 135 with monochromatic light at room temperature led to the formation of two main reaction products: the methoxymalonate 137 (main, carbene insertion) and the diazomalonate 136 (minor, isomerization), the ratio of which varied depending on the wavelength of the irradiating light.[98]

It is significant that the maximum yield of isomerization was observed on irradiation in a part of the spectrum (300 nm) in which the formed diazomalonate 136 has an absorption minimum between two maxima (UV: 251 and 344 nm). Apparently, irradiation close to the absorption maxima of this photosensitive reaction product causes secondary photolysis and completely destroys 136.

Thermolysis of the diazirine 135 (IR: 1755, 1730 cm\(^{-1}\)) results in the formation of insignificant quantities of the diazoester 136 (IR: 2123, 1758 cm\(^{-1}\)) along with the malonate 137. As in the case of the cyclic analogue 139a (Scheme 34), the rates of decomposition of the diazirine 135 in H\(_2\)O appeared to be higher than those in dioxane over a 30–70 °C temperature range, which clearly points to a similarity of their mechanisms of isomerization.[98]

Scheme 33. Decomposition of diethyl diazirine-3,3-dicarboxylate (135).

Scheme 35. Thermolysis of spirocyclic dialkyl diazirinedicarboxylates.

In contrast, the bis(carbamido)diazirine 131 is known to be reasonably stable over several weeks at room temperature.[100] The diazirines 131 and 135, originating from the diazobarbituric acid 132[95] and the diazomalonic ester 136,[96] respectively, have also been reported. It was disclosed that thermolysis of dialkyl diazirine-3,3-dicarboxylates (Scheme 35) tends towards isomerization into the diazo partners, whereas in photoreactions both isomerization and nitrogen elimination compete.

Kinetic measurements on thermolysis of the diazirines 139a and 139b in mixtures (CDCl\(_3)/\text{MeOH}, \text{CDCl}_{3}/\text{H}_2\text{O}, \text{or C}_6\text{D}_6/\text{MeOH}) at 50 °C showed that their half-decay periods were 1.3–4.1 h.[99] Two competitive processes were thus observed: isomerization with the formation of the diazo compounds 140a and 140b (22–47%) and elimination of nitrogen with formation of the Wolff rearrangement products 141 and 142 (40–78%). The elimination products should originate from the diazirines 139a and 139b, the diazo compounds 140a and 140b being stable under the thermolysis conditions. It is interesting that thermolysis carried out in more polar reaction media (MeOH, 40 °C) in practice gave the diazo compound 140a quantitatively.[100] Moreover, the diazirine 139a rapidly turns into the diazo isomer 140a in thermal fashion only in solution, remaining unchanged over several months in crystalline form.[102]
The results obtained were confirmed by calculations relating to the potential energy barrier to the thermal isomerization of the diazirine to the diazo compound in the gas phase (about 30–37 kcal mol\(^{-1}\)). At the same time the barrier for the return isomerization of the diazo to the diazirine compound is about 53–60 kcal mol\(^{-1}\), considerably higher than the energy of activation for Wolff rearrangement (47–48 kcalmol\(^{-1}\)). The thermolysis of the diazirine therefore should not lead to loss of nitrogen.

The polarity of a reaction medium essentially influences not only the reaction pathway, but also the rate of isomerization of the diazirines to the diazo compounds 140a or 140b (Scheme 36). Their isomerization in water thus proceeds approximately 10 times more rapidly than in dioxane, due to the fact that the diazirine moiety is considerably less polar than the diazo group and that a polar solvent (H\(_2\)O) stabilizes an increase in polarity in a transition state better than a less polar one (dioxane).

![Scheme 36. Photolysis of spirocyclic diazirines in various solutions.](image)

The diazirines 139a and 139b are almost inert with respect to long-wavelength light (\(\lambda > 320\) nm). In contrast, short-wavelength irradiation (\(\lambda < 210\) nm) appeared to result in fast and almost unidirectional processes, with only slight isomerization to the diazo compounds 140a and 140b (0–8%), against nitrogen abstraction to afford 141–144 (49–97%). The yields of the diazo compounds 140a and 140b calculated by IR spectroscopy did not exceed 1–2% over the courses of the reactions. The lack of the diazo compounds among photolysis products is not in fact surprising because they are also sensitive to the irradiation. It is necessary to note that the lifetimes of the diazirines 139a and 139b in a solution are not long, varying from 3.5 h (CDCl\(_3\)) to 4 h (C\(_6\)D\(_6\)) at 50 °C.

In general, a decrease in the wavelength of initiating light (Table 1) considerably shifted the photolysis of the diazirine 139a (UV: 244, 284 nm) towards the nitrogen abstraction products 142 and 144a relative to isomerization into the diazo compound 140a (UV: 248, 329 nm). Similar, but more strongly expressed dependence was observed for 140a.

### 3. Isomerization of Diazo Compounds to Diazirines

In spite of the fact that photochemical isomerization of diazirines to diazo compounds became known almost simultaneously with their discovery, the first example of return isomerization was found only in 1971. The number of discovered isomerizations of diazirine compounds remains rather limited to date. This might be due to a variety of difficulties. Namely: i. several types of diazo compounds, such as diazoalkanes or halogenodiazomethanes, are too labile to be investigated on this subject, ii. a number of diazirines, such as carbonyldiazirines, appear to be of low stability, iii. attempts to obtain disubstituted or hindered diazirines, such as diphenyl- or Boc-carbamidodiazirine, have failed, and iv. study of fast isomerization processes has become possible only recently, thanks to the development of powerful and high-speed techniques.

According to calculations, the ΔE values for isomerizations of diazomethanes 1 to diazirines 2 range from 22.2 (R = BH\(_2\)) to −12.4 kcal mol\(^{-1}\) (R = F). Diazomethanes substituted with the groups −CH=CH\(_2\), −CH=O, −C=CH\(_2\), −C=N, and −CH\(_3\) appear to be more stable than the corresponding diazirines by 5.6, 12.6, 7.1, 9.5 and 1.9 kcal mol\(^{-1}\), respectively. The first four groups would be expected to provide π-acceptor stabilization of the diazomethanes. These substituents thus define which of the two isomers is more stable, which is largely attributable to the influences of electronegativity and conjugation on the stabilities of the diazomethanes.

#### 3.1. Diazomethanes

Because of the low thermal and photostabilities of simple alkyl diazomethanes, data for their possible isomerization into diazirines are not known. Only fluorinated alkyl groups or Si derivatives significantly increase the stabilities of the corresponding diazomethanes and make it possible to observe their conversion into the isomeric diazirines. Long-wavelength irradiation of these diazo compounds results in low-to-medium yields of diazirines, whereas short-wavelength excitation leads to nitrogen abstraction. No data on their thermal isomerization have been reported.

Irradiation of the diazomethane 14a (UV: 260, 400 nm) with long-wavelength light (Scheme 37) led to its total disappearance and the partial formation of the diazirine 13a (UV: 310 nm) along with the carbene reaction products 15a and 16a. No diazirine 13a was observed on short-wavelength irradiation of 14a and only products of photodegradation were obtained.

![Table 1. Conditions and products of reactions of the diazirine 139a in MeOH.](image)
The monosubstituted diazomethane 14b (UV: 260, 400 nm)\textsuperscript{[28,29]} gave trace amounts of the isomeric 13b (UV: 310 nm) only on irradiation with long-wavelength light. Use of the perhalogenodiazomethane 14c under similar conditions also resulted in the formation of the isomeric diazirine 13c (UV: 310 nm) in low yield.\textsuperscript{[29]}

Photolysis of (trimethylsilyl)diazomethane (76a, Scheme 38) in an Ar matrix ($\lambda > 360$ nm) produced a photostationary mixture of the diazirane 76a (IR: 2080 cm\textsuperscript{-1}) and the diazirine 75a (IR: 1640 cm\textsuperscript{-1}).\textsuperscript{[68]} Prolonged irradiation of this equilibrium mixture in an Ar matrix led to elimination of nitrogen from both isomers and the formation of the triplet carbene 145a (ESR spectrum), with subsequent stabilization as the silene 77a on heating above 45 K.\textsuperscript{[107]} It was found that irradiation of the diazomethane 76a in solution also led to the formation of the diazirane 75a at room temperature.\textsuperscript{[68,69]} Newly formed 75a was stable enough to be isolated and characterized under these conditions. Photolysis of 76a at 4°C with short-wavelength light (>300 nm) led to fast disappearance of the diazomethane and the very clean formation of the silene 77a.\textsuperscript{[107]} The less substituted diazomethanes 76b and 76c showed similar behavior.\textsuperscript{[70]}

Irradiation of the bis(diazomethyl)silanes 79a–c (IR: 2082, 2073 cm\textsuperscript{-1}) with blue light in argon matrices initially gave the bis(diaziryl)silanes 78a–c (IR: 1642, 1639, 1636 cm\textsuperscript{-1}) and small amounts of the silirenes 80a–c (Scheme 39).\textsuperscript{[71,72]} Short-wavelength irradiation of 79a–c (305 nm) rapidly resulted in the disappearance of the diazirane and the silirenes 80a–c were the only products. Photolysis of the silyldiazomethane 83a (IR: 2070 cm\textsuperscript{-1}, Scheme 40) in a benzene/MeOH solution (Pyrex filter, 6 h) drove the reaction towards the silyldiazirane 82a (IR: 1620 cm\textsuperscript{-1}, isolated by chromatography on SiO$_2$) along with products of nitrogen abstraction (146, 147, and others).\textsuperscript{[73,74]} Continued irradiation of 83a in MeOD (18 h) as well as photolysis in tBuOH decreased the amounts of the diazirane 82a (9% and 38%, respectively).

In contrast, use of an optical filter (phenanthrene in MeOH) resulted in an increase in the yield of the diazirane 82a after 3 h of irradiation in both alcohols (54% in MeOH and 68% in tBuOH).

A low yield of the disubstituted diazirane 82b (IR: 1610 cm\textsuperscript{-1}) was obtained on irradiation of the disubstituted diazomethane 83b (IR: 2030 cm\textsuperscript{-1}) in a benzene/tBuOH mixture (7 h) (Scheme 40). This diazirane was also isolated by chromatography (SiO$_2$) and appeared to be stable under ambient conditions (m.p. 142 °C).

The presence of the second substituent attached to a linear diazo group thus complicates, but does not exclude, its isomerization into the diazirane ring, although the opposite opinion had originally been expressed.\textsuperscript{[73]}

### 3.2. Diaryldiazomethanes

Diazomethanes of this type are reasonably stable, whereas the diaziranes are almost unknown. Formation of diaziranes with two aromatic rings on photoexcitation of the corresponding diazomethanes has been observed only for two similar structures and only when the π→π* absorption band was activated.\textsuperscript{[84]} Thermal diazo-to-diazirane isomerization is not known, though the reverse reaction has been reported.

One initial product of the photolysis of 9-diazo-1,8-diazafluorene (111a, IR: 2091 cm\textsuperscript{-1}) with long-wavelength light (350 nm) in MeOH, cyclohexane, or benzene is, apparently, the diazirane 110a (Scheme 41). Analysis of the reaction mixture (NMR) showed that the diazirane 110a gradually accumulated during photolysis and reached its maximum yield after 2 h (about 20%). Further irradiation reduced the yield to almost zero and replaced 110a with products of carbene reactions (112a (42%), 113 (16%), and others). It should be noted that although the diazirane 110a has been isolated by chromatography (SiO$_2$), only the NMR spectrum in the form of a set of multiplets has been reported.
The dependence of the diazirine formation on the wavelength of the irradiating light was studied. On photolysis at ca. 310 nm, into a $\pi \rightarrow \pi^*$ absorption band, the excited diazofluorene 111a rearranged to the diazirine 110a (8.8% at 18% conversion) and lost nitrogen to form the carbene products. However, when 111a was photolyzed at ca. 420 nm, into the $\pi \rightarrow \pi^*$ band, no diazirine was formed.

The sensitized photolysis of 111a in MeOH ($\lambda > 380$ nm, benzil as the sensitizer) led to the elimination of nitrogen with the quantitative formation of fluorene 113 and no diazirine 110a being detected.

Irradiation of the isomeric 3,6-diazafluorene 111b (IR: 2078 cm$^{-1}$, Scheme 41) in cyclohexane (350 nm) gave only small amounts of the diazirine 110b along with the insertion product 112b (85%).[108] The same reaction in benzene solution (350 nm, 10 min) also led to a low yield of the diazirine 110b (8.5%, detected by NMR). It is interesting that reduction of the concentration of the initial diazo compound 111b resulted in reduction of the relative yield of the diazirine 110b: for a $5.5 \times 10^{-3}$ m solution of 111b in MeOH the yield of 110b was 20% whereas for a $1.2 \times 10^{-3}$ m solution of 111b it was 10% (no other characteristics of the diazirine 110b were reported).

### 3.3. Diazoketones

Diazoketones are much more stable than diazoalkanes and could be used under ambient conditions and in their pure forms. Their cyclic isomers are of low stability, as already became clear at the first attempt at their synthesis.[88] Data for isomerizations of diazoketones to $\alpha$-keto-diazirines are not numerous. Only long-wavelength light initiated these isomerizations, with low-to-medium yields. Thermal isomerization is unknown.

The first stable $\alpha$-keto-spirodiazirines – 116a and 116b (Scheme 42) – were obtained during the course of the photolysis of the strained tricyclic diazoketone 118a.[88] The acid 119a was identified as the main product, together with the minor $\alpha$-keto-diazirine 116a. It has appeared much more stable (m.p. 65 °C) than the previously obtained $\alpha$-keto-diazirine 114, which decomposed even at room temperature.[86] For better understanding of the role of the double bonds in stabilization of the diazirine cycle the saturated analogue – the diazoketone 118b – was synthesized and subjected to photolysis. Under similar conditions the saturated analogues – the diazirine 116b (isolated by TLC/SiO$_2$) and the acid 119b – were obtained with approximately the same yields.

It was thus postulated that $\alpha$-keto-diazirines can be stabilized not only by conjugation[109] or by a neighboring amide moiety,[92,104] but also by some other still unknown factors.[88]

Another stable spirodiazirine – compound 115 – was obtained from the diazocamphor 122 (Scheme 43).[87] On irradiation of 122 with visible light two parallel processes were discovered: isomerization to the diazirine 115 (IR: 1750 cm$^{-1}$) and elimination of nitrogen followed by rearrangement to form either the ester 124 (reaction in EtOH) or other products (reaction in hexane). The new $\alpha$-keto-diazirine 115 was found to be stable under ambient conditions and to be tolerant of isolation by chromatography (SiO$_2$) and recrystallization (m.p. 95–96 °C). It should be noted that the diazirine 115, like many other camphor derivatives, is a very volatile substance and could be easily sublimed.[87]
Isomerization between Diazo Compounds and Diazirines

expected product of Wolff rearrangement. Photolysis with a Pyrex filter ($\lambda > 280$ nm) both in a matrix and in the gas phase, as well as short-wavelength irradiation ($\lambda > 210$ nm) in a matrix, yielded only the ketene 121.

Scheme 45. Photolysis of (perfluoroalkyl)diazoketones.

It is interesting that room-temperature photolysis of 120a with long-wavelength light ($\lambda > 320$ nm) is now used for preparative-scale synthesis of 117a in 45% yields.[90,91]

Photolysis of close analogues – the diazoketones 120b and 120c (Scheme 45) – in a polycrystalline phase at 12 K ($\lambda > 335$ nm) also gave the reasonably stable diazirines 117b (IR: 1752 cm$^{-1}$) and 117c (IR: 1762 cm$^{-1}$), which survived a short period of warming to room temperature without changes.[91]

3.4. Diazoamides

Both diazoamides and carbamidodiazirines are stable under ambient conditions, being not only detectable, but also isolable and characterizable. Visible light irradiation of diazoamides has given a few diazirines, but UV photolysis has resulted in the formation only of nitrogen elimination products. The presence of a second substituent attached to an amide moiety blocks diazirine formation when a linear derivative is formed, but does not preclude the formation of the diazirine if two substituents attached to an amide moiety are closed into a cycle. Thermal diazo-to-diazirine isomerization for these pairs has not been described, but the reverse reaction occurs.

Diazoamides are known as the first class of compounds to have demonstrated isomerization to stable diazirines upon light activation.[104] Irradiation of N-diazoacetylpiperidine (153a, Scheme 46) with visible light gave N-[(diazirinylcarbonyl)piperidine (154a, IR: 1655 cm$^{-1}$) in low yield. UV light caused nitrogen elimination and the formation of the azabicycle 155. Isomerization of the diazoamide to the diazirine appeared to be successful only in the case of the monosubstituted derivative 153a. When a second substituent was attached to a diazo moiety – in 153b – no diazirine 154b was observed. The assumption was made that bulky substituents hinder the formation of diazirine cycles or cause rapid reverse reactions. This was confirmed by the fact that attempts to prepare diphenyldiazirine (108) in the same way as the spirofluorendiazirine 110a by a “dark” pathway failed,[83,84] whereas 3-alkyl-3-phenyldiazirines are known and stable.[75]

Scheme 46. Photolysis of diazoamides.

Irradiation of diazoacetylphenylalanine (156, Scheme 47) and diazoacetylproline (158a) with visible light ($\lambda > 400$ nm) gave the stable diazirines 157 (UV: 310 nm, m.p. 104 °C) and 159a (IR: 1658 cm$^{-1}$, m.p. 98 °C), each with only one substituent attached to a diazirine moiety.[104] Close analogues such as ethyl diazoacetate (160), diazoacetone (161), and diazoacetophenone (162) are also monosubstituted diazocarbonyls and might also have given monosubstituted diazirines, but did not.[92] In this they resemble the disubstituted diazoamides 153b, 158b, and 163 which gave no detectable diazirines upon irradiation.

Scheme 47. Propensities of diazocarbonyls to isomerization.

The occurrence of isomerization is affected not only by the number of substituents, but also by the light wavelength. Irradiation of the diazoamide 126e with visible light (Scheme 48) thus drove the reaction towards the diazirine 125e whereas use of UV light led to the formation of the cyclic lactams 165e and 166e.[104,111]

Scheme 48. Photolysis of diazomonoamides.
The lightly substituted diazoamides 126a and 126d formed the stable diazirines 125a and 125d on irradiation with visible light. The methylphenylamide 126c and the diphenylamide 126b were also converted into the corresponding diazirines 125c and 125b, so aromatic substituents attached to the amide moiety did not essentially affect the course of visible light photolysis. Irradiation of the diazoamides 126b and 126c with UV light, however, led to the formation of N-methyl and N-phenyloxindoles as the main identified products, with the diazirines 125b and 125c thus being bypassed.

These experiments demonstrated that visible light generally initiated isomerization of α-diazoamides to diazirines irrespective of substitution on the amide group. It was proposed that the irradiation generates the diazoamide exited states 167 (Scheme 49) with oscillatory energy low enough to allow the isomerization process to compete successfully with the formation of carbene. In fact, diazo-to-diazirine photoisomerization is observed just in cases of amides of diazooacids and not of acids themselves or their esters. It appears to be the case that the amide nitrogen plays the main role in the isomerization. In the structure 168a (X = NR) it might participate in delocalization of a positive charge and thus promote the formation of the diazirine cycle in 125. The structure 168b (X = O), an ester case, should experience a minimal contribution to charge stabilization in the intermediate, promoting diazirine ring closure only slightly. The formation of structure 168c (X = CH₂) for stabilization of ketones is difficult to imagine at all.

This mechanism also explains why no diazirine has been formed from a diazoamide of a malonic acid semi-ester: the C atom bearing a diazo group is quaternary in this case and a structure of type 168a would become unstable.

It is interesting that cyclic diazoamides (Scheme 50) also tend to isomerize into stable diazirines in spite of the fact that the diazirine rings are doubly substituted in such cases. Irradiation of the diazoindoline 128a (IR: 2085, 1670 cm⁻¹) in MeOH (290 nm) in the presence of oxygen led to the insertion of the formed carbene into the O–H bond of MeOH to produce 129a (30%) and alternatively demonstrated reduction to 130a (25%). Interruption of photolysis at approximately 50% conversion of 128a, however, allowed the isolation of the intermediate keto-diazirine 127a (IR: 1740, 1690, 1630 cm⁻¹) by chromatography (SiO₂).

Similarly, the diazoindoline homologue 128b (IR: 2110, 1680 cm⁻¹, Scheme 50) also gave the diazirine 127b (IR: 1730, 1620 cm⁻¹) on irradiation in MeOH.

The diazobarbituric acid 132, another cyclic diazodi- amide, formed the stable diazirine 131 on irradiation under ambient conditions (Scheme 51).

Diazodicarbonyl compounds, diazodiesters in particular, are quite stable and storable even at room temperature in darkness for a long time without significant changes. Diazirines related to diazodiesters, namely diazo-Meldrum’s acid and diazomalonic esters, are the only known compounds of this type. They have proven to be reasonably stable under ambient conditions and have been studied in some detail. The degree of isomerization on photolysis depends strongly on the wavelength of irradiation: the shorter the wavelength, the lower the yield of isomerization. Thermal diazo- to-diazirine isomerization has not been described for these pairs, but return reactions occur in solutions, as in the diazoamide case.

The first isomerization of diazo-Meldrum’s acid (140a, Scheme 52) to the corresponding diazirine was observed in 1978, when it was used in syntheses of cyclopropanes. Direct photolysis of 140a (UV: 332, 249 nm) in the presence of an excess of cyclohexene (Pyrex filter, λ > 350 nm) caused excitation of the n→π* transition in 140a (λmax = 332 nm) and led to its isomerization to the diazirine 139a with a yield of 35% (m.p. 84 °C, IR: 1769 cm⁻¹).

The target product of carbene decomposition, the corresponding cyclopropane 169, appeared to be a minor one. Use of a quartz filter (λ = 253.7 nm), however, resulted in excitation of the π→π* transition in 140a (λmax = 249 nm) and the formation of diazirine 139a decreased to 4% while the corresponding cyclopropane 169 became the main product. Back “dark” isomerization of the diazirine 139a to 140a proceeds at room temperature within a few weeks.

Scheme 50. Photolysis of cyclic diazoamides.

Scheme 51. Decomposition of the diazobarbituric acid 132.

3.5. Diazodiesters

Long-wavelength excitation of the diazo compound 132 in alcohol led to the formation of the diazirine 131, which appeared stable at room temperature. Short-wavelength light caused nitrogen elimination and gave 133 (reduction) and 134 (Wolff rearrangement), although yields and characteristics of the photolysis products were not reported.
Isomerization between Diazo Compounds and Diazirines

This experiment started a new phase of study of intermediates in the course of photolytic decompositions of diazo compounds and also made diazo-Meldrum’s acid the main object of these investigations.

Testing of photodecomposition of 140a in protic media (H2O, MeOH) became the next step of the study (Scheme 53). It was shown that the diazo compound 140a is inclined to Wolff rearrangement, like its carbocyclic “relatives” and unlike its acyclic analogue, the diazomalonic ester 136.

Photolysis of 140a in a poly(methyl methacrylate) (PMMA) film (254 nm, 22 °C) showed some differences from a solution reaction: 140a disappeared (IR: 2170 cm–1) and the ketoacid 141a (IR: 1810 and 1770 cm–1) was formed (Scheme 54). The formation of the diazirine 139a was not observed and the absence of the ketene 170 was explained in terms of its fast reaction with water adsorbed in the polymeric film. It was found that the quantum yield of decomposition of diazo-Meldrum’s acid (140a) had increased from 0.37 in MeOH (0.27 in CHCl3) to 1.0 in a PMMA film.

One of the deactivation pathways of exited 140a* involves interconversion to the corresponding diazirine 139a formed on long-wavelength irradiation (350 nm) of diazo-Meldrum’s acid (140a) in solution[100] as the main photoproduct for diazo compounds in general[14d,108] If the radiationless decay channels in excited 140a* are coupled to C=N=N bond bending of this kind, the rigid matrix could suppress this motion and enhance the probability of nitrogen extrusion and subsequent rearrangement.[112]

Detailed investigation of the mechanism of photodecomposition of 140a has shown that the direction of photolysis is critically influenced by the wavelength of the exciting light (Table 2, Scheme 55).[80]

Table 2. Reaction conditions and yields of products (at low levels of conversion) on photolysis and thermolysis of the diazo compound 140a.

<table>
<thead>
<tr>
<th>Reaction conditions</th>
<th>Yields of reaction products [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>139a</td>
</tr>
<tr>
<td>hv, 254 nm</td>
<td>7</td>
</tr>
<tr>
<td>hv, 254 nm, sens.</td>
<td>0</td>
</tr>
<tr>
<td>hv, 300 nm</td>
<td>17</td>
</tr>
<tr>
<td>hv, 350 nm</td>
<td>55</td>
</tr>
<tr>
<td>hv, 355 nm</td>
<td>94</td>
</tr>
<tr>
<td>Δ, 80 °C, MeOH</td>
<td>0</td>
</tr>
</tbody>
</table>

One of the deactivation pathways of exited 140a* involves interconversion to the corresponding diazirine 139a formed on long-wavelength irradiation (350 nm) of diazo-Meldrum’s acid (140a) in solution[100] as the main photoproduct for diazo compounds in general[14d,108] If the radiationless decay channels in excited 140a* are coupled to C=N=N bond bending of this kind, the rigid matrix could suppress this motion and enhance the probability of nitrogen extrusion and subsequent rearrangement.[112]

Detailed investigation of the mechanism of photodecomposition of 140a has shown that the direction of photolysis is critically influenced by the wavelength of the exciting light (Table 2, Scheme 55).[80]

Scheme 52. Photolysis of diazo-Meldrum’s acid in cyclohexene.

Scheme 53. Photolysis of diazo-Meldrum’s acid in protic media.

On irradiation of 140a with short-wavelength light (λ > 210 nm) in H2O or MeOH, two processes are observed: 1) isomerization to the diazirine 139a (minor), and 2) loss of nitrogen (main) with formation of 141a or 142a (Wolff rearrangement) and of 144a (reduction).

Photolysis of 140a in a poly(methyl methacrylate) (PMMA) film (254 nm, 22 °C) showed some differences from a solution reaction: 140a disappeared (IR: 2170 cm–1) and the ketoacid 141a (IR: 1810 and 1770 cm–1) was formed (Scheme 54).[112–114] The formation of the diazirine 139a was not observed and the absence of the ketene 170 was explained in terms of its fast reaction with water adsorbed in the polymeric film. It was found that the quantum yield of decomposition of diazo-Meldrum’s acid (140a) had increased from 0.37 in MeOH (0.27 in CHCl3) to 1.0 in a PMMA film.

The following mechanism was suggested for the reaction (Scheme 55).[80] Short-wavelength irradiation (254 nm) of 140a (UV: 248, 329 nm) in solution (MeOH) at room temperature thus showed that the main pathway of its decomposition (at 10% conversion) is nitrogen elimination and formation of the keto ester 142a. Long-wavelength irradiation (355 nm) leads mainly to isomerization to the diazirine 139a (UV: 244, 284 nm). Triplet-sensitized photolysis gave Meldrum’s acid (144a) quantitatively.

Scheme 54. Photolysis of diazo-Meldrum’s acid in PMMA.

Scheme 55. Mechanism of photodegradation of diazo-Meldrum’s acid.

Short-wavelength irradiation (254 nm) of 140a (UV: 248, 329 nm) in solution (MeOH) at room temperature thus showed that the main pathway of its decomposition (at 10% conversion) is nitrogen elimination and formation of the keto ester 142a. Long-wavelength irradiation (355 nm) leads mainly to isomerization to the diazirine 139a (UV: 244, 284 nm). Triplet-sensitized photolysis gave Meldrum’s acid (144a) quantitatively.

The following mechanism was suggested for the reaction (Scheme 55).[80] Short-wavelength irradiation of the diazo compound 140a excites its molecules to the S2 level (alternatively, a set of highly excited singlet states – S5, S7 – could be populated by molecules, which could relax to the dissociative S2 state by ultrafast internal conversion[115]). A proportion of them (about 34%, quantum yield of photolysis at λ = 254 nm around 0.34) has time to lose nitrogen and to transform into the ketene 170 (Wolff rearrangement). The
others, due to internal conversion, pass to the $S_1$ level, at which a small proportion of the molecules (about 3%) can still transform into the diazirine 139a. Another small proportion falls from the $S_1$ to the $T_1$ level, at which they lose nitrogen and form Meldrum’s acid (144a). All remaining molecules, which had no opportunity to react, reverted to the ground state $S_0$ through dark deactivation processes.

Excitation with long-wavelength light (355 nm) allows molecules of 140a to reach only the lowest excited level $S_1$, at which isomerization to diazirine 139a takes place only with a tiny yield. The higher excited level $S_2$, at which molecules can lose nitrogen, is not accessible now, so the reaction does not go this direction. The absence of phosphorescence or fluorescence at deactivation testifies in favor of a fast thermal rather than a photochemical transition from the level $S_1$ to the ground state $S_0$ (this conclusion confirms a low quantum yield at $\lambda = 350$ nm, around 0.025). Triplet-sensitized excitation transforms the molecules to the $T_1$ level, at which only the formation of the reduced product 144a is possible.

A detailed study of excitation processes of diazo-Meldrum’s acid (140a) by high-speed IR spectroscopy has confirmed the suggested decomposition scheme.\[115\]

From the practical point of view, the longer the wavelength of light acting on the diazo compounds 140a and 140b (Table 3), the higher are the yields of the diazirines 139a and 139b obtained [5–12% at $\lambda > 210$ nm (quartz filter) and 43–44% at $\lambda > 310$ nm (glass filter)].[103] A similar pattern was observed on irradiation of 140a in cyclohexene.[106] It should be noted that photochemical formation is still the only accessible method for synthesis of the diazirines 139a and 139b. It is interesting that solvent is also capable of influencing the direction of the photochemical process (Table 3). Irradiation of the diazo compounds 140a and 140b in pure MeOH with short-wavelength light ($\lambda > 210$ nm) leads to the Wolff rearrangement products 141 or 142 in high yields, whereas use of H$_2$O/THF or MeOH/THF mixtures reduces the total yield of nitrogen elimination products 141 or 142 and 144a or 144b and leads to the formation of small amounts of the isomeric diazirine 139a or 139b (IR: 139a: 1790 cm$^{-1}$, 139b: 1770 cm$^{-1}$).[103]

Photolysis of 140b in a Me$_2$S/MeOH mixture with long-wavelength light ($\lambda > 310$ nm) led to a high yield of the diazirine 139b (43%) together with small amounts of nitrogen abstraction products: the keto ester 142b (18%) and the sulfonyl ylide 143b (2%).[116]

Numerous data on the behavior of cyclic diazodicarbonyl compounds have given new impetus to a revision of the properties of their linear analogues (Scheme 56).[80,101]

It has been reported that irradiation of the diazomalonic ester 136 (UV: 251, 344 nm) at room temperature leads to the formation of two main products: the methoxymalonate 137 (elimination of nitrogen) and the diazirine 135 (isomerization, UV: 244, 291 nm).

Indeed, both the diazoester 136 and its cyclic analogue 140a display proportional dependence of the product ratios for these two processes on the wavelength of the irradiating light: the greater the wavelength, the higher the yield of

<table>
<thead>
<tr>
<th>$\lambda$ [nm]</th>
<th>Time [h]</th>
<th>Solvent</th>
<th>Yields of reaction products [%]</th>
<th>139a,b</th>
<th>141 or 142</th>
<th>144a,b</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;210</td>
<td>1–2</td>
<td>H$_2$O or MeOH[a]</td>
<td>5–12</td>
<td>56</td>
<td>64</td>
<td>3–6</td>
</tr>
<tr>
<td>&gt;210</td>
<td>1–2</td>
<td>MeOH</td>
<td>0</td>
<td>&gt;95</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>&gt;280</td>
<td>6</td>
<td>H$_2$O or MeOH[a]</td>
<td>25</td>
<td>30</td>
<td>31</td>
<td>7–9</td>
</tr>
<tr>
<td>&gt;310</td>
<td>9</td>
<td>H$_2$O or MeOH[a]</td>
<td>43</td>
<td>13</td>
<td>18</td>
<td>5–13</td>
</tr>
</tbody>
</table>

[a] As a solution in THF.

Scheme 56. Photolysis of the diazomalonic ester 136.

Table 3. Dependence of photolysis of the diazo compounds 140a and 140b (product yields) on the irradiating light wavelength and on the solvents.

4. Conclusion

The valence isomerism between diazo compounds and diazirines is a unique example of induction of profound changes by shifting of single chemical bonds that act like switches between linear and cyclic forms, producing pairs of compounds amazingly different from each other in their physical and chemical properties. The collected observations on these isomerizations are still not large in number even for the two classes of compounds. The isomerizations can be initiated thermally and/or photochemically, the yields of diazirines or diazo compounds obtained in this way not being high as a rule. Shorter-wavelength light mainly initiates nitrogen elimination, whereas longer-wavelength irradiation leads to isomerization products to some degree. Clearly, thermal isomerization is effective only in cases of thermodynamically stable products.

In certain cases diazo-to-diazirine isomerization (barbituric acid or Si derivatives) or diazirine-to-diazoo compound evolution (H, alkyl, α-halo, monoaryl derivatives) are in fact unidirectional processes. In other cases isomerization can be proceeded reversibly, although the yields of original
compound resulting from two consecutive isomerizations will not be high [about 3% for the α-ketone family, 6% for the malonic ester family, 9% for the α-amide family, 14% for the α,α-difluoroalkyl family, 20% for the diazafluorene family, and 39% for the Meldrum’s acid family (very rough yields are given)].

Interestingly, several functional isomers other than diazirines and diazo compounds exist for CH$_3$N$_2$ sets of atoms (cyanamides, isocyanamides, nitrylimines and carbodi-imides) and can also be involved in mutual valence isomerization.\[94\]

Certainly, diazo–diazirine isomerism has a great effect on many aspects of chemistry and ranks with other electrocyclic reactions involving isomerism of heterocyclic three-membered rings, including the oxaziridine-to-nitronite\[117\] aziridine-to-azonethine ylide,\[118\] epoxide-to-carbonyl ylide,\[119\] and azirine-to-nitrile ylide\[120\] rearrangements.

Success in experimental chemistry has initiated the development of a theory. A significant number of calculations utilizing different approaches have been performed to explain the formation or lack thereof of these or other intermediates during thermal and photochemical isomerization.\[20,87,98,102,115,121\] However, the following phrases still apply often enough:

“... there are still controversies about the photolytic and thermolysis reaction mechanisms of diazirines ...”\[121a\]  
“... experimental information has never been successfully rationalized from a mechanistic point of view”,\[121b\]  
“... which is an artefact of the calculations...”,\[20\]  
“... these complexities have made a comprehensive understanding of diazirine photochemistry an elusive goal”,\[122\]  
“... no rules exist to predict the relative efficiency of the formation of the diazo intermediate competes with the production of carbene”.\[67\]

Nevertheless, considerable progress in chemical theory should form a good basis for further discoveries of new fundamental principles of mutual isomerization between diazirines and the diazo compounds as well as their use.

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MICROREVIEW
S. M. Korneev


[29] Diazo compounds 14a, 14b are poorly stable and were used after photogeneration from the corresponding diazirines 13a and 13b in the form of crude reaction mixtures.


[35] For the formation of azines several mechanisms involving participation not only of diazo compounds but also of carbenes and diazirines have been suggested. Their occurrence in a reaction thus cannot unequivocally specify their precursor. All in all they could appear only as a result of some bimolecular reaction. See, for example, ref. 13b,34,42,46.


[41] a) M. G. Rosenberg, U. H. Brinker, J. Org. Chem. 2001, 66, 1517–1522; b) The scavenger product 37 of unspecified stereochemistry is obviously formed from the initial cycloaddition product (the corresponding 4,5-dihydro-3H-pyrazole is not shown) of the diazo compound 36 to diethyl fumurate; c) Fumarates usually react with diazo compounds with high yields. See, for example ref. 41d,42,43.


[49] a) M. G. Rosenberg, U. H. Brinker, J. Org. Chem. 2001, 66, 1517–1522; b) The scavenger product 37 of unspecified stereochemistry is obviously formed from the initial cycloaddition product (the corresponding 4,5-dihydro-3H-pyrazole is not shown) of the diazo compound 36 to diethyl fumurate; c) Fumarates usually react with diazo compounds with high yields. See, for example ref. 41d,42,43.


[51] C60 reacts with diazomethane to yield the fulleroid, but whereas carbene adds to C60 to afford the methanofullere-