

The Structure of Diazoketones. A Study of Hindered Internal Rotation^{1,2}

Fred Kaplan and Gilbert K. Meloy³

Contribution from the Department of Chemistry, University of Cincinnati, Cincinnati, Ohio 45221. Received August 23, 1965

Abstract: Studies of hindered internal rotation about the carbon-carbon bond in diazoketones by high-resolution nuclear magnetic resonance spectroscopy have yielded information important to mechanistic interpretations of reactions of diazoketones. It has been conclusively demonstrated that diazoketones exist as an equilibrium mixture of *cis* and *trans* forms. The *cis* form, in which the diazo group and the carbonyl group are in a *cis* relationship, is highly preferred in alkyl diazoketones. In diazoacetic esters, the *cis* and *trans* forms are present in approximately equal amounts. The energy barriers to free rotation about the carbon-carbon bond have been determined.

Diazoketones were known as early as 1894;⁴ however, their great value as synthetic intermediates was not recognized until after 1928 when Arndt and Amende⁵ found that diazoketones could be prepared in very high yield by the reaction of diazomethane with an acid chloride. Following this discovery, the value of diazoketones in organic synthesis was established in a series of publications by a number of workers.⁶⁻⁹ Since the appearance of these publications extensive investigations of the chemistry of diazoketones have disclosed that a wide variety of products may be obtained in their reactions. The formation of products is influenced by the molecular structure of the diazoketone as well as the reaction conditions. A strong effort has been directed to elucidate the mechanistic pathways involved leading to products; however, the existence of conformational isomers of diazoketones has not been considered in explaining the formation of reaction products.

Nuclear magnetic resonance (nmr) spectroscopy has proved to be a uniquely powerful tool in the investigation of structural isomerism. It has permitted an evaluation of the energy barrier to interconversion of two structural isomers in equilibrium as well as their rates of interconversion.^{10,11} Studies of this type have been reported for amides,¹² nitrites,¹³ and nitrosamines¹⁴ as well as many other compounds¹¹ in which structural isomerism is observed owing to a slow rate of free rotation or inversion. In amides, nitrites, and nitrosamines, *cis* and *trans* isomers arise from restricted free rotation about the central C-N, O-N, or N-N bond due to interaction of a lone pair of electrons with the π system.

A similar situation is possible in diazoketones. Free rotation about the central C-C bond might be hindered through interaction of the lone pair of electrons on the α carbon with the π system of the carbonyl group. By analogy to amides, nitrites, and nitrosamines, an equilibrium of two forms of diazoketones would be expected. The *cis* and *trans* designation is derived from the geometry of the π system. A preliminary report¹⁵ of the



temperature dependence of nmr spectra of α -diazooacetone has confirmed the existence of an equilibrium. This presents the strong possibility that the reaction products of diazoketones are determined by conformational factors. One of the many products obtained from diazoketones may arise from only the *cis* form, while another may arise from only the *trans* form. Thus, the importance of a variable temperature study of the nmr spectra of various diazoketones was evident with respect to the effect it will have on interpreting the chemistry of diazoketones.

Experimental Section

Materials. Previously reported diazoketones which were used in this study were prepared from diazomethane and the appropriate acid chloride and were purified by fractional distillation *in vacuo*, column chromatography, or recrystallization. Experimental and literature values for physical constants were in good agreement.

Methyl diazoacetate and ethyl diazoacetate were gratefully obtained from Dr. Geraldine Krueger of this department.

2-Diazoacetaldehyde had not been reported previously. A vessel at Dry Ice temperature containing approximately 6 ml of formyl fluoride prepared by the procedure of Olah and Kuhn¹⁶ was connected to a length of glass tubing which terminated just above the surface of a vigorously stirred ethereal solution of approximately 0.3 mole of diazomethane.¹⁷ The Dry Ice was removed and the formyl fluoride was warmed and distilled into the diazomethane vessel which was packed in Dry Ice and wrapped in aluminum foil to exclude light. The reaction mixture was stirred overnight. The ether was removed under reduced pressure using a water aspirator in connection with a rotary evaporator yielding 0.38 g of a yellow liquid; infrared (carbon tetrachloride): 3.5 (w), 4.74 (s), 5.81 (m), 6.12 (s). The nmr spectrum in deuteriochloroform contained the expected peaks and pattern. Several additional

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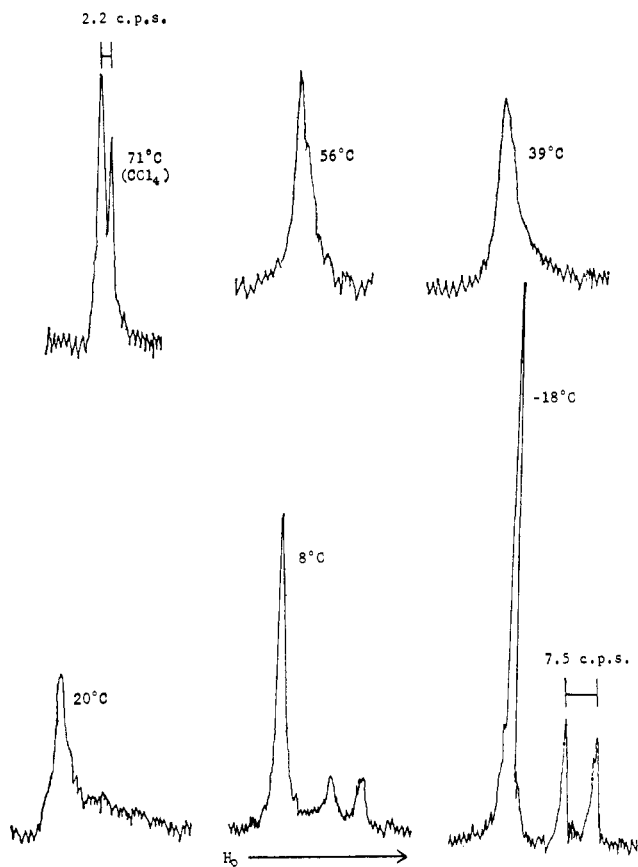


Figure 1. Temperature dependence of the nmr spectrum of the methine proton of α -diazoacetaldehyde.

peaks were present indicating impure 2-diazoacetaldehyde. Attempts to obtain pure 2-diazoacetaldehyde by chromatography through alumina (Woelm, basic, activity grade No. 1) resulted in decomposition of the material and purification by differential extraction proved unsuccessful.

The residue obtained upon evaporation of the ethereal reaction mixture therefore was used without further purification. The regions of aldehyde and methine proton resonance in the nmr spectrum were not complicated with resonance lines of the impurities.

Experimental Method. All nmr spectra were obtained with a Varian Associates Model A-60 high-resolution nmr spectrometer equipped with a Varian Associates Model V-6040 variable-temperature unit which allowed temperature control of the sample to $\pm 2^\circ$. Samples were 40.3 \pm 0.9 wt % in deuteriochloroform except as noted. Tetramethylsilane was added to each sample as an internal reference. Spectra were obtained at a series of temperatures. Chemical shifts were measured by the audiooscillator side band technique¹⁸ and are in cycles per second from tetramethylsilane.

Spectra were recorded at a linear sweep rate of approximately 0.017 part per million per second at a sweep width of 250 cps. The value of the applied radiofrequency field, H_1 , was adjusted so that there was no noticeable radiofrequency saturation. At each temperature, the magnetic field was adjusted to optimum homogeneity using the tetramethylsilane resonance line as a reference. All compounds were done at least in duplicate.

Fractional populations, P , of the *cis* and *trans* isomers were determined with the integration circuit of the A-60 nmr spectrometer. A total of 20 integration curves were recorded for most of the samples. Half of these were recorded using an upfield sweep and the other half were recorded using a downfield sweep. The nmr line widths at half maximum intensity, W , were measured on the recorded spectra.

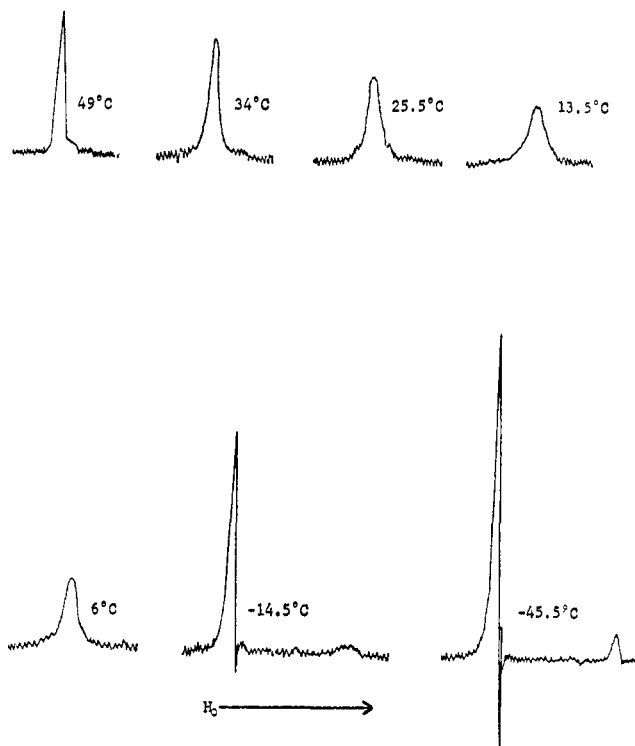
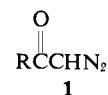


Figure 2. Temperature dependence of the nmr spectrum of the methine proton of α -diazoacetone.

Results

In α -diazoacetaldehyde (**1a**) the methine and aldehyde protons exhibit very broad resonance lines at



1a , R = H	d , R = <i>t</i> -C ₄ H ₉	h , R = C ₆ H ₅
b , R = CH ₃	e , R = C ₆ H ₅ CH ₂	i , R = <i>p</i> -NO ₂ C ₆ H ₄
c , R = C ₂ H ₅	f , R = CH ₃ O	j , R = <i>p</i> -CH ₃ OC ₆ H ₄
	g , R = C ₂ H ₅ O	

approximately 30° . When the temperature of the sample in carbon tetrachloride is raised to 71° both regions of the spectrum exhibit time-average doublets with a coupling constant of 2.2 cps. At temperatures less than or equal to 8° , the regions in which the methine and aldehyde proton resonances occur consist of a singlet and a doublet, ($J = 7.5$ cps) of unequal intensity. The ratio of the area of the singlet to that of the doublet is approximately 7:3. In the methine proton region of the spectrum the singlet appears at a lower field than the doublet but this is reversed in the region of aldehyde proton resonance. The temperature dependence of the nmr spectrum of the methine proton of α -diazoacetaldehyde is shown in Figure 1.

Other alkyl diazoketones (**1b**, **1c**, and **1e**), exhibit similar nmr spectra which are temperature dependent. This is represented by the spectra of α -diazoacetone (**1b**) in Figure 2. At approximately 30° , the region of the methine proton resonance consists of a single, sharp or slightly broadened line. As the temperature of the sample is lowered, this signal increases in width and at various temperatures the diazoketones exhibit two singlets in the methine proton region of their nmr spectra. The intensity of the low-field singlet is approximately nine times that of the higher field singlets. In

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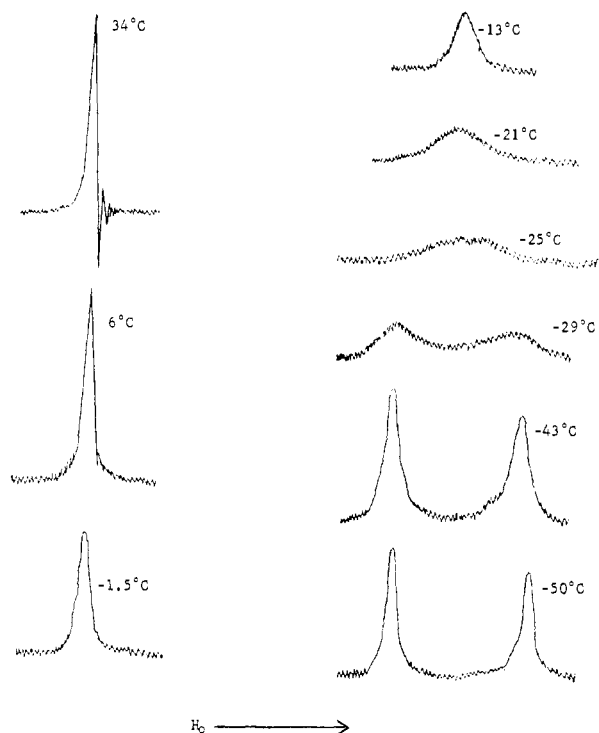


Figure 3. Temperature dependence of the nmr spectrum of the methine proton of methyl diazoacetate.

the spectrum of α -diazoacetone, the methyl proton resonance also exhibits temperature dependence. At low temperatures the signal consists of a high-intensity singlet and a low-intensity singlet; the high-intensity singlet being at a higher field. At approximately 30° a sharp singlet is observed.

The nmr spectrum of 1-diazo-3,3-dimethyl-2-butanone (**1d**) shows no broadening of the methine proton resonance line over the temperature range studied (-34 to +40°). On the other hand, the region of methine proton resonance for the aryl diazoketones (**1h-j**) showed slight broadening at the lowest temperature (-40°) at which their nmr spectra were recorded.

The nmr spectra of the diazoacetic esters (**1f** and **1g**) exhibit the same type of temperature dependence as the alkyl diazoketones; however, two distinct peaks for the methine proton are not observed until a lower temperature (-30 to -50°) is attained and the intensities of the two peaks are nearly equal. Figure 3 is representative of the temperature dependence of the nmr spectra for these compounds.

Data pertinent to this study were best obtained from the methine proton resonance region. This region contained no other absorptions and the chemical shift difference between the *cis* and *trans* absorptions was greatest at low temperatures. The chemical shifts of methine protons of the time-average resonance lines and the *cis* and *trans* forms are shown in Table I. The low-field resonance line is assigned to the *cis* form of diazoketones while the resonance line at higher fields and of lower intensity is assigned to the *trans* form. The reasons for this assignment will be discussed later. Chemical shifts of the methine protons in these compounds steadily shift downfield as the temperature of the sample is lowered. This is due to a hydrogen-bonding effect.

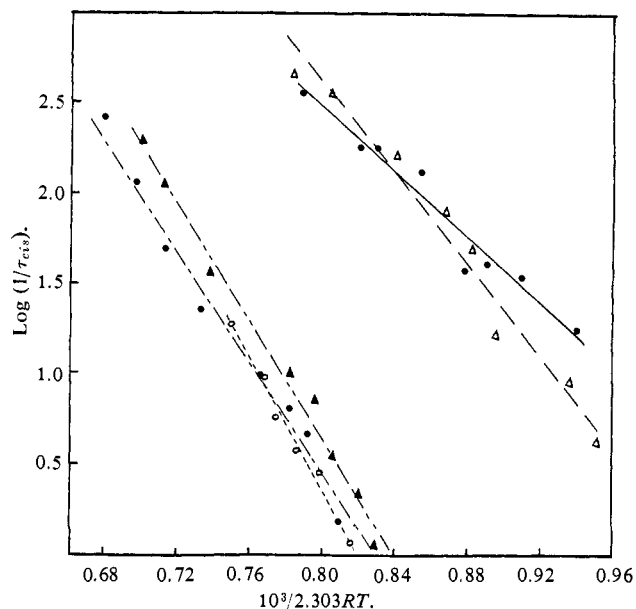


Figure 4. Arrhenius plots for the process of internal rotation about the central C—C bond of diazoketones, RCOCHN_2 : —, $\text{R} = \text{CH}_3\text{O}$; ---, $\text{R} = \text{C}_2\text{H}_5\text{O}$; ···, $\text{R} = \text{CH}_3$; -·-·, $\text{R} = \text{C}_6\text{H}_5$; - - - - , $\text{R} = \text{C}_6\text{H}_5\text{CH}_2$.

The fractional populations, P_{cis} and P_{trans} , of the *cis* and *trans* forms appear in Table II with the equilibrium constants, K_{eq} , which were determined from the frac-

Table I. Chemical Shifts (δ) of the Methine Proton Resonance Line of Several Diazoketones (RCOCHN_2) in Deuteriochloroform

R	Concn ^a	δ_{av}^b ($T, ^\circ\text{C}$)	δ_{cis}^b ($T, ^\circ\text{C}$)	δ_{trans}^b ($T, ^\circ\text{C}$)
H	c	320.5 (71) ^d	342.5 (-40)	325.8 (-40) ^e
CH ₃	40	334.0 (34)	350.4 (-45)	321.3 (-45)
CH ₃	20	325.5 (34)	339.7 (-45)	313.9 (-45)
C ₂ H ₅	40	332.4 (34)	347.3 (-45)	317.4 (-45)
<i>t</i> -C ₄ H ₉	40	341.7 (34)	351.8 (-34)	...
C ₆ H ₅ CH ₂	40	308.1 (35)	312.4 (-39)	297.8 (-39)
CH ₃ O	40	292.7 (34)	310.9 (-43)	295.1 (-43)
C ₂ H ₅ O	40	290.1 (39)	306.0 (-41)	293.9 (-41)
C ₆ H ₅	16	356.6 (36)
<i>p</i> -NO ₂ C ₆ H ₄	6	362.5 (36)
<i>p</i> -CH ₃ OC ₆ H ₄	8	353.7 (36)

^a Per cent by weight. ^b In cycles per second from tetramethylsilane, $\nu_0 = 60.00$ Mcps. ^c Concentration unknown. ^d Doublet, $J = 2.2$ cps. ^e Doublet, $J = 7.5$ cps.

tional populations. The difference in standard free energy, ΔF , of the *cis* and *trans* forms was calculated from

$$\Delta F = -2.303RT \log K_{eq}$$

Additional studies of α -diazoacetone show that populations of the *cis* and *trans* forms are not appreciably altered with a change in solvent (Table III) or temperature. The average value of P_{cis} at seven different temperatures from -45 to 0° is 0.916 ± 0.013 . The values are scattered with no significant trend with respect to temperature.

The mean lifetimes, τ , were determined following the method of Bovey, *et al.*¹⁹ The general expression for

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Table II. Fractional Populations, Equilibrium Constants, and the Standard Free-Energy Difference of the *cis* and *trans* Forms of Diazoketones (RCOCHN₂), 40% by Weight Solution in Deuteriochloroform

R	P_{cis}	P_{trans}	$K_{eq}(T, ^\circ C)$	$\Delta F,$ kcal/mole ($T, ^\circ C$)
H ^a	0.69 ± 0.02 ^c	0.31 ± 0.02	0.449 (-20)	0.40 (-20)
CH ₃	0.924 ± 0.008	0.076 ± 0.008	0.082 (-40)	1.16 (-40)
CH ₃ ^b	0.903 ± 0.002	0.097 ± 0.002	0.180 (-40)	0.79 (-40)
C ₂ H ₅	0.941 ± 0.001	0.059 ± 0.001	0.063 (-40)	1.28 (-40)
<i>t</i> -C ₄ H ₉	>0.99 ^d	>0.01 ^d
C ₆ H ₅ CH ₂	0.962 ± 0.002	0.038 ± 0.002	0.040 (-40)	1.49 (-40)
CH ₃ O	0.538 ± 0.004	0.462 ± 0.004	0.859 (-50)	0.07 (-50)
C ₂ H ₅ O	0.54 ± 0.01	0.46 ± 0.01	0.840 (-50)	0.08 (-50)

^a Concentration unknown. ^b 20% by weight solution in deuteriochloroform. ^c Average deviation involving at least two separate samples. ^d The *trans* resonance line was not observed.

Table III. Solvent Effects on Populations, P_{cis} and P_{trans} , for α -Diazoacetone (CH₃COCHN₂)

Solvent	P_{cis}	P_{trans}
Neat liquid	0.929	0.071
40% in CDCl ₃	0.924	0.076
20% in CDCl ₃	0.903	0.097
40% in acetone	0.928	0.072

The mean lifetimes of the individual species, τ_{cis} and τ_{trans} , were derived from the expressions $\tau_{cis} = \tau/P_{trans}$ and $\tau_{trans} = \tau/P_{cis}$.^{11,20} The rates of interconversion of the *cis* to *trans* form and *trans* to *cis* form are $1/\tau_{cis}$ and $1/\tau_{trans}$, respectively. Table IV illustrates the temperature dependence of the rate of interconversion of *cis* and *trans* forms of diazoketones. Values of the energy of activation, E_a , identified with

Table IV. Temperature Dependence of the Rate of Interconversion of the *cis* and *trans* Forms of Diazoketones (RCOCHN₂), 40% by Weight Solution in Deuteriochloroform

R	$T, ^\circ K$	$1/\tau_{cis},$ sec ⁻¹	$1/\tau_{trans},$ sec ⁻¹	R	$T, ^\circ K$	$1/\tau_{cis},$ sec ⁻¹	$1/\tau_{trans},$ sec ⁻¹
CH ₃	322.0	260	3180	C ₆ H ₅ CH ₂	291.0	18	474
	313.0	120	1470		285.0	9.6	244
	302.8	49	596		282.0	5.9	148
	298.5	23	282		278.0	3.9	100
	285.8	13	154		274.0	3.0	72
	279.5	6.6	80		268.2	1.2	31
	275.5	4.7	57		265.5	0.9	22
	269.5	1.5	18				
CH ₃ ^a	322.0	206	1910	CH ₃ O	279.0	457	533
	313.0	124	1160		271.5	347	405
	302.0	84	285		260.0	168	196
	298.5	30	282		252.0	80	93
	286.5	11	104		248.0	50	58
	278.0	4	41		244.0	16	19
					233.5	9.2	11
			230.0	4.1	4.8		
C ₂ H ₅	312.5	197	3140	C ₂ H ₅ O	277.0	368	439
	307.0	116	1850		266.5	182	218
	296.5	37	590		263.5	179	213
	279.5	9.9	120		256.0	130	155
	274.5	7.1	113		249.0	38	46
	271.1	3.5	56		245.5	41	49
	266.5	2.1	34		240.5	35	42
	263.5	1.2	18		232.5	18	21

^a 20% by weight solution in deuteriochloroform.

spectral line shape resulting from exchange between two species used by Rogers¹² was programmed for an IBM 1620 computer. The program utilized a subroutine which allowed solutions of the expression to be plotted with the IBM 407 printer. Average values of the chemical shift of the methine proton and isomer population data for diazoketones were substituted into the expression and spectra were computed for a number of arbitrary τ values. Plots of τ vs. the peak widths at half maximum intensity, W , of the computed spectra were then constructed and used to determine experimental τ values from the observed experimental W 's.

the energy barriers restricting free rotation about the central carbon-carbon bond in diazoketones and the frequency factor, A , were obtained by a least-squares fitting of the data in Table IV to the Arrhenius equation.

$$\log(1/\tau_{cis}) \text{ or } \log(1/\tau_{trans}) = \log A - E_a/2.303RT$$

Linear plots of $\log(1/\tau_{cis})$ vs. $10^3/2.303RT$ are shown in Figure 4. The absolute error in E_a is ± 3 kcal/mole. This is due mainly to the small half-widths, W , of the broadened nmr signals which result from large dif-

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Table V. Values of E_a , $\log A$, ΔF^*_{298} , and T_c for Hindered Internal Rotation about the Carbon-Carbon Bond in Diazoketones (R₂COCHN₂)

R	<i>cis</i> → <i>trans</i>			<i>trans</i> → <i>cis</i>			T_c , °C
	E_a , kcal/mole	$\log A$	ΔF^*_{298} , kcal/mole	E_a , kcal/mole	$\log A$	ΔF^*_{298} , kcal/mole	
CH ₃	15.5 ± 0.9 ^b	12.8	15.4	15.5 ± 0.9 ^b	13.9	13.9	12.8
CH ₃ ^a	15.9 ± 0.6	15.0	15.4	15.9 ± 0.6	16.1	14.1	13.5
C ₂ H ₅	16.1 ± 0.6	13.6	15.3	16.2 ± 0.6	14.8	13.5	6.5
C ₆ H ₅ CH ₂	18.2 ± 0.6	14.9	15.3	18.2 ± 0.6	16.3	13.4	1.0
CH ₃ O	12.5 ± 0.9	12.6	12.8	12.5 ± 0.9	12.7	12.7	-25.0
C ₂ H ₅ O	9.0 ± 0.8	9.7	13.3	9.0 ± 0.8	9.8	13.2	-32.5

^a 20% by weight solution in deuteriochloroform. ^b Errors represent the precision of the Arrhenius plots.

ferences in the isomer populations. Except in the case of the diazoesters, the broadest nmr signal observed in the time-averaging process was approximately 4 cps. Many of the measurements were made on peaks which had half-widths of 3 cps or less; thus, a small error (± 0.3 cps) in the measurement of W leads to an error in the mean life times and the energy of activation.

The free energies of activation, ΔF^* , were computed from the relationship

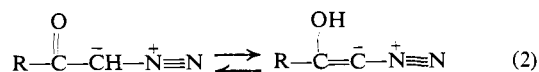
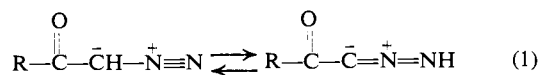
$$\Delta F^*_T = 2.303RT \log (\tau_x KkT/h)$$

where $\tau_x = \tau_{cis}$ or τ_{trans} and is the least-squares value at the temperature, T , obtained from the Arrhenius plot. The transmission coefficients, K , are assumed to be unity. Table V lists the energies of activation, E_a , frequency factors, A , the free energies of activation, ΔF^* , and the temperatures of coalescence, T_c .

Discussion

In the nmr spectrum of diazoketones, the methine proton exhibits a sharp to slightly broadened absorption peak which increases in width and finally splits into two peaks as the temperature is lowered. This change in absorption pattern is characteristic of two species in equilibrium in which a single time-average resonance line is observed when the rate of interconversion is rapid and a resonance line for each of the two species is observed when the rate of interconversion is slow.

The values of the C¹³-H¹ coupling constants of the methine proton for the time-averaged species and for the major species at low temperatures are identical ($J_{C^{13}-H^1} = 199$ cps) for **1b**, **1c**, and **1g**. This rules out the possibility that the equilibrium arises from intermolecular exchange between two species such as diazoisodiazo tautomerism (eq 1) or keto-enol tautomerism (eq 2). In these cases the same C¹³-H¹ coupling con-



stant would not be observed for the time-averaged species because of rapid interchange of the proton between different molecules. This is sufficiently rapid to "average out" spin states arising from interactions of the proton and C¹³ nucleus. Identical $J_{C^{13}-H^1}$ coupling constants as observed for the time-average species at high temperatures and for the major species at a low temperature are expected for situations in which the

character of the C-H bond has not been altered. This definitely confirms the existence of an equilibrium of the *cis* and *trans* forms arising from rotational isomerism in diazoketones.

In the low-temperature nmr spectrum of α -diazoacetaldehyde (**1a**) the difference in magnetic environment of the protons in the *cis* and *trans* forms results in a singlet and a doublet ($J = 7.5$ cps) in the methine proton region. The singlet is of higher intensity and at a lower field than the doublet (Figure 1). The spin-spin coupling of the *trans*-related protons is expected to be larger than that of the *cis*-related protons as is exemplified by the observed coupling constants in a variety of *cis* and *trans* compounds. In ethylenes the coupling constant of vinyl protons *trans* to one another is greater than the coupling constant of vinyl protons *cis* to one another.²¹ In addition experimental and theoretical evidence indicates a dependence of coupling constants on the dihedral angle between the interacting vicinal protons in nonethylenic compounds.²² A larger coupling constant is predicted when the dihedral angle is 180° (a *trans* relationship) in contrast to a dihedral angle of 0° (a *cis* relationship). This generality has also been documented for compounds which have partial double-bond character. In N-phenylformamide²³ and formamide²⁴ where the vicinal protons can be in *cis* or *trans* relationships, the coupling constants for the *cis* protons are 2 and 2.1 cps in contrast to 11 and 13 cps for the *trans* protons, respectively. Thus if *trans* coupling constants are larger than *cis* coupling constants in compounds of comparable bonding, the high-field doublet ($J = 7.5$ cps) of lower intensity must arise from the *trans* form of α -diazoacetaldehyde while the low-field singlet ($J < 0.3$ cps) of higher intensity arises from the *cis* form. The high-temperature nmr absorption of the methine proton of α -diazoacetaldehyde is a time-average doublet with a coupling constant of 2.2 cps. This is the weighted average of the coupling constants for the *cis* and *trans* forms and is comparable in magnitude to the coupling constant observed in acetaldehyde, $J = 2.8$ cps.²⁵

One may use the assignment of chemical shifts in α -diazoacetaldehyde to predict that the absorption signal

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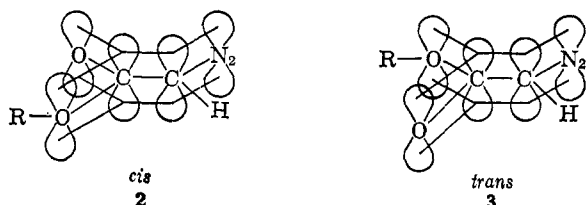
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(25) Y. Fujiwara and F. Fujiwara, *Bull. Chem. Soc. Japan*, **36**, 574 (1963).

of the methine proton of the *cis* form of diazoketones will always occur at lower fields than the signal of the *trans* form. This permits an assignment of the two peaks observed for the methine proton at low temperature in the nmr spectra of **1b**, **1c**, **1e-g**. The resonance line at lower field and of higher intensity is assigned to the *cis* form while the higher field signal of lower intensity is assigned to the *trans* form.

The ratio of the *cis* to the *trans* isomer varies from approximately 9:1 (**1b**, **1c**, and **1e**) to 7:3 (**1a**) to 1:1 (**1f** and **1g**). **1d** and **1h-j** are special cases which will be considered later. The high preference for the *cis* form in **1b**, **1c**, and **1e** compared to **1a** can be explained on the basis of increased steric interactions between the R group and the diazo group. The ratio of the *cis* to the *trans* form increases as the steric requirements of the substituent increases. However, the preference of the *cis* form of diazoketones cannot be solely attributed to steric factors. If this were the case, a greater preponderance of the *trans* form of α -diazooacetaldehyde would be expected in the equilibrium mixture in contrast to the observed *cis* to *trans* ratio of 7:3. In diazoacetic esters (**1f** and **1g**) populations of the *cis* and *trans* forms are approximately the same. In these compounds the π systems in the *cis* (**2**) and *trans* (**3**) forms have essentially the same geometry which results in similar interactions.



In 1-diazo-3,3-dimethyl-2-butanone (**1d**), the low-temperature nmr spectra did not indicate the presence of two isomers. Only one resonance line was observed in the region of methine proton resonance absorption throughout the entire temperature range studied. This can be explained by assuming: (a) the mean lifetime, τ , is very small over the entire temperature range so that only an average resonance line is observed; (b) chemical shifts of the *cis* and *trans* conformers are accidentally the same; or (c) the solution consists of only one of the isomers. The first possibility is unlikely by analogy to other alkyl diazoketones studied in which the two isomers were easily detected at similar temperatures, the coalescence points being within the range 0–14°. The second possibility is also unlikely since the methine protons of the *cis* and *trans* isomers are in completely different magnetic environments, and by analogy to other alkyl diazoketones. It is thus concluded that 1-diazo-3,3-dimethyl-2-butanone exists mainly in the *cis* form with less than 1% of the *trans* form present. Occurrence of only the *cis* isomer in 1-diazo-3,3-dimethyl-2-butanone is best rationalized on the basis of a strong steric interaction between the *t*-butyl group and the diazo group in the *trans* form. Similar arguments may be used to explain the appearance of one peak in the spectra of aryl diazoketones (**1h-j**); however, one cannot exclude the strong possibility that the cross-conjugated system gives rise to a temperature of coalescence which was not attained. The insolubility of the aryl compounds at -40°

in the solvent system studied prevented further lowering of the temperature.

Temperature dependence studies of the nmr spectrum of diazoacetone at two different concentrations in deuteriochloroform illustrates the effect of concentration on the chemical shift of the methine proton in the *cis* and *trans* forms. This effect is shown in Table VI. An increase in concentration or a lowering

Table VI. The Effects of Concentration and Temperature on the Chemical Shifts of the *cis*- and *trans*-Methine Protons in Diazoacetone ($\text{CH}_3\text{COCHN}_2$)

Concn by wt, %	T , $^\circ\text{C}$	δ_{cis} , cps	δ_{trans} , cps
40	-6.5	344.2	316.0
40	-17.0	346.5	317.8
40	-45.5	350.5	321.3
20	-45.5	339.7	313.9

of temperature results in increased intermolecular hydrogen bonding, a deshielding effect, and therefore a shift of the methine proton resonance to a lower field. It is not surprising that the effect of intermolecular hydrogen bonding is greater in the *cis* form than in the *trans* form where approach to the methine proton by the donor atom is less susceptible to influence by the polar carbonyl group. The magnitude of the C^{13} -H coupling constant for the methine proton in diazoketones ($J_{\text{C}^{13}\text{-H}} = 199$ cps) indicates a relatively high amount of s character^{26,27} for the CH bond (41%) which facilitates its acidity and its ability to participate in hydrogen bonding. Morrison and Yates²⁸ have demonstrated the acidity of the methine proton by showing that it can be exchanged with D_2O in the presence of a variety of bases.

The barrier to free rotation found for diazoketones in this study ranged in value from 9 to 18 kcal/mole. The values of 15.5 and 16.1 kcal/mole for **1b** and **1c** are essentially the same as would be expected since the electronic and steric nature of the molecules is not significantly different. However, **1e** has a slightly higher energy of activation (18.2 kcal/mole). While the absolute errors involved make this difference questionable, a slightly higher activation energy might be expected for **1e**, arising from an intramolecular association of the aromatic nucleus and the methine proton or a larger bulk effect.

Diazoacetic esters, **1f** and **1g**, possess a lower energy of activation (9–12 kcal/mole) than the diazoketones studied (15–18 kcal/mole). This is attributed to the presence of a cross-conjugated system, which tends to reduce the double-bond character of the central carbon-carbon bond, and thus the barrier to free rotation. This is also reflected in the temperature of coalescence.

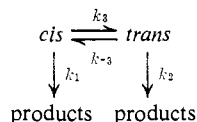
The existence of an equilibrium mixture of *cis* and *trans* forms of diazoketones must be taken into account in the mechanistic interpretation of the chemistry of diazoketones. If the rate of interconversion of the *cis* and *trans* isomers is faster than the over-all rate of decomposition (the first-order rate constant for the de-

(26) J. N. Shoolery, *J. Chem. Phys.*, **31**, 1427 (1959).

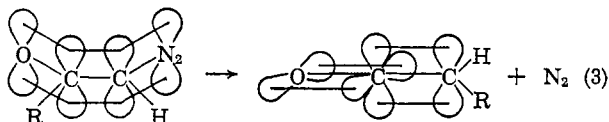
(27) N. Muller and D. E. Pritchard, *ibid.*, **31**, 768 (1959).

(28) H. Morrison and P. Yates, *Chem. Ind. (London)*, 331 (1962).

composition of diazoacetone in *t*-butyl alcohol at 80° is $1.68 \times 10^{-4} \text{ sec}^{-1}$ compared to an estimated rate constant of 10^3 sec^{-1} for the interconversion of *cis* and *trans* forms at this temperature), one need not consider the possibility that products of diazoketone reactions arise from certain preferred conformations. On the other hand, the ratio of products which might arise from different conformations of diazoketones would be a function of k_3 and k_{-3} rather than k_1 and k_2 if interconversion of *cis* and *trans* forms were slow.



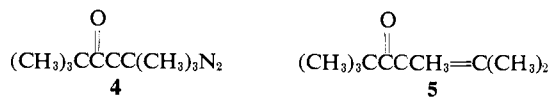
Knowledge that the *cis* conformer is preferred in the alkyl diazoketones presents the attractive possibility that the occurrence of Wolff rearrangements to yield ketenes, $\text{RHC}=\text{C}=\text{O}$, arises solely from the *cis* form and that it proceeds *via* a smooth concerted process with migration and loss of nitrogen occurring simultaneously (eq 3). The *cis* form presents the desirable situation of the migrating group being *trans* to the



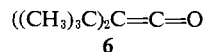
leaving group. On the other hand, if the rearrangement does not proceed through a concerted mechanism and proceeds *via* a carbene intermediate, a preference for geometry would not be observed. The value of the suggestion that the Wolff rearrangement occurs only in the *cis* form is seen in its immediate application in explaining results obtained by Newman²⁹ and Franzen.³⁰ Decomposition of **4** leads to **5** in 80 to 92% yield under

(29) M. S. Newman and A. Arkell, *J. Org. Chem.*, **24**, 385 (1959).

(30) V. Franzen, *Ann.*, **602**, 199 (1957).

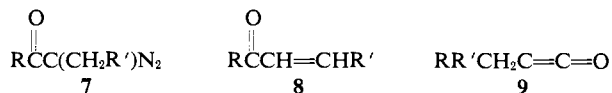


thermal, photolytic, or copper-catalyzed conditions. Only a very small amount of the rearrangement product (**6**) was obtained. Consideration of models of the



cis form of **4** shows that it would be virtually nonexistent due to the large steric interaction of the *t*-butyl groups. Thus the *trans* form is highly preferred resulting in a negligible occurrence of the rearrangement process.

Photolytic and silver oxide catalyzed decomposition of **7** yields the α,β -unsaturated ketone (**8**) as the major product at room temperature; however, at higher temperatures, the ketene rearrangement product (**9**) is ob-



tained. The preference of the *trans* form at room temperature as a result of steric interactions leads to **8**. On the other hand, when the temperature is raised, enough energy may be available to overcome steric interactions and give an appreciable amount of the *cis* form which leads to the rearrangement product. The absence of a migrating group *trans* to the leaving nitrogen, would also tend to increase the possibility of the formation of a carbene.

The present literature only hints at the role of *cis* and *trans* forms in the reactions of diazoketones. The influence of equilibrium ratios on the products resulting from decompositions will be the subject of a future publication.

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