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ISOMERIZATION OF STILBENES

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Contents

Summary

In the present study the following cis and trans stilbenes have been synthesized: stilbene, p-chlorostilbene, p-nitrostilbene, all-trans azoxystilbene, cis-trans-cis azoxystilbene, p-aminostilbene, p-N-acetyl-aminostilbene. Decarboxylation of p-hydroxy-and p-acetoxy-l-carboxy stilbene have been studied and in all cases only the trans isomer has been obtained.

The following cis stilbene derivatives have been prepared by irradiation of the trans derivatives: stilbene, p-hydroxystilbene, p-acetoxystilbene, p-aminostilbene, cis-trans-cis and all-cis azoxystilbene. The latter two compounds are extremely unstable and isomerize during purification. The reaction rates, summarized below, have been obtained from experiments planned primarily to obtain optimum conditions for the preparation of new stilbene derivatives.

Rates of trans-cis isomerization at 50° C have been obtained for:

stilbene	k 1.8 . 10^{-4} sec $^{-1}$	in benzene solution
p-acetoxy	1.2	in benzene
p-hydroxy	2.0	in ethanol
p-amino	9.8	in 50% ethanol-2 <u>N</u> HCl

Rate constants for thermal, that is, cis-trans isomerization have been evaluated for trans-cis-trans azoxystilbene. Its rate constant at 0°C in 10% benzene n-hexane is 6.9 . 10^{-5} sec^{-1}. Therefore no pure trans-cis-trans azoxystilbene could be isolated. The thermal isomerization of cis aminostilbene in 2 n hydrochloric acid-50% ethanol has been studied at 40 and 80°C. The energy of activation has been found to be 15.5 kcal/mole. At 50° the rate constant of cis-trans

isomerization is then $k = 4.2.\ 10^{-5}\ \text{sec}^{-1}$. From the rate constant for the reverse reaction an equilibrium constant of $K = \frac{k\ \text{trans - cis}}{k\ \text{cis - trans}} = 23$ is calculated and thus trans aminostilbene as the cation can be isomerized under the influence of ultra violet light to the extent of 96%, although the actual yield must undoubtedly be smaller due to secondary reactions. The pK of cis and trans p-aminostilbene has been measured in 30% methanol citrate buffer. It is found that the two isomers have, within experimental error, identical pK values of 4.10 at 25°C. Hammetts substituent constant is therefore of the order of $\varepsilon = 0.06$. Under certain conditions, it seems possible to diazotize cis aminostilbene to yield cis stilbene-diazonium salts. The spectra of both the cis and trans diazonium ion have been measured as well as their coupling product with H-acid. There is good evidence that the reduction of cis stilbene-diazonium ion with hypophosphorous acid yields mainly cis stilbene.

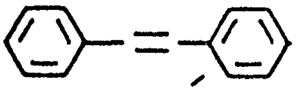
Systematic collation of the spectra of the monosubstituted stilbenes prepared, for both the cis and trans isomer, have been made and the results compared with analogs in the benzene series.

In addition, infrared spectra have been measured. The cis derivatives show a sharp characteristic absorption band at 915-920 wave numbers. For the trans-derivatives a characteristic absorption band is found at 957-968 wave numbers.

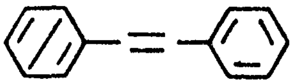
Introduction

Stilbene is conventionally represented as a resonance hybrid of structures such as I-III. In the lowest molecular energy level which is reached by absorption of light from the ground level, it has usually been supposed that ionic structures (III) are fairly important. In classical language, this corresponds to an electron oscillating from one end of the molecule to the other, and hence being responsible for the intense absorption. In principle, such a description of the molecule is quite proper; but in practice it suffers from the considerable drawback that there seems at present no satisfactory way of calculating the relative weights of the various types of structures.

Thus, in p-aminostilbene, in addition to the Kekule structures, IV, we expect ionic structures such as (V) and (VI), which are similar to III except that the charge on the amino nitrogen can only be positive. But there is no available estimate of the relative weights of (IV), (V) and (VL) though that of (V) is usually supposed to exceed that of (III) in the unsubstituted. In the excited level, nothing is known of the weights.



I KEKULÉ



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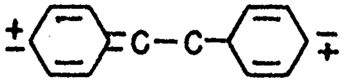

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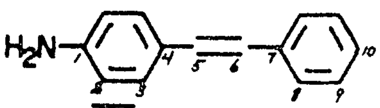

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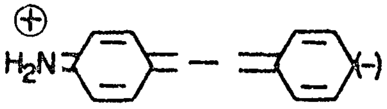

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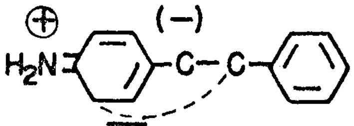
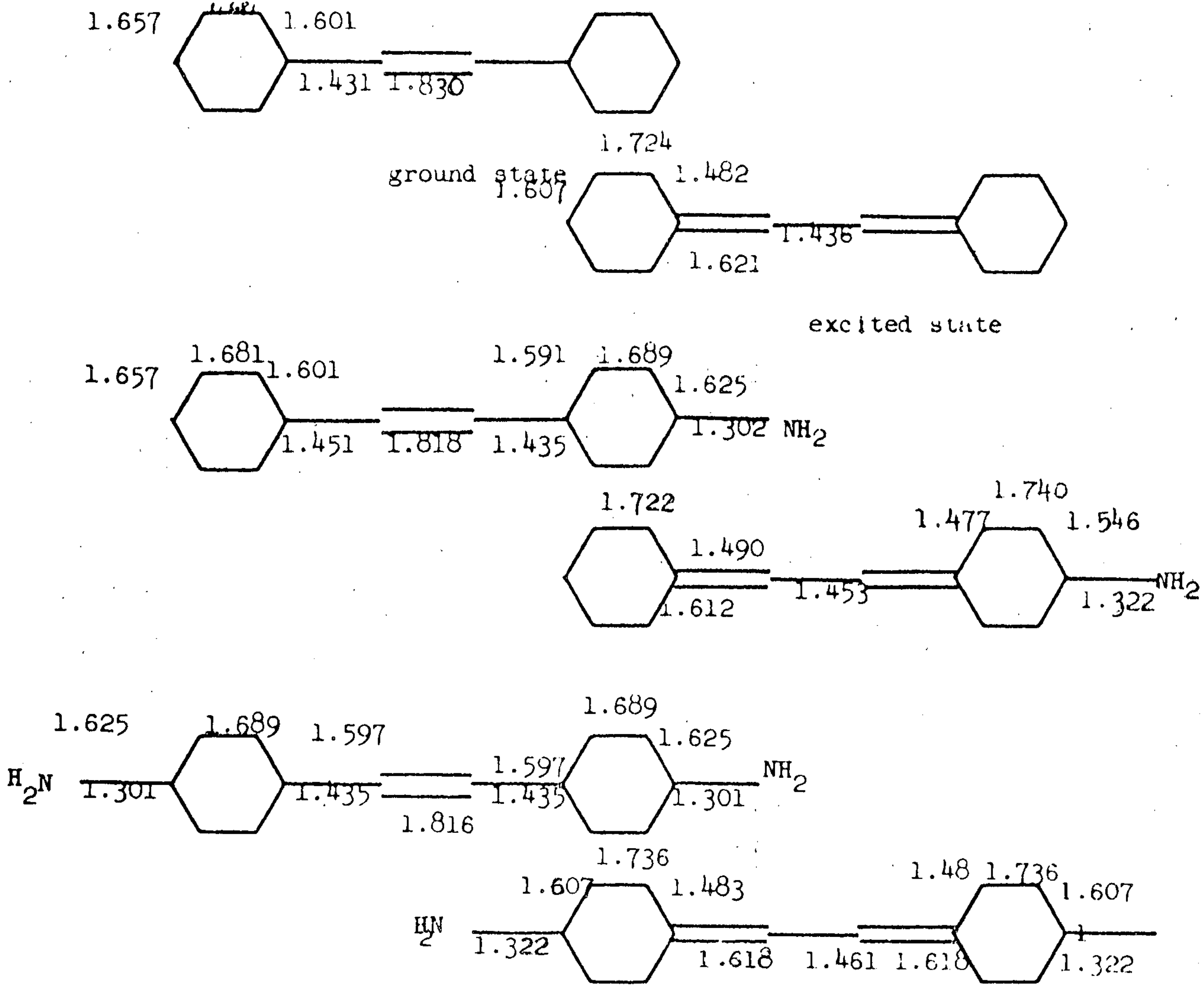


VI

Coulson and Jacobs[1] have calculated the charge distribution and bond orders in stilbene, 4-aminostilbene and 4,4'-diaminostilbene for both the ground state and the excited state. Bond order values are indicated below:



In all these molecules, the excitation appears to reside almost entirely in the central ethylenic link converting - = - into = - = . This appears almost unaffected by the presence of one or two p-amino substituents.

In the ground state of stilbene there is very little quinoid character of the kind represented in (III), so it appears that these particular structures are not very important. On excitation, there is rather more quinoid character, and in the amino compounds the quinoid character of the substituted ring is greater still. This indicates the importance of structures such as (V) and (VI). The apparently great importance of (VI) in the excited state is unexpected, but seems to be an explanation of the shifts in the ultra violet spectra as outlined in part V.

Alternation of charge migration in 4-aminostilbene is shouwn in Figure 1 . The electronic excitation, it appears, to some extents destroys these alterations, though it increases the average charge migration. Quite apart from any other considerations, this would imply a greater reactivity in the excited state than in the ground state. Thus the general picture is that of an increased asymmetery of charge resulting in reduced bonding and a greater proportion of electrons free to initiate reactions, particularly with electrophilic reagents.

Section I Synthesis of Stilbene-Derivatives

General considerations: Stilbenes are readily prepared by a variety of methods. All these methods have been reviewed adequately in E.H. Rodd's "Chemistry of Carbon Compounds" Vol. IIIB. The majority of these syntheses result in the formation of the trans derivative. This may be because the reaction yields sterospecifically the trans compound and, or because the reaction conditions favor the thermodynamically more stable trans compound. For the preparation of cis stilbenes three methods

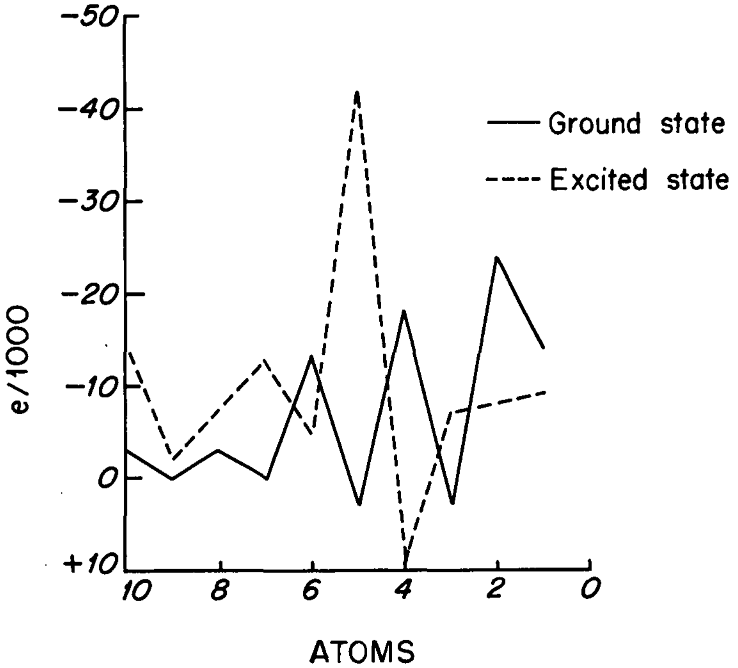


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Fig. 1. Charge distribution in the ground and excited states.

The atoms are numbered for convenience along the chain consecutively from the NH_2 group; thus, 5 and 6 are the atoms of the central ethylenic link. The unit charge is e/1000.

are available, namely, a) the catalytic semi-hydrogenation of a diphenylacetylene, b) decarboxylation of a stilbene-α-carboxylic acid, and c) irradiation of a trans stilbene with ultraviolet light. In the majority of cases reported the catalytic reduction of a diphenylacetylene results in the formation of a mixture of 1:2 diphenylethane and stilbene which is not easily seperable. For this reason, method b) and c) were used throughout.

1) Cis and trans stilbene

Trans stilbene. A pure sample of this compound was recrystallized from chloroform and n-hexane and the crystals vacuum dried. The melting point was 123°C.

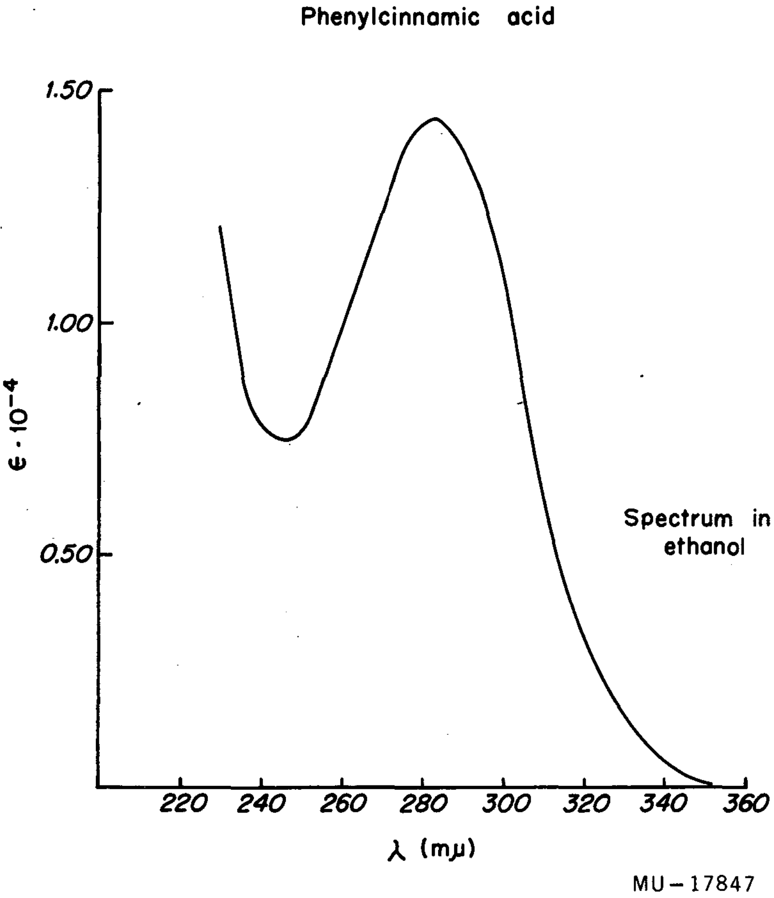
Preparation of phenylcinnamic acid[2]. 40.5 ml freshly purified benzaldehyde, 54.6 g phenylacetic acid, 40 ml trimethylamine and 80 ml acetic anhydride were refluxed for 5 hours. The reaction mixture was then steam distilled and the remaining solution cooled, whereupon phenylcinnamic acid crystallized. The product was crystallized from acidified ethanol and then recrystallized from ethanol-water 3:2.35.2 g of white crystals were obtained. M.P. 170°C. U.V. spectrum in ethanol λmax 283 mμ ε= 1.45. 10^4, I.R. spectrum in $CHCl_3$.

Decarboxylation of phenylcinnamic acid[3]. 23.0 g phenylcinnamic acid were decarboxylated in 140 ml quinone and 2 g copper chromite at 210-220°C. After heating, the reaction mixture was poured into 480 ml 10% HCl and extracted with ether. The ether extract was washed with 100 ml 10% sodium carbonate solution and then with distilled water. After drying, the ether extract , the slightly yellow oil was distilled twice at 4 mm Hg. and the colorless oil further purified by crystallization from n-hexane at dry-ice-acetone temperature. 8.2 g product were obtained. In the ultraviolet an absorption maximum at 278 mu is observed with an extinction coefficient $\varepsilon = 1.08 \cdot 10^4$.

2) <u>p-Chlorostilbenes</u>

<u>Trans p-chlorostilbene</u>. Trans p-chlorostilbene was prepared by the method of Meerwein. 64.0 g of p-chloroaniline was dissolved in 240 ml of 6 <u>N</u> hydrochloric acid, 300 g of ice was added and a solution of 35 g sodium nitrite run in slowly with stirring. The temperature was maintained at -5 $^{\circ}$C and the diazotization was complete in an hour/ One hundred and ten g sodium-acetate and 20 g couprous-chloride suspended in 150 ml water was added to the diazotized solution and 74 g cinnamic-acid in 600 ml acetone was run in with stirring. After standing for 6 hours, the solution was steam-distilled and the residue extracted with benzene. The benzene was shaken with 6 <u>N</u> ammonium hydroxide, dried, and the solvent distilled off. The residue was recrystallized from ethanol, acetic acid, ethanol, n-hexane, and finally from acetic acid. The melting point was 123.5-124.5°. Ultraviolet spectrum in ethanol λmax. 313 mμ $\varepsilon = 2.98 \cdot 10^4$ and λ max 300 mμ $\varepsilon = 3.10 \cdot 10^4$. Infrared spectrum was taken in carbon disulfide.

<u>p-Chloro-1'-carboxy-stilbene</u>. The piperidine-catalyzed condensation which ordinarily gives the decarboxylated condensation product gave, in this case, the carboxylic acid. p-Chlorobenzaldehyde, 70 g and 68 g phenylacetic acid, together with 20 g piperidine were heated at 160°C for 6 hours. On cooling, the mass was taken up in benzene and shaken



Spectrum of phenylcinnamic acid in ethanol.

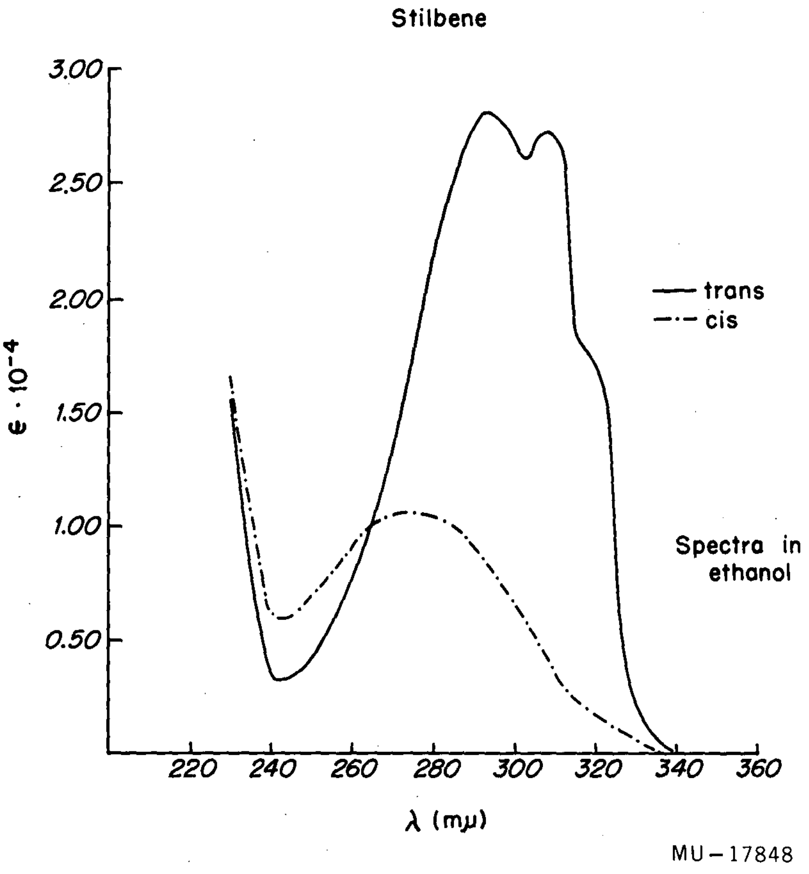


Fig. 3. Ultraviolet spectrum of cis and trans stilbene in ethanol.

with 2 N hydrochloric acid. The acid was removed from the benzene layer with 6 N sodium-hydroxide. On acidification of the water layer, white crystals of the acid formed. Recrystallization from ethanol and ethanol-water mixture gave white crystals of M.P. 200-201. Ultraviolet spectrum in ethanol: λ max 285 mμ $\varepsilon = 1.67 \cdot 10^4$ (ethanol was acidified) I. R.

Cis-p-Chlorostilbene. One g of p-chloro-1-carboxystilbene was decarboxylated with 0.2 g copper chromite in 10 ml quinoline. The reaction temperature was 225°C and the reaction time 5-8 min. The hot solution was poured into ice cold 3 N HCl and extracted with ether. After washing of the ether with sodium carbonate solution and water, and drying over magnesium-sulfate, 0.74 g crude material was obtained. The crude material was dissolved in n-hexane, filtered from the undissolved trans compound, and after evaporation of the solvent, the oil distilled at 1.5 mm, 118-120° C. The distilled oil was recrystallized from n-hexane (dry-ice acetone bath). Ultraviolet spectrum λmax 283 mμ $\varepsilon = 1.10 \cdot 10^4$, I. R. spectrum.

3) p-Hydroxystilbenes

p-Hydroxy-1-carboxystilbene. p-Hydroxy-1-carboxystilbene was prepared according to Zincke[4]: 0.5 mole sodium salt of phenylacetic acid; 0.32 mole of p-hydroxybenzaldehyde, 0.75 mole of acetic-anhydride and 0.5 ml pyridine were refluxed for 7 hours. The acetylated product was separated with the addition of 150 ml of water. The separated oil

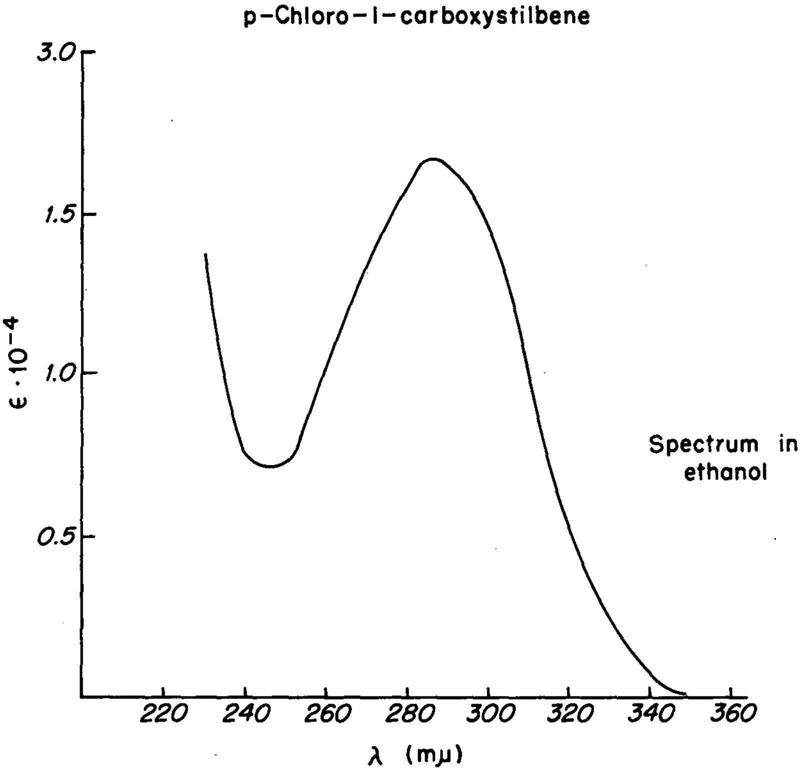


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Fig. 4. Ultraviolet spectrum of p-chloro-l-carboxystilbene in acidified ethanol.

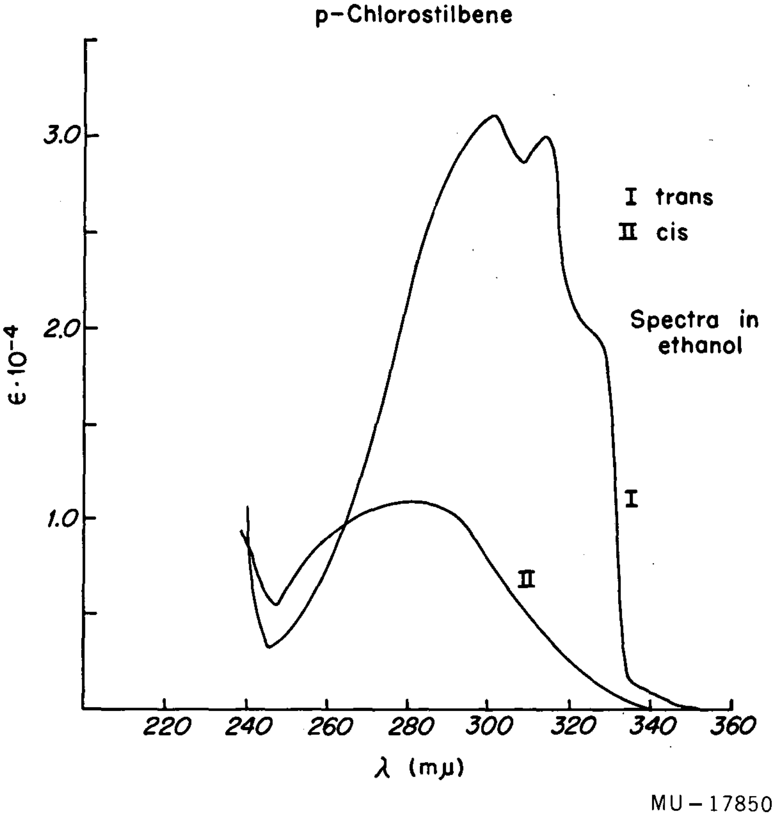


Fig. 5. Ultraviolet spectrum of p-chlorostilbenes in ethanol.

was heated with 2 N sodium-hydroxide for one hour, whereupon a yellow oil separated. The reaction mixture was then acidified and the crystalline material extracted with 10% sodium carbonate solution. The undissolved material contains p-hydroxystilbene. After filtration, the filtrate was acidified and the crystalline material recrystallized from ethanol water. The M.P. of the acid was 223.5-224.5°C. Ultraviolet spectrum in ethanol shows a maximum at 312 mμ $= 1.95 . 10^{4}$; yield: 72%.

trans-p-Hydroxystilbene. a) The material which is insoluble in sodium-bicarbonate was crystallized from ethanol to constant melting point of 182-183°C. It shows two absorption maxima at 320 mμ $\varepsilon = 2.75 . 10^{4}$ and 305 mμ $\varepsilon = 2.80 . 10^{4}$ in ethanolic solution. b) Hydrolysis of trans p-Acetoxystilbene. 20 mg trans p-acetoxystilbene were dissolved in 1.5 ml pyridine and 1.5 ml 0.1 N sodium hydroxide-solution at room temperature. Samples were taken from the reaction mixture after 3,5, and 15 minutes and after 18 hours. After evaporation of the solvent in vacuum and acidifying with a few drops of 1.0 N hydrochloric acid, the residue was extracted with ether. Spectral data of the ether extract are summarized in Table 1.

Table 1

Hydrolysis of trans p-acetoxystilbene

	λmax	λmax	$\frac{E_{300}}{E_{320}}$	solvent
trans p-acetoxystilbene	312	300	1.55	ether
3 min hydrolysis	320	306	1.02	ether
15 min hydrolysis	320	306	1.00	ether
18 hrs	320	306	1.00	ether
trans p-hydroxystilbene	320	306	1.00	ethanol

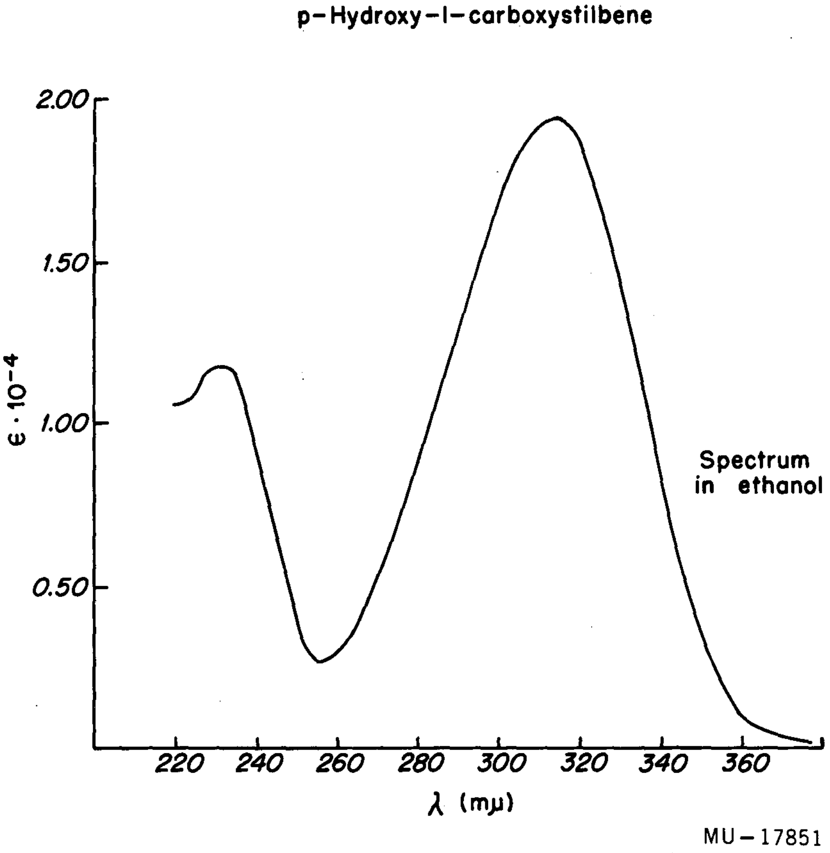


Fig. 6. Ultraviolet spectrum of p-hydroxy-l-carboxystilbene in ethanol.

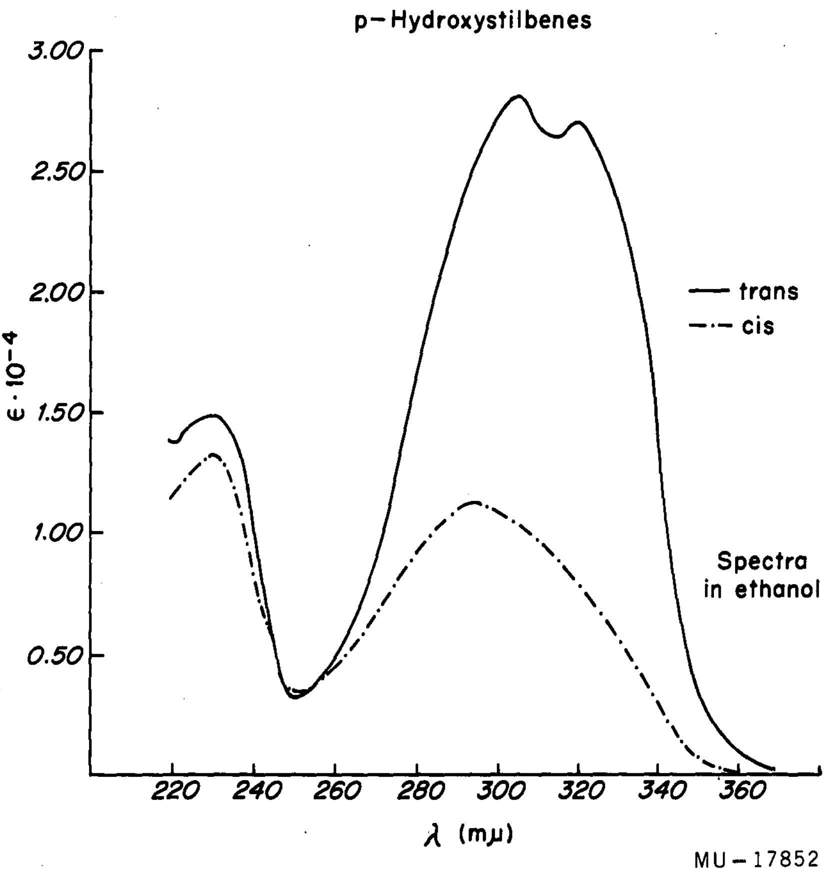


Fig. 7. Ultraviolet spectra of p-hydroxystilbenes in ethanol.

The rate of hydrolysis is given approximately by the ratio of the optical densities at wavelength 300 and 320 mμ. The data indicate that in 50% pyridine and 0.05 N sodium hydroxide solution at room temperature, trans p-acetoxystilbene is quantitatively hydrolyzed in about 5 min.

4) p-Acetoxystilbenes

p-Acetoxy-1-carboxystilbene. Forty-one/grams p-hydroxy-benzaldehyde, 45.8 g phenylacetic-acid, 92 ml freshly distilled acetic-anhydride and 32.5 ml triethylamine were refluxed for 7 hours. Acetic anhydride was destroyed by the addition of water whereupon a red oil separated. This oil was washed with water and dried. 31.7 g crystallized. The ultraviolet spectrum shows an absorption maximum at 295 mμ in ethanol.

trans p-Acetoxystilbene. Trans-p-acetoxystilbene was prepared from 1.0 g trans p-hydroxystilbene, 11 ml acetic anhydride and 0.5 g anhydrous sodium acetate and the mixture heated for 15 min. After decomposition of excess acetic anhydride with water and crystallization from ethanol-water, ethanol and benzene-n-hexane, white crystals of M.P. 148-149°C were obtained. The ultraviolet spectrum shows two maxima in ether at 300 and 312 mμ with extinction coefficients of 2.85 . 10^4 and 2.55 . 10^4.

Decarboxylation of p-Acetoxy-1-carboxystilbene. Two g acid were heated for 5 min in 10 ml quinoline and 1 g copper chromite. The crude reaction mixture was fractionally crystallized from ether, 50%, 15%, 5% and ether n-hexane. None of the fractions contained any cis p-acetoxystilbene. In all of the samples the I.R. band at 10.9 μ was missing.

cis-p-Hydroxystilbene; decarboxylation of p-hydroxy-1-carboxystilbene. Decarboxylation was carried out in the usual way, using 0.2 g copper chromite catalyst per g of acid. At 230°C after 10 min no trace of cis p-hydroxystilbene could be detected spectroscopically. It was then decided to lower the reaction temperature. Experiments were carried out at 120° and 165°C with a concentration of catalyst of 1.5 g/g acid. After one hour at 165°C less than 7% of the acid was decarboxylated. Decarboxylation at 220°C for 10 min and careful fractionation of the decarboxylated products from an aluminum-oxide column using n-hexane, 10%, 30%, 40%, 50%, 70% ether n-hexane mixtures was unsuccessful. Since isomerization of the labile cis p-hydroxystilbene might have occurred due to the aluminum oxide, a further decarboxylation experiment was carried out using 0.5 g catalyst/g acid and a reaction temperature of 210°C. The ether extract was then fractionally crystallized from ether-n-hexane and n-hexane at -20°C. 30 mg compound from n-hexane solution were obtained which had an absorption maximum at 305 mμ. This compound thus contains about 50% cis p-hydroxystilbene (as calculated from the ultraviolet spectrum). The over all yield is thus of the order of 3% or less. (See also Section II)

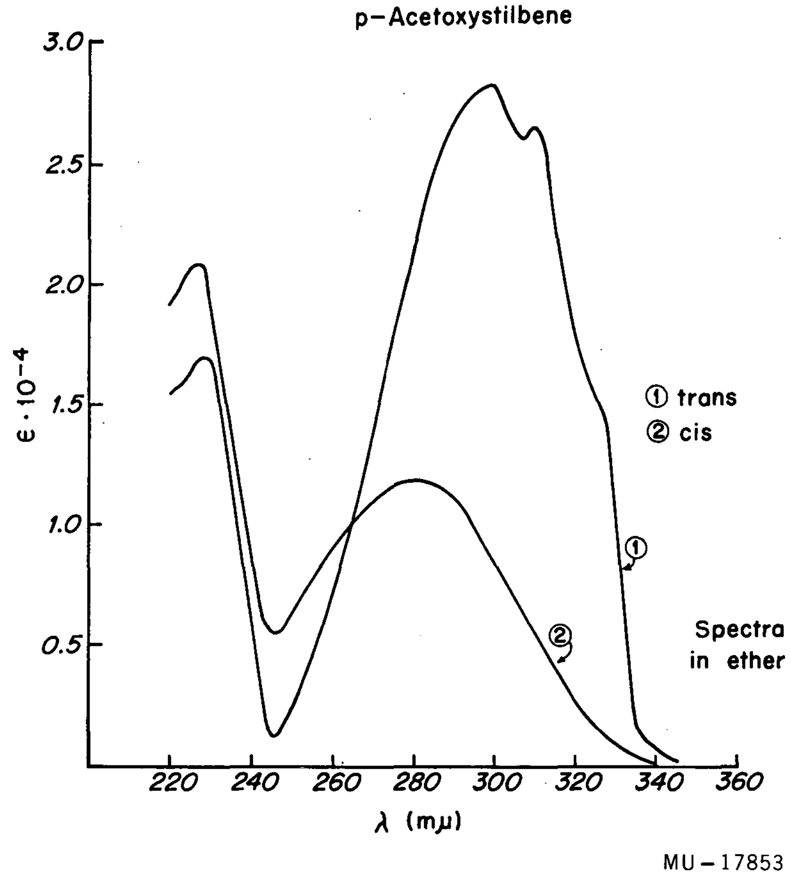


Fig. 8. Ultraviolet spectra of p-acetyoxystilbene in ether.

5) p-Nitrostilbenes

p-Nitro-1-carboxy-stilbene. Potassium p-nitrophenylacetate, 31.5 g, 28 g of freshly purified benzaldehyde and 100 ml acetic anhydride were heated on a steam bath for 23 hours. The resulting red solution was poured into 500 ml of water and warmed; a red oil separated and gradually solidified. It was dissolved in 400 ml 0.8 N sodium hydroxide and filtered hot. On acidification with hydrochloric acid, a thick, white precipitate formed. The precipitate was filtered and crystallized from ethanol and acetic acid. M.P. 227-228°C; the ultraviolet spectrum in ethanol shows an absorption maxima at 270 mμ and an extinction coefficient $\mathcal{E} = 2.0 \cdot 10^4$.

trans p-Nitrostilbene. trans p-Nitrostilbene was available and was recrystallized from ethanol and two times from acetic acid. The yellow needles had a M.P. of 157-158°C. The ultraviolet spectrum shows two maxima at 349 mμ and 238 mμ with extinction coefficients of $2.37 \cdot 10^4$ and $1.2 \cdot 10^4$, respectively. The infrared spectrum was measured in carbon disulfide and chloroform.

Decarboxylation of p-Nitro-1-carboxystilbene. According to H. W. Alter[5] decarboxylation at 220° C requires 15 min. This heating period proved to be far too long, and in several experiments yields of only 5% cis p-nitrostilbene were obtained.

Decarboxylation of 1.5 g in 10 ml quinoline and 0.2 g copper chromite at 220°C for 3-5 min yields 76-88 % crude. After chromatography on aluminum oxide with n-hexane, a product with M.P. 60.5-62°C was obtained in 66% yield. The ultraviolet spectrum shows two maxima at 326 mμ and 240 mμ with extinction coefficients of $1.66 \cdot 10^4$ and $\mathcal{E} = 1.30 \cdot 10^4$, respectively. The infrared spectrum shows no absorption at 10.45, thus indicating a reasonably pure cis compound.

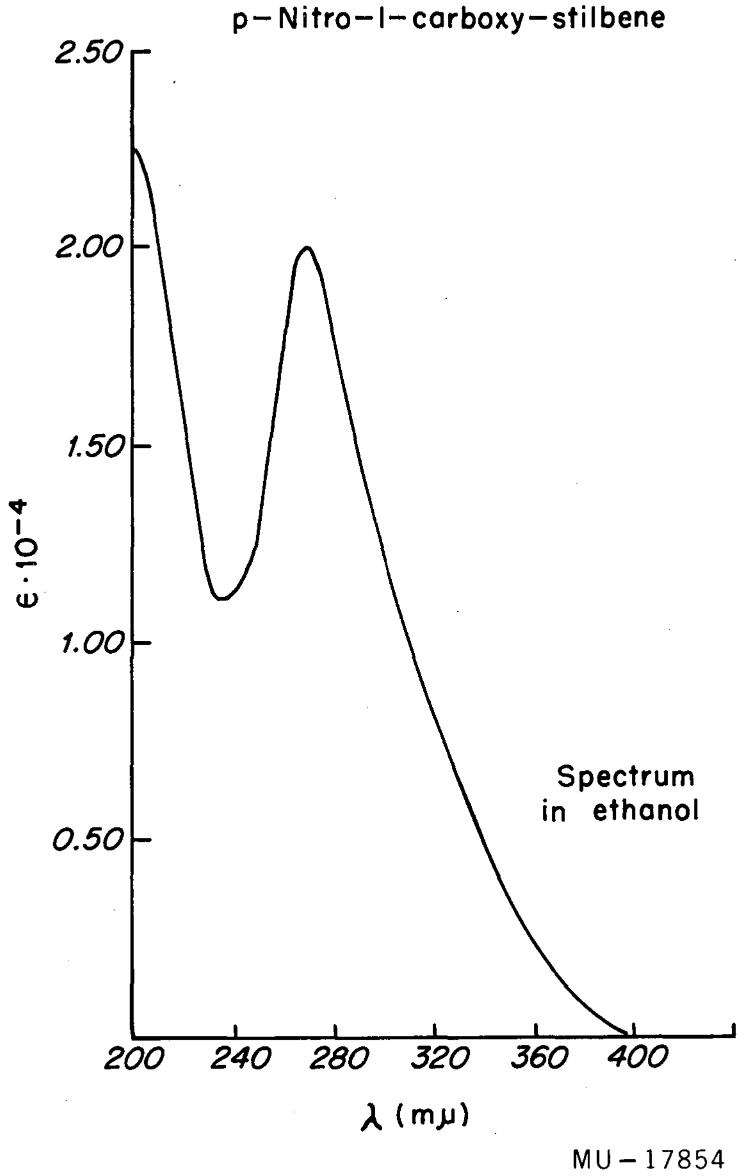


Fig. 9. Ultraviolet spectrum of p-nitro-1-carboxy-stilbene in ethanol.

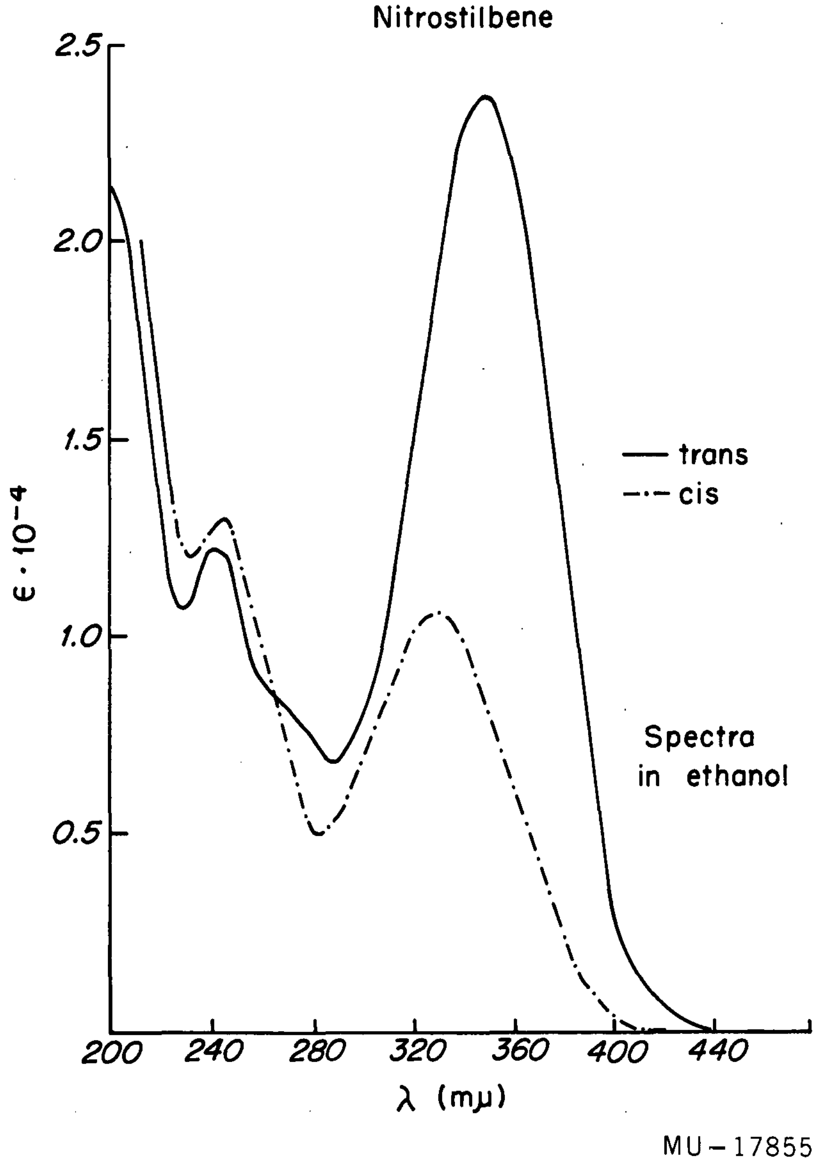


Fig. 10. Ultraviolet spectra of p-nitrostilbenes in ethanol.

6) Azoxystilbenes

Three principal methods can be used to prepare azoxy compounds: a) condensation of a nitroso compound with an N-arylhydroxylamine, b) reduction of a nitroaryl compound under a variety of conditions, and c) oxidation of an azo compound with peracids.

Preparation of azoxystilbenes according to method c) would, in general, lead to epoxidation of the ethylene bond in stilbene although under special conditions it might be possible to prepare azoxystilbene by this route. It has been reported that cis-azoxystilbene can be prepared by this route. Method a) requires the preparation of both the nitroso as well as the hydroxylamine. Drehfahl[6] has not been able to prepare 4-nitroso stilbene nor stilbenyl-4-hydroxylamine by a variety of methods. All trans and cis-trans-cis azoxystilbenes were therefore prepared by reduction of the corresponding nitrostilbene with magnesium metal and ammonium chloride in methanol solution.

all trans-Azoxystilbene. Two g of trans p-nitrostilbene was dissolved in 170 ml of hot methanol and 15 ml saturated aqueous ammonium chloride. Gradually, 4 g of magnesium turnings were added while stirring. The reaction proceeded without additional heating. After half an hour, a yellow precipitate formed. Stirring was continued for one and one-half hours. After evaporation of the solvent, the residue was taken up in benzene and the hot solution was filtered from unreacted magnesium and magnesium chloride.

Fractional crystallization from benzene gave yellow needles; M.P. 263-265°C in 36% yield. All trans-azoxystilbene is slightly soluble in ether, chloroform, carbon disulfide, and methanol. Ultraviolet spectrum in chloroform, λ max 400 mμ $\varepsilon = 4.45 \cdot 10^4$, λ max 285 mμ $\varepsilon = 2.23 \cdot 10^4$.

cis-trans-cis Azoxystilbene. One g cis p-nitrostilbene was dissolved in 40 ml of methanol and 7 ml saturated ammonium chloride solution. While stirring, a total of 2 g of magnesium turnings were added within two hours. The reaction temperature was kept at 0° C. After evaporation of the solvent, the residue was taken up in benzene without heating. After filtration the solution was diluted with 10 volumes of petroleum ether. At -30°C yellow crystals appear. Fractional crystallization from ethanol yields yellow crystals of melting point 126-127°C. Ultraviolet spectrum: λ max 370, mμ $\varepsilon = 2.0 \cdot 10^4$. In the infrared spectrum no absorption at 960 cm^{-1} is detectable and only the typical band at 915 cm^{-1} is found.

7) Thermal stability of azoxystilbenes

Thermal stability of all-trans azoxystilbene. Azoxystilbene was not prepared in the dark. In order to determine whether the prepared compound consisted of a mixture of all-trans and trans-cis-trans azoxystilbene, a sample was refluxed in benzene for 14 hours in the dark. Under these conditions, any trans-cis-trans azoxystilbene should have been isomerized to the all-trans modification. No change in the ultraviolet spectrum could be detected. The azoxystilbene of M.P. 263°C is therefore the all-trans modification.

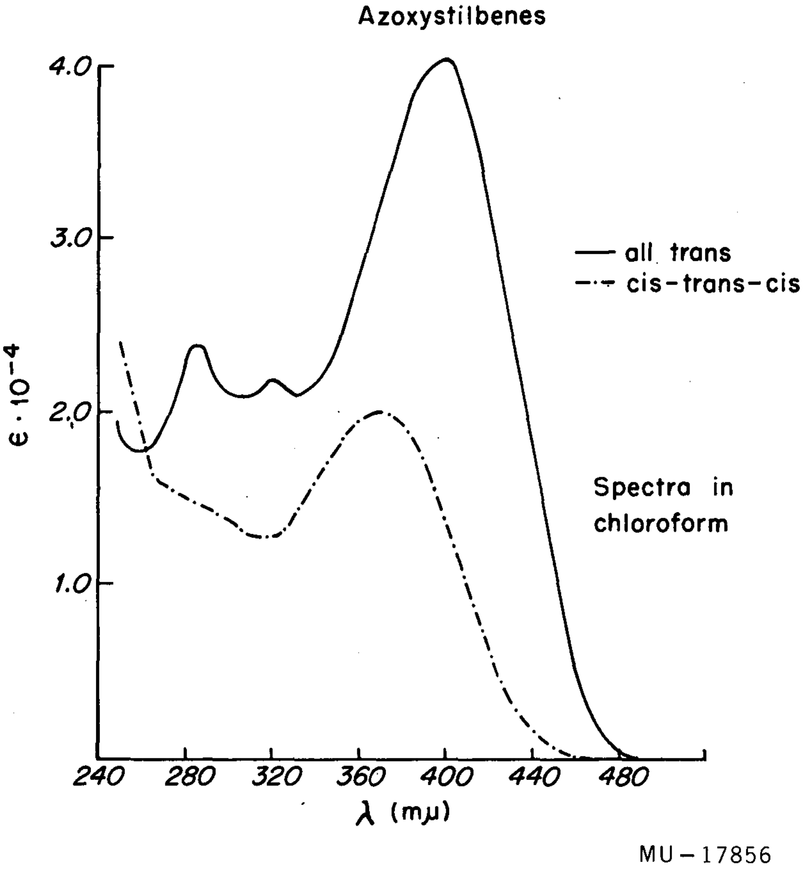


Fig. 11. Spectra of azoxystilbenes in chloroform.

Thermal stability of cis-trans-cis azoxystilbene. As with the all-trans modification, a sample was heated for 30 min. at 80°C in ethanol in the dark. No change in the ultraviolet spectrum could be detected. The azoxystilbene of M.P. 126°C is therefore the cis-trans-cis modification. A longer heating period results in partial isomerization. When the compound is refluxed for 6.8 hours in benzene the absorption max. shifted from 376 mμ to 385 mμ. The reaction has not been studied in detail. Assuming that no rearrangement and only isomerization of the ethylenic double bond had occurred, a rough calculation would indicate that about 10-20% of the cis-trans-cis azoxystilbene had been isomerized to the all-trans modification.

Thermal isomeraztion of trans-cis-trans azoxystilbene

Fifty mg trans azoxystilbene were irradiated for 48 hours in benzene, the solvent removed and the residue digested in petroleum ether and centrifuged. After discarding the supernatant, the residue was digested in 10% benzene-petroleum in which trans azoxystilbene is not very soluble. Ultraviolet spectra were taken of this solution, the entire experiment being performed in the dark and at 0°C.

In Table 2 and Figure 12, changes in spectra are shown for the thermal isomerization of trans-cis-trans azoxystilbene.

Table 2

Thermal isomerization of trans-cis-trans azoxystilbene

Time	λ max 1 in mμ	λ min in mμ	λ max$_2$ mμ	$\frac{E\ \lambda max1}{E\ \lambda\ min}$	$\frac{E\ \lambda max2}{E\ \lambda min}$	$\frac{E\lambda max2}{E\ \lambda max\ 1}$
1 hr after irradiation was stopped	320	347	383	1.18	1.15	0.99
12 hours 6°C	323	347	384	1.07	1.26	1.17
32 hours 0°C	326	347	385	1.07	1.27	1.19
32 hours 0°C + 30 hrs. 25°C	326	347	385	1.07	1.27	1.19

Both the first and second absorption maxima show a bathochromic shift as isomerization proceeds; also the optical densities increase.

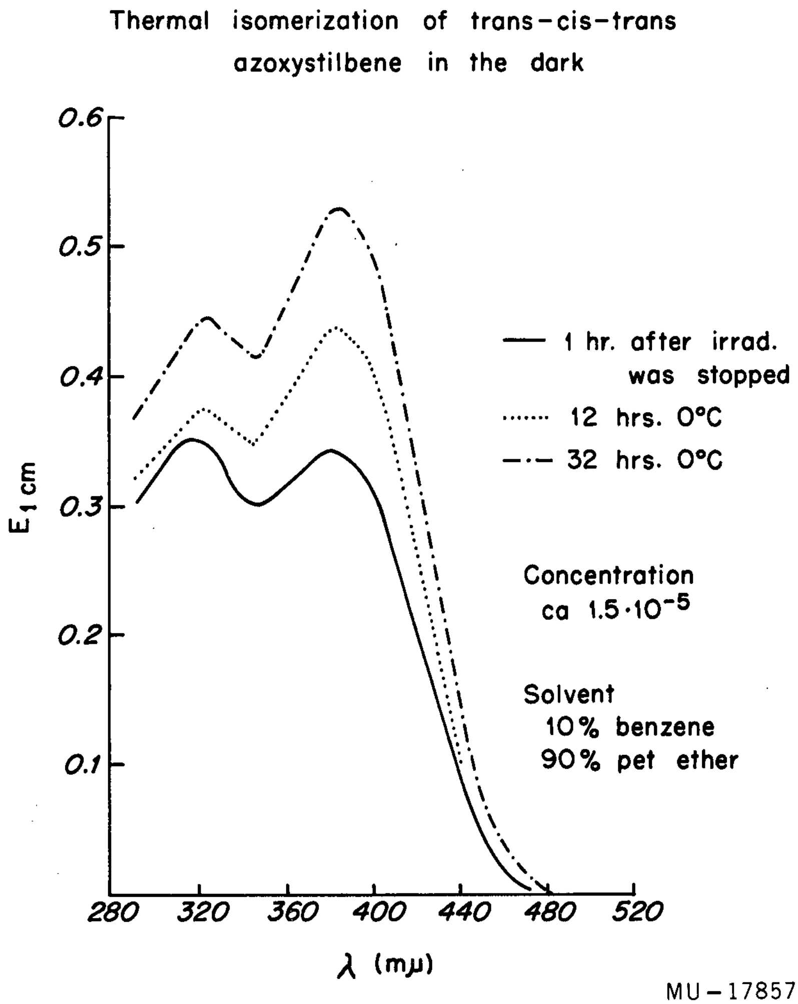
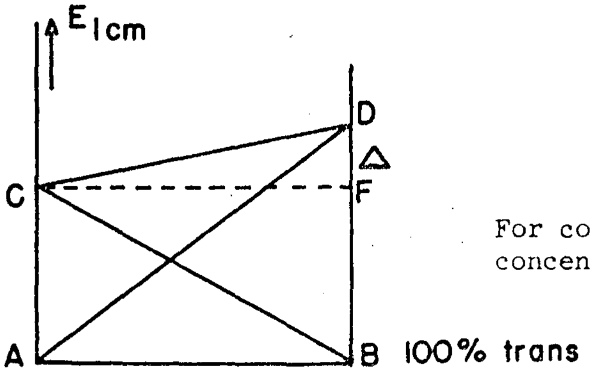


Fig. 12. Thermal isomerization of trans-cis-trans azoxystilbene in the dark. Solvent: 10% benzene, 90% petroleum ether.

Calculation of the rate constant for thermal isomerization of trans-cis-trans azoxystilbene:

If the percent of cis-trans-cis azoxystilbene is plotted against the optical density for pure compounds, a straight line is obtained. The value decreases linearly from the initial value to 0 for 0% cis-trans-cis. This is represented as line C-B in the following diagram. Similarly, the percentage of the trans compound can be plotted against the optical density (line A-D). For any fixed position, then, the optical density of the mixture is given by the algebraic sum of the components. Line C-D then represents the optical density for mixtures from 0% to 100% all-trans-azoxystilbene. The increase Δ is thus a linear function of the percentage of all-trans compound in the mixture.



For constant, total concentration

Table 3

Summary of Data for Various Wave Lengths

ΔE_{12} refers to the increase in optical density after 12 hours

ΔE_{32} refers to the increase after 32 hours

Wave-length mμ	ΔE_{32}	ΔE_{12}	% trans	k in hrs.^{-1}
300	0.075	0.020	27	0.260
320	0.090	0.020	22	0.245
347	0.115	0.050	43.5	0.239
370	0.160	0.080	50.0	0.250
400	0.180	0.090	50.0	0.250
420	0.130	0.060	46.2	0.244

The rate constant for the first-order isomerization of cis-trans-cis azoxystilbene to all-trans azoxystilbene is, therefore, $6.9 \pm 0.3 \cdot 10^{-5}$ sec $^{-1}$ at $0^{\circ}C$, corresponding to a half-life of $1/2 = 167 \pm 4$ min. Inspection of Table 3 indicates that the rate constant does not vary appreciably over the entire range of the spectrum. The first absorption maximum at 320 mμ must therefore be attributed to trans-cis-trans azoxystilbene and cannot be due to some impurity.

8) p-Aminostilbenes

Stilbene and nitrobenzene are reduced catalytically (Raney nickel, Palladium) at very different rates. However, the selective reduction of nitrostilbenes under the same conditions yields only aminodiphenyl ethanes.[7] Chemical reduction of aromatic nitro compounds in basic or neutral medium can in general not be carried out at room temperature. Weygand[8] reduced cis-4-nitrostilbene in water-ethanol at reflux temperature with ferrous sulfate and ammonia. He obtained a red oil in 72% yield with a boiling point of 147-150°C at 0.2 mm Hg. No spectral data were reported. All efforts to duplicate his work failed, since, under these conditions, isomerization of the cis compound occurs.

Chemical reduction of cis-p-nitrostilbene in glacial acetic acid with zinc metal can be carried out at room temperature in 70% yield. Under these conditions, trans p-aminostilbene hydrochloride is obtained in less than 2%.

Trans-para-aminostilbene-hydrochloride

1) Reduction with ferrous sulfate and ammonia:

Ten g p-nitrostilbene was dissolved in hot ethanol and added to a solution of 110 g ferrous sulfate heptahydrate, 165 ml ethanol and 200 ml consentrated aqueous ammonia within one hour. The reaction mixture was refluxed for an additional hour. After distillation, of most of the solvent, the alkaline solution was extracted with ether, and the amine precipitated from the ether solution with hydrogen chloride gas; 7.1 g trans aminostilbene hydrochloride was obtained.

2) Reduction with zinc metal in acetic acid:

One g trans p-nitrostilbene was dissolved in 100 ml glacial acetic acid and 4 g zinc dust added. While stirring vigorously, 10 ml concentrated hydrochloric acid were added during one hour at room temperature. After dilution with 100 ml water, 0.8 g trans aminostilbene-hydrochloride crystallized at 0°C. The crude material was recrystallized three times from ethanol hydrochloric acid.

The hydrochloride crystallizes in silvery plates which turn yellow when exposed to light and air. The ultraviolet spectrum in 50% ethanol-2 M hydrochloric acid shows two maxima at 309 mμ and

and 297 mμ, with extinction coefficients of $\varepsilon = 2.60 \cdot 10^4$ and $2.68 \cdot 10^4$, respectively.

Trans-p-aminostilbene

The slightly yellow hydrochloride was suspended in 1 M hydrochloric acid and extracted with ether to remove impurities and the ether discarded. The suspension was then filtered and the silvery plates dissolved in cold 0.1 M sodium hydroxide and immediately extracted with ether. After drying the ether solution, the solvent was removed and the residue crystallized several times from benzene-n-pentane. M.P. 149-150 (Lit: 151°C; Weygand, loc. cit.). Since trans-p-aminostilbene is not stable in basic solution, the hydrochloride was dissolved in 10^{-3} M hydrochloric acid-30% methanol. This tock solution was then added to 30% methanol sodium hydroxide solution immediately prior to taking the ultraviolet spectrum. The pH of this solution was 11.2 at 25°C. the absorption spectrum shows a single maximum at 324 mμ and an extinction coefficient of $3.14 \cdot 10^4$. Spectra are shown in Figure 35.

Cis-para-aminostilbene hydrochloride

1) Reduction of cis-p-nitrostilbene using the ferrous sul-
procedure as for the
fate ammonia/trans compound, proved to be unsuccessful. Several attempts were made and the spectrum of the crude ether extract,

measured in 2 N hydrochloric acid 50 % ethanol, indicated that the cis p-aminostilbene had isomerized to the trans modification. Stroemer[9] obtained a red oil which did not crystallize. When he dissolved the red oil in benzene, a trace of iodine isomerization of the cis compound occurred within 30 min. at room temperature. He was also unable to prepare the cis-hydrochloride from ethanol and a small amount of concentrated hydrochloric acid. Instead, he isolated always the trans p-aminostilbene-hydrochloride. In view of this great instability of the cis p-aminostilbene, it is surprising that vacuum distillation at a temperature of 147-150°C and 0.01 mm Hg. should result in a pure cis aminostilbene (Weygand[8]).

2) Reduction with zinc metal in glacial acetic acid.

2.63 g cis p-nitrostilbene was dissolved in 100 ml acetic acid and 12 ml concentrated hydrochloric acid. 12 g zinc was then added within about 2 hours, while stirring. The reaction temperature was kept below 30°C and the mixture kept at 5°C over night. After evaporation of the solvent at room temperature in the vacuum, the solid was dissolved in a small amount of 0.25 n chilled hydrochloric acid. The solution was quickly filtered from 55 mg of trans p-aminostilbene. Cis p-aminostilbene-hydrochloride did not crystallize from this solution nor did it crystallize from 50% ethanol 2 n hydrochloric acid. It can be crystallized as the oxalate from ethanol-water as a white solid, and as the hydrochloric from 1 n hydrochloric acid. The solid cis aminostilbene hydrochloride is stable in the dark at 0°C and no ismoreization could be detected within 3 months.

Spectra are shown in Figure 37 and are summarized below:

λ max 299 mµ ε = 3.20 . 10^{-5} m in 30% methanol pH 11.58; ε = 1.44 . 10^{4}

λ max 279 mµ ε = 3.20 . 10^{-5} m in 30% methanol pH 2.10 ε = 1.09 . 10^{4}

9) Thermal Isomerization of cis-p-Aminostilbene at 40°C

A saturated solution of trans p-aminostilbene hydrochloride in 2 n hydrochloric acid, 50% ethanol was irradiated for 1 hr. After dilution of 0.5 ml to 10 ml with 2 n HCl-50% ethanol, the spectrum was measured, and by solving simultaneous equations for two wave-lengths, the amount of trans aminostilbene calculated. Table 4 gives, in addition, the total calculated concentration of cis and trans p-aminostilbene.

It is seen from the data that the assumption is not justified, since a large trend, a factor of 2, is observed for the total concentration, while the figures indicating the percentage of trans p-aminostilbene show an even bigger trend.

Table 4

Total Calculated Concentration of cis and trans p-aminostilbene

Wave-lengths mμ	C tot. 10^5	% trans
320 and 310	8.62	3.7
320 and 300	6.4	10.7
310 and 300	5.3	19.8
310 and 280	4.8	24.3

It must therefore be concluded, that some unknown compound or compounds, which absorb in the same region of the spectrum, must be produced during irradiation. The freshly irradiated solution, after dilution as indicated above, was then heated at $40^{o}C$ in a water-bath and spectra taken at various time intervals. Figure 13 demonstrates the build-up of trans p-aminostilbene. Rough data on the rate of isomerization can be obtained in the following way:

$$E = \mathcal{E}_c C_c + \mathcal{E}_t C_t \quad (1)$$

$$C_o = C_c + C_t \quad (2)$$

where,

E = opt. density

$\mathcal{E}_c, \mathcal{E}_t$ = Extinction coefficient for cis resp. trans component

C_c, C_t = Concentration for cis resp. trans component

Substitution of equation (2) into (1) yields equation (3):

$$E = \mathcal{E}_c C_o + C_t (\mathcal{E}_t - \mathcal{E}_c) \quad (3)$$

Since, during isomerization ${}_cC_o$ and $(\mathcal{E}_t - \mathcal{E}_c)$ are constant, the optical density is directly proportional to the concentration of the trans compound. Assuming, that some unknown compound makes a constant unknown contribution E_x to the optical density, equation (3) expands to:

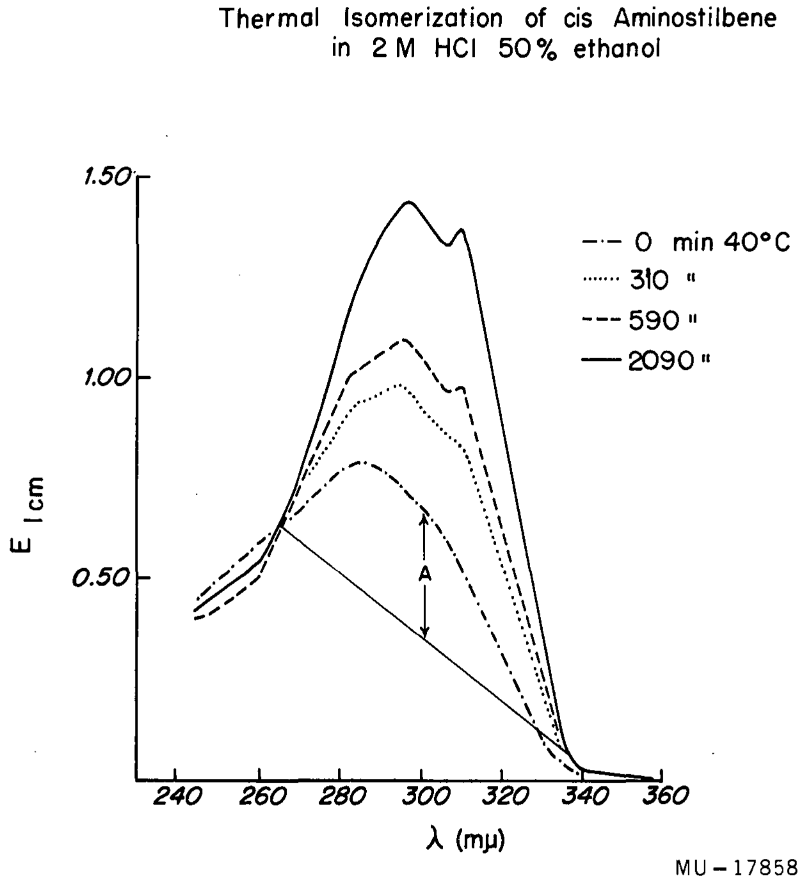


Fig. 13. Thermal Isomerization of cis-p-Aminostilbene at 40°C in 2 n HCl-50% ethanol.

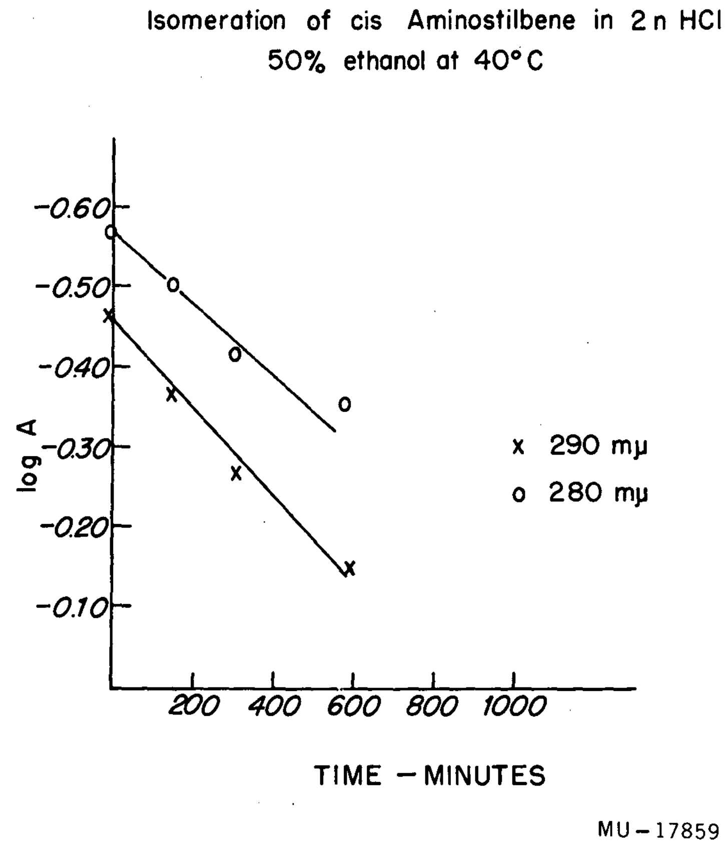


Fig. 14. Thermal Isomerization of cis-p-Aminostilbene at 40°C in 2 n HCL-50% ethanol.

$$E = E_x + \mathcal{E}_c C_o + C_t (\mathcal{E}_t - \mathcal{E}_c) \qquad (4)$$

Thus it is seen that the optical densities in the region of the maximum absorption can be used to calculate the rate of isomerization. In Figure 13 the base line has been drawn between the "isobestic point" at 265 mμ and 340 mμ.

For a particular wavelength the difference of the optical densities of the absorbing material, i.e., at 0 min heating, and the baseline, is then proportional to the amount of trans p-aminostilbene. In Figure 14 the logarithm of this value, log A, has been plotted as a function of time. From the slope of this line, the rate constant is calculated to be of the order of $1.9 \cdot 10^{-5}$ sec^{-1} corresponding to a half-life of about 600 min.

The experiment was repeated at 80°C at which temperature cis p-aminostilbene isomerizes with a rate constant of $3.2 \cdot 10^{-4}$ sec^{-1} Corresponding to a half-life of 36 min. The data are shown in Figures 15 and 16.

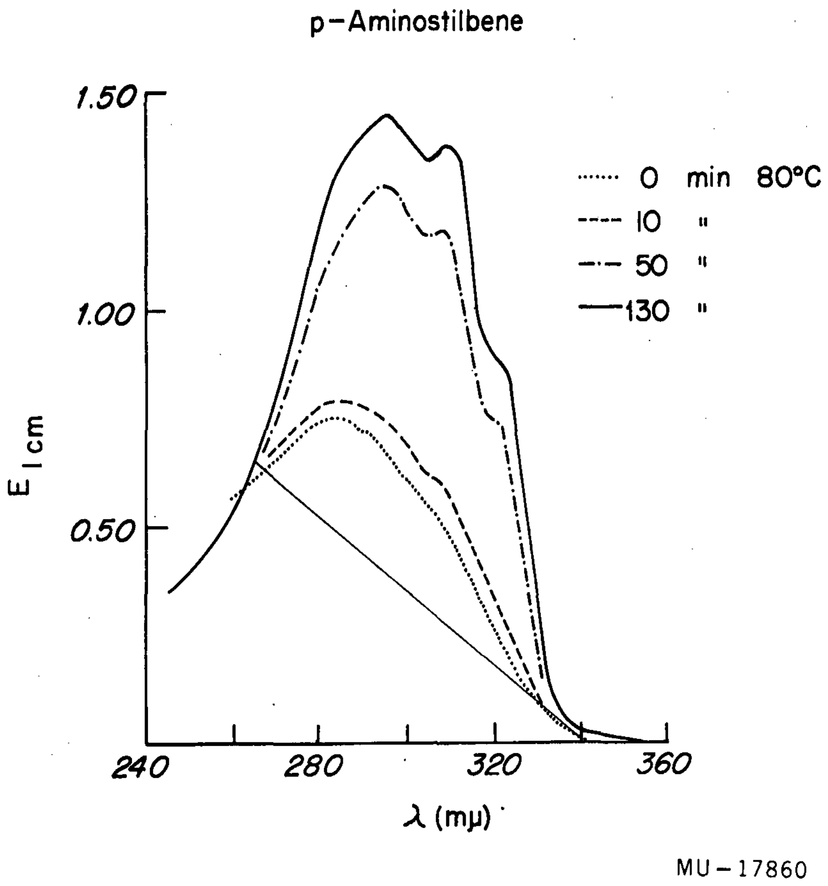


Fig. 15. Thermal Isomerization of cis-p-Aminostilbene at 80°C in 2n HCl-50% ethanol.

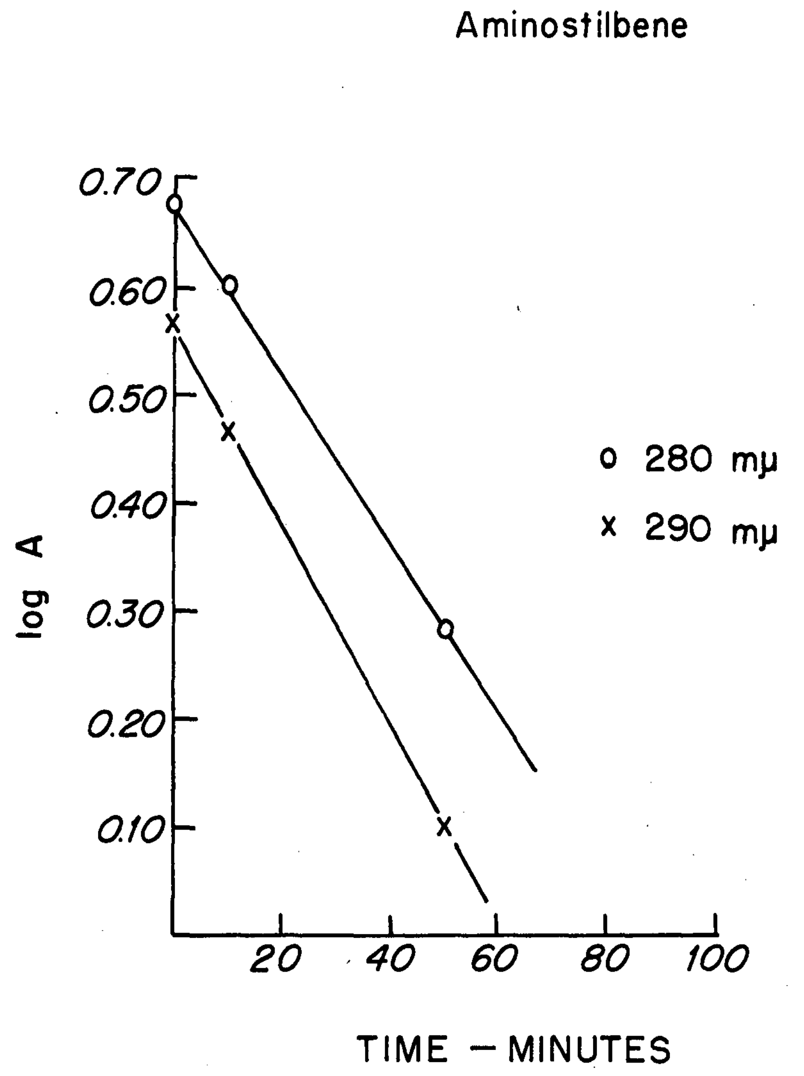


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Fig. 16. Thermal Isomerization of cis-p-Aminostilbene at 80°C in 2 n HCl-50% ethanol.

Thermal isomerization of cis p-aminostilbene

Isomerization of cis p-aminostilbene at pH 8.5 in a 30% methanol phosphate buffer was studied as a function of time. Figure 17 shows the changes in spectrum. Although the changes at 25°C are small and can be neglected in the determination of the p_K measurement, they are large enough to explain, why the ferrous sulfate reduction of cis p-aminostilbene yielded only trans aminostilbene. In Figure 18-log A (see also section on thermal isomerization in 50% ethanol, 2 n hydrochloric acid) is plotted as a function of time. The first order rate constant for cis trans isomerization is therefore of the order of 2.10^{-6} $\sec^{-1}$. at 25°C. Assuming a 2 resp. 2.5 fold increase in rate for 10°C, then a rate factor of 130-600 will be calculated for isomerization at 95°C. Consequently, the time required for isomerization of 99% of the produced cis amine would be about 50 to 280 min. The time for rerrous sulfate reduction of cis nitrostilbene and subsequent distillation of most of the solvent from the reaction mixture is, however, about 3 hours!

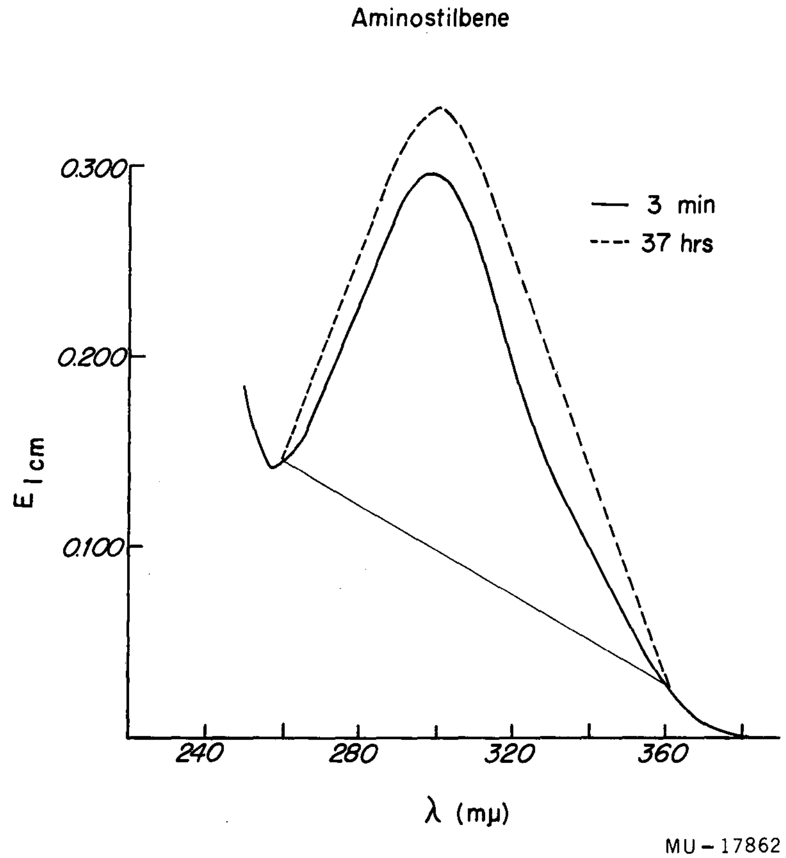

Fig. 17. Thermal Isomerization of cis-p-Aminostilbene at 25°C in Phosphate Buffer of pH 8.5 and 30% Methanol.

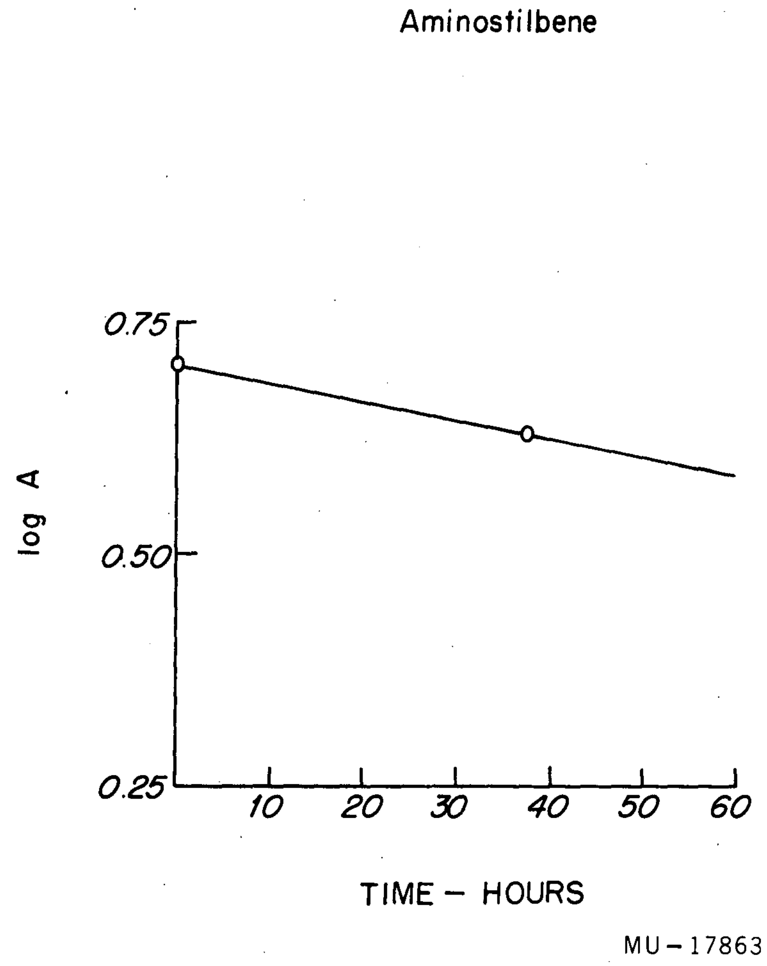

Fig. 18. Thermal Isomerization of cis-p-Aminostilbene at 25°C in Phosphate Buffer of pH 8.5 and 30% Methanol.

10. N-Acetyl-p-aminostilbenes

trans-N-Acetyl para-aminostilbene. 100 mg of trans aminostilbene hydrochloride was dissolved in 10 ml acetic-anhydride and 0.5 ml 0.1 m sodium hydroxide added. After warming for 5 min. all the stilbene derivative had dissolved. The temperature was kept at 50° C for another 5 min. and then water added dropwise until a precipitate had formed. After filtration, the compound was crystallized from ethanol-water, ethanol and finally several times from benzene. M.P. 233-235° C (Literature, 225°C). Products obtained by fractional crystallization from benzene, 80% benzene-n-hexane and 60% benzene-n-hexane have identical melting points and show absorption maxima each at 312 and 300 mμ in benzene-n-hexane solution and ether.

cis-N-acetyl para-aminostilbene. 100 mg cis aminostilbene hydrochloride was dissolved in 30 ml acetic-anhydride and 0.5 ml 0.1 sodium hydroxide added. Aftet 2 hours standing at 50°C, water was added dropwise until a white precipitate formed. The solid precipitate was recrystallized from ethanol-water and was further purified by fractional crystallization from ether-n-hexane. M.P. 129-131 U.V. spectrum shows an absorption maxima at 296 mμ ε= 8, 0 10^3. in ether.

Section II. Irradiation of trans Stilbene Derivatives

1) Apparatus and general considerations. Conflicting results are reported in the literature on the isomerization of trans stilbene. Pailer[10] irradiated stilbene as a saturated solution in benzene. After 8 days irradiation in a quartz flask with a mercury lamp, he was able to isolate a yellow compound in 7% yield to which he assigned the structure of a 1,2,3,4 tetraphenylcyclobutane. Unfortunately, he gives no spectral data for this compound.

Buckles[11], on the other hand, reports that after irradiation of both cis and trans stilbene in 0.02 m ethanolic solution for 20 days, he was able to isolate phenanthrene in high yield. Buckles used silica cells placed about 5 cm away from a Hanovia mercury arc.

In view of these conflicting results, trans stilbene was irradiated to test the efficiency of the apparatus and to get information on optimum conditions to be used for the production of other cis stilbene derivatives. The following trans compounds were irradiated in benzene solution: stilbene, p-acetoxystilbene, azoxystilbene all-trans, as well as cis-trans-cis, p-aminostilbene. Hydroxystilbene was irradiated in absolute ethanol and the cation of p-aminostilbene in 50% ethanol-2 n hydrochloric acid. Where kinetic data are given these have to be considered as rough estimates since all these data were obtained in order to find optimum conditions for the preparation of isomers.

Solvents for Irradiation

The choice of solvent was governed by the following considerations:

1. The solvent must be transparent in the region in which the compound subjected to irradiation absorbs.
2. Dissociation energies of the various bonds of the solvent molecule should be higher than the energy of the photons which reach the solvent.
3. If the solvent absorbs at somewhat shorter wavelengths than the compound subjected to irradiation it may be used as a photosensitizer.

Aliphatic hydrocarbons, such as iso-octane, have been used by various workers. However, the dissociation energy of the C-H bond (about 100 kcal/mole) and the C-C bond 70-80 kcal/mole) are too low and may lead to formation of radicals which may add to the ethylenic double bond. Dissociation energies for theC_H bonds of aromatic hydrocarbons are so high that wavelengths near the limits of those transmitted by quartz would be necessary. For this reason benzene was generally used as a solvent, since, in addition to acting as a solvent, it will act as a sensitizer. For p-hydroxy and p-aminostilbene, ethanol was used as a solvent. The cation of p-aminostilbene was irradiated in 50% ethanol-2 n hydrochloric acid.

Apparatus for Irradiation of trans Stilbene-Derivatives

Reaction Vessel:

A 150 ml Victor Erlenmeyer flask was connected by way of a groun d joint to a high intensity reflux condenser, the latter being connected to a water aspirator. The Vicor glass of 1 mm wall thickness has a useful transmission to 2400 Å.

Light Source:

A Hanovia type medium pressure mercury lamp with an input of 125 Watts was used. The most intense lines are at 2537, 3126-3131 and 3650-3663 Å. The line at 2537 Å is usually reversed on account of absorption of resonance radiation by the mercury vapor in the lamp itself. Less intense lines are observed at 2652-54, 2804, 3021 Å.

Operation of the Irradiation equipment

50 ml of a 10^{-3} m solution f stilbene were pipetted into the Vicor Erlenmeyer. This corresponds to a liquid layer of 2.2 cm. After connection to the reflux condenser, the water aspirator was turned on until the solution just barely boiled. After a few minutes, the mercury lamp was started and the vacuum steadily decreased until the solution reached its equilibrium temperature of 50^{0}C. The vacuum inside the reaction flask was adjusted so that the solution was refluxing gently. In this way, adequate mixing of the solution is ob-

tained and a film of solvent vapor protects the solution from the oxygen of the air. Radicals produced by the irradiation with the mercury lamp, thus, cannot enter into secondary reactions with oxygen of the air. See also Figure 19.

2. Irradiation of trans-Stilbene

Irradiation of 2.10^{-3} m stilbene solution in benzene was studied as a function of time. Aliquots were drawn from the irradiation solution and, after removal of the solvent in vacuum, the spectrum taken in ether. Figure 20 shows the changes on irradiation. It is seen that the maximum at 308 mμ disappears within 1 1/2 hours, whereas the main absorption maximum at 294 mμ shifts to about 285 mμ within 2 hours. in Table 5, the optical densities, E, for different wavelengths and 4 time-intervals, together with the extinction coefficients for the cis and trans isomer, are reported.

Calculation of the Amount of trans stilbene

If it is assumed that no reaction other than isomerization occurs, the amount of trans and cis stilbene at any fixed time can be calculated by solving the two simultaneous equations:

$$E_1 = \varepsilon_{c1} C_c + \varepsilon_{t1} C_t$$

$$E_2 = \varepsilon_{c2} \varepsilon_c + \varepsilon_{t2} C_t$$

where E_1 is the optical density at wavelength 1 and E_2 the optical density at wavelength 2. ε_{t1} and ε_{c1} are the extinction coefficients for the pure trans isomer and cis isomer, respectively.

In Table 6 are shown the results for 4 different time intervals and 3 different sets of wavelengths. The Table also records the total concentration of cis and trans compounds. It is seen, that the calculated total concentration steadily increases in time, and becomes much

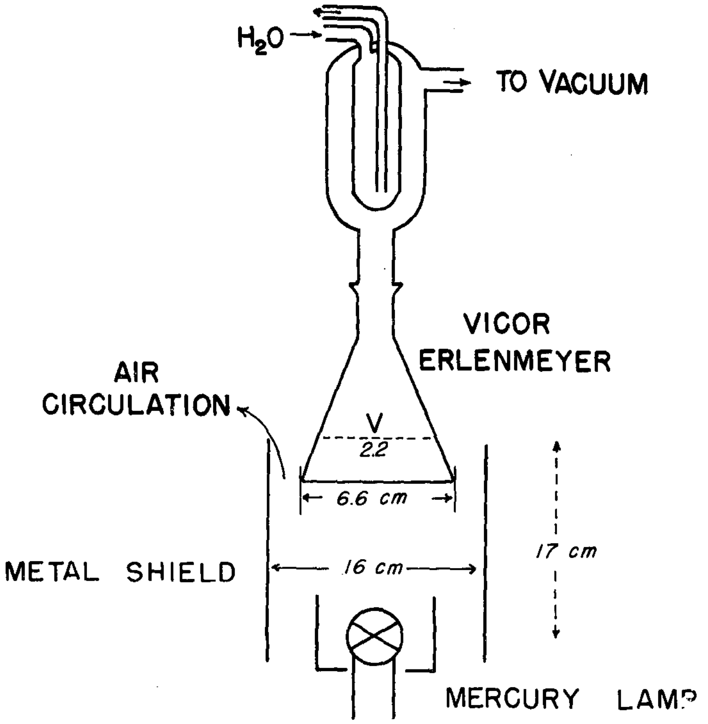

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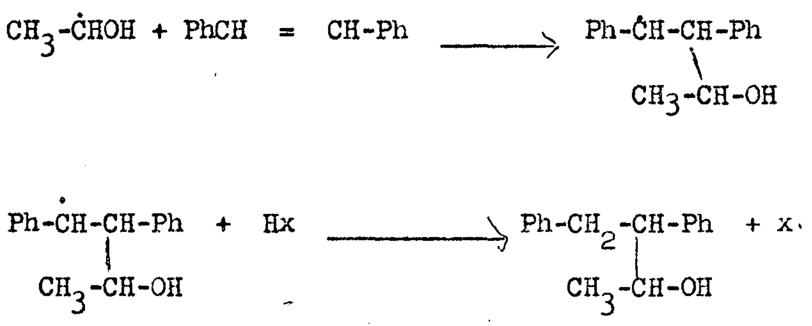
Fig. 19. Irradiation Apparatus.

larger than the analytical concentration of $3.00 \cdot 10^{-5}$. Comparison of the spectra of the irradiated solutions with the spectrum of phenantrene as reported in the literature, indicates that only small concentrations of phenantrene are built up under these experimental conditions. Rough calculations using the extinction coefficients reported for cyclohexane as a solvent indicate that phenanthrene can only be a minor constituent in this reaction mixture and that furthermore, the amount of calculated phenanthrene decreases with time.

3. Irradiation of trans p-Hydroxystilbene

The isomerization of a $1.0 \cdot 10^{-3}$ m solution in ethanol was studied as a function of time. The absorption maxima at 320 mμ disappears within 30 min and the second maximum of slightly higher intensity at 305 mμ gradually shifts to 295 mμ. After 16 hours, irradiation, p-hydroxystilbene is completely destroyed. The ultraviolet spectrum then resembles very much that of benzene with many sharp maxima between 230 and 270 mμ. The light source is apparently strong enough to produce $CH_3\dot{C}HOH$ radicals which then undergo reaction with the olefine, according to the following equations:

$$CH_3\text{-}CH_2\text{-}OH + h\nu \longrightarrow CH_3\text{-}\dot{C}H\text{-}OH + H^{\cdot}$$



$$CH_3\text{-}\dot{C}HOH + PhCH = CH\text{-}Ph \longrightarrow Ph\text{-}\dot{C}H\text{-}\underset{\displaystyle CH_3\text{-}CH\text{-}OH}{CH}\text{-}Ph$$

$$Ph\text{-}\dot{C}H\text{-}\underset{\displaystyle CH_3\text{-}CH\text{-}OH}{CH}\text{-}Ph + Hx \longrightarrow Ph\text{-}CH_2\text{-}\underset{\displaystyle CH_3\text{-}CH\text{-}OH}{CH}\text{-}Ph + x\cdot$$

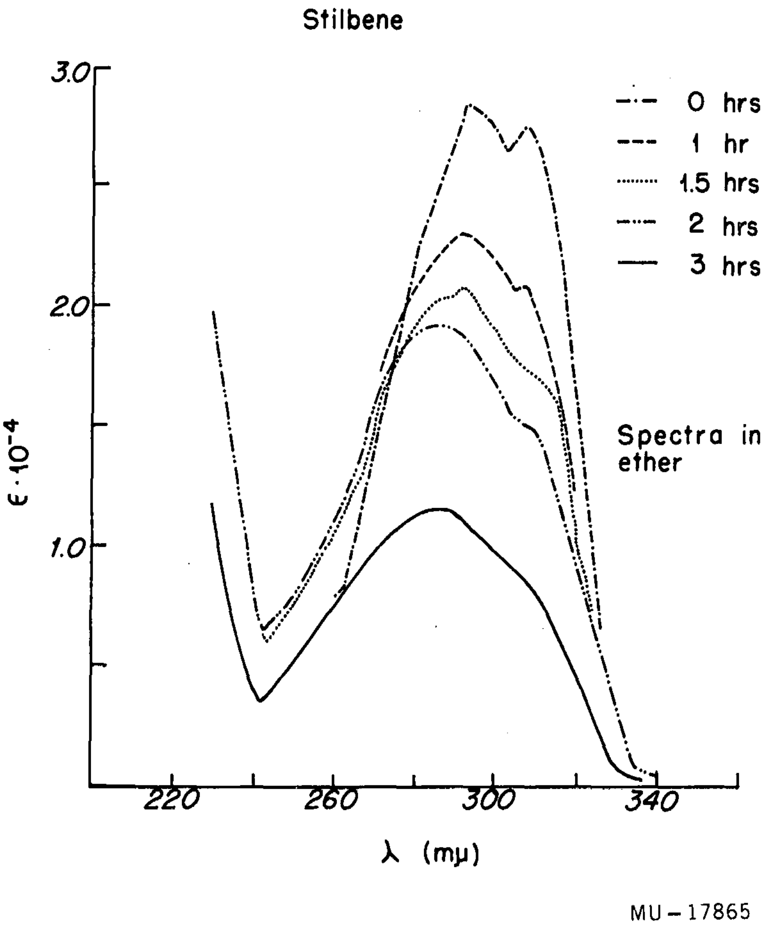


Fig. 20. Irradiation of trans stilbene in benzene-solution (Spectra were taken in ether).

Table 5

Irradiation of trans Stilbene

Wavelength in mμ	Time			
	0.5 hours	1 hour	1.5 hours	two hours
320	E 0.450	0.370	0.295	0.260
	ε_c $1.92 \cdot 10^3$			
	ε_t $1.727 \cdot 10^4$			
310	E 0.650	0.570	0.480	0.410
	ε_c $3.96 \cdot 10^3$			
	ε_t $2.663 \cdot 10^4$			
300	E 0.730	0.650	0.560	0.500
	ε_c $6.602 \cdot 10^3$			
	ε_t $2.717 \cdot 10^4$			
290	E 0.760	0.680	0.615	0.565
	ε_c $9.603 \cdot 10^3$			
	ε_t $2.682 \cdot 10^4$			
280	E 0.660	0.610	0.570	0.545
	ε_c $1.062 \cdot 10^4$			
	ε_t $2.142 \cdot 10^4$			

Table 6

Irradiation of trans Stilbene

Wavelengths	Time							
	0.5 hrs		1 hr		1.5 hrs		2 hrs	
	% trans	c total 10^5	% trans	ctotal 10^5	% trans	ctotal 10^5	% trans	ctotal 10^5
320 and 290	82.1	3.20	55.2	3.56	37.8	3.82	33.6	3.67
320 300	73.9	3.39	50.5	3.82	34.5	4.09	32.5	3.76
310 280	--	--	47.3	3.88	36.6	3.91	27.6	4.01
Average value	78.0	3.29	51.0	3.75	36.3	3.93	31.2	3.81
				5.10^{-7}		8.10^{-8}		

From the slope in Figure the first order rate constant is calculated as k 1.8 . 10^{-4} $\sec^{-1}$ at 50°C. This corresponds to a half-life of 65 min.

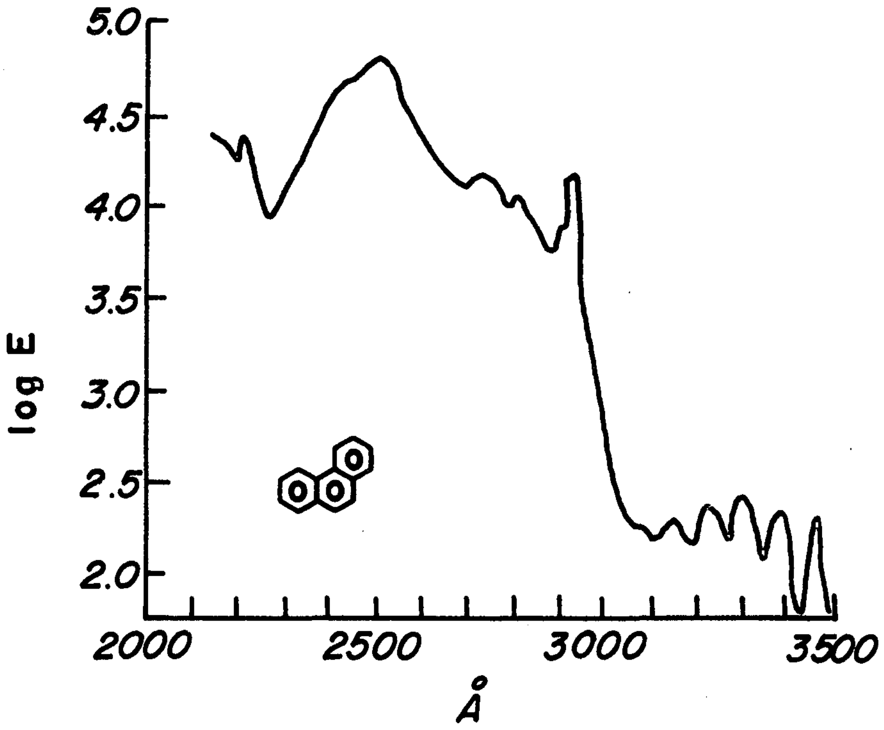


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Fig. 21. Spectrum of Phenanthrene in cyclohexane.

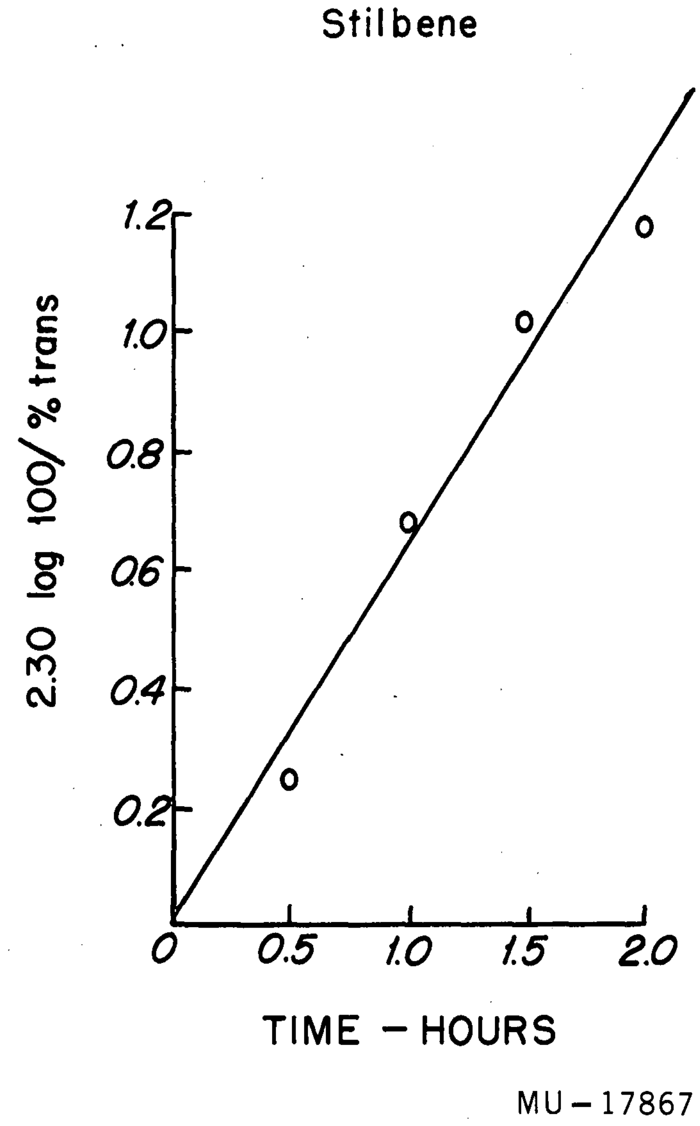


Fig. 22. Irradiation of trans Stilbene in benzene solution.

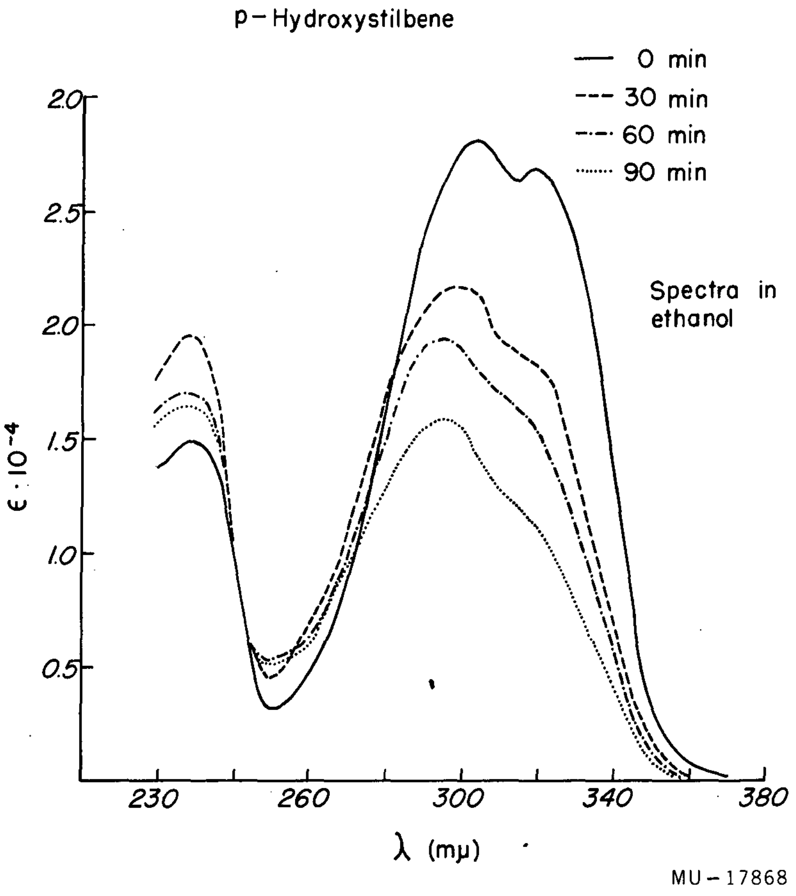


Fig. 23. Irradiation of trans p-Hydroxystilbene in ethanol (Spectra in ethanol).

Urry[12] has shown that, by using a large excess of alcohol, a number of alcohol-olefine combinations yield 1:1 addition products.

Using extinction coefficients for the pure cis and trans p-hydroxystilbene, one arrives at the following values for the isomerization of trans p-hydroxystilbene concentration (2.0 . 10^{-5} m in ethanol). The data are summarized in Table 7.

Table 7

	Irradiation of 0.5 hr		Irradiation 1 hr	
Calculated from wavelengths mM	% trans p-OH stilbene	total stilbene concentration	% trans p-OH stilbene	total stilbene concentration
290 and 270	15.8	$3.18 . 10^{-5}$	22.4	$2.79 . 10^{-5}$ m
320 300	27.7	2.61		
340 320	11.5	3.57		
340 310	17.0	3.13	1.2	3.48
340 300	16.8	3.14		

The calculated total stilbene concentration throughout is much higher than the concentration of the original trans p-hydroxystilbene. This clearly demonstrates that isomerization is not the sole process. In further experiments batches of 50 ml of a 4.10^{-3} m p-hydroxystilbene-solution in benzene was irradiated for 90 min. After evaporation of the solvent in vacuum, the residue of 392 mg was digested with 20% ether n-hexane and chilled to -20°C. Filtration yielded a solution which contained a mixture of trans and cis p-hydroxystilbene.

229 mg were obtained after evaporation of the solvent. On digestion, with n-hexane, cooling to -20°C, the filtrate was again evaporated. 86.5 mg 22% of an oil was obtained.

Chromatography from an aluminum oxide column, using n-hexane as the solvent, resulted in isomerization of the oil. The absorption maximum of this chromatographed material showed a peak at 302 mμ and a shoulder at 320 mμ. From the spectrum it can be calculated that 23.7% of the compound had isomerized to the trans modification. No further attempts to purify the material obtained from fractional crystallization have been made. However, information with regard to purity can be obtained in the following way:

$$E_j = \alpha c_o \varepsilon_{cj} + (1-\alpha) c_o \varepsilon_{tj} \quad (1)$$

E_j = optical density at wavelength j

ε_{cj} and ε_{tj} = extinction coefficients of the cis and trans p-hydroxystilbene

$\varepsilon\, c_o$ = analytical concentration = $c_c + c_t$

α = % cis p-hydroxystilbene in the mixture

Equation (1) can be rearranged to:

$$\frac{E_j}{c_o \alpha} - \left(\frac{1-\alpha}{\alpha}\right) \varepsilon_{tj} = \varepsilon_{cj} \quad (2)$$

For an assumed α, ε_c can be calculated for various wavelengths and the calculated value compared with the value calculated from the analytical concentration c_0 and the optical density.

From inspection of Figure 23, one would expect a large error at wavelengths greater than 320 mμ.

$$\frac{\varepsilon_{\text{observed}} - \varepsilon_{\text{calculated}}}{\varepsilon_{\text{observed}}} = V$$

Figure 24 shows the results calculated for 80%, 95% and 99% cis p-hydroxystilbene as a function of wavelength. The figure clearly indicates that cis p-hydroxystilbene obtained by fractional crystallization as described above can contain only small amounts of the order of 1% trans p-hydroxystilbene.

In Figure 25 log A is plotted as a function of time. Irradiation for up to 90 min is strictly a first order reaction. From the slope of the straight line, the first order rate constant is calculated to be $k\ 2 \cdot 10^{-4}\ \text{sec}^{-1}$ at 50°C corresponding to a half-life of about 60 minutes.

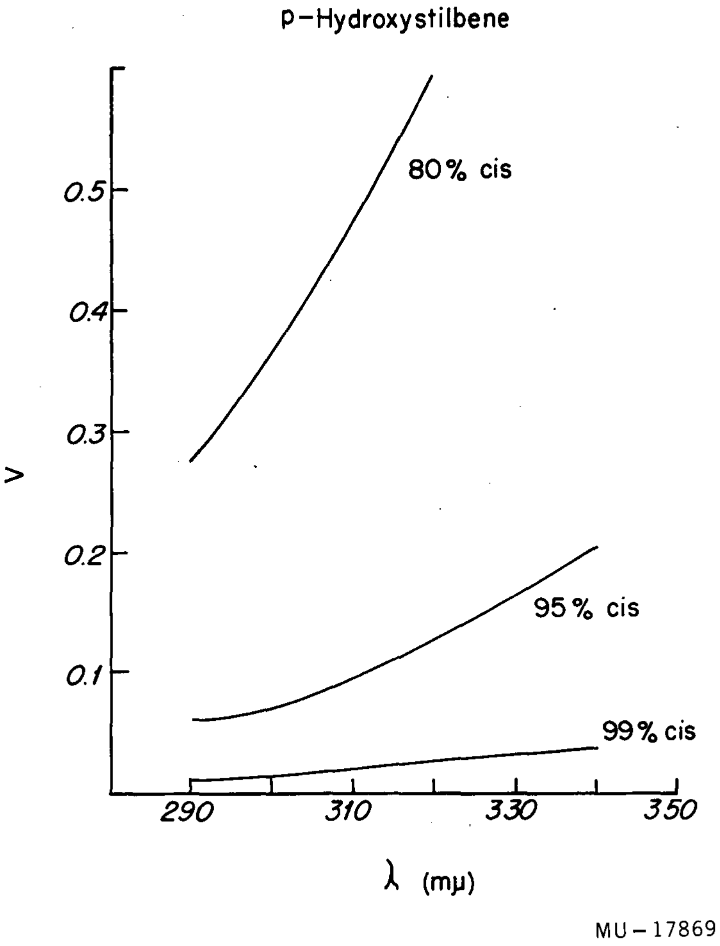


Fig. 24. Cis p-Hydroxystilbene (see text for explanation).

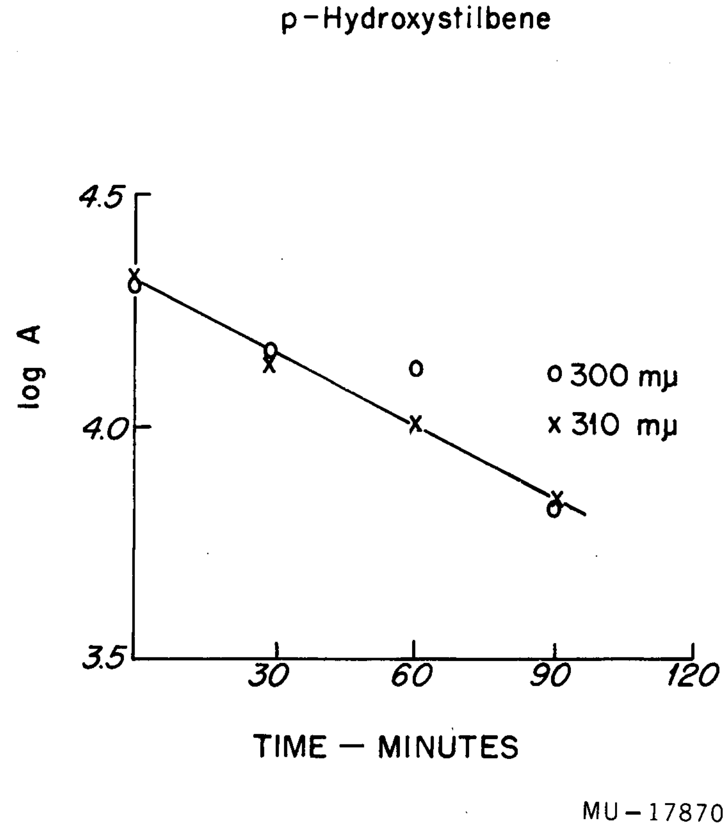


Fig. 25. Rate of trans-cis Isomerization of p-Hydroxystilbene under the Influence of Ultraviolet Light.

4. Irradiation of trans p-Acetoxystilbene

50 ml of a 2.10^{-3} m solution in benzene were irradiated for various lengths of time. Aliquots were taken and, after evaporation of the solvent, the spectra measured in ether. From Figure 26 it is seen, that after 1 1/2 hours the maximum at 310 mμ disappears and the main absorption band is shifted to about 295 mμ. On continued irradiation, the absorption maximum shifts further to 285 mμ. In Table 8, the percentage of cis compound, as well as the calculated total concentration, are reported for irradiation times of 1/2 hour, 1,2.3.4 hours. Calculations are rather inaccurate for 1/2 hour, since the differences become small, when solving the two simultaneous equations. It is interesting to note, that, within experimental error, the total concentration of cis and trans compound remains at the analytical level thus indicating that no serious side reaction such as formation of the dimer or production of phenanthrene derivative occurs.

Table 8

Irradiation of trans p-Acetoxystilbene

Wavelength mμ	Irradiation time 0.5 hr		1 hr		2hr		3 hr		4 hr	
	%cis	$c_{total} .10^{-5}$	% cis	c_{total} 10^5	% cis	c_{total} 10^5	% cis	c_{total} 10^5	% cis	c_{total} 10^5
320 and 300	(18.2)	4.75					71.0	3.76		
320 290	(18.1)	4.5	29.6	4.0	47.3	3.81				
310 290			36.7	4.2	54.9	4.11	70.8	3.8	82.4	3.94
300 280			25.7	3.8	52.7	4.02	75.4	4.00	84.0	4.05
Average	(18)	(4.60)	30	4.0	51.6	3.98	72.4	3.85	83.2	4.0

From the slope in Figure 27, the first order rate constant is calculated as $k = 1.2 . 10^{-4}$ sec^{-1} at 50°C. This corresponds to a half-life of roughly 100 min.

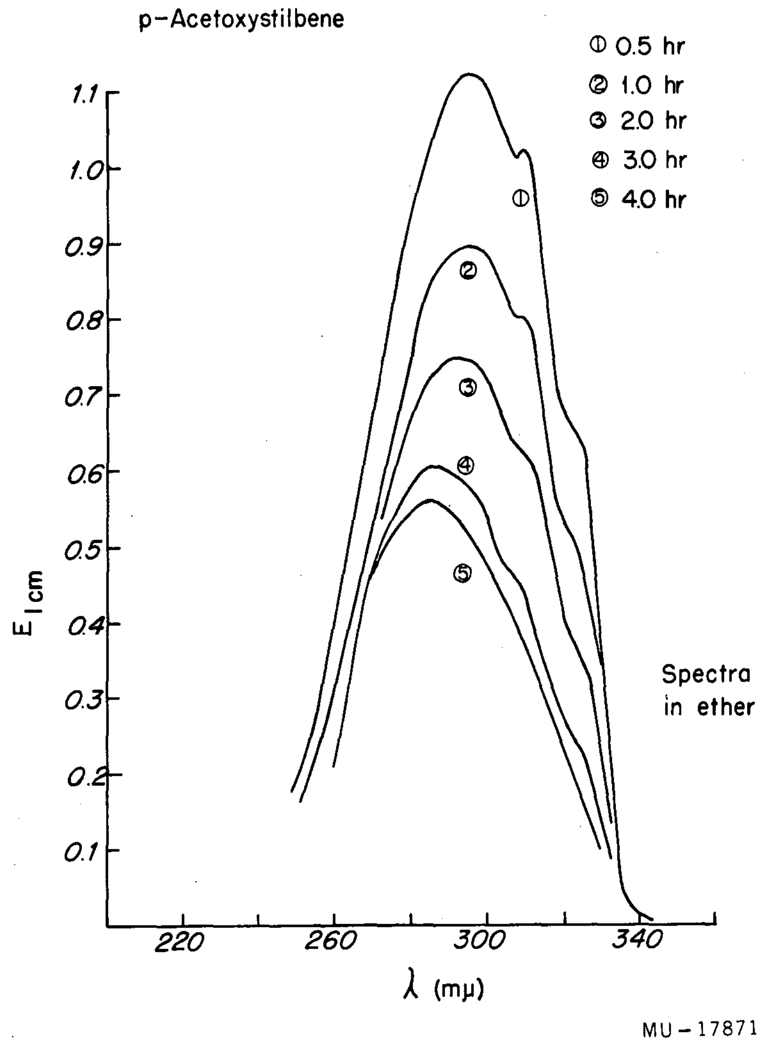


Fig. 26. Irradiation of trans-p-Acetoxystilbene in Benzene.

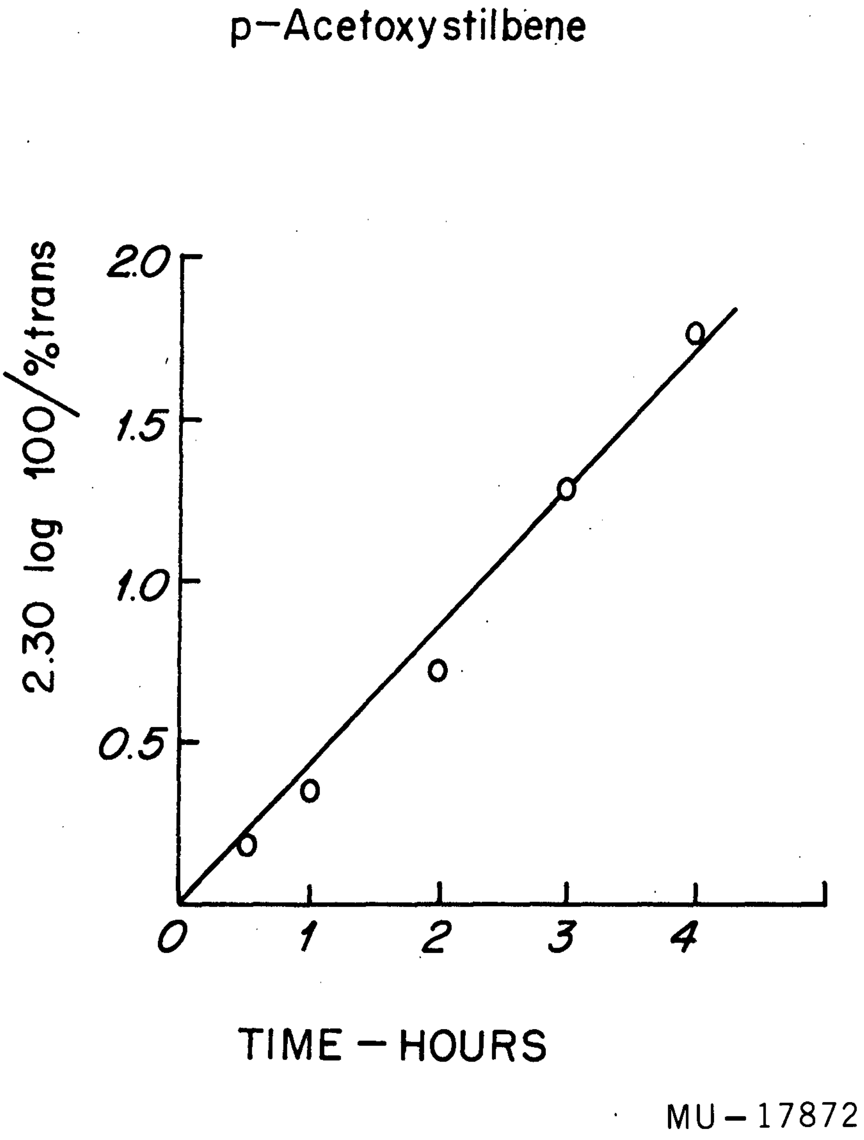


Fig. 27. Irradiation of trans-p-Acetoxystilbene.

Irradiation of Azoxystilbenes

Many azoxy compounds are converted to ortho-hydroxyazo compounds when their solutions are exposed to light. Badger[13] has studied azoxystilbene. He found that the rate of formation of o-hydroxy-azobenzene in n-hexane and benzene is very slow. The yield varied with the time of exposure, but was generally about 5-15% for 1 month irradiation in sunlight. Since the rate of the rearrangement to o-hydroxy-azo compounds is thus seen to be rather slow, attempts were made to prepare trans-cis-trans azoxystilbene the geometrical isomer of the all-trans modification, as well as the all-cis modification.

Irradiation of all-trans azoxystilbene

Irradiation was first studied as a function of time. A 2.10^{-3} m solution in benzene was irradiated for 8, 20, and 48 hours. It is seen from Table 9 that the absorption maximum is shifted to slightly lower values. The change is further illustrated by the ratio of the optical densities, recorded in Table 9.

Table 9

Irradiation time in hours	λ max. mμ	$\frac{E\ 400}{E\ 440}$	$\frac{E\ 400}{E\ 420}$	$\frac{E\ 400}{E\ 380}$	$\frac{E\ 400}{E\ 350}$	
0	400	2.08	1.16	1.16	1.64	spectra in benzene
20	398	2.13	1.18	1.17	2.06	
48	394	2.21	1.21	1.14	1.94	

Furthermore, the optical density and λ maxima do not change within one hour at 25°C. Despite the fact that the irradiated equilibrium mixture consists mainly of all-trans modification, it seemed impossible to isolate some trans-cis-trans azoxystilbene.

A total of 160 mg of all-trans azoxystilbene was irradiated in batches of 53 ml each for a period of 48 hours. After irradiation was stopped, the solvent was quickly removed at 0° C in vacuum, and the residue stored over dry ice in the dark. The three batches were then combined.

Purification (a), fractional crystallization:

160 mg of the irradiated product were dissolved in benzene at 20°C to give a saturated solution. The solution was then let to crystallize at 6°C and filtered. The mother liquor was then concentrated in vacuum and again let to crystallize, filtered and the operation repeated once more. Spectral data indicate, that the three crystalline fractions are essentially pure trans azoxystilbene. In the mother liquor of the third crystallization, the absorption maximum is shifted to 395 mμ; the minimum is shifted to longer wavelengths and a second maximum appears at 323 mμ.

After evaporation of the solvent, the residue was dissolved to give a saturated solution in petroleum ether-benzene 1:1 and again let to crystallize. The mother liquor probably contains a mixture of compounds. The ultraviolet spectrum of this mixture indicates a further hypsochromic shift of 13 mμ for the first absorption maximum, a bathochromic shift for the minimum of 24 mμ, whereas the second absorption maximum is not shifted at all. Also, the intensity of the second maximum increases by a factor of 2.2. A further fractional crystallization from petroleum ether yields a crystalline material, whose first absorption maximum is shifted back to 393 mμ. It seems probable, therefore, that a substantial amount of the enriched trans-cis-trans azoxystilbene has been isomerized back to the trans modification. The data are summarized in Table 10.

Table 10

Solvent		λ max	λ min	λ max			amt.
1. cryst. from benzene	cr	400	305				
	ml	400	305				
2. cryst. " "	cr	400	305				
	ml	400	305				
3. cryst. " "	cr	400	305				
	ml	395	342	323	$\frac{E\ 395}{E\ 342}$ 1.40	$\frac{E\ 395}{E\ 323}$ 1.30	
pet. ether benzene 1:1	cr	400	303				
	ml	382	366	323	$\frac{E\ 382}{E\ 366}$ 1.02	$\frac{E\ 382}{E\ 326}$ 0.58	30 mgr
pet. ether	cr	393	365	328	$\frac{E\ 393}{E\ 365}$ 1.07	$\frac{E\ 393}{E\ 328}$ 0.96	10 mgr
	ml	313			shoulder at 380-400		20 mgr

cr = crystalline fraction
ml = mother liquor

All spectra were taken in benzene as solvent with a maximum optical density of about 0.6

Purification b) by column chromatography of the irradiated material

Dimensions of the column: diameter: 1 cm
length : 12 cm
material: Aluminum oxide

eluent solvent	volume ml	λ max mμ	$\frac{E\ 390}{E\ 420}$	$\frac{E\ 390}{E\ 370}$
10% benzene-pet. ether	50	390	1.5	1.1
	25	390	1.5	1.1
15% benzene pet. ether	25	390	1.5	1.1
	25	390	1.5	1.1
25% benzene pet. ether	25	394	1.4	1.1
Benzene	25	397	1.2	1.2

All spectra were taken in benzene. Using petroleum-ether as eluting solvent, no compound came off the column. Up to 15% benzene , an apparently uniform material came off the column. The absorption maximum was, however, at higher wavelength than was obtained by fractional crystallization. The fractional crystallization procedure as outlined in a) is too time-consuming whereas the column-chromatography procedure does not yield a pure product. By first chromatographing on aluminum oxide and subsequent fractional crystallization from benzene-petroleum ether, it should, however, be possible to obtain a pure trans-cis-trans azoxystilbene. The first absorption maximum seems to be about 380-385 mμ in benzene; the second at 323 mμ. Irradiation of all trans azoxystilbene in benzene leads to a mixture of three compounds:

a) unreacted all-trans azoxystilbene λmax 400 mμ in benzene

b) trans-cis-trans azoxystilbene λmax 390 mμ in benzene

Its infrared spectrum shows no band in the region of 920 cm^{-1} typical for a cis stilbene and no band at 3600 cm^{-1} typical for a phenolic hydroxyl group.

c) An unidentified compound soluble in petroleum ether having a λ max 310 in petroleum ether. The compound, or compounds, seem to have a trans stilbene nucleus and have no phenolic hydroxyl group.

Irradiation of cis-trans-cis Azoxystilbene

Irradiation was first studied as a function of time. A 2.10^{-3}m solution in benzene was irradiated for 8 to 20 hours. In the ultraviolet spectrum a slight hypsochromic shift was observed. The change is further illustrated by the ratio of optical densities. The data are summarized in Table 11.

Table 11

Irradiation of cis-trans-cis Azoxystilbene in benzene solutions

Irradiation	λ max mμ	$\frac{E\ 370}{E\ 350}$	$\frac{E\ 380}{E\ 420}$
0 hrs	377	1.23	2.64
8 hrs	376	1.28	2.47
20 hrs	374	1.32	2.45

After evaporation of the solvent at 12°C in vacuum, the residue was digested in petroleum ether, which had previously been cooled to -25°C. No fractionation was obtained. Similarly, chromatography from an aluminum oxide column with petroleum ether as the eluting solvent was unsuccessful. A scale model indicates, that the all cis azoxystilbene should probably have a spiral structure. Since the rate for the thermal isomerization of trans-cis-trans azoxystilbene to the all trans azoxystilbene has a half-life of only about 160 min at 0°C, it may well be that the all cis isomer can not be isolated under the relatively mild conditions used in this experiment.

Irradiation of trans p-Aminostilbene

Initial experiments on the production of cis p-aminostilbene were made by irradiating the free amine in benzene for periods of 10 to 20 hours in a dry nitrogen atmosphere. After evaporation of the solvent in the vacuum, the residue was chromatographed fron an aluminum oxide column using n-hexane and n-hexane-benzene mixtures as the eluting solvent. Spectra, taken in 50% ethanol-2 n hydrochloric acid, were identical with trans aminostilbene hydrochloride. It thus becam evident that cis aminostilbene had isomerized during isolation and, or, chromatographic purification.

In subsequent experiments, irradiation of trans p-aminostilbene hydrochloride was studied as a function of time. Figure 28 shows the spectral changes that occur for irradiation times up to 240 min. The extinction coefficients rapidly decrease with increasing irradiation time, and the absorption maximum at 295 mμ disappears within 30 min. Prolonged irradiation results in the decomposition of cis p-aminostilbene. The low absorption in the region of 250 mμ furthermore, indicates that no appreciable amounts of a phenanthrene derivative were built up. Thus, as in the case of irradiation of trans p-hydroxy stilbene, cis p-aminostilbene cation is destroyed by secondary reactions, whose rates are very much slower than trans-cis isomerization. Due to these secondary products, the rate of isomerization can not be calculated from the extinction coefficients of cis and trans amino stilbene cations at two different wavelengths. Rough data can, however, be obtained by the base-line method as outlined in the thermal isomerization of cis p-aminostilbene. In Figure 29, -log A is plotted as a function of irradiation time. Irradiation up to 30 min. is strictly a first order reaction. From the slope of the straight line the first order rate constant is calculates to be $k = 8.1 \, . \, 10^{-4}$ sec^{-1}, corresponding to a half-life of 14 min.

Table 12 summarizes the data on the rate of trans-cis isomerization effected by ultarviolet light in various solvents. These irradiation studies were made in order to find optimum conditions for the production of cis stilbene-derivatives. The rate constants are, therefore, of limited accuracy. The rate constant for the p-aminostilbene cation is about 5 times as high as for the other three compounds and is probably due to acid catalysis.

Table 12

Effect of Ultraviolet light on trans-cis Isomerization at 50°C

Compound	solvent	rate constant 10^4 sec^{-1}
stilbene	benzene	1.8
p-acetoxy	benzene	1.2
p-hydroxy	ethanol	2.0
p-aminostilbene	50% etanol 2 m HCl	9.9

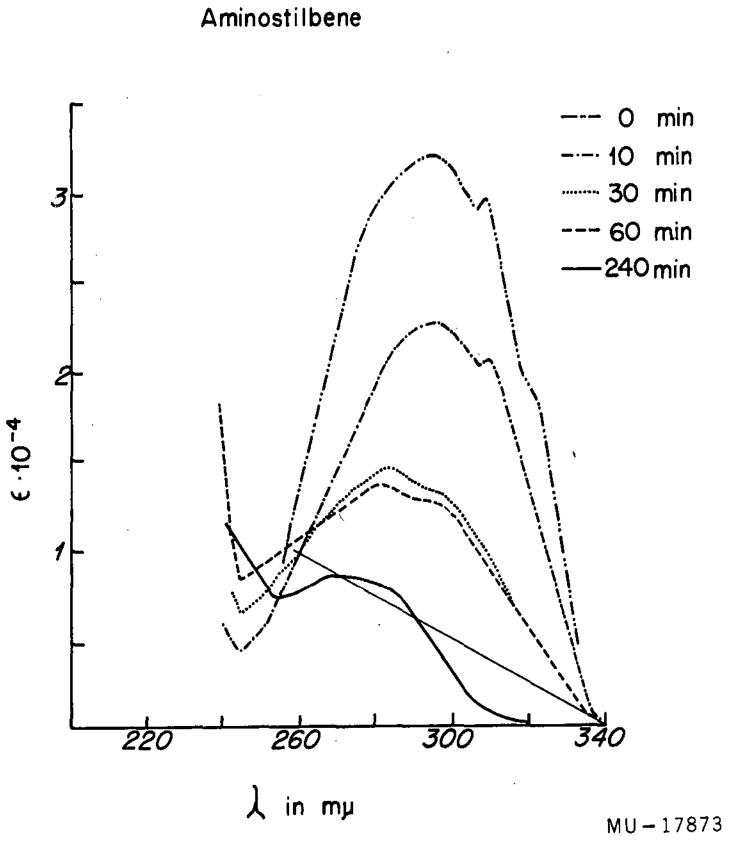


Fig. 28. Irradiation of trans p-Aminostilbene in 50% ethanol -2 n HCl solution.

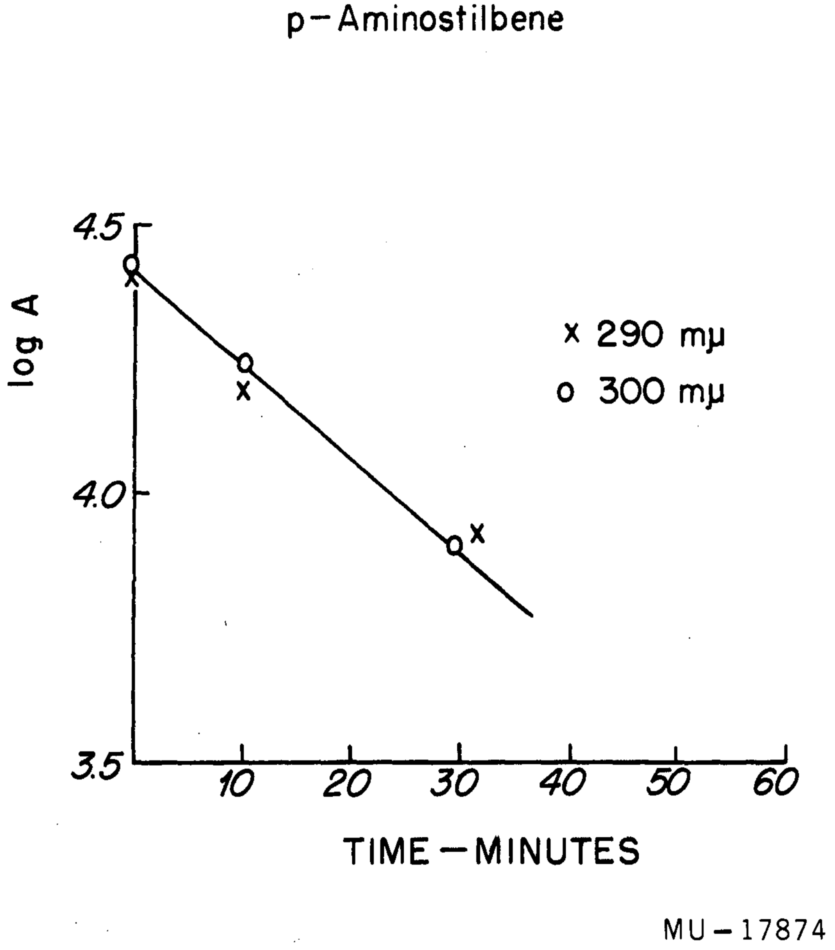


Fig. 29. Rate of trans-cis Isomerization of p-Aminostilbene at 50°C.

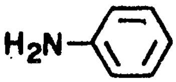
SECTION III p_K of cis and trans aminostilbene cation

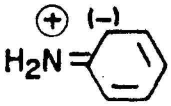
1) General considerations:

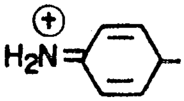
The basic strength of an amine is prescribed by the position of the equilibrium in the system

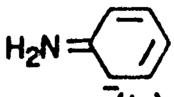
$$RNH_2 + \overset{\oplus}{H} \rightleftarrows \overset{\oplus}{RNH_3}$$

which, in turn, will be determined by the relative thermodynamic stabilities of RNH_2 and its cation $\overset{\oplus}{RNH_3}$. With aniline the resonance structure of the neutral molecule will be stabilized by the considerable delocalization of electrons which is possible, since they may occupy all the positions denoted by the four structures (i) -(iv). In the anilinium cation the unshared pair on the nitrogen has been localized by forming a covalent bond with the acid proton and hence structures resembling (ii)-(iv) are no longer possible. The analine molecule will therefore be greatly stabilized relative to its cation, because of the much greater delocalization, which is possible in the former. This means that the above equilibrium will be displaced largely towards the left side, i.e., aniline will be a very weak base.

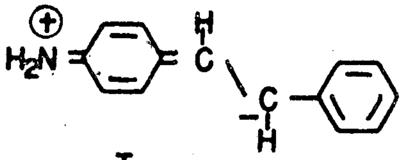

(i)


(ii)


(iii)


(iv)

All of this will, of course, apply equally well to the two amino stilbenes. Structures (II) and (III) will be analagous to (ii)-(iv). In addition, structures like (I), (IV) and (V) will be of importance. If structure (IV) were of great importance to the stabilization of the free base, it would follow, that the pK'of the trans aminostilbene should be much smaller than the one for the cis amine. On the other hand, if structures (I), (II), (III) and (V) are more important, then one would expect the pK of the two amines to be of the same order of magnitude.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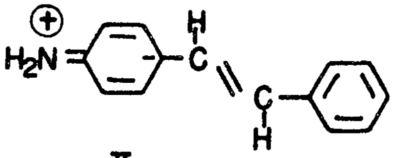
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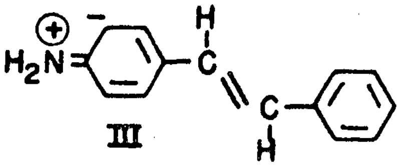
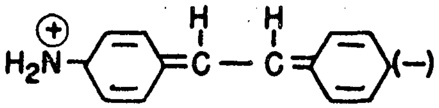
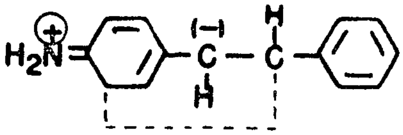

III


IV


V

The pK of both, cis and trans, para aminostilbene have now been measured in 30% metanol buffer solutions. Since trans p-aminostilbene cation is rather insoluble in water and moderate concentrations of methanol, no direct titration was attempted. Instead, citrate buffered solutions of constant ionic strength were used and the differences in the spectra recorded. The average value for the p_k of trans p-aminostilbene at 25°C is 4.20, while the average value of the cis isomer is 4.21 under the same conditions. The true thermodynamic equilibrium constant can be calculated according to the equation (1).

$$p_{K_s} = P_{K_s} + \log \frac{f_b}{f_s} \qquad (1)$$

where k_s is the concentration dependent equilibrium constant, f_b the activity coefficient for the free base and f_s the activity coefficient for the cation. Although the activity coefficients are not known, they may be approximated by equation (2).

$$-\log f_i = \frac{0.5\, z_i^{2} \sqrt{\mu}}{1 + \sqrt{\mu}} \qquad (2)$$

in which μ is the ionic strength and z_i is the charge of species i. If equation (2) is introduced, then equation (1) becomes:

$$p_{K_s} = p_{K_s} + \frac{0.5\,(z_i^{2} - z^{2})\sqrt{\mu}}{1 + \sqrt{\mu}} \qquad (3)$$

For an ionic strength of 0.065 the correction factor in equation (3) becomes 0.10 so that for

trans p-aminostilbene $p_{K_s} = 4.10$
cis p-aminostilbene $p_{K_s} = 4.11$

The reaction constant in the Hammett equation has been reported by Jaffe[14] to be 3.435, the p_K for aniline as 4.320 for the 30% methanol. It is therefore possible to calculate the substituent constants σ for both cis and trans para-phenethenyl, Ph-CH=CH-,

$$p_{K_{\text{analine}}} - p_{K_{\text{aminostilbene}}} = \sigma . \rho$$

The substituent constants are calculated to be:

trans p-phenethenyl $\sigma = 0.064$
cis p-phenethenyl $\sigma = 0.061$
p-phenyl $\sigma = 0.009$

For comparison the value of p-phenyl aniline is given. Thus it can be concluded that structure IV cannot be of great importance.

2) <u>Measurement of the p_K of trans-aminostilbene</u>

(a) Preliminary measurements. In order to establish the changes in spectrum for the free base and its cation Perkampus's buffers for 30% metanol were used. Table 13 gives the composition and pH of these buffers.

Table 13

Perkampus Buffers

pH		ml 0.2 m aq. citric acid	ml 0.2 m aq. Na_2HPO_4
0.2	0.63 m HCl	-----	------
1.3	0.054 m HCl	-----	------
2.03	---------	44.1	2.0
3.20	---------	37.9	14.2
3.92	---------	30.5	28.8
4.72	---------	20.2	31.8
5.55	---------	16.4	38.6
6.65	---------	12.2	47.6
8.24	---------	0.7	52.2
11.2	0.009 m NaOH	----	-----

The volume of citric acid and sodium phosphate were added to 30 ml of methanol and the solution made up to 100 ml solution. It is seen that the ionic strength of these buffers varies greatly with the pH of the buffers. In Figures 30, 31 and 32, the optical densities for a 2.5 . 10^{-5} m trans p-aminostilbene solution are plotted for various wavelengths as a function of the pH. It is seen that the optical densities are nearly constant between pH 0 and 2.5 and again between pH 6 and 11. From these plots a rough estimate of the p_K of trans-aminostilbene cation is about 4.2 Solid trans p-aminostilbene, and to a lesser extent the hydrochloride, becomes slightly brown when standing in air and exposed to normal indirect light. It was therefore decided to determine whether any change could be observed when solutions at various pH were stored for some time. The results are as follows: the cation is stable at pH below 2.0. At a pH of 3.2, the maxima at 297 mμ and 307 mμ shift to a slightly higher wavelength with concurrent lowering of the extinction coefficients. In 25 hours, at room temperature, this change is of the order of 1.2. At a pH of 11.2, a large change in spectrum is observed. At this pH the maximum shifts from 324 mμ to 300 mμ. Figures 33 and 34 show these changes. The change of the spectrum can, however, be neglected for very short periods of time.

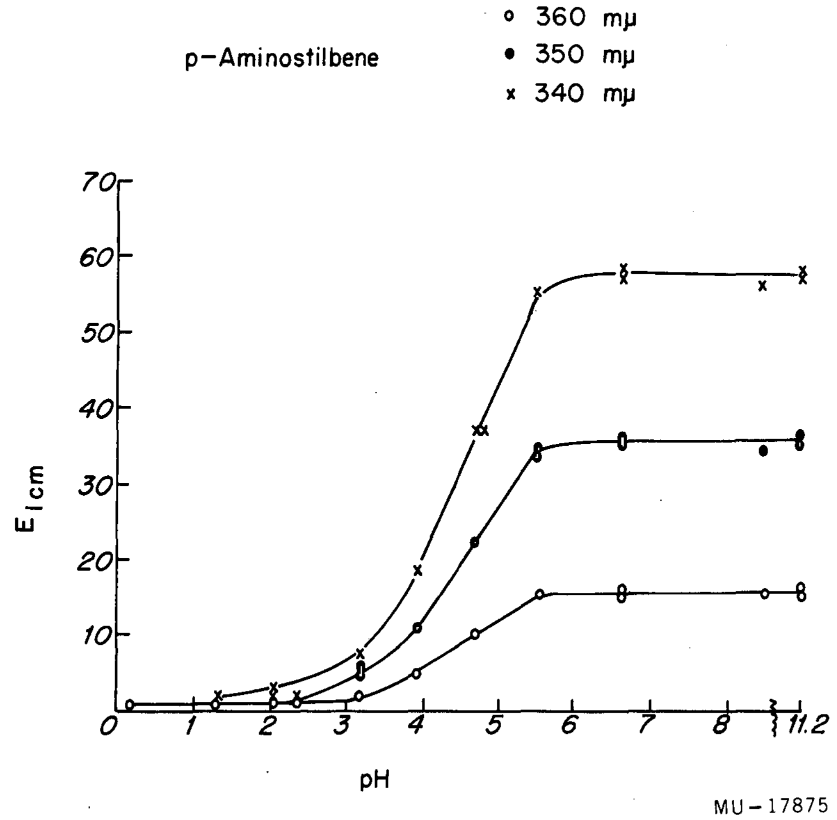


Fig. 30. trans p-Aminostilbene Change of spectrum as a function of pH.

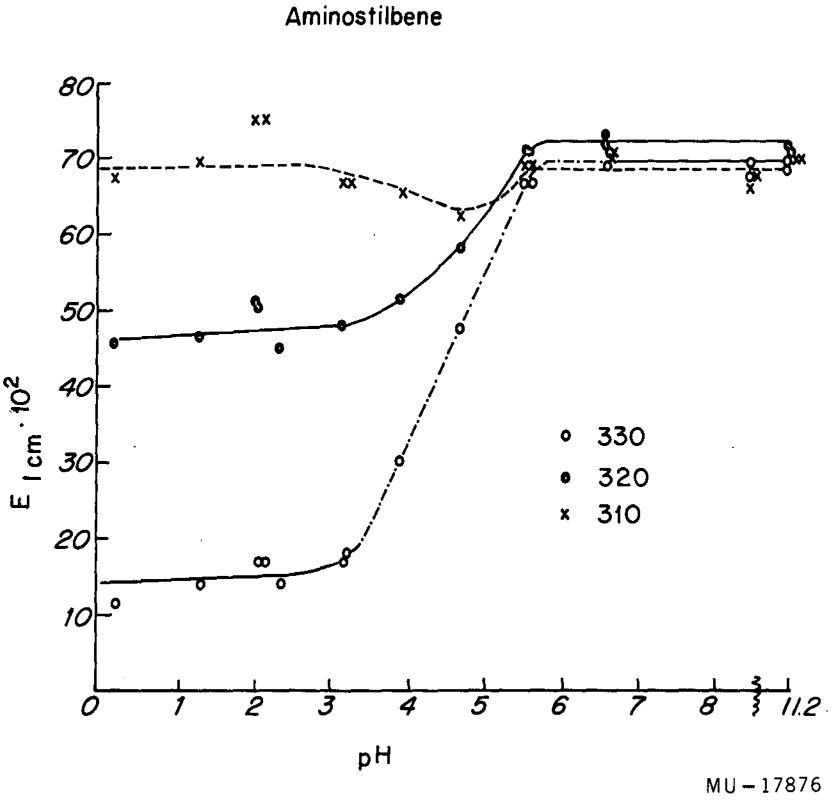


Fig. 31. trans p-Aminostilbene Change of spectrum as a function of pH.

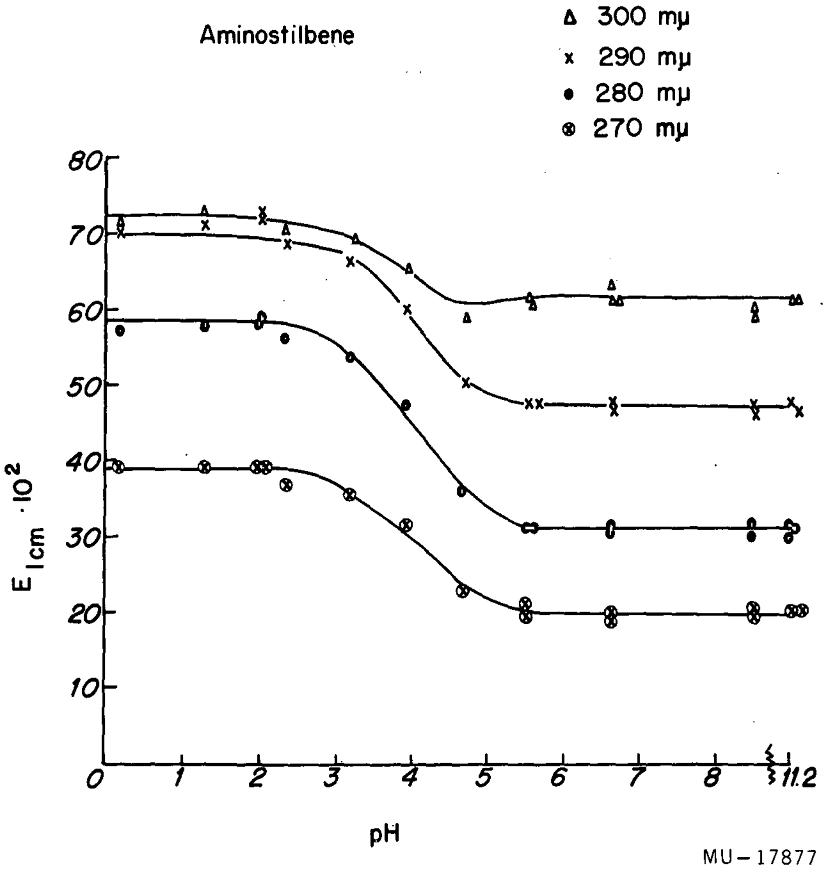


Fig. 32. trans p-Aminostilbene Change of spectrum as a function of pH.

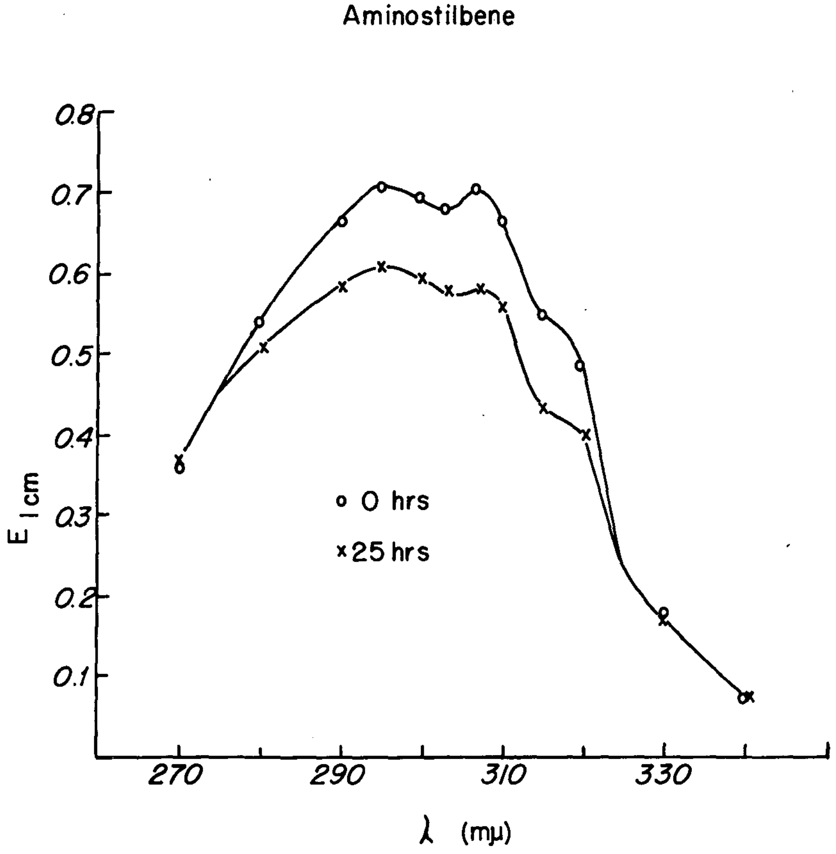


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Fig. 33. Stability of trans p-Aminostilbene in 30% methanol-buffer of pH 3.2 at 25°C.

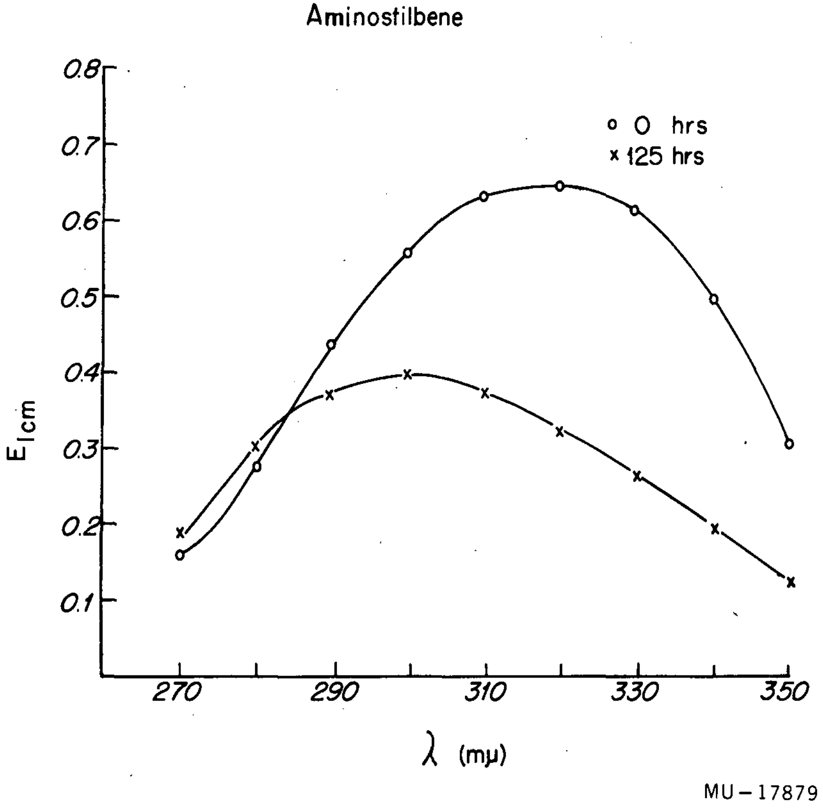

Fig. 34. Stability of trans p-Aminostilbene in 30% methanol-buffer of pH 11.2 at 25°C.

2b Precision Measurement

Stock solution: 53.12 mg freshly prepared trans aminostilbene hydrochloride was dissolved in 30 ml methanol and 10 ml 0.10 m HCl. The solution was made up to 100 ml with distilled CO_2 free water. The stock solution was diluted 1:10 by taking 10 ml and diluting with 30% methanol to 100 ml. Thus the concentration in this dilute solution is $2.30 \cdot 10^{-4}$ molar for the amine and 10^{-3} molar for the H^+.

Table 14

Buffer solutions for the Determination of the p_K of Aminostilbenes

pH	ml HCl 1.0 m	ml NaOH 1.0 m	ml citric acid 0.2 m	ml NaCl 1 m	ionic strength μ
2,1	1.00	---	---	6.25	$7.25 \cdot 10^{-2}$
3,8	---	4.00	25.0	3.25	$7.25 \cdot 10^{-2}$
4.3	---	5.50	25.0	1.75	$7.25 \cdot 10^{-2}$
4.8	---	7.25	25.0	0.00	$7.25 \cdot 10^{-2}$
11.6	---	1.00	---	6.25	$7.25 \cdot 10^{-2}$

30 ml methanol and distilled CO_2 free water was added to make up 100 ml buffer solution.

Spectroscopic Measurements

1) Blank: 1.00 ml 10^{-3} m H^+ 9.0 ml buffer were made to 10.0 ml

2) Amine: 1.00 ml 2,3 . 10^{-4} molar amine + 9.0 ml buffer were made up to 10.0 ml. To minimize errors, all solutions were made up immediately before the spectra were taken. In all cases the same volumetric equipment was used. Corrections were made for the small contributions from the blank for each individual buffer.

pH Measurement at 25°C

A battery operated pH meter, Beckman Model N, a 4990-80 General Purpose glass-electrode, and a calomel electrode 4970, fiber type, were used for pH measurement. The instrumnet was standardized with a Beckman buffer 14044 of pH 4.01 and checked with a Coleman buffer pH 2.00(#54). pH values of methanol buffer solutions have been measured by Perkampus et al, (loc.cit.) with hydrogen-calomel electrodes. For McIlvaine buffer in 30% methanol, they reported a pH of 2.48 which is in good agreement with the value pf 2.52 at 25°C found for the glass electrode calomel system. The pH of the methanolic buffers is constant after a period of 15 sec., and shows no drifting within 20 min, thus indicating that the equilibrium at the surface is established very rapidly.

The effect of the methanol concentration on the extinction coefficient was also determined. It was found that up to 87% methanol no change in the extinction coefficient of the free base and its corresponding acid can be observed.

The effect of the ionic strength on the extinction coefficients was determined. Within the range of mμ 0.009 and 0.315 no change could be observed for both the free amine and its cation. Table 15 gives the corrected optical densities for 1 cm cell thickness, and a concentration of 2.30 . 10^{-5} min in 30% methanol. The spectra are reported in Figures 35 and 36.

Table 15

p_K of trans Aminostilbene

pH		wavelengths in mμ							
		340	330	320	290	280	270	χ max	λ max
2.10	E_{1cm}	0.015	0.12	0.455	0.685	0.555	0.360	295	307
	$\varepsilon . 10^{-3}$	0.650	5.20	19.80	29.70	24.20	15.60	31.80	30.6
3.87	E_{1cm}	0.195	0.320	0.535	0.535	0.450	0.280	297	307
4.32	E_{1cm}	0.330	0.445	0.595	0.595	0.395	0.240		308
4.85	E_{1cm}	0.460	0.570	0.650	0.650	0.480	0.320	322	310
11.63	E_{1cm}	0.575	0.685	0.700	0.700	0.435	0.270	324	
	$\varepsilon . 10^{-4}$	2.50	2.97	3.04	1.89	1.16	0.65	314	

where E_{1cm} stands for the optical density and is the extinction coefficient at a particular wavelength .

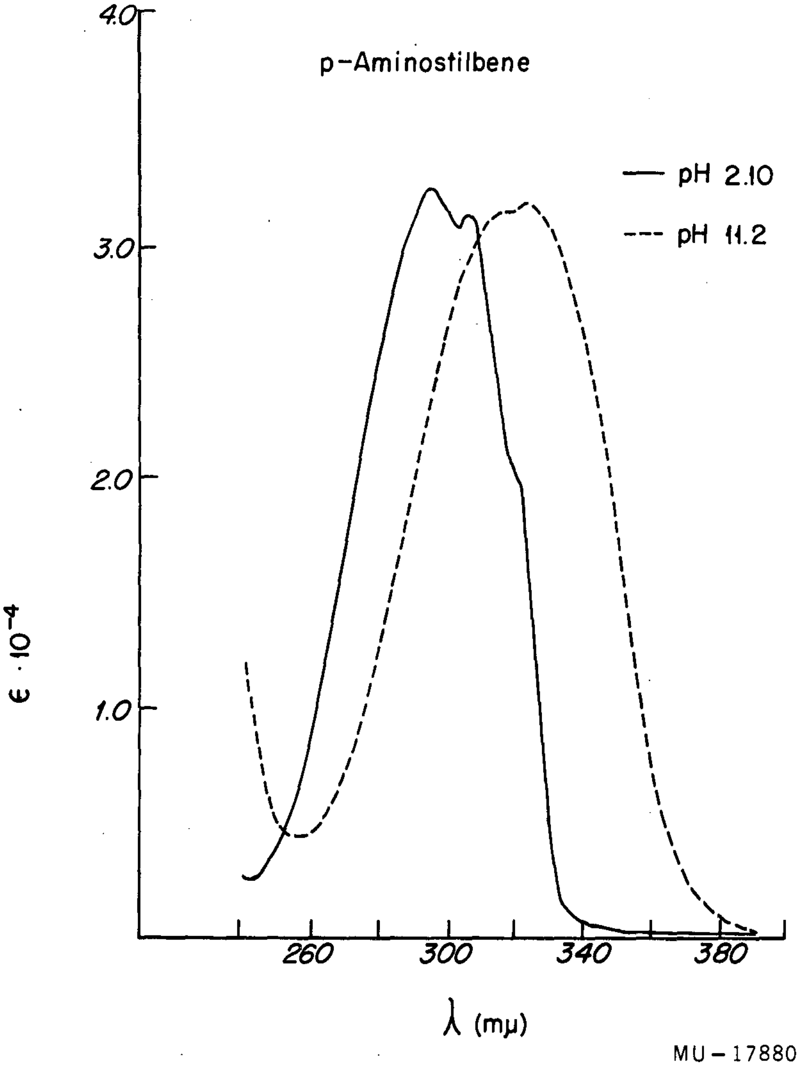

Fig. 35. Spectrum of trans p-Aminostilbene and its cation in 30% methanol.

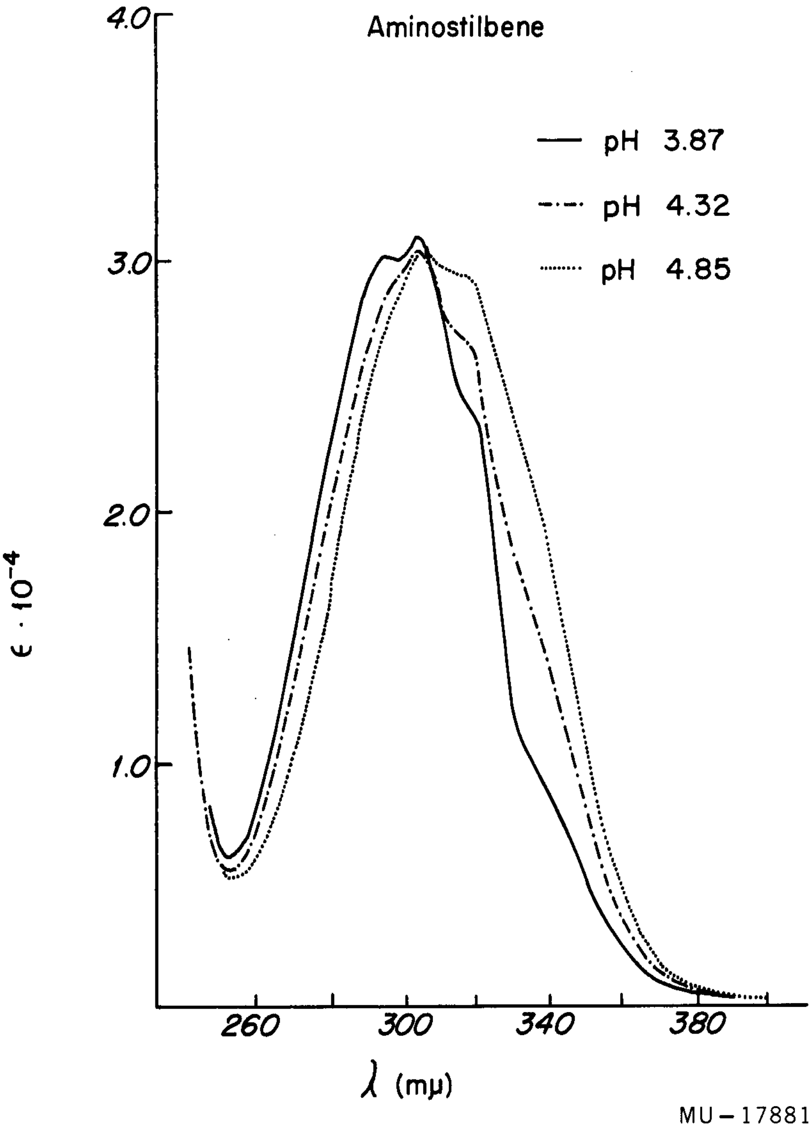

Fig. 36. Spectra of trans p-Aminostilbene at various pH in 30% methanol.

Calculation of the p_K

$$p_K = pH + \log \frac{c1}{c2} \qquad (1)$$

c1= concentration of the cation of the amine

c2 =concentration of the free amine

$$E_1 = C_1 \varepsilon_{11} + C_2 \varepsilon_{12} \qquad (2)$$

$$E_2 = C_1 \varepsilon_{12} + C_2 \varepsilon_{22} \qquad (3)$$

At constant pH, E_1 = optical density for wavelength 1

ε_{11} = extinction coefficient for wavelength 1 and the ammonium ion

ε_{12} = extinction coefficient for wavelength 1 and the amine

E_2 = optical density for wavelength 2

ε_{21} = extinction coefficient for wavelength 1 and the ammonium ion

ε_{22} = extinction coefficient for the amine at wavelength 2

By solving equation (2) and (3) for C_1 and C_2 the following expressions are obtained:

$$C_2 = \frac{E_2 \varepsilon_{11} - E_1 \varepsilon_{21}}{\varepsilon_{11} \varepsilon_{22} - \varepsilon_{12} \varepsilon_{21}} \qquad (4)$$

and

$$C_1 = \frac{E_1 \varepsilon_{22} - E_2 \varepsilon_{12}}{\varepsilon_{11} \varepsilon_{22} - \varepsilon_{12} \varepsilon_{21}} \qquad (5)$$

so that:

$$\frac{C1}{C2} = \frac{E_1 \varepsilon_{22} - E_2 \varepsilon_{12}}{E_2 \varepsilon_{11} - \varepsilon_1 \varepsilon_{21}} \qquad (6)$$

and

$$p_K = pH + \log \frac{E_1 \varepsilon_{22} - E_2 \varepsilon_{12}}{E_2 \varepsilon_{11} - E_1 \varepsilon_{21}} \qquad (7)$$

Inspection of equation (7) shows that the p_K is a complex funtion of both the extinction coefficients and optical densities. Since both nominator and denominator are differences, only those wavelengths were used for calculation in which these differences were significant. In all cases the total concentration

$$c_{tot} = c_1 + c_2$$

wascalcualted and all data rejected which were not within 3% of the experimental value. Table 16 gives the results for buffers of pH 3.87, 4.32 and 4.85. Inspection of the data, furthermore, indicates that the material used for p_K measurement is reasonably pure, since the p_K calculated from three different pH shows no significant trend.

Table 16

p_K of trans p-aminostilbene in 30% methanol at 25.0°C

p_H	wavelength mμ	$c_{total} \cdot 10^5$	p_{K_s}
3.87	340 - 290	2.290	4.19
	340 - 280	2.240	4.17
	340 - 270	2.240	4.17
	330 - 290	2.310	4.13
	320 - 290	2.340	4.12
average		2.284	4.16
4.32	340 - 370	2.331	4.22
	340 - 290	2.304	4.22
	340 - 280	2.395	4.25
	340 - 270	2.294	4.21
	330 - 280	2.321	4.20
	330 - 270	2.306	4.19
	320 - 290	2.313	4.21
	320 - 270	2.301	4.20
	290 - 270	2.327	4.18
average		2.321	4.21
4.85	320 - 290	2.290	4.22
	320 - 280	2.258	4.16
	320 - 270	2.294	4.23
	290 - 280	2.297	4.21
	290 - 270	2.277	4.25
average		2.282	4.21
over all average		2.301	4.20

3) Measurement of the p_K of cis p-Aminostilbene

The procedure for measurement of the p_{Ks} of cis p-aminostilbene is identical with the one for the trans isomer. Table 17 gives the corrected optical densities for 1 cm cell thickness and a concentration of $3.15 \cdot 10^{-5}$ m in 39% methanol. Spectra of the cation and the free base are shown in Figure 37. For stability of the cis amine see the section under the heading *Isomerization of cis aminostilbene*.

Table 17

P_{K_s} of cis-aminostilbene

		Wave length in mμ						
P_H		340	330	320	310	300	270	260
2.10	$E_{1cm} . 10^2$	1.0	3.0	9.5	17.0	25.0	32.0	27.0
	$.10^{-3}$	0.31	0.99	2.97	5.32	7.82	10.0	8.44
3.85	E_1 cm $.10^2$	5.0	9.5	16.0	23.5	31.0	29.0	24.0
4.27	E_1 cm $. 10^2$	8.5	13.5	21.0	29.5	35.0	27.0	21.5
4.79	$E_{1cm}.10^2$	13.0	20.0	26.5	34.5	39.0	24.5	19.0
11.58	E_1 cm $.10^2$	17.5	25.0	32.5	40.5	45.0	23.5	17.5
	$.10^{-3}$	5.47	7.82	10.15	12.66	14.07	7.34	5.47

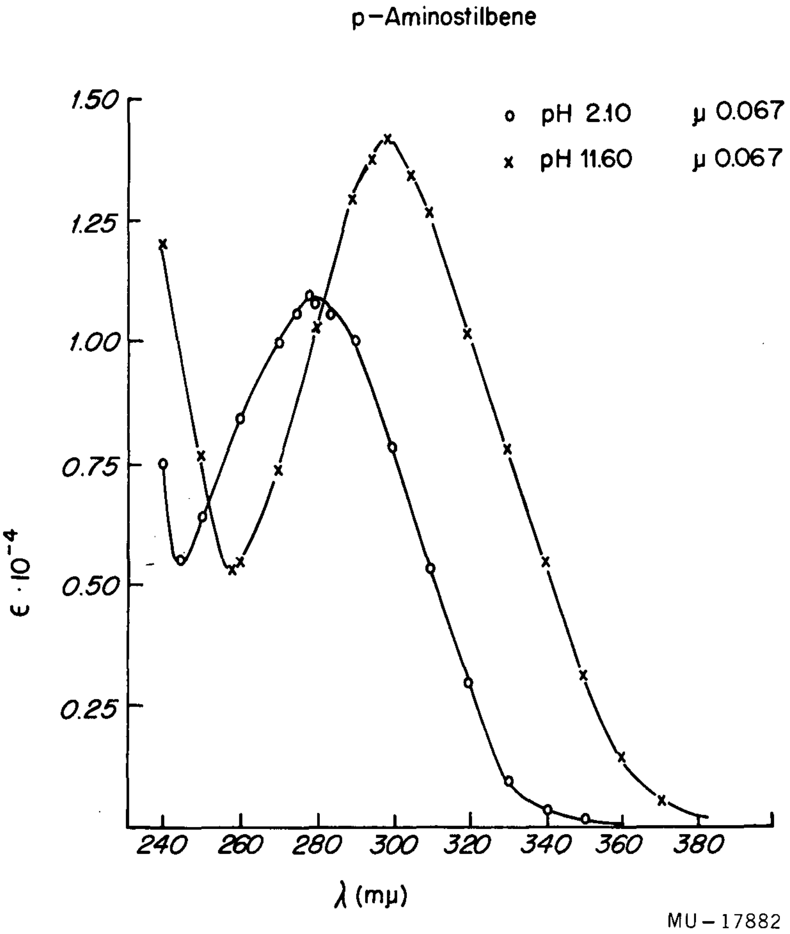

Fig. 37. Spectrum of cis p-Aminostilbene and its cation in 30% methanol.

Table 18

p_K of cis-p-aminostilbene in 30% methanol at 25.0°C

p_H	wavelength	$c_{total} \cdot 10^5$	p_K
3.85	330 - 320	3.057	4.19
	330 - 310	3.094	4.21
	330 - 300	3.214	4.23
	330 - 260	3.176	4.22
	320 - 310	3.128	4.22
	320 - 270	3.148	4.22
	300 - 270	3.165	4.18
average		3.140	4.21
4.27	330 - 300	3.262	4.21
	330 - 260	3.153	4.25
	320 - 270	3.136	4.23
	310 - 260	3.256	4.20
	300 - 270	3.142	4.24
average		3.189	4.23
4.79	330 - 310	3.049	4.14
	330 - 260	3.124	4.20
	320 - 270	3.064	4.21
	310 - 260	3.111	4.23
	300 - 270	3.082	4.26
average		3.086	4.20
over all average		3.14	4.21

SECTION IV

p-Diazostilbenes and their decomposition products.

1) General Considerations. Previous work on the isomerization of stilbenes was either done in the gas phase[16)] or in the pure liquid phase[17,18]. The compounds were mainly p-substituted or p-p'-disubstituted stilbenes. In all cases studied so far, the ionic contributers to the resonance hybid were such that a partial positive charge was associated with an atom attached to the stilbene nucleus. In this respect cis diazostilbene offers unique possibilities. Diazocompounds can be decomposed by two different mechanisms:

a) The ionic mechanism of the decomposition of diazonium cations is supported by the experimental observation that the reaction is strictly first order in aqueous acid solutions and that the rate is independent of the nature and concentration of the anion in dilute solution.[19]

$$Ar\text{-}\overset{+}{N}_2 \xrightarrow{11} \overset{+}{Ar} + N_2$$

$$\overset{+}{Ar} + X^- \longrightarrow Ar\text{-}X$$

X^- being a nucleophilic species such as Cl^- etc.

b) Free radical mechanism: When diazoiumsalts are dissolved in aqueous hypophosphorous acid they are reduced to hydrocarbons. The reaction is strongly catalyzed by traces of oxydizing agents, such as cupric ion, and are strongly inhibited by benzoquinone. Both of these observations support a free radical mechanism as suggested by Korhblum[20].

$$\overset{+}{ArN_2} \quad H_3PO_2 \rightleftharpoons Ar\text{-}N\ N\text{-}O\text{-}\overset{H}{P}\text{-}OH + H^+$$

$$Ar\text{-}N\ N\text{-}O\text{-}\overset{H}{P}\text{-}OH \longrightarrow Ar\cdot + H_2\dot{P}O_2 + N_2$$

$$H_2PO_2 \quad Ar\text{-}N_2 \longrightarrow Ar\text{-}H \quad H_2PO_2$$

$$Ar\cdot \quad H_3PO_2 \longrightarrow Ar\text{-}H + H_2PO_2$$

Thus by decomposition of cis diazoniumstilbene it is possible to generate either a stilbene-radical or stilbene carbonium ion depending on the conditions used. If now the life time of the free radical resp. carbonium ion is larger than the time required for one vibration within the molecule (ca 10^{-13} sec) then one would expect, that the isolated product would be a trans stilbene. In other words, the rate of the secondary reaction is slow enough that the free radical resp. carbonium ion can isomerize. On the other hand, if the rate of the secondary reaction is very fast, then isomerization of the free radical resp. carbonium ion will not be possible and the product will be a cis stilbene. Careful analysis of the products of the reaction wil thus give information regarding the life-time of the free radical resp. carbonium ion.

2) Stilbene diazonium salts. Trans stilbene diazoium salt. 1 g of trans p-aminostilbene hydrochloride was dissolved in 300 ml of ethanol at 60° C, the solution cooled to 5°C and filtered from undissolved salt. 0.3 ml of cold concentrated sulfuric acid was then added, and then slowly 0.54 ml n-butylnitrite added while stirring. After 1 1/2 hrs a small portion was diluted with 10 volumes of cold ether and the solution cooled to -30°C. Since no diazonium sulfate crystallized, the bulk of the remaining solution was used in further experiments without isolation of the diazonium salt. A small aliquot of the ethanolic stilbene diazonium sulfate solution was diluted about 200 times with 6 n hydrochloric acid. It showd an absorption maximum at 395 mμ

Cis stilbene dizonium salts. Since no trans stilbene diazonium sulfate could be precipitated when Knoevenagels procedure was used, and since generally cis stilbenes are much more soluble than trans stilbenes, no attempt was made to prepare cis stilbene diazonium sulfate. Instead, it was hoped that it would be possible to precipitate cis diazostilbene cation as the fluoborate. In order that good yields results in the preparation of diazofluoborates, diazotisation of the amines is generally carried out in strong mineral acid using very concentrated solution.

1) 500 mg of cis p-aminostilbene hydrochloride was dissolved in 3 ml cold 2 m hydrochloric acid. While stirring vigorously 2.2 ml 1 m sodium nitrite solution was added. During diazotisation a large amount of a orange precipitate was formed which was filtered off. The filtrate on addition of 1.1 ml 2.8 m sodium fluoborate resulted in the formation of a small amount of diazonium fluoborate while the solution showed an intense yellow color. Solution 1, table 21. The ultraviolet spectrum of this solid diazofluoborate showed an absorption maximum at 380 $m\mu$ in water as well as in saturated sodium bisulfate solution. Infrared spectra could not be taken since the available silverchloride cells prooved unsatisfactory even when D_2O was used instead of water. In view of these technical difficulties no further attempts were made to produce solid diazonium salts.

2) 300 mg of cis p-aminostilbene-hydrochloride was suspended in 100 ml of 4 molar hydrochloric acid at 0°C. The spectrum of the insoluble portion (104 mg) revealed that no isomerization of the aminostilbene cation had occured. To the filtrate were then added small portions of 0.2 molar sodium nitrite solution. After each addition a drop of thereaction solution on potassium-jodid-starch paper produced an intense blue color. As long as aminostilbene was still present in excess, nitrite was used up rapidly, and

subsequent drops of solution failed to produce the blue color with the starch paper, the time required being less than 5 min. With the last portion of nitrite added, that is, when an initial excess nitrite was no longer used up, a blue color could be detected even after 10 min. had elapsed. Thus by using this technique, the actual concentration of nitrite in the reaction medium was always very small and consequently any side reaction, due to excess of nitrite, was minimized. The total time required for diazotisation was about 45 min. An aliquot of this diazonium solution (solution 11, table 21) diluted with 0.02 m hydrochloric acid showed an absorption maximum at 395 mμ and an extinction coefficient of about $2 \cdot 10^5$. This absorption maximum is identical with the trans stilbene diazonium ion. That isomerization during diazotisation had occurred, is revealed by the products obtained on decomposition of the diazosolution (see under decomposition experiments.)

3) In order to determine whether cis aminostilbene cation or cis stilbene diazonium ion was isomerized during diazotisation 300 mg of cis aminostilbene hydrochloride was dissolved in 100 ml water at 0°C. After addition of 3.25 ml of 1 m hydrochloric acid - corresponding to 2.5 equivalents of H^+ per mole of amine- diazotisation was carried out as described above (solution 111, table 21(. 1 1/2 hours after the first addition of sodium nitrite aliquots were diluted with hydrochloric acid of various concentration as indicated in table 19. Inspection of table 19 suggests that some isomerization during diazotisation occurs. Furthermore the bathochromic shift observed by increasing the concentration of hydrochloric acid is only partially due to the solvent.

TABLE 19

Influence of the solvent on the spectrum of cis stilbenediazonium ion (solution 111) at 0°C.

Concentration of HCl molar	Time after Dilution, Min.	Absorp. Maximum mμ	Opt. Density E_{1cm}	Time after Dilution Min	Absorp Maximum mμ	Opt Density E_{1cm}
10^{-3}	2	390	0.48	155	390	0.37
10^{-2}	2	390	0.52	155	390	0.48
1	2	393	0.48	155	393	0.42
12	2	396	0.56	155	402	0.42
	12	398	0.55			

TABLE 20

Califbration curves for cis and trans stilbene mixtures in CS_2. c_{total} 0.278 m/l throughout

c_{trans} molar/et	c_{cis} molar/et	optical densities at 10.45 μ	optical densities at 10.88 μ
0.278	0.000	0.899	0.010
0.251	0.0278	0.867	0.035
0.195	0.0834	0.696	0.090
0.139	0.139	0.533	0.158
0.0834	0.195	0.311	0.211
0.0278	0.251	0.118	0.268
0.000	0.278	0.029	0.310

Reduction of cis stilbene-diazonium solutions. Diazo solutions, described in the previous section, were diluted with an equal volume of 50% hypophosphorous acid, in some cases a small amount of cupric sulfate was added, and the reaction mixture stored at 5°C until a small aliquot q added to a dilute aqueous H-acid solution of p_H 8, no longer produced a red color. The reaction, using cupric ion as a catalyst, requires about 10 min. for completion, whereas the uncatalysed reaction takes between 2 and 16 hours for completion.

The reaction mixture was then extracted with ether, the ether washed with aqueous sodium carbonate solution and then several times with water. After evaporation ofthe ether the residue was taken up in n-hexane in which both cis and trans stilbene is soluble.

Infrared spectra were taken in CS_2 and the optional densities determined at 10.45μ for the trans component and 10.88μ for the cis component. The concentration of the cis and trans component were then determined from previously established calibration curves.

The optical densities are plotted as a function of concentration in Fig. 38 using a NaCl-cell of 0.136 mm thickness. Inspection of these curves indicates that Beer's law is obeyed up to concentrations of 0.25 moles/lt. In Table 21 experimental results for the decomposition in 25% hypophosphorous acid solution are tabulated. In column 2 the wavelength of the absorption maximum for a particular diazonium solution is given. Per cent trans stilbene indicates the ratio of the concentration of trans stilbene and the sum of cis and trans stilbene multiplied by 100, percent total stilbene indicates the ratio of the weight of cis and trans stilbene found spectroscopically and the weight of sample used for the spectroscopic determination.

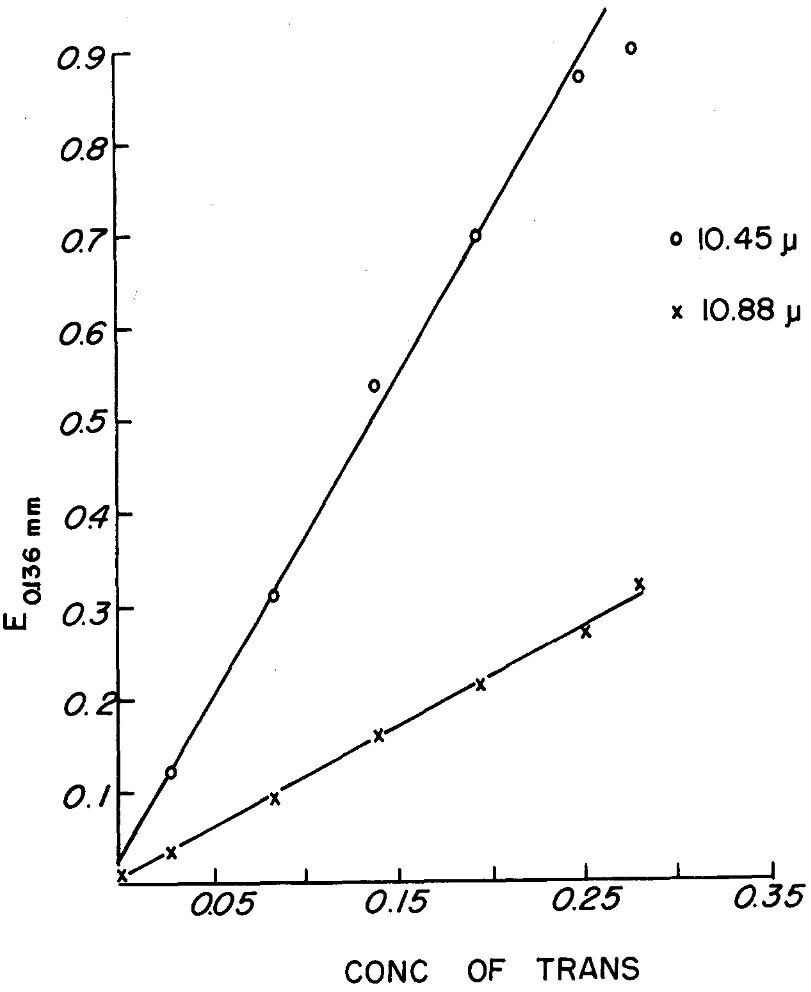

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Fig. 38. Cis-trans Stilbene mixtures. Optical densities for the two characteristic wavelengths and a total concentration of 0.278 m in Carbondisulfide.

TABLE 21

Decomposition in 25% hypophosphorous acid

Solution	Conditions used for reduction	Absorp. max. mμ	%trans stilbene	% total stilbene
1	cupric ion catalysis	380	12	55
1	no catalyst	380	20	40
11	cupric ion catalysis	395	98	57
111	cupric ion catalysis	390	50	60

The table clearly indicates that a stilbene diazonium solution with an absorption maximum near 380 mμ is associated with the cis isomer, whereas a stilbene diazonium solution showing an absorption maximum at the wavelength of the trans isomer results in the formation of only trans stilbene. Furthermore, the % total stilbene is consistently below 100%. Extraction of the acidic reaction mixture with ether and redissolving of the ether extract in n-hexane gives rise to a mixture of at least 3 compounds, namely cis and trans stilbene and one or more additional neutral compounds, whose structure can not be a 1:2-disubstituted ethylene.

4) Coupling products of diazostilbenes

Although H-acid, 8 aminonaphtol-3,6 disulfonic acid, may be coupled with diazo solution in the 2 or 7 position, the reaction product is a pure 2 substituted H-acid, since in bicarbonate solution, coupling in the 7 position is prevented due to the much lower reactivity of this position at the pH. Furthermore, the azo-compound, once formed, will not couple with a second molecule of diazostilbene so that there is no doubt as to the structure and purity of the dye formed.[21] Coupling of cis diazostilbene(U.V. 380 mμ) with H-acid under the same conditions results in the formation of a red dye with absorption maxima at 535 mμ in 6 n HCl and 545 mμ in bicarbonate solution.

SECTION V

Ultraviolet Spectra of Stilbene Derivatives

The spectra of the stilbene derivatives studied are shown in connection with the individual compounds. All spectra were taken on a Cary Recording Spectrophothometer. Spectra of p-acetoxy-and p-acetoaminostilbene were measured in ether, since the spectra in alcoholic solvents might be altered due to trans-esterfication. These absorption maxima have been corrected; a bathochromic shift of 7 mμ being assumed. Spectra of p-aminostilbenes were measured in 30% methanol. The spectrum of the p-aminostilbenes cation is not affected in the region of pH 0-3. Similarly, the above a pH of 5.5 the extinction coefficients are constant. For further references see the section on p_K measurement. Absorption maxima, bathochromic shifts and extinction coefficients are summarized in Table 22. For comparison in Table 23, corresponding data for monosubstituted benzene derivatives are recorded. δ corresponds to the bathochromic shift in mμ from the corresponding unsubstituted stilbene resp. benzene absorption maximum.

Table 22

U.V. spectra of mono substituted stilbene derivatives

	cis			trans					
	λ max mμ	δ	$\varepsilon \cdot 10^{-4}$	λ $\max_1$ mμ	δ	$\cdot 10^{-4}$	λ $\max_2$ mμ	δ	$\varepsilon \cdot 10^{-4}$
Stilbene	278	0	1.08	296		2.83	308	0	2.77
p-chloro	283	+5	1.10	301	+5	3.10	314	+6	2.98
p-OH	295	+17	1.10	305	+9	2.80	320	+12	2.75
p-acetoxy	287	+9	1.00	307	+11	2.85	3.9	+11	2.55
p-methoxy	288	+10	1.3	305	+9	2.9	323	+15	2.8
p-acetamino	303	+25	0.80	307	+11	---	319	+11	---
p-amino	299	+21	1.44	324	+16	3.14 or	324	+28	3.14
p-NH_3	278	0	1.11	297	+1	2.68	309	+1	2.77
p-NO_2	326	+48	1.06	349	+53	2.37	349	+41	2.37

Table 23

U.V. spectra of mono substituted benzene derivatives[23]

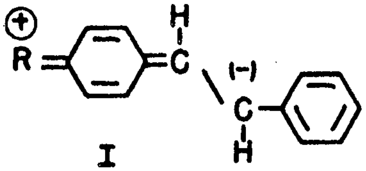
	$\lambda\ max_1$ mμ	δ	$\varepsilon \cdot 10^{-3}$	$\lambda\ max_2$ mμ	δ	$\varepsilon \cdot 10^{-2}$
benzene	203.5	---	7.4	254	---	2.04
chloro	209.5	- 6	7.4	263	-10	1.90
hydroxy	210.5	- 7	6.2	270	-16	14.50
methoxy	217	-14	6.4	269	-15	14.8
amino	230	-17	8.6	280	-26	14.3
acetaniline	242	-39	1.4	280	-26	5.0
aniline cation	203	0	7.50	254	0	1.60
nitro	268.5	-65	7.80	350	96	2.00

Substituents on the benzene and stilbene nucleus show bathochromic shifts of the same order of magnitude. These data then confirm Coulson's conclusion that structure V for the stilbene derivatives must be of great importance in the excited state. Whereas the extinction coefficients of the first absorption maximum for benzene derivatives are of the same order of magnitude, the extinction coefficients of the second absorption maximum are markedly increased, when substituents are introduced. Thus it is seen, that aniline with an absorption maximum of 280 mμ shows a seven-fold increase in the extinction coefficient over benzene.

In both the cis and trans stilbenes no such great changes are observed. Most of the trans stilbenes show fine structure in the region of 320-290 mμ. In general, two distinct absorption maxima separated by about 12 mμ and a shoulder separated from the first absorption maximum by about 25 mμ can be recognized. P-aminostilbene in 0.009 m sodium hydroxide 30% methanol shows a shoulder between 310 and 320 mμ. The lack of fine structure is, however, probably due to the increased polarity of the solvent. P-nitrostilbene shows no fine structure. Beale [22] attributes the fine structure of trans stilbene to an ethylenic C=C stretching frequency. In the cis stilbene series no fine structure is observed.

From figure I, the structures expected to be of importance in light absorption would be

a) in the ground state:



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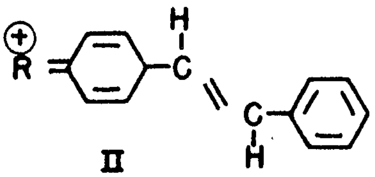

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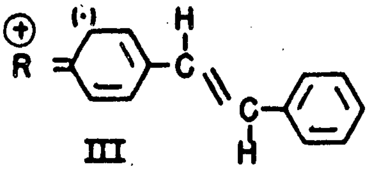
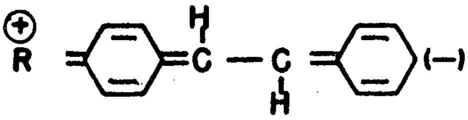
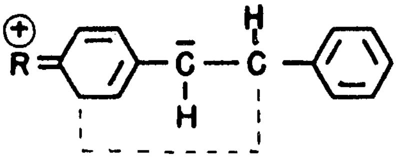


III

b) in the lowest excited state:



IV



V

Structures IV and V should make their greatest contribution to the resonance-hybrid when the molecule is planar and should be of little importance in the ground state of the molecule. If structure V is the main contributor to the excited state, then the influence of a substituent R would be expected to be nearly the same for both the cis and trans isomer. On the other hand, if structure IV is the main contributor to the excited state, then the influence of the substituent would be expected to be different for the two isomers. The delta values indicated in Table 22 are seen to be very much the same for the cis and trans isomer.

SECTION VI

Infrared spectra of Stilbene Derivatives

cis and trans stilbene - The main absorption bands for cis and trans stilbene are shown in Table 24.

Table 24

Main Absorption Bands of Stilbene

trans		cis	
wave number cm^{-1}	extinction coefficient	wave number cm^{-1}	extinction coefficient
3050	56	3087	44
3011	80	3030	52
957	254	923	88
762	---	781	218
687	340	695	312

The exact position of the ethylenic C-H stretching band in the 3100-3000 cm^{-1} region is influenced by the substitution of the C=C bond and thus could be of analytical value. However, the aromatic C-H stretching bands overlap with the former. Characteristic C-H out-of-plane bending bands in the infrared spectra of linear trans oelfines have been assigned to 980-965 cm^{-1} with extinction coefficients of about 100. In contrast, the cis R_1 $CH=CHR_2$ band has originally been placed at 980-965 cm^{-1} but has subsequently been revised to 690 cm^{-1}.

In Table 25 the characteristic bands are listed, with the corresponding extinction coefficients for compounds measured in solution. It is seen, that the frequency of absorption for all cis isomers lies about 50 wave numbers below the value of the trans isomer.

Table 25

Infrared spectra of mono substituted stilbene derivatives.

Stilbene derivative	cis			trans		
	wave number	ε	solvent	wave number	ε	solvent
p-nitro	915	48	CS_2	966 953	120 120	$CHCl_3$
azoxy	916	--	CS_2	968 950	---	wt. oil
azo	918	95	CS_2	---	---	---
p $NH_3^{+}Cl$	917	--	wt. oil	957	---	wt. oil
p N-acetylamino	918	--	wt. oil	968	---	wt. oil
stilbene	923	88	CS_2	957	254	CS_2
p-chloro	916	57	CS_2	958	268	CS_2
p-hydroxy	---	--	---	957	---	wt. oil
p-acetoxy	915	71	CS_2	969	---	wt. oil

wt. oil = white oil

References

1. C. A. Coulson and J. Jacobs, J. Chem. Soc., 1949, 1953
2. R. E. Buckles in "Organic Synthesis" 33, 88, 1953
3. R. E. Buckles in "Organic Synthesis" 33, 88, 1953
4. Th. Zincke, Ann. 349, 190, 1906
5. H. W. Alter, Thesis, University of California, Berkeley, 1948
6. G. Drehfal, B, 91, 264, 1958
7. F. Bergmann, J. Org. Chem. 12, 61, 1947
8. C. Weygard, B, 71, 2474, 1938
9. R. Stroemer, B, 55, 1233, 1922
10. M. Pailler, Monats., 79, 615, 1948
11. R. E. Buckles, J. Am. Chem. Soc., 77, 1040, 1955
12. W. H. Urry, J. Am. Chem. Soc., 75, 250, 1954
13. G. M. Badger, J. Chem. Soc., 1954, 2243
14. H. H. Jaffe, Chem. Rev., 53, 167, 1953
15. H. H. Peskampus, Z. für Electrochemie, 61, 837, 1957
16. G. B. Kistiakowski, J. Am. Chem. Soc., 54, 2208, 1932
17. T. W. J. Taylor, J. Chem. Soc., 1938, 2078
18. M. Calvin and H. W. Alter, J. Chem. Phys., 19, 768, 1951
19. W. A. Waters, J. Chem. Soc., 1942, 266
20. N. Kornblum, J. Am. Chem. Soc., 72, 3013, 1950
21. H. Zollinger, Birkhauser, 1958
22. L. Daub, J. Am. Chem. Soc., 69, 2714, 1947