Anal. Calcd for $C_{13}H_{24}ClNO_6$: C, 47.92; H, 7.43; N, 4.29. Found: C, 47.86; H, 7.53; N, 4.19.

On attempts to prepare a crystalline free base from the pure hydrochloride by neutralization, IXc readily lost an acetyl group yielding an oily monoacetate.

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The Addition of Aromatic Nitroso Compounds to Conjugated Dienes. II

MUSHTAQ AHMAD[1] AND JAN HAMER

Department of Chemistry, Tulane University, New Orleans, Louisiana 70118

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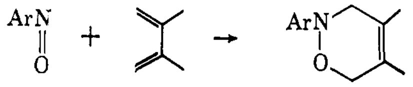
The addition of seven *para-* or *meta*-substituted arylnitroso compounds to 2,3-dimethyl-1,3-butadiene has been studied kinetically between 2 and 30° in dichloromethane. Rate constants and activation parameters have been obtained. A considerable substituent effect is observed ($\rho = +2.53$). The reaction appears to obey the isokinetic relationship, with $\beta = 470°K$.

In an earlier paper[2] we established that the 1,4-cycloaddition reaction between 2,3-dimethyl-1,3-butadiene and *p*-bromonitrosobenzene has a first-order kinetic dependence on the conjugated diene and on the nitroso derivative. In order to suppress an alternative reaction path, the Guggenheim method[3] was employed to provide kinetic data for the reaction between nitrosobenzene and the same conjugated diene. From the rate constants at 2 and 25° the ρ constant of this reaction in dichloromethane solution was tentatively established as $+2.51 \pm 0.04$.



In an effort to gain further insight in the nature of the transition state and to determine electronic factors that activate aromatic nitroso compounds towards a 1,4 cycloaddition reaction we have undertaken a more extensive kinetic study of this reaction involving seven aromatic nitroso derivatives.

The selection of the aromatic nitroso compounds was based on the following criteria. First, the nitroso compounds were to be monomeric in solution. Second, if an alternative reaction path was detected by the formation of more than one reaction product the data were discarded. The sole exception made was for the parent compound nitrosobenzene. Third, essential irreversibility was required of the 1,4 cycloaddition reaction in the temperature range studied.

Results of the kinetic runs of seven aromatic nitroso compounds and 2,3-dimethyl-1,3-butadiene are summarized in Table I at up to five temperatures in dichloromethane solution. The rate constants were obtained spectrophotometrically by methods reported earlier in detail.[2,3] The clear facilitation of the reaction by electron-withdrawing substituents is illustrated in the Hammett plots at 2 and 25° (Figures 1–3). In Figures 1 and 2, ordinary σ values were plotted *vs.* log k_X/k_0, yielding a ρ value at 2 and 25° of +2.53 and +2.50, respectively. In Figure 3, Taft σ^0 values[4] were employed at 25° in order to provide a comparison of Hammett plots. The correlation coefficient is not significantly different and was found to be +2.30. It should be noted that this series is constituted by both *para-* and *meta*-substituted nitrosobenzene derivatives. The simple linearity of the $\sigma\rho$ relationship including *para-* and *meta*-substituted nitrosobenzene derivatives may imply the existence of only a single electronic effect influencing the rate of the 1,4 cycloaddition reaction in the case under study.

TABLE I

RATE CONSTANTS OF THE 1,4 CYCLOADDITION REACTION BETWEEN NITROSOBENZENE OR DERIVATIVES AND 2,3-DIMETHYL-1,3-BUTADIENE IN DICHLOROMETHANE AT VARIOUS TEMPERATURES

		Rate constant, $k \times 10^3$, l./mole × sec[a]				
Substituent	Temp, +0.1°	2	10	18	25	30
None		0.284	...	...	2.10	...
p-Cl		0.810	...	...	5.05	7.11
m-Cl		1.44	2.66	4.49	7.64	8.79
p-Br		1.10	...	3.84	7.60	8.29
m-Br		1.55	2.81	4.58	7.97	9.64
p-I		1.39	2.59	4.39	7.77	8.81
p-CH_3		0.105	0.213	0.389	0.726	0.817

[a] Average value for three to four determinations. Deviation of average value not less than 0.5 but not more than 3%.

A Hammett ρ constant of 2.57 has been reported[5] for the reaction between 1,3-cyclohexadiene and substituted nitrosobenzene derivatives. The following substituents were employed for the determination of the ρ constant: *p*-methoxy, *p*-methyl, *p*-chloro, *m*-nitro, and *p*-nitro. Inclusion of the nitro derivatives in this series creates two complications in the determination of the rate constants, and hence of the ρ constant, which apparently were ignored. The first one is that for *m*-nitro- and *p*-nitronitrosobenzene in solution an equilibrium exists between monomer and dimer which favors the dimer.[6] The second one is that the nitronitroso compounds with another diene, 2,3-dimethyl-1,3-butadiene, were each found to yield two reaction products in approximately equal amounts.[7] Although this may not be the case with 1,3-cyclohexadiene, doubts are raised. Considering these complications and the fact that different conjugated dienes were employed, the close agreement between the value of our ρ constant and the

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[1] Abstracted from the Ph.D. dissertation of M. Ahmad presented to Tulane University, June 1965.

[2] J. Hamer, M. Ahmad, and R. O. Holliday, *J. Org. Chem.*, **28**, 3034 (1963).

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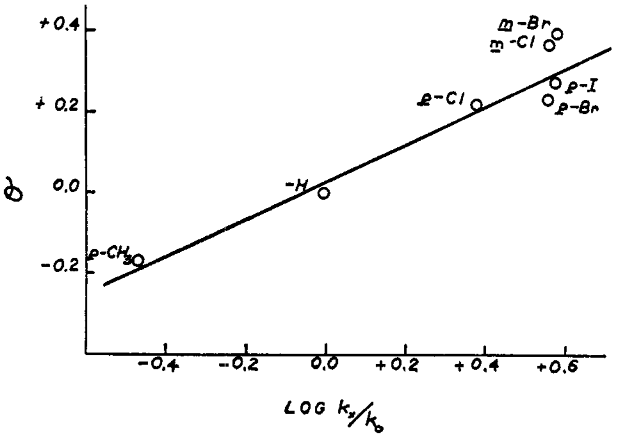

Figure 1.—Correlation of log k_x/k_0 and Hammett σ values for the addition of aromatic nitroso compounds to 2,3-dimethyl-1,3-butadiene in dichloromethane at 2 ± 0.1°.

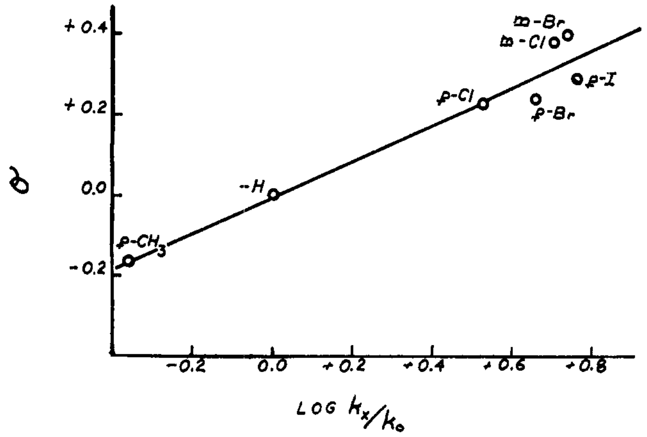

Figure 2.—Correlation of log k_x/k_0 and Hammett σ values for the addition of aromatic nitroso compounds to 2,3-dimethyl-1,3-butadiene in dichloromethane at 25 ± 0.1°.

value reported by Kresze and co-workers is quite surprising.

In a recent kinetic study[8] of the 1,3 cycloaddition reaction of a series of *meta-* and *para*-substituted aryl azides to norbornene facilitation of the cycloaddition by electron-withdrawing substituents or the phenyl ring was also observed. The Hammett ρ value at 25° was reported to be +0.85. Although sizable, the substituent effect on the azide group in a 1,3 cycloaddition reaction is clearly much less pronounced than the same effect on the nitroso group in a 1,4 cycloaddition reaction.

The activation parameters at 25° for the reaction between 2,3-dimethyl-1,3-butadiene and arylnitroso compounds have been summarized in Table II. The large negative entropy of activation is indicative of a highly ordered, cyclic transition state proposed quite generally for concerted cycloaddition reactions, because in these reactions translational and rotational degrees of freedom of the reactants are converted into vibrational degrees of freedom of the transition state. A comparison of the activation parameters reported here with the parameters reported for "conventional" Diels–Alder reactions[9] shows that they fall in the same range. A striking similarity is also observed with the activation parameters of 1,3 cycloaddition reactions such as the addition of aryl azides to norbornene.[8,10]

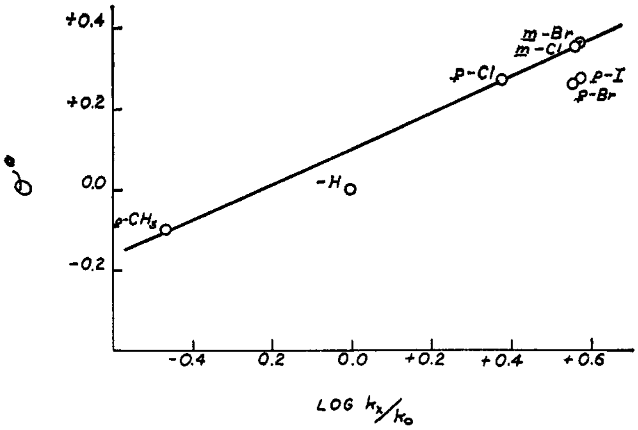

Figure 3. Correlation of log k_x/k_0 and $\sigma°$ for the addition of aromatic nitroso compounds to 2,3-dimethyl-1,3-butadiene at 25 ± 0.1°.

Table II

Activation Parameters of the 1,4 Cycloaddition Reaction between Nitrosobenzene or Derivatives and 2,3-Dimethyl-1,3-butadiene in Dichloromethane

Substituent	E_{act}, kcal/mole	ΔH^*,[a,b] kcal/mole	ΔS^*,[a,c] eu
None	14.2	13.6	−30.0
p-Cl	12.6	12.0	−33.4
m-Cl	12.1	11.5	−34.6
p-Br	12.4	11.8	−33.5
m-Br	11.9	11.3	−34.8
p-I	12.0	11.4	−34.7
p-CH_3	14.4	13.9	−29.4

[a] Calculated at 25 ± 0.1° from the relationship $\Delta H^* = E_{act} - RT$ and from the Eyring equation. [b] Maximum error, 0.8 kcal/mole. [c] Maximum error, 2.9 eu.

The high value of the ρ constant for the reaction between arylnitroso compounds and 2,3-dimethyl-1,3-butadiene suggested an isokinetic relationship,[11] but the present data do not permit a definite conclusion on this point.

Experimental Section

Preparation and Purification of Materials.—Spectrograde dichloromethane was obtained from Eastman Organic Chemicals. From the same source 2,3-dimethyl-1,3-butadiene was obtained, bp 69–70°, $n^{22}D$ 1.4377. The diene was purified by distillation prior to usage. The purity of the diene was ascertained by gas–liquid partition chromatography, employing the Perkin-Elmer Model 154 gas chromatograph (column packing, 20% F-1 on Chromosorb P 30–60 mesh, column temperature 100°). A single peak was obtained.

Crude nitrosobenzene[12] was purified by repeated recrystallizations from methanol. It was further purified by absorption on an alumina column from petroleum ether (bp 38–54°) solution from which it was eluted with a 1:1 by volume mixture of petroleum ether and benzene. The purified nitrosobenzene was obtained in 20% yield, mp 68° (lit.[12] mp 68°).

p-Chloronitrosobenzene was prepared from *p*-chloronitrobenzene by reduction to *p*-chlorophenylhydroxylamine using zinc and ethanol. This was oxidized by treatment with sodium

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[8] P. Scheiner, J. H. Schomaker, S. Deming, W. J. Libbey, and G. P. Nowack, *J. Am. Chem. Soc.*, **87**, 306 (1965).

[9] A. Wassermann, "Diels–Alder Reactions," Elsevier Publishing Co., Inc., New York, N. Y., 1965.

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[11] For an extensive review and discussion on this relationship, see J. E. Leffler and E. Grunwald, "Rates and Equilibria of Organic Reactions," John Wiley and Sons, Inc., New York, N. Y., 1963, pp 315–403.

[12] G. H. Coleman, C. M. McCloskey, and F. A. Stuart, "Organic Syntheses," Coll. Vol. II, John Wiley and Sons, Inc., New York, N. Y., 1955, p 668.

dichromate and sulfuric acid for 30 min at −5 to −10°. The crude *p*-chloronitrosobenzene was steam distilled twice. It was then purified chromatographically by absorption on alumina and elution with diethyl ether. Finally the compound was recrystallized, from ethanol, mp 88°, yield 29% (lit.[6] mp 88°).

p-Bromonitrosobenzene was prepared by the oxidation of N-(4-bromophenyl)hydroxylamine with sodium dichromate and sulfuric acid at −5 to −10° during a period of 25 min. The crude *p*-bromonitrosobenzene was purified by repeated recrystallization from ethanol, mp 95°, yield 35% (lit.[13] mp 95°).

p-Iodonitrosobenzene was prepared by reducing *p*-iodonitrobenzene with zinc and ethanol to *p*-iodophenylhydroxylamine. This was added to ferric chloride solution in water and ice. The crude product, *p*-iodonitrosobenzene was filtered and steam distilled twice. The final purification was accomplished by repeated recrystallizations from ethanol at low temperatures (−25 to −45°), mp 104°, yield 20% (lit.[14] 104°).

p-Methylnitrosobenzene was prepared by the oxidation of N-(4-methylphenyl)hydroxylamine with sodium dichromate and sulfuric acid at −5 to −10° during a period of 25 min. The crude *p*-methylnitrosobenzene was purified by steam distillation and chromatographically by absorption on alumina. It was eluted with diethyl ether. The final purification was accomplished by recrystallization from ethanol at low temperatures (−25 to −45°), mp 48°, yield 30% (lit.[15] 48–49°).

m-Chloro- and *m*-bromonitrosobenzenes were prepared from their corresponding nitro compounds by the method described by Lutz and Lytton.[14] These compounds were steam distilled twice and further purified by repeated recrystallizations: *m*-chloronitrosobenzene, mp 72° (lit.[16] mp 72°), yield 25%; *m*-bromonitrosobenzene, mp 78° (lit.[16] mp 78°), yield 30%.

Kinetic Measurements. 1. Mechanics of Measurements.—A Beckman Model DB spectrophotometer was used for these studies. Solutions were measured in a 1.00-cm silica cell (3-ml capacity) fitted with a ground-glass stopper. The spectrophotometer cell compartment was thermostated by means of circulating water jacket. Within the cell-compartment temperature measurements were made with a caliberated thermometer. Observations of the closed compartment over prolonged periods showed that temperature variation was less than $\pm 0.1°$ at the temperatures employed, 2, 10, 18, 25, and 30°. A Mettler analytical balance was used for weighings and hypodermic syringes were employed to measure the small volumes of liquids.

2. Determination of Rates.—Samples of 2,3-dimethyl-1,3-butadiene, and arylnitroso compounds were accurately weighed into volumetric flasks and solutions were made up with spectrograde quality solvents, acetonitrile, benzene, carbon tetrachloride, chloroform, cyclohexane, dichloromethane, and nitromethane. Plots of absorbances versus concentrations were constructed for the aromatic nitroso compounds at about 720 mμ in appropriate solvents. The concentrations of arylnitroso compounds employed were such that they obeyed Lambert-Beer's Law. The reactant solutions were placed in a water bath thermostated at the reaction temperature 1.5 hr prior to each run. At time zero, a 5.0-ml portion of the arylnitroso compound solution was transferred by means of a syringe into 5.0 ml of conjugated diene solution and the stop watch was started. Mixing was carried out in a flask (25-ml capacity) maintained at the reaction temperature. A portion (3 ml) of the reaction mixture was transferred by means of hypodermic syringe into the cell, placed in the themostated cell compartment and the absorbance was measured at appropriate time intervals. The reactions were followed more than 80% completion. A typical run lasted for more than 90 min.

Plots of log $a(b - x)/b(a - x)$ *vs.* t were constructed, the specific rate constants were obtained from the slope and the initial concentrations. Rate constants presented in Table I are average of two or more determinations, using different initial concentrations of conjugated dienes and arylnitroso compounds for each run. The average deviation (0.5–3%) showed the method to be satisfactorily precise.

As a check on the accuracy of the initial rate method, the rate constant of the reaction between *p*-bromonitrosobenzene and 2,3-dimethyl-1,3-butadiene at 2° was also determined by pseudo-first-order technique (Guggenheim method).[3] Using a large initial 2,3-dimethyl-1,3-butadiene concentration (1.25 *M*) and a low initial *p*-bromonitrosobenzene concentration (0.025 *M*), the reaction was followed at 720 mμ to more than 80% completion.

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The Addition of Aromatic Nitroso Compounds to Conjugated Dienes. III. Effect of Solvent on Reaction Rates and Equilibrium Constant

MUSHTAQ AHMAD[1] AND JAN HAMER

Department of Chemistry, Tulane University, New Orleans, Louisiana 70118

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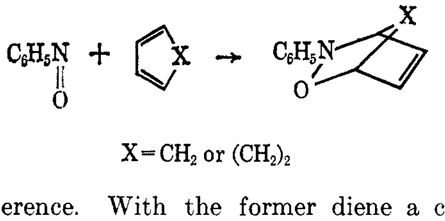
The influence of solvent on reaction rate and equilibrium constant for the 1,4 cycloaddition of nitrosobenzene to cyclic conjugated dienes has been studied. The reaction is essentially insensitive to solvent. Thermodynamic parameters for the equilibrium reaction between 1,3-cyclopentadiene and nitrosobenzene have been determined.

The 1,4 cycloaddition of nitrosobenzene to 1,3-cyclohexadiene or 1,3-cyclopentadiene exhibits a notable difference. With the former diene a cycloadduct is obtained which does not dissociate into its components at or around room temperature, while the cycloadduct obtained from the latter diene dissociates quite appreciably under these conditions.[2]



X = CH_2 or $(CH_2)_2$

The difference in the thermal stability of the cycloadducts may be rationalized by assuming that the cycloadduct of 1,3-cyclohexadiene is the more stable one, and that the activation energy for its formation is larger, so that the activation energy for the reverse reaction will be far larger for the 1,3-cyclohexadiene adduct than for the 1,3-cyclopentadiene adduct.

These assumptions are not unreasonable, since in the 1,3-cyclopentadiene cycloadduct the methylene bridge will cause a larger ring strain than the ethylene bridge in the 1,3-cyclohexadiene cycloadduct. That the transition state leading to the 1,3-cyclohexadiene cyclo-

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[1] Abstracted from the Ph.D. dissertation of M. Ahmad presented to Tulane University, June 1965.

[2] For an extensive review on the addition of nitroso compounds to conjugated dienes, see J. Hamer and M. Ahmad, "1,4-Cycloaddition Reactions," J. Hamer, Ed., Academic Press Inc., New York, N. Y., 1966, Chapter 12.