

## MECHANISM OF ANIONIC COORDINATION DIMERIZATION OF ISOPRENE

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The mechanism of controlled anionic coordination dimerization of isoprene (*i.e.* 2-methyl-1,3-butadiene) in the system tetrahydrofuran–isoprene–alkali metal–dialkylamine was investigated by using absorption spectrophotometry in the range of visible radiation and gas chromatography. The effect of the alkali metal (Li, Na, K) and dialkylamine (dicyclohexylamine, N-isopropylcyclohexylamine, N-methylisopropylamine) on the absorption spectra was tested. By comparing chromatographic and spectrophotometric data, the absorption bands in the range of visible radiation were identified with the existence of  $\pi$ -complexes between oligomeric forms of isoprene and alkali metal dialkylamide.

The anionic coordination polymerization of isoprene still remains the object of an intensive study of the reaction mechanism. Papers by Kašpar and Trekoval dealing in great detail with the mechanism of anionic-coordination polymerization of isoprene in benzene with butyllithium<sup>1</sup> and with the kinetics of polymerization of isoprene in benzene initiated with ethyl-, butyl- and hexyllithium<sup>2</sup> are a contribution to this topic. Up to now, the mechanism of controlled anionic coordination dimerization of isoprene has been presented in a very schematic way<sup>3</sup>. A typical sign indicating the anionic coordination dimerization of isoprene to monoterpene  $\beta$ -myrcene, *i.e.* 3-methylene-7-methyl-1,6-octadiene, which proceeds in the reaction system tetrahydrofuran–isoprene–alkali metal–dialkylamine<sup>4</sup> consists in an intensive colouration of the reaction mixture which changes with the reaction time.

We investigated the absorption spectra of the reaction system of controlled anionic coordination dimerization of isoprene in the range of visible radiation with the aim to elucidate the reaction mechanism. The effect of the character of the alkali metal and of the structure of dialkylamine used was examined. The composition of the reaction system was investigated by gas chromatography.

## EXPERIMENTAL

### Chemicals

Isoprene (pure, Fluka K. G.), dialkylamines (chromatographically pure) and tetrahydrofuran (pure, Apolda) were distilled with sodium in nitrogen atmosphere at atmospheric pressure; tetrahydrofuran was dried with sodium and naphthalene several days before distillation.  $\beta$ -Myrcene (pure, Koch-Light) was distilled with sodium at reduced pressure in nitrogen atmosphere. The compounds were stored over the Potasit molecular sieve (0.4 mm). Sodium (pure, USSR) and potassium (pure, Ferak Berlin) were used in the pulverized form (grain diameter 1–2 mm) prepared by shaking the respective metal in boiling toluene (pure, Lachema Brno), distilled with sodium in nitrogen atmosphere before use. Lithium (pure, USSR) was used in the form of cubes, edge 3–5 mm. Nitrogen (for electric bulbs, Technoplyn, Kyje) was purified with deoxidizing catalysts Cu–Ni and on the Calsit molecular sieve (0.5 mm).

### Methods of Measurement

Compounds in the molar ratio THF : isoprene : metal :  $R^1R^2NH = 13:1:1:1$  (volume *c.* 10 ml) were mixed in a 50 ml reactor with a magnetic stirrer washed with nitrogen against a stream of nitrogen at room temperature. To a homogeneous so-called catalytic solution formed with all alkali metals after 30 min of the reaction, isoprene was added under the same conditions so as to obtain a reaction system with the ratio of the compounds employed THF : isoprene : metal :  $R^1R^2NH = 13:13:1:1$ .

The polymerization of  $\beta$ -myrcene proceeded so that to the catalytic solution with the molar ratio of the compounds used THF : isoprene : Na : N-isopropylcyclohexylamine = 13 : 1 : 1 : 1,  $\beta$ -myrcene was added against a stream of nitrogen, which gave rise to a reaction system with the molar ratio of the compounds used THF : isoprene : Na : N-isopropylcyclohexylamine :  $\beta$ -myrcene = 13 : 1 : 1 : 1 : 6. The reaction was carried out at room temperature. Samples taken from the reaction systems through a teflon packing for spectrophotometric measurements were 1 ml in volume, those taken for gas chromatographic measurements were 5  $\mu$ l in volume.

### Analytical Methods

The composition of the reaction systems was analyzed by gas chromatography using a Chrom 4 apparatus (Laboratorní přístroje, Prague) with flame-ionization detection. The controlled dimerization of isoprene was investigated using a glass packed column 2.5 m long, inner diameter 2 mm, packed with 15% Apiezon L and 3% NaOH on Chromaton N-AW-HMDS. 3  $\mu$ l of the reaction mixture was injected into the column. The concentrations of isoprene and  $\beta$ -myrcene were determined from calibration plots. The concentration of higher oligomers was additionally calculated from the difference between the concentrations of isoprene and  $\beta$ -myrcene and expressed as the concentration of the dimer. The moment at which isoprene is added to the catalytic mixture is regarded as the beginning of the reaction. The conversion of isoprene at this moment was nonzero (considered the loss of isoprene during the preparation of the catalytic solution), the concentration of  $\beta$ -myrcene was zero, that of oligomers expressed as dimers corresponded to the conversion of isoprene at this point.

The controlled polymerization of  $\beta$ -myrcene was investigated on a glass packed column, 2.5 m long, inner diameter 2 mm, packed with 5% XE-60 on Chromaton N-AW-DMS. 1  $\mu$ l of the reaction mixture was injected into the column.

The absorption spectra in the 360–700 nm range were recorded with a Specord (Carl Zeiss, Jena) spectrophotometer at room temperature. Samples containing Na and K were measured in cells provided with NaCl windows separated with a teflon distance film, 0.01 mm thick. Samples containing Li were measured in a quartz cell, 1 mm thick. The wavelengths of maxima of the absorption spectra bands were read off with an accuracy of  $\pm 1$  nm.

## RESULTS AND DISCUSSION

A spectrophotometric investigation of the system with the molar ratio of the compounds used THF : isoprene : dicyclohexylamine : sodium = 13 : 13 : 1 : 1 revealed that the dependence of absorbancy on the wavelength in the range of visible radiation (Fig. 1) exhibits a single band at  $\lambda_{\max}$  430 nm at the beginning of the reaction; the intensity of the band passes through a maximum, after which the absorption decreases. A new band with  $\lambda_{\max}$  485 nm appears simultaneously with the decrease. The reaction mixture containing potassium behaved similarly, with the only difference that both maxima shifted towards higher wavelengths (441 and 500 nm). A different spectrum was observed for the reaction mixture containing lithium, where an un-

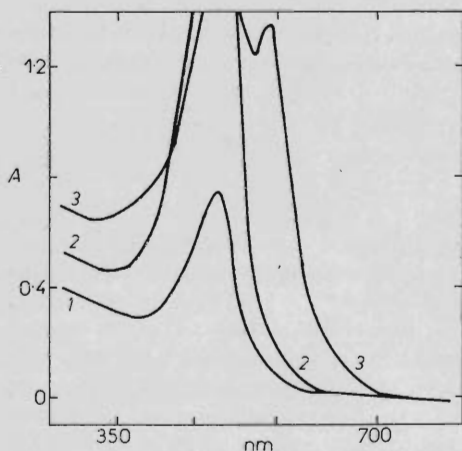


FIG. 1

Dependence of absorbancy ( $A$ ) on wavelength for the system THF–isoprene–Na–dicyclohexylamine at the molar ratio of components 13 : 13 : 1 : 1. Reaction time: 15 min, 2 30 min, 3 60 min

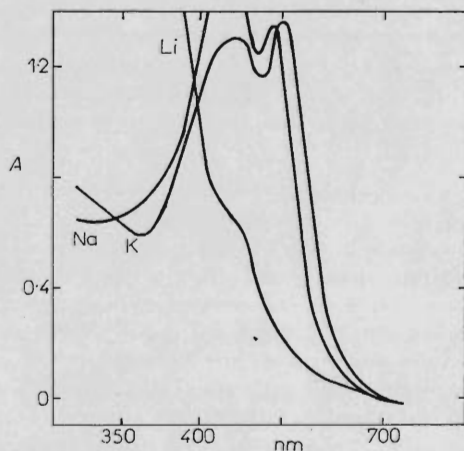


FIG. 2

Absorption spectra of the system THF–isoprene–metal–dicyclohexylamine at the molar ratio of components 13 : 13 : 1 : 1 at the time 50 min

pronounced band appeared with  $\lambda_{\max}$  432 nm; no further bands were observed (Fig. 2). Gas chromatography showed that the reaction did not occur in the presence of lithium.

Table I shows absorption maxima for the system containing sodium and various dialkyl amines. The position of the maximum near 430 nm is virtually independent of dialkyl amine used. A weak bathochromic effect on the maximum near 490 nm can be observed with amines possessing sterically less demanding substituents.

Parallel chromatographic determinations of the loss of isoprene, increase in  $\beta$ -myrcene and in higher oligomeric forms of isoprene show (Fig. 3) that the content of  $\beta$ -myrcene passes through a maximum some 30 min after isoprene was added to the catalytic solution. Hence, it is obvious that absorption bands with the maxima at 430 and 441 nm for Na and K respectively are bound to the presence of  $\beta$ -myrcene in the reaction mixture. This finding has been corroborated by other model experiment spectra of the system with the polymerization of  $\beta$ -myrcene which were studied (Fig. 4). At the beginning of the reaction, the spectrum of this system exhibits only a single absorption band with  $\lambda_{\max}$  430 nm, which disappears with increasing reaction time (with decreasing concentration of  $\beta$ -myrcene). An absorption band

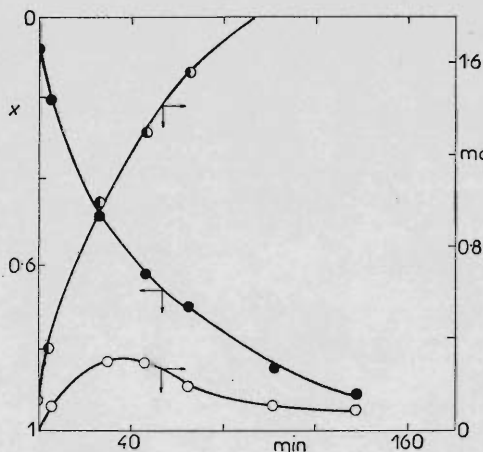


FIG. 3

Dependence of the conversion of isoprene  $x = ([I]_0 - [I])/[I]_0$  and of the concentration of  $\beta$ -myrcene  $\circ$  and higher oligomers of isoprene  $\bullet$  on time for the system THF-isoprene-Na-dicyclohexylamine at the molar ratio of components 13 : 13 : 1 : 1  $\bullet$

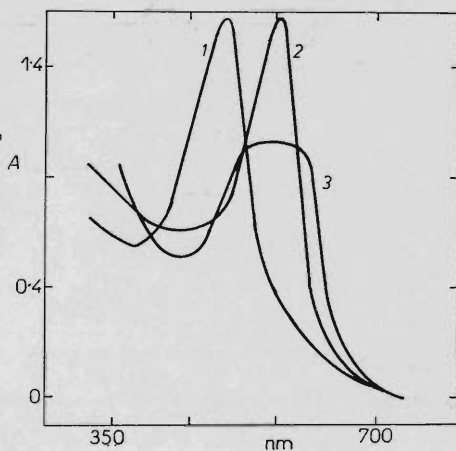
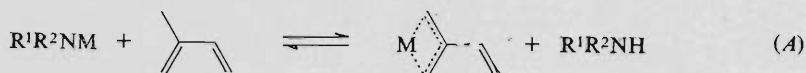


FIG. 4

Dependence of absorbance ( $A$ ) on wavelength for the system THF-isoprene-Na-N-isopropylcyclohexylamine- $\beta$ -myrcene at the molar ratio of components 13 : 1 : 1 : 1 : 6. Reaction time: 1 h, 2.6 h, 3.15 h

with  $\lambda_{\max}$  515 nm and a wide absorption band with a flat maximum at 480–550 nm appear simultaneously after a very long reaction time.

The basic step in the dimerization of isoprene to  $\beta$ -myrcene is the metalation of methyl in the molecule of isoprene<sup>3</sup> with an alkali metal (M) to yield a compound in the anion of which one may assume delocalization of the electron pair and consequently, the formation of  $[\text{isoprene}]^- \text{M}^+$ . This metalation can be regarded as an equilibrium reaction between alkali metal dialkylamide and isoprene, affected by a specific reaction medium (THF):



Here, the alkali metal dialkylamide is considered to be an initiation agent, similarly to the anionic telomerization of dialkylamines with isoprene<sup>5</sup> or styrene<sup>6</sup>. The equilibrium (A) is also affected by the anionic affinity of the alkali metals used<sup>7,8</sup>; in the case of lithium and dicyclohexylamine under the reaction conditions used, the equilibrium (A) is shifted completely to the left. The formation of  $\beta$ -myrcene may then be described by reactions subsequent to the introductory metalation (A), thus

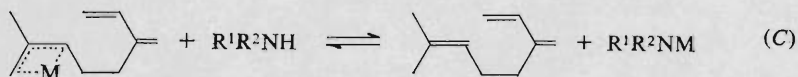
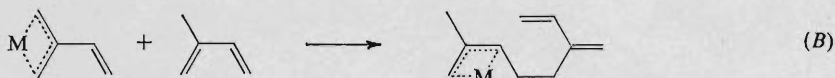
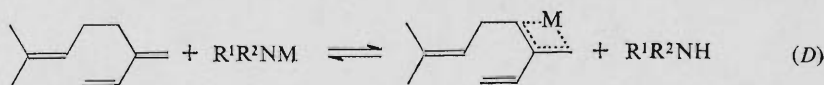


TABLE I

Dependence of the structure of dialkylamine on the position of absorption bands ( $\lambda_{\max}$ , nm)

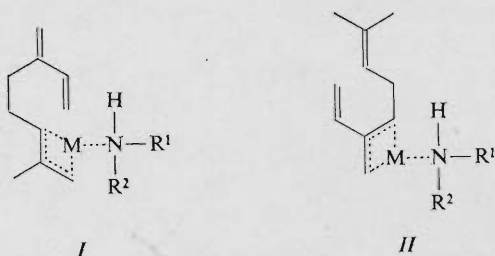
$\text{R}^1$	$\text{R}^2$	1. maximum	2. maximum
Cyclohexyl	cyclohexyl	430	485
Isopropyl	cyclohexyl	429	490
Isopropyl	isopropyl	428	490
Methyl	isopropyl	432	495

In THF, isoprene alone and  $\beta$ -myrcene exhibit the highest absorption band in the range 270 nm. Poly(2-methyl-1,3-butadiene)ylsodium, poly(2-methyl-1,3-butadiene)-ylpotassium and poly(2-methyl-1,3-butadiene)yllithium in THF had<sup>9</sup> absorption bands with maxima below 400 nm. A similar absorption could be expected for 2-methyl-1,3-butadienyl- and 3-methylene-7-methyl-1,6-octadienylsodium, potassium and lithium. Hence, the absorption maxima at 430 nm and 441 nm recorded in this study for Na and K respectively are related to the presence of 3-methylene-7-methyl-1,6-octadienylsodium or potassium affected with dialkylamine (*cf.* maxima of absorption bands of the systems 9-alkylfluorene–cesium (sodium) cyclohexylamide–cyclohexylamine<sup>10</sup>). The high molar absorption coefficient (order of magnitude  $10^4$ – $10^5$  l mol<sup>-1</sup> cm<sup>-1</sup>) in the respective maxima of the bands suggested that these bands arise by the “electron-transfer” transition<sup>11</sup>. Not only complex *I* derived from the product of addition (*B*), but also complex *II* obtained by the metalation of  $\beta$ -myrcene analogous to the metalation of isoprene (*A*) may appear in the reaction system. The coloured complexes *I* and *II* are stabilized with an electron pair of the THF oxygen atom. The maximum near 490 nm is related with an exchange of the alkali metal between isoprene trimers ( $C_{10}$ ): The broad absorption maximum 480–550 nm appearing after a very long reaction time of the polymeriza-



tion of  $\beta$ -myrcene is obviously connected with an exchange of the alkali metal between higher oligomers of  $\beta$ -myrcene ( $C_{20}$  and higher) and dialkylamine. Gas chromatography has revealed that unlike the dimerization of isoprene, the trimerization of isoprene and dimerization of  $\beta$ -myrcene are not selective under the given conditions, which could be due to the two ways of formation of metalated  $\beta$ -myrcene (*cf.* complexes *I* and *II*).

The participation of more or less strong complexes in the reaction mechanism of controlled dimerization of isoprene to  $\beta$ -myrcene may explain the high selectivity of the reaction and the specific structure of the dimer formed.



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