

## GAS CHROMATOGRAPHY WITH STATIONARY PHASES CONTAINING SILVER NITRATE

## VI. THE METHYLCYCLOHEPTENES AND METHYLENECYCLOHEPTANE\*

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It has been shown previously<sup>1-5</sup> that the complex-forming silver nitrate-glycol phase can be conveniently employed for the gas chromatographic separation of different types of isomeric olefins.

In order to gain information on the behavior of olefins possessing a seven-membered ring, the study of the relationship between structure and complex stability has been extended in the present work to the series of the isomeric methylcycloheptenes and methylenecycloheptane (compounds I-V, Table I). Furthermore, a rapid and precise method was needed for the determination of these isomers at equilibrium<sup>6</sup>.

TABLE I

RETENTION VOLUMES OF THE ISOMERIC METHYLCYCLOHEPTENES AND METHYLENECYCLOHEPTANE  
Stationary phase 30 g AgNO<sub>3</sub>/100 ml triethylene glycol; column dimensions 3 m × 0.6 cm; weight ratio of solid support<sup>1</sup> to liquid phase 3:1; helium flow rate 120 ml/min; temperature 40°.

No.	Compound	B.p. at 760 mm(°C)	$r^*$	$r^{**}$	$R^{***}$
I	Methylenecycloheptane	138.2	1.81	0.97	3.20
II	1-Methylcycloheptene	137.2	1.33	0.72	3.14
III	3-Methylcycloheptene	129.8	3.97	2.14	2.64
IV	4-Methylcycloheptene	130.6	3.13	1.68	2.69
V	5-Methylcycloheptene	131.1	3.52	1.89	2.72
VI	Cycloheptene	116.4	2.98	1.61	—

\* Relative to benzene.

\*\* Relative to toluene.

\*\*\* Relative to methylcyclohexane on a 150 ft. capillary column coated with squalane (temperature 25°; nitrogen pressure 8.5 p.s.i.).

The difficulties encountered in the separation of compounds I-V are illustrated by the fact that a mixture of the compounds gives only two or at most three poorly resolved peaks when examined in columns packed with non-complex forming phases, e.g. silicone gum rubber,  $\beta,\beta'$ -oxydipropionitrile and di-2-ethylhexyl tetrachlorophthalate. For instance, a mixture of I-V gives only two peaks on a 2.5 m × 0.6 cm

\* For Part V of this series, see ref. 5.

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column filled with 10% silicone gum rubber on Chromosorb (temperature  $70^\circ$ ; helium flow rate 30 ml/min), the first peak corresponding to the lower boiling isomers III-V (Table I) and the second to a mixture of I and II. The situation is even less satisfactory with more polar phases as differences in the volatility and polarity of the isomers examined seem to be counteractive. For example, a  $2\text{ m} \times 0.6\text{ cm}$  column packed with 20%  $\beta, \beta'$ -oxydipropionitrile on Chromosorb (temperature  $25\text{--}40^\circ$ ; helium flow rate 85 ml/min) gives only three overlapping peaks, while a  $3\text{ m} \times 0.6\text{ cm}$  column containing 10% di-2-ethylhexyl tetrachlorophthalate on Chromosorb (temperature  $75^\circ$ ; helium flow rate 85 ml/min) proves to be completely ineffective in the present case.

Experiments with a 150 ft. capillary column coated with polypropylene glycol (temperature  $55^\circ$ ; nitrogen pressure 12 p.s.i.) showed some resolution of the closely boiling isomers I and II and of III, IV and V, respectively. Better separation is obtained (Fig. 1) with a 150 ft. capillary column coated with the less polar squalane (temperature  $25^\circ$ ; nitrogen pressure 8.5 p.s.i.). Although the resolution observed is still not satisfactory for quantitative analysis, a complete separation of the isomers with a longer column of this type is feasible.

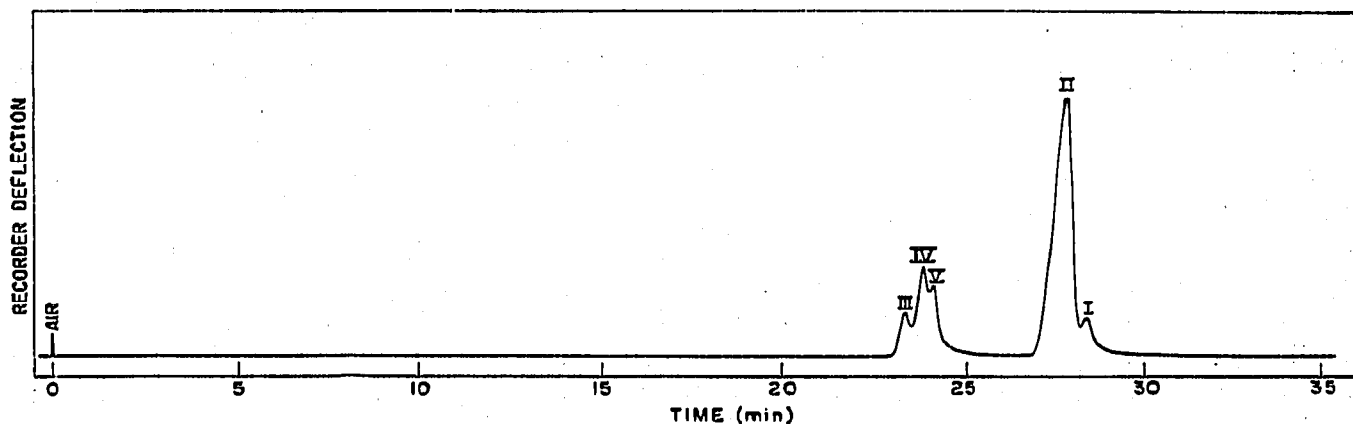


Fig. 1. Chromatography of a mixture of the four isomeric methylcycloheptenes (II-V) and methylene-cycloheptane (I) on a 150 ft. capillary column coated with squalane (column C).

Examination of compounds I-V on columns containing silver nitrate-glycol showed that smooth separation can be obtained by proper choice of the salt concentration, type of glycol and working temperature. Solutions of silver nitrate in concentrations varying from 10 to 30% in ethylene glycol, triethylene glycol and tetraethylene glycol were examined at temperatures from  $20^\circ$  to  $70^\circ$ . The best separations were achieved (Fig. 2) on a  $3\text{ m} \times 0.6\text{ cm}$  column filled with silver nitrate-triethylene

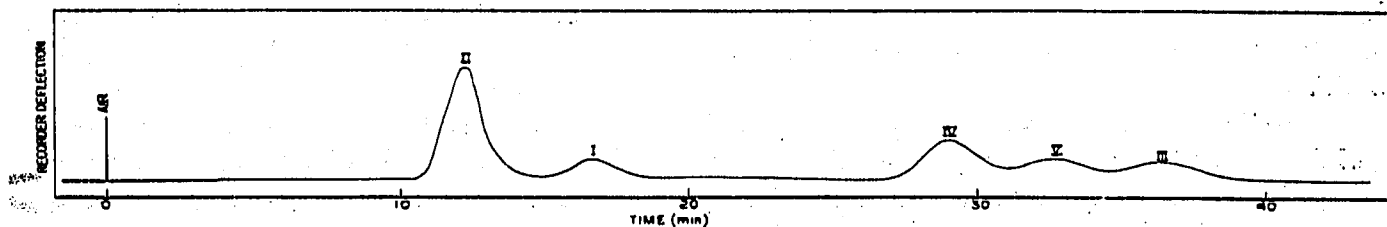


Fig. 2. Chromatography of a mixture of the four isomeric methylcycloheptenes and methylene-cycloheptane on a silver nitrate-triethylene glycol column (column A).

glycol on 30–60 mesh firebrick (solution concentration 3 g/10 ml; weight ratio of support<sup>1</sup> to liquid phase 3:1; helium flow rate 120 ml/min; temperature 40°). The retention volumes of the isomers, relative to benzene and toluene, are summarized in Table I.

Quantitative analysis of synthetic blends of I–V, containing more than 5 % of each component, showed that the isomers can be determined with an accuracy of at least  $\pm 1$  % of the total. In addition to its application to equilibrium studies<sup>6</sup>, the method was employed on a preparative scale (see Experimental) for the isolation of the previously unknown 4-methylcycloheptene and of an enriched sample of 5-methylcycloheptene.

#### DISCUSSION OF RESULTS

It has been shown<sup>7,8</sup> that the relative retention volumes of closely boiling isomers parallel the stabilities of the silver ion–olefin complexes formed during the gas chromatographic process. On this basis, an interpretation of the data given in Table I can be made, as follows:

(a) 1-Methylcycloheptene (II) shows the lowest retention volume among the isomers examined. This is in accord with the behavior of 1-alkylcycloheptenes possessing smaller ring systems<sup>1–4</sup> and can be attributed to the decrease in complex stability caused by steric hindrance of the alkyl substituent at the double bond.

(b) 3-Methylcycloheptene (III) shows the highest retention volume among the isomers. Examination of models of this compound, based on the chair, boat and skewed boat conformations of the cycloheptene ring shows there is practically no steric interference by the methyl group in the approach to the double bond. A second factor which probably enhances the relative stability of the complex formed by III is the inductive effect of the methyl substituent. It has been already observed, both in cyclic<sup>1–3</sup> and in open-chain olefins<sup>5,8</sup>, that the inductive effect of a methyl group in the 3-position is stronger than that exerted by the same substituent at a more remote position.

(c) Among the three closely boiling isomers III–V, which have the same type of endocyclic bond (disubstituted) and are therefore easily distinguished from II (trisubstituted double bond), the 4-methylcycloheptene (IV) forms the least stable complex ( $r_{IV} < r_V < r_{III}$ ). An examination of models of IV shows that this is probably due mainly to steric factors, because there is a certain hindrance of the double bond by the 4-methyl group in the presumably predominant chair conformer (Fig. 3 a). A clear steric effect is also evident in the twist-boat conformation (Fig. 3 b).

(d) Models of 5-methylcycloheptene (V) show that, although steric hindrance of the double bond by the methyl substituent may exist in the boat conformation, there is no interference in the more stable chair conformation (Fig. 3 c) or in the twist-boat conformation. This would explain the higher retention volume of V as compared to IV.

(e) The retention volume of methylenecycloheptene relative to that of 1-methylcycloheptene ( $r_I:r_{II} = 1.36$ ) is considerably lower than that observed for corresponding pairs of methylenecyclohexane–1-methylcyclohexene analogues possessing smaller ring systems<sup>1–4</sup> (for instance, a ratio of 7.1:1 was found for the retention volumes of the methylenecyclohexane–1-methylcyclohexene pair of isomers).

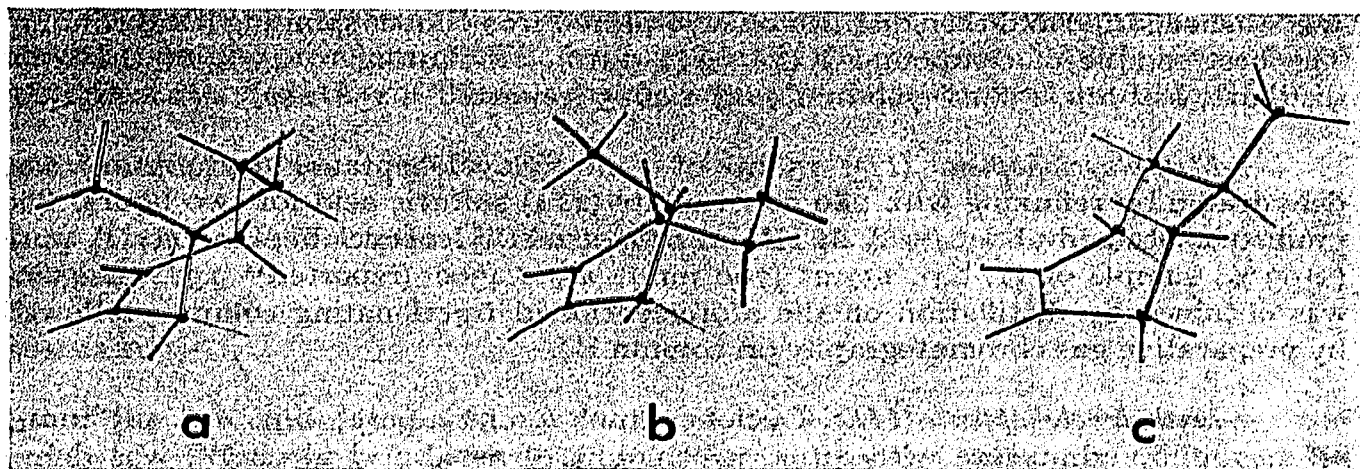


Fig. 3. Models of 4-methylcycloheptene (a and b) and 5-methylcycloheptene (c).

This observation is probably due in part to the stronger complexation ability of the endocyclic double bond in a 7-membered ring as compared to a 6- or 5-membered ring<sup>8,9</sup>. On the other hand, it may be dependent to some extent on the existence of certain steric hindrance of the double bond in methylenecycloheptane due to the flexibility of the cycloheptane ring. By analogy with the conformational analysis of cycloheptane<sup>10</sup> and cycloheptanone<sup>11</sup>, one can expect that in methylenecycloheptane the ring will predominantly possess the twist-chair and twist-boat conformations. Examination of models shows that in the twist-chair form of I there appears to be a somewhat stronger hindrance of the double bond by the ring  $\alpha$ -hydrogens compared to that in methylenecyclohexane, especially if opening (widening) of the bond angles in the cycloheptane ring is considered<sup>10</sup>. On the other hand, considerable steric hindrance of the double bond by one of the  $\text{C}_4$  hydrogens is observed in the twist-boat conformation.

## EXPERIMENTAL

### *Apparatus and procedure*

Two Perkin-Elmer Model 154 Fractometers, one provided with a thermistor detector cell and the other with a flame ionization detector, were used in the study.

The following columns were mainly employed:

Column A. An analytical silver nitrate-triethylene glycol column (see text and Table I).

Column B. A preparative column, 2.5 m  $\times$  10 mm, packed with the same stationary phase as column A.

Column C. A 150-ft. Golay capillary column, coated with squalane.

### *Preparation of pure compounds*

*Methylenecycloheptane (I)*. Cycloheptyl carbinol, b.p. 111–112° (20 mm),  $n_D^{17}$  1.4771, was prepared<sup>12</sup> by the action of formaldehyde on cycloheptylmagnesium bromide and then esterified with acetic anhydride. The resulting cycloheptylcarbonyl acetate, b.p. 115–116° (20 mm),  $n_D^{17}$  1.4504, was pyrolyzed at 530° in a pyrex tube reactor of 40 cm length and 25 mm diameter, filled with pyrex beads. The product

was washed, dried and then distilled on a 70-plate Piro-Glover spinning band column. The best sample of compound I (> 99 % pure), amounting to 45 % of the total distillate, had b.p. 138.2° (760 mm);  $n_D^{20}$  1.4615 (reported<sup>13</sup>, 138–140°;  $n_D^{20}$  1.4611).

*1-Methylcycloheptene (II)*. 75 ml of 1-methylcycloheptanol (99 % pure) was dehydrated by refluxing with 280 ml of dilute (1:4) sulfuric acid for two hours. The product contained about 94 % of II and 6 % of methylenecycloheptane (I). A pure (>99 %) sample of II, b.p. 137.2° (760 mm),  $n_D^{20}$  1.4590 (reported<sup>14</sup> 138°; 1.4580) was obtained by distillation on the aforementioned fractionating column, followed by preparative gas chromatography on column B.

*3-Methylcycloheptene (III)*. Cycloheptanol (99.5 % pure; b.p. 92° (25 mm);  $n_D^{20}$  1.4760), in admixture with an equal amount of *tert.*-butyl alcohol<sup>15</sup>, was dehydrated at 250° over Harshaw alumina<sup>16</sup>. Under these conditions the cycloheptene obtained (b.p. 116.4°,  $n_D^{22}$  1.4575) was 99.5 % pure and free of contaminating 1-methylcyclohexene\*. The freshly distilled olefin was reacted with N-bromosuccinimide in the presence of benzoyl peroxide and the resulting 3-bromocycloheptene, b.p. 40–41° (1 mm),  $n_D^{20}$  1.5326 (reported<sup>17</sup> 59° (5.2 mm),  $n_D^{25}$  1.5304), was treated as follows:

Magnesium (4.5 g, 0.185 mole) and dry ether (170 ml) were introduced into a three-neck flask provided with a condenser, a stirrer and a dropping funnel. After starting the reaction with a few drops of methyl iodide, a mixture of 3-bromocycloheptene (30 g, 0.17 mole) and methyl iodide (24.5 g, 0.18 mole) was added dropwise over a period of 1.5 h. The reaction was carried out at room temperature and under a constant stream of dry nitrogen\*\*. After stirring for another hour, the mixture was decomposed with ice and hydrochloric acid and the 3-methylcycloheptene obtained (16 g, 0.15 mole; yield, 88 %) was purified by distillation. The best portion, amounting to 35 % of the total distillate, was more than 99 % pure and had b.p. 129.8° (760 mm);  $n_D^{20}$  1.4565 (reported<sup>10</sup> for a sample of III of unspecified purity 130–132°;  $n_D^{22}$  1.4562).

*Analysis*. Calculated for C<sub>8</sub>H<sub>14</sub>: C, 87.28 % H, 12.72 %. Found: C, 87.05 %; H, 12.49 %.

The structure of compound III was confirmed by N.M.R. and infrared spectroscopy<sup>20</sup>.

*4-Methylcycloheptene (IV)*. A sample of this compound was isolated in 97 % purity by preparative gas chromatography (column B) of an equilibrium mixture of the methylcycloheptenes<sup>6</sup>. B.p. 130.6 (760 mm);  $n_D^{20}$  1.4545.

*Analysis*. Calculated for C<sub>8</sub>H<sub>14</sub>: C, 87.28 %; H, 12.72 %. Found: C, 87.10 %; H, 12.43 %.

The position of the double bond in IV was confirmed by oxidation to  $\beta$ -methylpimelic acid, using the method of VON RUDLOFF<sup>21</sup>. The acid obtained had m.p. 49–50° (reported<sup>22</sup> for  $\beta$ -methylpimelic acid, 48–50°) and did not depress the melting point of a pure sample of the reference compound.

\* This compound is usually formed to the extent of 2–10 % when strongly acidic dehydrating agents such as  $\beta$ -naphthalenesulfonic acid or sulfuric acid are employed.

\*\* No reaction takes place when the original procedure of BERLANDE<sup>18</sup> for preparation of 3-alkylcycloalkenes is employed in the present case.

*5-Methylcycloheptene (V)*. A sample containing 92 % of V was prepared by gas chromatography on column B. The boiling point of the compound (Table I) was determined by extrapolation of the gas chromatography data obtained on column C.

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#### SUMMARY

The gas chromatographic behavior of the isomeric methylcycloheptenes and methylenecycloheptane was investigated using: (a) packed tubes containing conventional non-complex forming phases; (b) capillary tubes coated with squalane and polypropylene glycol; (c) packed columns containing complex forming silver nitrate-glycol solutions as the stationary liquid. Smooth separation of a mixture of the isomers is achieved on a silver nitrate-triethylene glycol column; by proper choice of salt concentration and working temperature the components can be quantitatively determined with an accuracy of  $\pm 1\%$ . On a preparative scale, the method was conveniently employed for the isolation of the previously unknown 4-methylcycloheptene.

By comparing the relative retention volumes of the isomers, correlations between complex stability and olefin structure were deduced, taking into consideration the peculiar conformations of the seven-membered ring system.

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