Gas–Liquid Partition Chromatographic Evidence that Alkyl–Phenyl Interactions are Specific for the Shape of the Alkyl Group

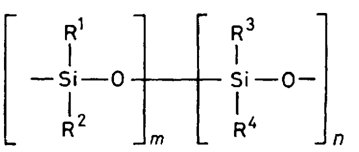
Tadashi Endo,*[a] Masato M. Ito,[a] Yoshinori Yamada,[a] Hiroko Saito,[a] Kazuhiro Miyazawa,[a] and Motohiro Nishio[b]

[a] *College of Science and Engineering, Aoyama Gakuin University, Chitosedai, Setagaya-ku, Tokyo 157, Japan*
[b] *Central Research Laboratories, Meiji Seika Kaisha, Ltd., Morooka, Kohoku-ku, Yokohama 222, Japan*

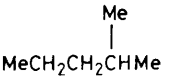
Gas chromatographic studies have shown that the weak interaction between an alkane sample and the phenyl group in a stationary liquid varies in strength with the geometrical shape of the alkyl group and is more attractive for a cyclic alkyl group than for the corresponding straight-chain alkyl group.

There is now substantial evidence for the existence of weak attractive interactions associated with phenyl (Ph) and alkyl groups. These include a dipole–induced dipole interaction between the 1,3-dioxane and Ph rings,[1] an alkyl–phenyl interaction,[2] and an alkyl–alkyl interaction[3] between two t-butyl groups. In gas–liquid partition chromatography (g.l.p.c.), weak interactions between sample molecules and the stationary phase play an important role in the separation of samples.[4] Little is known, however, on the geometrical shape-specificity of such weak interactions, which is significant for a better understanding of the high specificity of biological recognition. Here we report that the weak interaction between an alkane molecule (sample) and a Ph group in a stationary liquid in g.l.p.c. depends upon the three-dimensional shape of the alkyl group in the sample.

As stationary liquids we used four kinds of silicone oils

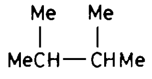


(1) $R^1 = R^2 = R^3 = R^4 = Me$
(2a) $R^1 = R^2 = R^3 = Me$, $R^4 = Ph$ ($m{:}n = 3{:}2$)
(2b) $R^1 = R^3 = Me$, $R^2 = R^4 = Ph$
(2c) $R^1 = Me$, $R^2 = R^3 = R^4 = Ph$ ($m{:}n = 1{:}1$)



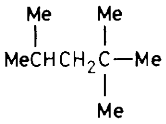
$\mathrm{MeCH_2CH_2\overset{Me}{C}HMe}$

(3a)



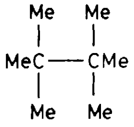
$\mathrm{Me\overset{Me}{C}H{-}\overset{Me}{C}HMe}$

(3b)



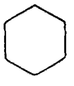
$\mathrm{Me\overset{Me}{C}HCH_2\overset{Me}{\underset{Me}{C}}{-}Me}$

(3c)

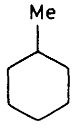


$\mathrm{Me\overset{Me}{\underset{Me}{C}}{-}\overset{Me}{\underset{Me}{C}}Me}$

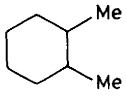
(3d)



(3e)



(3f)



(3g) *cis*
(3h) *trans*

$\mathrm{Me[CH_2]_nMe}$

(4a) $n = 4$
(4b) $n = 6$
(4c) $n = 5$

[(**1**) and (**2a**—**c**)]† with different numbers of Me and Ph groups. The retention time‡ was measured for eight pairs of branched or cyclic alkanes (**3**) and straight-chain alkanes (**4**), each pair consisting of two alkanes with the same number of carbon atoms: 2-methylpentane (**3a**)-n-hexane (**4a**); 2,3-dimethylbutane (**3b**)-(**4a**); 2,2,4-trimethylpentane (**3c**)-n-octane (**4b**); 2,2,3,3-tetramethylbutane (**3d**)-(**4b**); cyclohexane (**3e**)-(**4a**); methylcyclohexane (**3f**)-n-heptane (**4c**); *cis*-1,2-dimethylcyclohexane (**3g**)-(**4b**); and *trans*-1,2-dimethylcyclohexane (**3h**)-(**4b**). The relative retention (α)‡ was defined as the ratio of the retention time for sample (**3**) to that for sample (**4**).

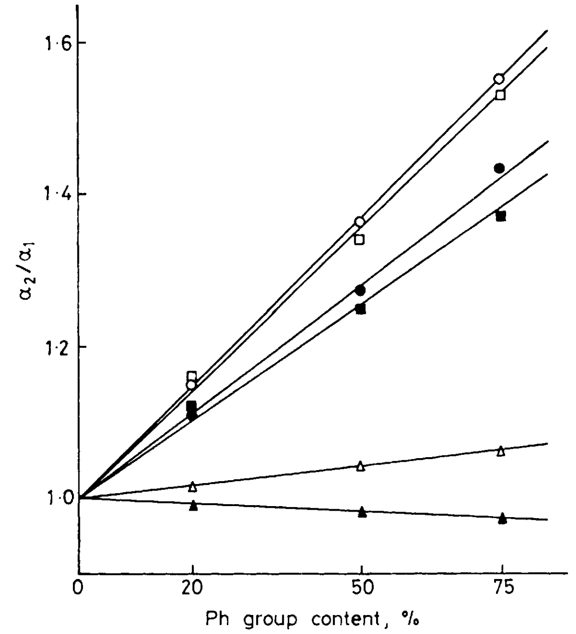


Figure 1. Dependence of the α_2/α_1 on the content (%) of Ph groups in the stationary liquid. Gas chromatographic conditions employed were as follows: stationary liquid, silicone oils (**1**) and (**2**) [20% (w/w) on acid-treated Celite 545]; temperature, 70 °C (unless otherwise noted). The α_{2c}/α_1 values for the pairs (**3a**)—(**4a**) and (**3c**)—(**4b**) are 0.96 and 0.92, respectively, at 70 °C. ▲, (**3b**)—(**4a**); △, (**3d**)—(**4b**) at 150 °C; ○, (**3e**)—(**4a**); ●, (**3f**)—(**4c**); □, (**3g**)—(**4b**); ■, (**3h**)—(**4b**).

In order to evaluate sample–stationary liquid interactions, we calculated the ratio of α_2 to α_1, where the subscripts 2 and 1 represent the stationary liquids employed. As can be seen from Figure 1, α_2/α_1 is linearly related to the content (%) of Ph groups in the liquid (**2**).§ The sample pairs cyclohexanes–straight-chain alkanes have α_2/α_1 values considerably larger than unity, indicating that the cyclic nature of the cyclohexanes leads to an increase in their solubility in (**2**) rather than in (**1**).¶ It is interesting to note that, among pairs of branched alkanes (**3a**—**d**) and straight-chain alkanes (**4**), only the pair (**3d**)-(**4b**) gives α_2/α_1 values larger than unity (*e.g.*, $\alpha_{2c}/\alpha_1 = 1.06$).

The α_{2c} and α_1 values were further measured at various temperatures. Plots of $\ln\alpha$ against T^{-1} showed a straight line for each sample pair examined. Since the relationship $\ln\alpha = -\Delta\Delta H/RT +$ constant holds, where $\Delta\Delta H$ is the difference in molar heat of solution between samples (**3**) and (**4**) ($\Delta\Delta H = \Delta H_3 - \Delta H_4$),[5] the slope of the plots yields $-\Delta\Delta H/R$. Table 1 summarises $\Delta\Delta H$ values in the liquids (**2c**) and (**1**) together with their differences. The $\Delta\Delta H$ values for the pairs (**3e**—**h**)-(**4**) have proved to be smaller in (**2c**) than in (**1**) by about −0.3 to −0.5 kcal mol^{-1}. For the pair (**3b**)-(**4a**), the $\Delta\Delta H$ value tends to be smaller in (**2c**) than in (**1**).

The $\Delta\Delta H_{2c}$ and $\Delta\Delta H_1$ values themselves reflect the differences in boiling points between samples (**3**) and (**4**). However,

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† Silicone oils were used as the stationary liquids: (**1**), Silicone OV-101 (100% Me); (**2a**), Silicone OV-7 (20% Ph and 80% Me); (**2b**), Silicone OV-17 (50% Ph and 50% Me); (**2c**), Silicone OV-25 (75% Ph and 25% Me). These were coated on acid-treated Celite 545 in a weight ratio of 1 to 5, and the stationary phases were packed in stainless-steel tubes (3 mm i.d. × 2 m). The carrier gas was nitrogen with a flow rate of 20 ml min^{-1}.

‡ Retention time was measured from the methane peak to correct for the free space in the system. The relative retention (α) is the mean value of four or more measurements, and was reproducible to <3% average deviation from the mean.

§ As was expected, on decreasing the amount of liquids (**1**) and (**2c**) from 20% to 2% (w/w), the α_{2c}/α_1 value for the pair (**3e**)-(**4a**) at 70 °C was reduced from 1.55 to 1.16.

¶ Since $\Delta\Delta G = -RT\ln\alpha$, the changes in $\Delta\Delta G$ for transfer of samples (**3e**—**h**) and (**4**) from liquid (**1**) to liquid (**2**) give negative values [*e.g.*, $\Delta\Delta G_{2c} - \Delta\Delta G_1 = -0.35$ kcal mol^{-1} for the pair (**3e**)-(**4a**) at 70 °C].

Table 1. Thermodynamic parameters (in kcal mol^{-1})[a] for solution of samples [branched (**3a**—**d**), cyclic (**3e**—**h**), and the corresponding straight-chain alkanes (**4**)] in the stationary liquids (**2c**) and (**1**).

Sample pair	$\Delta\Delta H_{2c}$	$\Delta\Delta H_1$	$\Delta\Delta H_{2c} - \Delta\Delta H_1$
(**3a**)—(**4a**)	-0.01 ± 0.04	0.05 ± 0.03	-0.06 ± 0.05
(**3b**)—(**4a**)	0.38 ± 0.05	0.49 ± 0.04	-0.11 ± 0.06
(**3c**)—(**4b**)	1.26 ± 0.05	1.28 ± 0.01	-0.02 ± 0.05
(**3d**)—(**4b**)	1.64 ± 0.05	1.28 ± 0.02	0.36 ± 0.06
(**3e**)—(**4a**)	-1.03 ± 0.03	-0.54 ± 0.03	-0.49 ± 0.04
(**3f**)—(**4c**)	-0.26 ± 0.04	0.08 ± 0.03	-0.34 ± 0.05
(**3g**)—(**4b**)	-0.09 ± 0.03	0.32 ± 0.01	-0.41 ± 0.03
(**3h**)—(**4b**)	0.29 ± 0.02	0.57 ± 0.02	-0.28 ± 0.03

[a] $\Delta\Delta H = \Delta H_3 - \Delta H_4$; 1 cal = 4.184 J. Temperature ranges: 70—130 °C for the C_6 and C_7 samples; 70—150 °C for the C_8 samples [90—150 °C for the pair (**3d**)—(**4b**)]. Other gas chromatographic conditions are as in Figure 1.†

the differences between these two parameters ($\Delta\Delta H_{2c} - \Delta\Delta H_1$) have no correlation with the differences in the boiling points. Thus, the enthalpy change ($\Delta\Delta H_{2c} - \Delta\Delta H_1$) can be regarded as a measure, though not strict, of the difference in the weak interaction of the Ph group in (**2c**) between a branched or cyclic alkyl group and the corresponding straight-chain alkyl group.

On the basis of the experimental results presented here, we propose that the alkyl–phenyl interaction is specific for the three-dimensional shape of the alkyl group. The interaction of a Ph group is more attractive with a cyclohexyl group, and probably with a branched alkyl group, than with the corresponding straight-chain alkyl group. This type of specificity of weak interactions would contribute to high selectivity in chemical as well as biochemical reactions.

We thank Mr. Tsunenobu Sato, Miss Emi Nakashiro, and Mr. Kazuo Guro for valuable assistance, and Drs. Naoya Nakagawa, Shinsaku Shiraishi, and Kunio Nikki for helpful discussions.

Received, 5th August 1983; Com. 1059

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