Separation Science and Technology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713708471

Stationary-mobile phase distribution coefficient for polystyrene standards

F. Torrens[a]; V. Soria[a]
[a] Universitat de València, Burjassot (València), Spain

To cite this Article Torrens, F. and Soria, V.(2002) 'Stationary-mobile phase distribution coefficient for polystyrene standards', Separation Science and Technology, 37: 7, 1653 — 1665

To link to this Article: DOI: 10.1081/SS-120002742

URL: http://dx.doi.org/10.1081/SS-120002742

SEPARATION SCIENCE AND TECHNOLOGY, 37(7), 1653–1665 (2002)

STATIONARY–MOBILE PHASE DISTRIBUTION COEFFICIENT FOR POLYSTYRENE STANDARDS

F. Torrens* and V. Soria

Institut Universitari de Ciència Molecular and Institut de
Ciència dels Materials (ICMUV), Universitat de València,
Dr. Moliner 50, E-46100 Burjassot (València), Spain

ABSTRACT

The measured shifts of the retention volume V_R of polystyrene (PS) towards lower values in benzene–methanol (Bz–MeOH), and towards higher values in butanone–heptane (But–Hep) are in agreement with our theoretical model, in which both MeOH and But are adsorbed on Lichrospher. This paved way for us to model the chromatographic stationary (s)-phase as MeOH and the mobile (m)-phase as Bz–MeOH, and to calculate the distribution coefficients for PS. For But–Hep, the s-phase has been modeled as But, and the m-phase as But–Hep. A linear relation for the experimental equilibrium distribution P_{sm} of PS is shown between the s- and m- phases in Bz–MeOH and But–Hep vs. the logarithm of the molecular mass $\log M_w$. The s- and m-phases for PS in Bz–MeOH and But–Hep are modeled, and $\log P_{sm}$ is calculated. The results indicate the preference of PS for Bz–MeOH and But. The calculations predict a V_R shift of PS towards lower values in Bz–MeOH, and towards greater values in But–Hep. The different

---

*Corresponding author.

www.dekker.com

adsorptions on Lichrospher of MeOH (multilayer) and But (monolayer) affect the magnitude of the V_R shift.

Key Words: Distribution coefficient; High performance liquid chromatography–size-exclusion chromatography; Ternary polymeric system; Transient stationary phase; Polystyrene

INTRODUCTION

There are many applications of molecular segregation phenomena associated with the flow of polymer molecules through porous media. The segregation processes reflect interplay between hydrodynamic and thermodynamic effects, which often allow remarkably effective separations. The most important application of these effects leads to the separation of polymers in accordance with their hydrodynamic size, and the process is recognized as the basis of size-exclusion chromatography (SEC). An attractive interaction between the polymer in solution and the solid portion of the porous medium can substantially affect molecular separation. From the theoretical point of view, the complementary models of Casassa (1) and di Marzio and Guttman (2) are appropriate for different types of porous media. However, the complex structure of the pore space in real chromatographic materials must be recognized, as must the fact that any particular model of the pore shape necessitates idealization.

Multicomponent eluents are often used in liquid chromatography (LC) under isocratic conditions in both organic and aqueous environments (3,4). In the case of SEC of polymers, the first application of the multicomponent eluents refers to a new mode of SEC, called critical SEC, where the retention volume V_R of a polymer sample exhibits no dependence on the molar mass (5,6). The second advantage in using this kind of eluents is concerned with the possibility of performing transient stationary (s)-phases by chemisorption of one or more components of the eluent on the active centres of the gel packing (7–10).

On the microscopic phase description entrapped in the pores of the packing material, some contributions dealing with chromatographic modes other than SEC in multicomponent eluents have been published (11–13). Jaroniec and Martire (14) described the solute retention in LC, with mixed eluents involving nonspecific solute–solvent and solvent–solvent interactions in both mobile (m)- and s-phases, as well as association equilibria in these phases. Boehm and Martire (15) reported a statistical thermodynamic treatment based on the Bethe–Guggenheim quasi-chemical approach, to predict solute distribution between a binary solvent m-phase and a s-phase consisting of a monolayer of solvent molecules sorbed on a chemically homogeneous planar support surface. The use of multicomponent mixtures as m-phases led to the formation of extra peaks often called *system peaks*, because of a thermodynamic phenomenon resulting from the perturbation of the chemical equilibrium (16). Size-exclusion chromatography was used for quantitative evaluation of the preferential solvation by analysis of an extra peak termed in this context as *vacant peak* (17–20).

García et al. (21) studied polymer retention in SEC with mixed eluents on silica-based gel packings. In a previous paper, an extension of this thermodynamic treatment including more elaborated models for the s-phase was proposed (22). The conventional Flory–Huggins formalism often used to deal with the liquid–liquid phase equilibrium in polymer solutions described the solute distribution (23,24). The theory of association equilibria for a binary mixture, when the polar component can undergo self-association was substantiated for the evaluation of the s-phase composition (25,26). The predictions of this analysis were compared with experimental data on distribution coefficients obtained from SEC experiments for a set of commercial (Waters Association, Milford, MA) narrow atactic polystyrene (PS) standards eluted on Lichrospher packing using benzene–methanol (Bz–MeOH) 80/20, v/v, and (But–Hep, 80/20, v/v) binary eluents.

The V_R shift of PS towards lower values in Bz–MeOH and towards higher values in But–Hep are in agreement with our theoretical model, in which both MeOH and But are adsorbed on Lichrospher under both static and flow conditions. This has paved way for us to model, in a first approximation, the chromatographic s-phase as MeOH and the m-phase as Bz–MeOH. A method that permits a semi-quantitative estimate of the distribution of any solute between any two media is presented. The model is based on a solvent-dependent conformational analysis program (SCAP) proposed by Hopfinger. The hallmark of our version of SCAP is that it has been designed for *all* solvents without previous parameterization. Solvent-dependent conformational analysis program is based on the division of $\Delta G^0_{\mathrm{solv}}$ in a system of increments by atoms or by groups. As an example, we have calculated the distribution coefficient P of a set of PS taken as PS-standard models. We have computed $\Delta G^0_{\mathrm{solv}}$ in MeOH, Bz–MeOH, But, and But–Hep, and $\log P$ for the Bz/MeOH–MeOH and But/Hep–But systems. We have calculated the distribution coefficients for random-coil monodisperse PS from one to 86 chain styrene units. We have optimized the molecular conformations with MM2 molecular mechanics (27). For But–Hep, we have modeled the s-phase as But, and the m-phase as But–Hep. This work is a first step in modeling SEC distribution coefficients of PS.

In the next section, the main features of the universal solvation model are described. Following that, the results are presented and discussed for some linear correlation models including the PS distribution coefficient P_{sm}, and for the free energies of solvation and distribution coefficients of PS in Bz–MeOH and But–Hep. The last section summarizes our conclusions.

ENERGIES OF SOLVATION AND DISTRIBUTION COEFFICIENTS IN GENERAL SOLVENTS

The basis for building a method that permits a semi-quantitative estimate of the distribution of any solute between any two media has been reported elsewhere (28–33) (see illustration in Ref. 34). The method is based on the model of Hopfinger (35,36). The main improvement introduced is the change in the standard Gibbs free energy parameter Δg_s^0 calculated using the generalized Born equation (37),

$$\Delta g_s^0 = \Delta g_o^0 \frac{1 - \frac{1}{\epsilon_s}}{1 - \frac{1}{\epsilon_o}} = \Delta g_o^0 \frac{\epsilon_o(\epsilon_s - 1)}{\epsilon_s(\epsilon_o - 1)} \tag{1}$$

where the subscripts o and s stand for 1-octanol and for a general organic solvent, respectively, and ϵ_o and ϵ_s are the relative dielectric constants.

The only needed parameters are the relative dielectric constant ϵ and molecular volume V_s of the organic solvent. V_s values have been calculated with a new version of program TOPO (38), which includes an actualized database of van der Waals radii (39). In this work, the following values have been used: $\epsilon =$ 2.274 (Bz), 32.63 (MeOH), 18.07 (But), 1.917 (Hep) (40,41), $V_s = 79.6\,\text{Å}^3$ (Bz), $36.4\,\text{Å}^3$ (MeOH), $74.6\,\text{Å}^3$ (But), and $119.1\,\text{Å}^3$ (Hep). The generalized SCAP method was applied previously to porphyrins, phthalocyanines, benzobisthiazoles, fullerenes, phenyl alcohols (28), acetanilides, local anaesthetics (29), barbiturates (29,31,32), lysozyme (30), and hydrocarbons (33).

CALCULATION RESULTS AND DISCUSSION

Linear Correlation Models

Philip showed a linear relation between the relative dielectric constant ϵ and the volume fraction of MeOH χ, in binary mixtures with Bz (42). Linear regressions were also shown for mixtures of Bz with phenol, *o*-cresol, *m*-cresol, *p*-cresol, phenyl methyl ether, *o*-tolyl methyl ether, *m*-tolyl methyl ether, *p*-tolyl methyl ether (43), toluene (44), camphor, menthol (45), oleates, and castor oil (46). Other linear models were shown for mixtures of heptane with carbon disulfide and 1-bromonaphthalene (47,48). Assuming linear correlations for ϵ and the effective molecular volume V_s, it has been obtained

$$\epsilon = 2.27 + 30.36\chi$$

and

$$V_s = 79.6 - 43.2\chi$$

for Bz–MeOH mixtures. Moreover, it has been calculated

$$\epsilon = 18.07 - 16.15\chi$$

and

$$V_s = 74.6 + 44.5\chi$$

for butanone–heptane (But–Hep) systems, where χ is the volume fraction of Hep. From these equations it has been calculated that $\epsilon = 8.35$ and $V_s = 71.0\,\text{Å}^3$ for Bz–MeOH (80/20, v/v), and $\epsilon = 14.84$ and $V_s = 83.5\,\text{Å}^3$ for But–Hep (80/20, v/v).

Soria et al. considered a set of PS of different molecular weights as solute, chromatographed in the binary eluent Bz–MeOH (80/20, v/v), which behaves as a good solvent (Bz) and a nonsolvent (MeOH) (22). They measured the retention volume V_R of PS in Bz–MeOH considering an ideal reference system such as PS in Bz. When going from pure Bz to its MeOH mixture, there is an increase in solvent–gel interactions and, therefore, a relative decrease in polymer–gel interactions (49). The V_R of macromolecules shifts towards lower values, in spite of smaller hydrodynamic volumes (50). This behavior is enhanced for the lowest molecular weight polymers and two positive combined effects may be invoked to explain it. The first one is that the relative shrinkage of coils decreases with decreasing molecular weight. On the other hand, it is known that preferential solvation in these systems is enhanced for low molecular weight samples (51,52). Successive preferential solvations along the column will yield a solvent richer in MeOH than the original mixture. The strong MeOH–gel interactions will prevent polymer–gel interactions and as a result V_R decreases. The preferential phenomenon being more important, as the molecular weight decreases, a similar trend is expected for V_R.

Values of the distribution coefficient P_{sm} for equilibrium partitioning of PS between the chromatographic s- and m-phases have been obtained directly from V_R considering an ideal reference system such as PS in Bz, according to:

$$[P_{sm}]_{Bz-MeOH} = \frac{(V_R - V_o)_{Bz-MeOH}}{(V_R - V_o)_{Bz}} \qquad (2)$$

and assuming $[P_{sm}]_{Bz} = 1$ for ideal SEC. The results are compatible with linear and nonlinear correlation models (Fig. 1). As an example, the data have been fitted to the equation:

$$P_{sm} = 0.998 - 0.154 \log M_w \quad (r = 0.947) \qquad (3)$$

where M_w is the weight average molecular mass (in kDa) of PS. Notice that the experimental results show a distinctive curvature, which might be attributed to end group effects. For $M_w = 1\,\text{kDa}$, the fit predicts $P_{sm} = 0.998$. As the theoretical

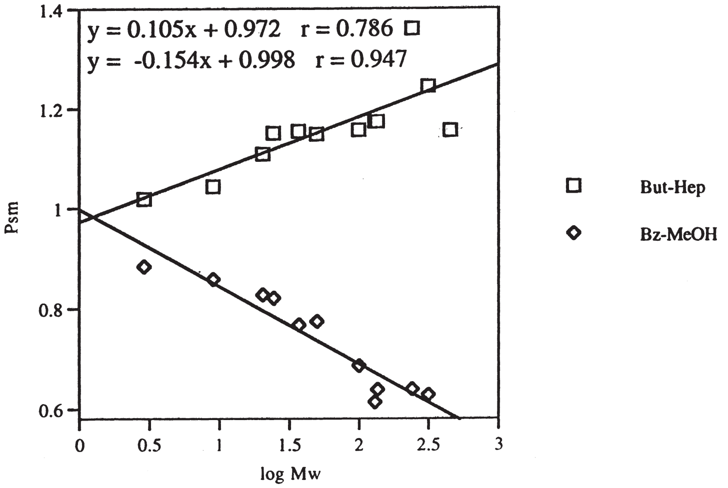

Figure 1. Experimental distribution coefficients for PS in Bz–MeOH (80/20, v/v) and in But–Hep (80/20, v/v) as a function of the logarithm of the molecular weight in kDa.

value is 1.000, an error of 0.2% can be estimated in first approximation. However, the estimate has been improved. As a nonlinear regression leads to an intercept of ca. 0.9, a greater error of 5% is finally proposed.

The elution of PS in But–Hep (80/20, v/v), in which But behaves as a good solvent and Hep as a nonsolvent, has been studied. In the But–Hep system there is a shift towards higher V_R when the thermodynamic quality of the solvent mixture decreases. The reasons are the same as above, i.e., shrinkage of the macromolecular coils and loss of eluent strength. In this case the difference rests on both effects working in the same direction. Moreover, as the relative shrinkage of macromolecules increases with increasing molecular weight, the differences in V_R of mixtures with respect to those of pure solvent follow the same trend and the higher differences appear with the highest molecular-weight samples.$[P_{sm}]_{But-Hep}$ has been calculated according to a formula analogous to Eq. (2), assuming $[P_{sm}]_{But} = 1$. The results (Fig. 1) have been fitted to:

$$P_{sm} = 0.972 + 0.105 \log M_w \quad (r = 0.786) \tag{4}$$

Notice that the experimental results show a distinctive curvature. For $M_w = 1$ kDa, the fit predicts $P_{sm} = 0.972$ with an error of 3%. The slope for But–Hep is, in absolute value, somewhat smaller than the slope for Bz–MeOH. This suggests that the V_R(But–Hep) shift will be smaller and in the opposite direction of the V_R(Bz–MeOH) shift, in agreement with experiment.

Free Energies of Solvation and Distribution Coefficients in Bz–MeOH

$\Delta G^0_{\mathrm{solv}}$ and $\log P$ have been calculated for PS from one to 86 chain styrene units. The results show that, although $-\Delta G^0_{\mathrm{solv}}$ increases, in general, with the number of monomeric units, N, in MeOH, this effect is more stronger in Bz–MeOH (Table 1). Thus, $\log P_{\mathrm{Bz/MeOH-MeOH}}$ results are positive. The corresponding interpretation is a strong preference of PS for Bz–MeOH with respect to MeOH. $\mathrm{Log}\, P_{\mathrm{Bz/MeOH-MeOH}}$ increases with N, rising two orders of magnitude on going from one to 86 units. Notice that for values of $\log P > 3$, more than 99.9% of PS is in the Bz–MeOH phase. Therefore, all the results but one predict a negligible quantity of PS in MeOH. Even, when a number of $\log P$ values are greater than the Avogadro number exponent 23 ($P > 10^{23}$) is, the explanation is that no PS would be present in MeOH to allow experiments for validation. However, all the $\log P$ figures are placed in Table 1 for the only purpose of comparison along the series.

The variation of the calculated P_{sm} for Bz/MeOH–MeOH with $N = 1–5$ is shown (Fig. 2). In the limit of low N the fit predicts $P_{\mathrm{sm}} = 0.001$ log unit. As the theoretical value is 1.000, an error of one log unit is estimated for small N.

In our model of PS eluted on Lichrospher with Bz–MeOH, MeOH (nonsolvent) represents the s-phase and Bz–MeOH characterizes the m-phase. In

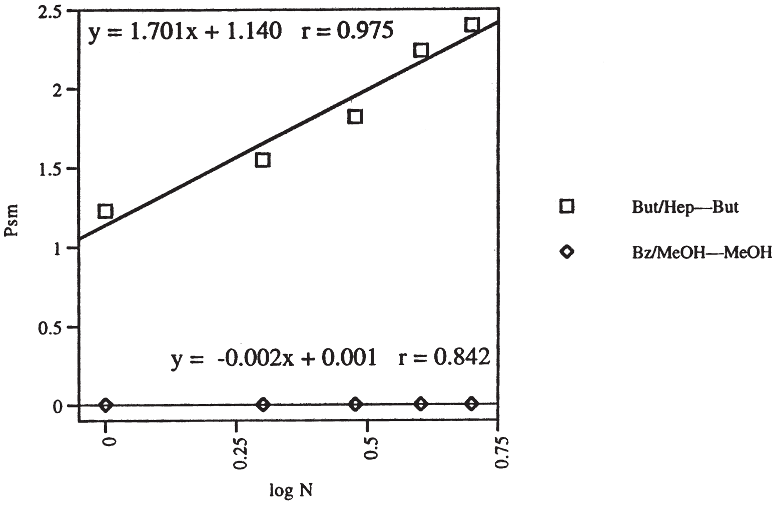

Figure 2. Calculated distribution coefficients for PS in Bz/MeOH–MeOH and in But/Hep–Hep as a function of the logarithm of the number of chain styrene units.

Table 1. Calculated Free Energies of Solvation and Distribution Coefficients for Styrene Oligomers

Number of Monomers	$\Delta G^0_{\text{solv,MeOH}}$[a]	$\Delta G^0_{\text{solv,Bz/MeOH}}$[b]	$\Delta G^0_{\text{solv,But}}$[c]	$\Delta G^0_{\text{solv,But/Hep}}$[d]	$\log P_{\text{Bz/MeOH-MeOH}}$[e]	$\log P_{\text{But/Hep-But}}$[f]
1	−7.26	−23.24	−24.84	−24.34	2.81	−0.09
2	−2.13	−53.15	−53.05	−51.95	8.96	−0.19
3	−3.70	−73.48	−74.89	−73.44	12.3	−0.26
4	−5.20	−93.76	−96.82	−94.82	15.6	−0.35
5	−6.56	−113.9	−118.3	−116.2	18.9	−0.38
6	−7.70	−133.3	−139.3	−136.7	22.1	−0.45
7	−8.73	−152.8	−160.4	−157.7	25.3	−0.46
8	−9.85	−172.5	−181.3	−178.3	28.6	−0.53
9	−11.37	−192.0	−202.3	−198.9	31.7	−0.60
10	−12.45	−212.0	−223.4	−220.0	35.1	−0.60
11	−13.98	−232.4	−245.2	−241.3	38.4	−0.68
12	−14.97	−251.6	−266.1	−262.0	41.6	−0.72
13	−16.43	−271.7	−287.8	−282.9	44.8	−0.85
14	−18.56	−293.4	−310.4	−305.1	48.3	−0.93
15	−20.34	−315.1	−333.2	−327.2	51.8	−1.06
16	−22.05	−335.5	−354.6	−348.8	55.1	−1.02
28	−40.32	−578.1	−615.5	−604.4	94.5	−1.95
86	−131.7	−1717	−1832	−1794	279	−6.63

[a] Gibbs free energy of solvation in MeOH (kJ mol^{-1}).

[b] Gibbs free energy of solvation in a Bz–MeOH (80/20, v/v) binary mixture (kJ mol^{-1}).

[c] Gibbs free energy of solvation in 2-But (kJ mol^{-1}).

[d] Gibbs free energy of solvation in a 2-But–Hep (80/20, v/v) binary mixture (kJ mol^{-1}).

[e] $P_{\text{Bz/MeOH-MeOH}}$ is the MeOH Bz–MeOH (80/20, v/v) binary mixture distribution coefficient.

[f] $P_{\text{But/Hep-But}}$ is the 2-But 2-But–Hep (80/20, v/v) binary mixture distribution coefficient.

accordance with our model, a rather strong V_R shift towards lower values is predicted. The V_R shift was measured experimentally (22) in agreement with our theoretical model. The corresponding interpretation is that the pore radius for Lichrospher drops due to the presence of adsorbed MeOH molecules inside the pore.

Free Energies of Solvation and Distribution Coefficients in Butanone–Heptane

The successful prediction of our model for Bz–MeOH led us to study the case when a good solvent can model the s-phase. This is the instance of But–Hep, where But (good solvent), which can be adsorbed on Lichrospher, can be taken as a model of the s-phase. $-\Delta G^0_{\mathrm{solv}}$ increases with the number of chain styrene units, *N*, in But and But–Hep (Table 1), but this effect is slightly more pronounced in But. Thus, $\log P_{\mathrm{But/Hep-But}}$ is found negative. The corresponding interpretation is a preference of PS for But with respect to But–Hep. In general, $-\log P_{\mathrm{But/Hep-But}}$ increases with *N*, rising two orders of magnitude in Table 1.

The variation of the calculated P_{sm} for But/Hep–But with $N = 1-5$ is displayed (Fig. 2). The results are compatible with linear and nonlinear correlation models. As an example, the data have been fitted to a linear equation. In the limit of low *N*, the fit predicts $P_{\mathrm{sm}} = 1.140$ log units with an error of ca. 0.1 log unit. Notice that the calculation results show a distinctive curvature.

In our model of PS eluted on Lichrospher with But–Hep, But represents the s-phase and But–Hep characterizes the m-phase. In accordance with our model, a moderate V_R shift towards higher values is predicted. The corresponding interpretation is the presence of an attractive interaction But–PS in the s-phase due to the presence of adsorbed But molecules inside the Lichrospher pore. Notice the opposite V_R shift in the Bz/MeOH–Bz and But/Hep–But experiments. The explanation is that in the former the nonsolvent (MeOH) is absorbed on Lichrospher, whereas in the latter the good solvent (But) is adsorbed on the gel.

Notice that $\log P_{\mathrm{Bz/MeOH-MeOH}}$ is very much greater than $|\log P_{\mathrm{But/Hep-But}}|$ in Table 1. Therefore, a greater V_R shift is predicted for Bz–MeOH than for But–Hep. The corresponding interpretation is that the adsorption is of a different type for MeOH and But on Lichrospher. On the one hand, MeOH, whose self-association by hydrogen bonds is well known, is adsorbed on Lichrospher forming a multilayer (22). On the other hand, But is an aprotic solvent, which cannot undergo self-association by hydrogen bonds due to the lack of polar hydrogen atoms in its molecular structure. Therefore, we propose in this work that But can be adsorbed on Lichrospher but forms only a monolayer. The greater V_R shift of PS in Bz–MeOH is in agreement with Fig. 1, where this binary eluent shows greater slope.

CONCLUSIONS

A method that permits a semi-quantitative estimate of the distribution of any solute between any two media is presented. The model is based on the modification of a previously established model known as SCAP and proposed by Hopfinger. The hallmark of our model is that it has been designed for *all* solvents without previous parameterization. As an example, the distribution coefficient P of a set of PS taken as PS-standard models is calculated. $\Delta G^0_{\mathrm{solv}}$ has been calculated in MeOH, Bz–MeOH, But, and But–Hep, and $\log P$ for the Bz/MeOH–MeOH and But/Hep–But systems. From the present results the following conclusions can be drawn.

1. Linear relations have been proposed for ϵ and V_s as functions of the volume fraction of one solvent in Bz–MeOH and But–Hep mixtures.
2. A linear correlation model of the experimental P_{sm} has been shown for equilibrium distribution of PS between the chromatographic s- and m-phases in Bz–MeOH and But–Hep binary eluents, as a function of $\log M_{\mathrm{w}}$. Both fits are in agreement with our theoretical model.
3. The Bz/MeOH–MeOH results indicate a strong preference of PS for Bz–MeOH and predict a V_{R} shift of PS towards lower values in Bz–MeOH relative to Bz. The But/Hep–But results show a moderate preference of PS for But and predict a V_{R} shift towards greater values in But–Hep. These results are in agreement with both the experiment and our theoretical model.
4. The different solvent characters of MeOH and But result in their different types of adsorption on Lichrospher that affect the magnitude of the V_{R} shift. MeOH is adsorbed forming a multilayer. However, we propose that But is adsorbed forming only a monolayer.

This work is a first step for modeling SEC distribution coefficients of PS. Work on designing the dependence of the properties of the s-phase and P_{sm} with PS M_{w} is in progress.

ACKNOWLEDGMENTS

The authors acknowledge financial support of the Dirección General de Enseñanza Superior of the Spanish MEC, Projects PB97-1383 and PM98-0856.

REFERENCES

1. Casassa, E.F. Theoretical Models for Peak Migration in Gel Permeation Chromatography. J. Phys. Chem. **1971**, *75*, 3929–3939.

2. di Marzio, E.A.; Guttman, C.M.; Polym. Lett. **1969**, *7*, 267.
3. Riedo, F.; Kováts, E. Adsorption from Liquid Mixtures and Liquid Chromatography. J. Chromatogr. **1982**, *239*, 1–28.
4. Riedo, F.; Kováts, E. *Theoretical Advancement in Chromatography and Related Techniques*; NATO ASI Series, Dondi, F., Giochon, G., Eds.; Kluwer: Dordrecht, 1992; 211–226.
5. Belenkii, B.G.; Gankina, E.S.; Tennikov, M.B.; Vilenchik, L.Z.; Dokl. Akad. Nauk SSSR **1976**, *231*, 1147–1149.
6. Belenky, B.G.; Gankina, E.S.; Tennikov, M.B.; Vilenchik, L.Z.; J. Chromatogr. **1978**, *147*, 99–110.
7. Figueruelo, J.E.; Soria, V.; Campos, A. *Liquid Chromatography of Polymers and Related Materials II*; Chromatographic Science Series No. 13, Cazes, J., Delamare, X., Eds.; Marcel Dekker: New York, 1980; 49–71.
8. Mori, S. *Steric Exclusion Liquid Chromatography of Polymers*; Chromatographic Science Series No. 25, Janca, J., Ed.; Marcel Dekker: New York, 1984; 161–211.
9. Dubin, P.L. *Aqueous Size-Exclusion Chromatography*; Journal of Chromatography Library No. 40, Dubin, P.L., Ed.; Elsevier: Amsterdam, 1988; Chap. 3.
10. Balke, S.T. *Modern Methods of Polymer Characterization*; Chemical Analysis No. 113, Barth, H.G., Mays, J.W., Eds.; John Wiley and Sons: New York, 1991; Chap. 1.
11. Jaroniec, M.; Martire, D.E.; Borówko, M. Theoretical Basis of Liquid and Sorption Chromatography with Mixed Mobile Phases and Its Connection with the Theory of Adsorption from Multicomponent Solutions. Adv. Colloid Interface Sci. **1985**, *22*, 177–227.
12. Boehm, R.E.; Martire, D.E.; Amstrong, D.W.; Bui, K.H.; Macromolecules **1983**, *16*, 466.
13. Boehm, R.E.; Martire, D.E.; Amstrong, D.W.; Bui, K.H.; Macromolecules **1984**, *17*, 400.
14. Jaroniec, M.; Martire, D.E. Description of Nonspecific and Specific Solute–Solvent Interactions in Liquid Chromatography with Mixed Eluents. J. Liq. Chromatogr. **1987**, *10*, 541–559.
15. Boehm, R.E.; Martire, D.E. Theory of Liquid Chromatographic Retention and Solute-Transfer Thermodynamics Using the Bethe–Guggenheim Quasi-Chemical Approach. J. Phys. Chem. **1994**, *98*, 1317–1327.
16. Knox, J.H.; Kaliszan, R. Theory of Solvent Disturbance Peaks and Experimental Determination of Thermodynamic Dead-Volume in Column Liquid Chromatography. J. Chromatogr. **1985**, *349*, 211–234.
17. Berek, D.; Bleha, T.; Pevna, Z. Determination of Preferential Solvation of Polymers in Mixed Solvents by Gel-Permeation Chromatography. J. Polym. Sci., Polym. Lett. **1976**, *14*, 323–327.

18. Soria, V.; Campos, A.; Figueruelo, J.E. Estudio de Sistemas Ternarios Polímero/Disolvente 1/Disolvente 2 por Cromatografía de Permeación de Gel. An. Quím. (Madrid) **1978**, *78*, 1026–1034.
19. Quivoron, C. *Steric Exclusion Liquid Chromatography of Polymers*; Chromatographic Science Series No. 25, Janca, J., Ed.; Marcel Dekker: New York, 1984; Chap. 5.
20. Porcar, I.; García, R.; Campos, A.; Soria, V. Size-Exclusion Chromatographic and Viscosimetric Study of Polymer Solutions Containing Nicotine or Silicic Acid. J. Chromatogr. A **1994**, *673*, 65–76.
21. García, R.; Celda, B.; Soria, V.; Tejero, R.; Campos, A. Non-Exclusion Phenomena in Size Exclusion Chromatography with Inorganic Porous Packing: A Thermodynamic Treatment. Polymer **1990**, *31*, 1694–1702.
22. Soria, V.; Campos, A.; Figueruelo, J.E.; Gómez, C.; Porcar, I.; García, R. Modelling of Stationary Phase in Size-Exclusion Chromatography with Binary Eluents. In *Strategies in Size Exclusion Chromatography*; ACS Symposium Series No. 635, Potschka, M., Dubin, P.L., Eds.; American Chemical Society: Washington, DC, 1996; Chap. 7, 103–126.
23. Flory, P.J. *Principles of Polymer Chemistry*; Cornell University Press: Ithaca, NY, 1953; Chap. 5.
24. Munk, P. *Modern Methods of Polymer Characterization*; Chemical Analysis No. 113, Barth, H.G., Mays, J.W., Eds.; John Wiley and Sons: New York, 1991; Chap. 5.
25. Prigogine, I.; Defay, R. *Chemical Thermodynamics*; Longmans Green: London, 1954; Chap. 26.
26. Pouchly, J.; Zivny, A. The Effect of Specific Interactions on the Sorption Equilibrium in the Polymer/Mixed Solvent System. Makromol. Chem. **1985**, *186*, 37–52.
27. Allinger, N.L. Conformational Analysis. 130. MM2. A Hydrocarbon Force Field Utilizing V_1 and V_2 Torsional Terms. J. Am. Chem. Soc. **1977**, *99*, 8127–8134.
28. Torrens, F.; Sánchez-Marín, J.; Nebot-Gil, I. Universal Model for the Calculation of All Organic Solvent–Water Partition Coefficients. J. Chromatogr. A **1998**, *827*, 345–358.
29. Torrens, F. Universal Organic Solvent–Water Partition Coefficient Model. J. Chem. Inf. Comput. Sci. **2000**, *40*, 236–240.
30. Torrens, F. Calculation of Partition Coefficient and Hydrophobic Moment of the Secondary Structure of Lysozyme. J. Chromatogr. A **2001**, *908*, 215–221.
31. Torrens, F. Submitted for publication
32. Torrens, F. Submitted for publication
33. Torrens, F. Free Energy of Solvation and Partition Coefficients in Methanol–Water Binary Mixtures. Chromatographia **2001**, *53*, S199–S203.

34. Torrens, F.; Sánchez-Marín, J.; Nebot-Gil, I. Characterizing Cavities in Model Inclusion Molecules: A Comparative Study. J. Mol. Graphics Mod. **1998**, *16*, 57–71.
35. Hopfinger, A.J. Polymer–Solvent Interactions for Homopolypeptides in Aqueous Solution. Macromolecules **1971**, *4*, 731–737.
36. Hopfinger, A.J.; Battershell, R.D. Application of SCAP to Drug Design 1. Prediction of Octanol–Water Partition Coefficients Using Solvent-Dependent Conformational Analyses. J. Med. Chem. **1976**, *19*, 569–573.
37. Born, M. Volume and Heat of Hydration of Ions. Z. Phys. **1920**, *1*, 45.
38. Torrens, F.; Ortí, E.; Sánchez-Marín, J. Vectorized TOPO Program for the Theoretical Simulation of Molecular Shape. J. Chim. Phys. Phys.-Chim. Biol. **1991**, *88*, 2435–2441.
39. Flower, D.R. SERF: A Program for Accessible Surface Area Calculations. J. Mol. Graphics Mod. **1997**, *15*, 238–244.
40. Maryott, A.A.; Smith, E.R. *Table of Dielectric Constants of Pure Liquids*; National Bureau of Standards Circular No. 514, Department of Commerce-National Bureau of Standards: Washington, DC, 1951.
41. Helmer, F.; Kiehs, K.; Hansch, C. The Linear Free-Energy Relation Between Partition Coefficients and the Binding, and Conformation Perturbation of Macromolecules by Small Organic Compounds. Biochemistry **1968**, *7*, 2858–2863.
42. Philip; Z. Phys. Chem. (Munich) **1897**, *24*, 18.
43. Philip; Haynes; J. Chem. Soc. **1905**, *87*, 998.
44. Grützmacher; Z. Phys. **1924**, *28*, 342.
45. Eggers; J. Phys. Chem. **1904**, *8*, 14.
46. Väisälä; Översikt av Finska Vetenskaps-Societetens Förhandlingar **1915**, *57*, 15.
47. Dobroserdov; J. Russ. Phys.-Chem. Soc., Chem. **1912**, *44*, 396.
48. Dobroserdov; J. Russ. Phys.-Chem. Soc., Chem. **1912**, *44*, 679.
49. Campos, A.; Figueruelo, J.E. Polymer Retention in Gel Permeation Chromatography in Pure and Mixed Eluents. Makromol. Chem. **1977**, *178*, 3249–3252.
50. Campos, A.; Soria, V.; Figueruelo, J.E. Polymer Retention Mechanism in GPC on Active Gels. 1. Polystyrene in Pure and Mixed Eluents. Makromol. Chem. **1979**, *180*, 1961–1974.
51. Hert, M.; Strazielle, C. Preferential Solvation in the Ternary System Polystyrene–Benzene–Methanol. Int. J. Polym. Matter. **1976**, *4*, 195–207.
52. Hert, M.; Strazielle, C.; Benoit, H. Influence of Molecular Weight, Polydispersity and Temperature on the Phenomena of Preferential Solvation of Linear Polystyrenes in Different Solvent Mixtures. Makromol. Chem. **1973**, *172*, 169–184.