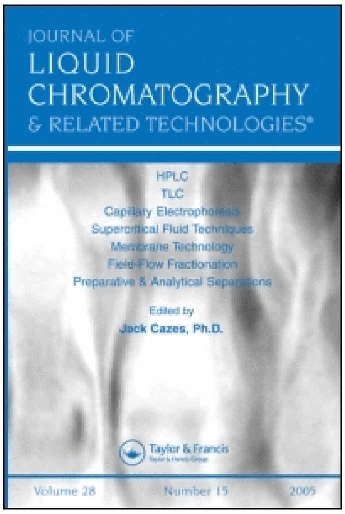

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Solute Retention in Column Liquid Chromatography. III. Computer Optimization of Mobile-Phase Compositions: Program Window

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SOLUTE RETENTION IN COLUMN LIQUID CHROMATOGRAPHY. III. COMPUTER OPTIMIZATION OF MOBILE-PHASE COMPOSITIONS: PROGRAM WINDOW

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ABSTRACT

A program is described that calculates solute retentions (thence optimized conditions for their separation) from data acquired solely from chromatographic measurements. A pre-sorting loop identifies the relevant (window-diagram boundary) pairs of solutes within a user-defined value of the most-difficult separation factor, S_f. The program run time is consequently shortened by several factors over previously-used "brute-force" techniques wherein all possible pairs are considered at each value of the independent parameter(s) to be optimized. The required CPU space reserved for arrays is thereby also diminished. The program was written for an APPLE II Plus system; statements not compatible with other versions of BASIC are pointed out and discussed.

INTRODUCTION

The major drawback to chromatographic separations in general is that it is impossible at the present time to predict on an a priori basis the precise set of conditions which will effect resolution of the mixture at hand. As a result, a number of optimization strategies have been proferred over the years, these including SIMPLEX (1) and the Laub-Purnell window-diagram strategy (2,3). The former makes use of what amounts to an intelligent yet near-random search for the **single** optimum of the parameter

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of interest and is hence subject to local minima. In contrast, the latter defines pictorially the **global set** of optima; it is then left to the user to superpose additional local criteria (such as analysis time, cost, and so forth). The overall **practical** optimum is then determined simply by inspection of the global set.

A number of requests have been received for the global optimization algorithm presented in a recent technical report by Laub (4) and so, the computer program is presented here in detail.

THEORY

The independent variable most frequently employed in optimizing column liquid-chromatographic separations is the composition of the mobile phase. As a result, there have been formulated over the years a number of relations which purport to describe solute retentions as a function of mobile-phase solvent/additive ratio in terms of mole- , weight- , or volume-fraction or molar or molal concentration. The most successful of these is that by McCann, Purnell, and Wellington (5), followed by Madden, McCann, Purnell, and Wellington (6), as described in the previous two papers. They modified the relation first proposed by Scott and Kucera (7) such that all isotherm shapes common to lc could be represented. The result, for which no exception is known at this time, can be expressed in terms of raw retentions with a given column and fixed flow rate as:

$$\frac{1}{t_{R(M)}} = \phi_A \left\{ \frac{1}{t_{R(A)}} + \frac{b\phi_S}{1 + b'\phi_S} \right\} + \frac{\phi_S}{t_{R(S)}} \qquad (1)$$

where values of b and b' are derived from an analysis of the experimental data.

The fitted parameters have yet to be rationalized either from one solute to the next or from one solvent system to another. Nevertheless, the ability to represent generally (hence predict) the variation of solute retentions as a well-defined function of mobile-phase composition represents a very considerable advance since relative retentions (i.e., separations) can then be reduced also to a mathematical formulation. The two relevant equations are:

$$\alpha_{i/j} = \frac{t'_{R(M)\,i}}{t'_{R(M)\,j}} \tag{2}$$

$$S_f = \frac{2R_s}{N^{1/2}} = \frac{t_{R(M)\,i} - t_{R(M)\,j}}{t_{R(M)\,i} + t_{R(M)\,j}} \tag{3}$$

where $\alpha_{i/j}$ and S_f are referred to here as the alpha value and the separation factor, and where R_s and N are the resolution and number of theoretical plates. The latter expression, derived initially by Jones and Wellington (8), has some advantage in practice (see preceding paper) since t_R represents a raw retention time, i.e., uncorrected for column void space. Thus, the dead time t_A (or peak baseline or half-height widths) need not be determined. In addition, for R_s set to unity (4σ separation), the number of plates required N_{req} to effect a separation is calculable directly as $(2/S_f)^2$. In contrast, capacity factors or adjusted retention times (hence t_A) must be known in order to do so with values of alpha, where (9):

$$N_{eff} = 16\left(\frac{\alpha}{\alpha - 1}\right)^2\left(\frac{k' + 1}{k'}\right)^2 \tag{4}$$

and where N and N_{req} are related by:

$$N_{eff} = N\left(\frac{k'}{k' + 1}\right)^2 \tag{5}$$

Eqn. 3 is therefore used in what follows.

When the separation factors of the relevant pairs of solutes (see later) are plotted graphically against the independent parameter (here, mobile-phase composition), the result (window diagram) resembles a set of inverted and partially-overlapped triangles. A perpendicular dropped to the abscissa from the point of the tallest open region (window) formed by the intersection of the sides of two of these triangles (or one triangle with an ordinate) then specifies the optimum mobile-phase composition. A horizontal line from the top of the window to the left-hand ordinate subsequently yields the most-difficult separation factor (all others are easier). The number of plates (hence the column efficiency) required to effect the separation can then be calculated. Reference back to eqn. 1 also provides the order of elution of the solutes at the chosen optimum (10).

PROGRAM DESCRIPTION

In the program that follows, it is assumed that the liquid-chromatographic separation of solutes is to be optimized in terms of mobile-phase composition in accordance with eqns. 1 and 3. Substitution of appropriate functions for other variables, such as $\log(t_{R(M)})$ against T^{-1}, could of course also be appended (11,12). For the sake of clarity, the program statements have not in many instances been concatenated where it would otherwise be possible (and even beneficial) to do so and, for the same reason, potential savings in execution time are sacrificed in favor of presentation of the logic in expanded form.

Data Input (Statements 1ØØØ–12ØØ)

```
1ØØØ   REM  DATA INPUT— INPUT THE SOLVENT AND SOLUTE
       NAMES, AND THE RESPECTIVE RETENTIONS. THEN DISPLAY
       THESE VALUES.
1Ø1Ø   HOME : PR#Ø : DIM N$(51), A(51), S(51), B1(51), B2(51), X(5ØØ),
       Y(5ØØ), M$(5ØØ)
1Ø2Ø   PRINT : PRINT : PRINT : PRINT : PRINT : PRINT
1Ø3Ø   PRINT "SOLVENT 'A' IS: ";
1Ø4Ø   INPUT A$
1Ø5Ø   PRINT : PRINT
1Ø6Ø   PRINT "SOLVENT 'S' IS: ";
1Ø7Ø   INPUT S$
1Ø8Ø   PRINT : PRINT
1Ø9Ø   PRINT "THE NUMBER OF SOLUTES (MAXIMUM OF 50) IS: ";
11ØØ   INPUT N
111Ø   HOME
112Ø   PRINT : PRINT
113Ø   PRINT "ENTER THE RESPECTIVE SOLUTE NAMES AND
       RETENTIONS WITH SOLVENTS 'A' AND 'S' "
114Ø   PRINT : PRINT
115Ø   PRINT "SOLUTE NAME, TR(A), TR(S), B1, AND B2" : PRINT
```

```
116Ø    FOR I = Ø TO N - 1: INPUT N$(I), A(I), S(I), B1(I), B2(I): NEXT I
1165    HOME : PRINT : PRINT : PRINT : PRINT
117Ø    PRINT "THE LOWER MOBILE-PHASE COMPOSITION PERCENT
        TO BE CONSIDERED IS (WHOLE NUMBER) ";
1175    INPUT DL
118Ø    PRINT : PRINT "THE UPPER MOBILE-PHASE COMPOSITION
        PERCENT TO BE CONSIDERED IS (WHOLE NUMBER) ";
1185    INPUT DU
119Ø    PRINT : PRINT "THE MOBILE-PHASE COMPOSITION PERCENT
        INTERVAL TO BE CONSIDERED IS (WHOLE NUMBER; SMALLEST
        PERMISSIBLE IS 1%) ";
12ØØ    INPUT D
```

These statements first clear the screen (1Ø1Ø), dimension the variables, and then query the user for the names of the solvents and the number of solutes. The program then clears the screen again (111Ø) and asks for the names of the solutes, the respective retentions with solvents A and S, and the fitted values of b (B1) and b' (B2) (113Ø ff.). The data entry format is as shown, namely, SOLUTE NAME (comma), TR(A) (comma), TR(S) (comma), B1 (comma), B2, then <RETURN>. The program then asks for the mobile-phase composition range and interval (e.g., every 1%, every 5%, etc.) to be considered (117Ø-12ØØ); note that the lowest permitted interval, for reasons of memory conservation, is 1%.

Data Verification (Statements 121Ø-137Ø)

```
121Ø    PR#1
122Ø    PRINT : PRINT
123Ø    PRINT TAB(26); "*****RETENTION DATA*****"
124Ø    PRINT : PRINT
125Ø    PRINT TAB(5); "SOLVENT 'A' IS "; A$
126Ø    PRINT TAB(5); "SOLVENT 'S' IS "; S$
127Ø    PRINT : PRINT
128Ø    PRINT TAB(5); "SOLUTE"; TAB(2Ø); "TR(A)"; TAB(35); "TR(S)";
        TAB(52); "B1"; TAB(27); "B2"
129Ø    PRINT
13ØØ    FOR I = Ø TO N - 1
131Ø    PRINT TAB(5); LEFT$ (N$(I),1Ø); TAB(2Ø); A(I); TAB(35); S(I);
        TAB(5Ø); B1(I); TAB(55); B2(I): NEXT I
133Ø    PRINT : PRINT : HOME
134Ø    PRINT "MIXTURES OF 'A' WITH 'S' WILL BE CONSIDERED AT
        EVERY "; D; "% FROM 'A' = "; DL; " TO "; DU; "%."
135Ø    PRINT : PR#Ø: PRINT : PRINT : PRINT : PRINT : PRINT
136Ø    PRINT "FIRST, HOWEVER, THE RELEVANT PAIRS OF SOLUTES
        FOR CALCULATION OF THE WINDOW DIAGRAM WILL BE
        DETERMINED."
```

The solute and solvent data are printed out on the hard-copy device PR#1. The program uses a simple loop (13ØØ,131Ø) to do so after the title (123Ø) and column headings (128Ø) are printed. Note that the solute names are contained as strings in the array N$(I), and that the retentions with solvents A and S (named A$ and S$) are in the arrays A(I) and S(I), respectively.

Determination of Relevant Pairs of Solutes (Statements 15ØØ-198Ø)

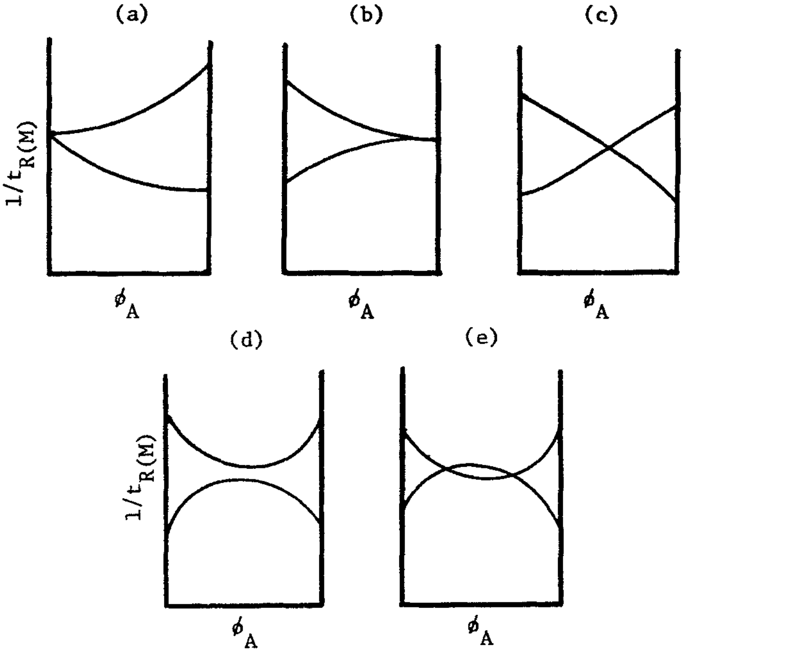
```
15ØØ   REM  THIS SECTION OF THE PROGRAM WILL DETERMINE THE
       RELEVANT PAIRS OF SOLUTES FOR CALCULATION OF THE
       WINDOW-DIAGRAM ARRAY.
151Ø   PRINT : PRINT : PRINT
152Ø   PRINT "ENTER THE UPPER LIMIT OF SEPARATION FACTOR
       (>Ø) TO BE CONSIDERED: ";
153Ø   INPUT MAX
154Ø   Z = Ø
155Ø   Z1 = Ø
156Ø   FOR J = Ø TO N - 2
158Ø   HOME : PRINT : PRINT : PRINT : PRINT : PRINT "THE NUMBER
       OF RELEVANT PAIRS": PRINT : PRINT : PRINT "FOUND SO FAR
       IS :";Z1
162Ø   FOR I = J + 1 TO N - 1
167Ø   LP = (A(I) - A(J))/(A(I) + A(J))
168Ø   IF (ABS(LP)) < MAX THEN GOTO 173Ø
169Ø   LQ = (S(I) - S(J))/(S(I) + S(J))
171Ø   IF (ABS(LQ)) > MAX THEN IF (LP/LQ) > Ø THEN GOTO 4ØØØ

       4ØØØ   FOR P = DL TO DU STEP D
       4Ø2Ø   COMP = P * Ø.Ø1
       4Ø3Ø   L1 = COMP * ((1/A(I)) + (B1(I) * (1 - COMP)/(1 + B2(I) * (1 -
              COMP)))) + (1 - COMP)/S(I)
       4Ø4Ø   L2 = COMP * ((1/A(J)) + (B1(J) * (1 - COMP)/(1 + B2(J) * (1 -
              COMP))) + (1 - COMP)/S(J)
       4Ø5Ø   SF = (L1 - L2)/(L1 + L2)
       4Ø6Ø   IF (ABS(SF)) > MAX THEN GOTO 4Ø8Ø
       4Ø7Ø   GOTO 173Ø
       4Ø8Ø   NEXT P
       4Ø9Ø   GOTO 185Ø

173Ø   Z1 = Z1 + 1
174Ø   HOME : PRINT : PRINT : PRINT : PRINT : PRINT "THE NUMBER
       OF RELEVANT PAIRS": PRINT : PRINT : PRINT "FOUND SO FAR
       IS :"; Z1: FOR PAUSE = 1 TO 1ØØ: NEXT PAUSE
175Ø   K = J
176Ø   FOR Z = Z TO (Z + 1)
177Ø   X(Z) = A(K)
```

```
1775   Y(Z) = S(K)
178Ø   M1(Z) = B1(K)
1785   M2(Z) = B2(K)
179Ø   M$(Z) = N$(K)
1795   K = I
18ØØ   NEXT Z
185Ø   NEXT I
19ØØ   NEXT J
19Ø5   IF Z1 = Ø THEN GOTO 33ØØ
191Ø   HOME : PR#1 : PRINT : PRINT
1915   PRINT TAB(26); "************************"
192Ø   PRINT : PRINT : PRINT TAB(5); "THE NUMBER OF RELEVANT
       PAIRS OF SOLUTES IS "; Z1; "."
193Ø   PRINT : PRINT
194Ø   PRINT TAB(5); "THE RELEVANT PAIRS ARE:" : PRINT
196Ø   FOR Z = Ø TO (Z1 * 2 - 1) STEP 2
197Ø   PRINT TAB(15); (LEFT$ (M$(Z),1Ø)); "/"; (LEFT$ (M$(Z + 1),1Ø))
198Ø   NEXT Z
```

Rather than calculating the separation factors for all pairs of solutes at all compositions, the program first determines the number and identity of pairs of solutes that have values of S_f less than the user-defined limit MAX at some point within the specified composition range of DL to DU% of A in (A + S). The task is straight-forward when the variation of solute retentions is known as a function of column composition. Five situations arise generally:



In situations (a) and (b), full overlap of the solutes occurs at one or the other of the ordinates. S_f is therefore Ø at each of these points. In the third case, (c), the order of elution of the solutes is reversed on passing from one extremum to the other. Hence, while S_f is greater (or less) than Ø at one ordinate, it will be less (or greater) than Ø at the other. Finally, situations (d) and (e) encompass those instances where the curves do not intersect at any or at more than one composition. These can be identified only by examination of the solute retentions at intermediate mobile-phase compositions.

In order to test for each of the above possibilities (hence identify the relevant pairs), the separation factors for each solute pair are calculated at each of the ordinates (154Ø-19ØØ) and, where necessary, at intermediate compositions (subroutine 4ØØØ-4Ø9Ø). First, however, and following a displayed message so indicating, the user is prompted to enter the upper limit of S_f which will be used to define what constitutes a relevant pair. Judicious choice of the limiting separation factor can lead to an enormous savings in the time of calculation of the window boundary, since whatever pairs are eliminated at this point will not be considered again. (An S_f of Ø.Ø2828 corresponds to a column of 5ØØØ plates and minimum resolution R_s of unity.) If no relevant pairs are found, the program branches at 19Ø5 to statement 33ØØ and displays a mesage so informing the user:

```
33ØØ   HOME : PRINT : PRINT : PRINT : PRINT : PRINT : PRINT "NO
       PAIRS FOUND— ALL COMPOSITIONS WILL PROVIDE GOOD
       RESOLUTION. WANT TO TRY A HIGHER VALUE OF SF (Y/N)?":
       INPUT ANS$
331Ø   IF ANS$ = "N" THEN GOTO 327Ø
332Ø   PRINT : PRINT : PRINT : GOTO 152Ø
```

The final task of this section of the program (191Ø-198Ø) gives a hard-copy print-out of the number and identity of the relevant pairs of solutes.

Calculation of the Window Boundary Array (Statements 3ØØØ-32ØØ)

```
3ØØØ   REM  THIS SECTION OF THE PROGRAM CALCULATES THE
       WINDOW DIAGRAM ARRAY, HERE, SF AS A FUNCTION OF
```

```
         MOBILE-PHASE  COMPOSITION  FOR  LIQUID  CHROMATOG-
         RAPHY.
3Ø1Ø     HOME : PR#Ø
3Ø2Ø     DIM Q$(1Ø1), R$(1Ø1), SFP(1Ø1)
3Ø4Ø     BSFP = Ø
3Ø45     FOR P = DL TO DU STEP D
3Ø5Ø     HOME : PRINT : PRINT : PRINT : PRINT : PRINT : PRINT : PRINT
         : PRINT
3Ø6Ø     PRINT  "THE  COLUMN  COMPOSITION  CURRENTLY  BEING":
         PRINT : PRINT "CONSIDERED IS "; P; "%"
3Ø7Ø     SFP(P) = MAX
3Ø75     COMP = P * Ø.Ø1
3Ø8Ø     Q$(P) = "(NONE)"
3Ø85     R$(P) = "(NONE)"
31ØØ     FOR Z = Ø TO (Z1 * 2 - 1) STEP 2
311Ø     L1 = COMP * ((1/X(Z)) + (M1(Z) * (1 - COMP)/(1 + M2(Z) * (1 -
         COMP)))) + (1 - COMP)/Y(Z)
3115     L2 = COMP * ((1/X(Z + 1)) + (M1(Z + 1) * (1 - COMP)/(1 + M2(Z + 1)
         * (1 - COMP)))) + (1 - COMP)/Y(Z + 1)
312Ø     SF = (L1 - L2)/(L1 + L2)
3125     IF (ABS(SF)) > SFP(P) THEN GOTO 317Ø
313Ø     SFP(P) = ABS(SF)
314Ø     Q$(P) = M$(Z): R$(P) = M$(Z + 1)
317Ø     NEXT Z
3175     IF SFP(P) < BSFP THEN GOTO 32ØØ
318Ø     BSFP = SFP(P)
3185     BA$ = Q$(P)
319Ø     BS$ = R$(P)
3195     OPT = P
32ØØ     NEXT P
```

Once the relevant pairs of solutes have been identified, separation factors for each are calculated in turn at each column composition and the lowest (most-difficult) is saved in the array subscripted as P. Thus, SFP(P) (313Ø) is the most-difficult (window-boundary) value of S_f at the column composition corresponding to P, while solutes Q$(P) and R$(P) (314Ø) are the names of the solutes. The **overall best** value of SFP(P), BSFP (318Ø), is updated on each pass through the outer loop, as are the names of the corresponding most-difficult solutes, BA$ (3185) and BS$ (319Ø). The **overall best** (optimum) column composition is also stored (3195) as OPT.

This section of the program is by far the slowest, the rate-limiting statements being 311Ø and 3115. To indicate that the computer is still working (and to time the program if desired), the composition currently being considered is displayed.

SFP(P), Q$(P), and R$(P) default (3Ø7Ø,3Ø8Ø,3Ø85) to the value of MAX and the string "(NONE)" if, at a given column composition, the separation factors of all relevant pairs of solutes exceed that of MAX (see later).

Data Output (Statements 32Ø5-329Ø)

```
32Ø5   PR#1
321Ø   HOME : PRINT : PRINT : PRINT TAB(5); "THE WINDOW-
       BOUNDARY DATA ARE:"
3215   PRINT : PRINT
322Ø   PRINT TAB(11); "SOLUTE"; TAB(36); "COL."; TAB(57); "SEPN."
3225   PRINT TAB(12); " PAIR"; TAB(36); "COMP."; TAB(16); "FACTOR"
323Ø   PRINT : PRINT
3235   FOR P = DL TO DU STEP D
324Ø   PRINT TAB(5); LEFT$ (Q$(P),1Ø); "/"; LEFT$ (R$(P),1Ø); TAB(37);
       P; TAB(54); (INT(1Ø ^ 5 * (SFP(P)) + 0.02))/1Ø ^ 5
3245   NEXT P
325Ø   HOME : PRINT : PRINT
3255   PRINT "THE BEST COLUMN COMPOSITION IS: "; OPT; "%."
326Ø   PRINT : PRINT "THE MOST-DIFFICULT SEPARATION FACTOR
       AT THIS COMPOSITION IS: "; BSFP; "."
3265   PRINT : PRINT "THE MOST DIFFICULT SOLUTES TO SEPARATE
       AT THIS COMPOSITION ARE: "; BA$; " FROM "; BS$; "."
327Ø   PR#Ø
3275   PRINT : PRINT : PRINT : PRINT : PRINT : PRINT : PRINT :
       PRINT : PRINT TAB(1Ø); "*****THAT'S ALL, FOLKS*****"
329Ø   END
```

A hard-copy print-out of the window-boundary array is accomplished by the loop, 3235-3245. For easier reading, the separation-factor data are truncated (324Ø) to five places. If at a given column composition the separation factors of all relevant pairs exceed the value of MAX, the solute-pair print-out is (NONE)/(NONE) and the separation factor printed is MAX. (A plot of the data in this composition region thus would show a flat top.) Also printed out (3255-3265) are the overall best column composition, the most-difficult S_f at this composition, and the associated (most-difficult) solute pair.

Generalization of the Algorithm

The program as written considers that inverse retentions vary in a non-linear fashion with mobile-phase composition. If the regression is in fact linear, eqn. 1 reduces to the trivial form:

$$\frac{1}{t_{R(M)}} = \phi_A \left(\frac{1}{t_{R(A)}}\right) + \phi_S \left(\frac{1}{t_{R(S)}}\right) \tag{6}$$

That is, both b and b' are negligible. The program and data entry procedure need not be modified in this instance other than to enter Ø when asked for values of B1 and B2.

The terms $(1/t_{R(i)})$ (i = A, S, or M) could of course also be used to represent ordinate data from some other function which may or may not be linear. For example, the (linear) diachoric solutions relation pertinent to retentions in gas chromatography is (13,14):

$$K^o_{R(M)} = \phi_A K^o_{R(A)} + \phi_S K^o_{R(S)} \tag{7}$$

where $K^o_{R(i)}$ are solute liquid-gas partition coefficients with the stationary phases A, S, and M (= A + S). To utilize the program, in this instance for optimization of the stationary-phase composition, Ø would be entered for B1 and B2, and $1/K^o_{R(i)}$ entered for "$t_{R(i)}$". Eqns. 6 and 7 would thereby be made equivalent. However, the value of "S_f" thence calculated would no longer be equal to $2R_s/N^{1/2}$ unless it were true that the sum of the raw retentions were much larger than twice the average of the column dead times:

$$\frac{K^o_{R(M)2} - K^o_{R(M)1}}{K^o_{R(M)2} + K^o_{R(M)1}} = \frac{t_{R(M)2} - t_{R(M)1}}{t_{R(M)2} + t_{R(M)1} - 2t_A} \tag{8}$$

Fortunately, this can be expected to be the case more often than not in open-tubular column gc, and will certainly be true for conventional packed-column gas chromatography.

In contrast, suppose that for some reason or another a particular liquid-chromatographic system were represented by the relation (cf. eqn. 1 of preceding paper):

$$\log k'_{(M)} = \log k'_{(S)} - S\ \phi_A \tag{9}$$

where S is an empirical constant and where it is assumed that t_A can be determined unambiguously. In order to identify the appropriate quantities for "$t_{R(A)}$" and "$t_{R(S)}$", eqn. 6 is rearranged to the form:

$$\frac{1}{t_{R(M)}} = \frac{1}{t_{R(S)}} - \phi_A \left(\frac{1}{t_{R(S)}} - \frac{1}{t_{R(A)}} \right) \tag{10}$$

Comparison of coefficients hence yields the identities:

$$\text{"}t_{R(S)}\text{"} = \frac{1}{\log k'_{(S)}} \tag{11a}$$

$$\text{"}t_{R(A)}\text{"} = \frac{1}{\log k'_{(S)} - S} \tag{11b}$$

Entry of these values for "$t_{R(A)}$" and "$t_{R(S)}$" would then yield a separation factor defined by:

$$10^{S_f} + k'_{(M)1} k'_{(M)2} = \frac{k'_{(M)1}}{k'_{(M)2}} = \alpha_{1/2} \tag{12}$$

for which a program statement could easily be added to retrieve the correct window-diagram boundary, here, alpha as a function of mobile-phase composition.

In the cases considered above, it was assumed that the example relations were linear. If this were not so, the program could still be made to function with appropriate (fitted) values of B1 and B2 defined analogous to those of eqn. 1. It appears, therefore, that the algorithm is likely to be useful in virtually any situation in chromatography wherein retentions can be described as a function of the parameter(s) to be optimized.

Commands Indigenous to APPLE BASIC

The only three commands used here which may not be compatible with other versions of BASIC are PR#1, PR#Ø, and HOME. The first two of these specify the hard-copy printer and the display unit, respectively, while the third command causes the display to clear and the cursor to be positioned in the upper left-hand corner of the screen. These commands appear in the following statements:

Command	Statement Nos.
PR#1	121Ø, 191Ø, 32Ø5
PR#Ø	1Ø1Ø, 135Ø, 3Ø1Ø, 327Ø
HOME	1Ø1Ø, 111Ø, 1165, 191Ø, 3Ø1Ø, 3Ø5Ø, 321Ø, 325Ø, 33ØØ

There may also be difficulty with multiple TAB statements depending upon the printer employed (here, an Epson MX-7Ø). We have found that substitution of POKE (36,nn) for TAB (nn) solves this problem.

ACKNOWLEDGMENT

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