

# Chromatographic behaviour of diastereoisomers XII<sup>☆</sup>. Effects of alumina on separations of esters of maleic and fumaric acids

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## Abstract

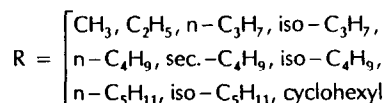
The thin-layer chromatographic separations on three different aluminas of twenty diastereoisomeric 1,2-disubstituted ethenes, ROOCCH=CHCOOR, were studied with 24 mobile phases having strength,  $\epsilon$ , in the range 0.210–0.250 and a wide variety of solvent selectivity effects. The relative retention of the diastereoisomers was always  $Z > E$  independently of the type of the alumina and the increase in the selectivity of the mobile phases and the effective volume of the group R as a result of an expected site chelation via the two ester groups in  $Z$  isomers only. A comparison shows that the separations of these diastereoisomers are similar with both alumina and silica using a given mobile phase. However, the overall separation obtained on any alumina is better than that found for silica.

## 1. Introduction

A series of papers (see, *e.g.*, refs. 1–6) have reported the thin-layer chromatographic (TLC) separation and relative retentions of more than 150 conformational flexible and rigid diastereoisomers. The role of steric effects, the adsorption of two adjacent solute groups on one adsorbent site or the so-called site chelation [7] and mobile phase selectivity effects [7–11] have been discussed in detail.

Recently, we reported [1] that the diastereoisomeric 1,2-dialkoxycarbonylethenes of type 1 show on silica a stronger retention of the  $Z$

isomer than that of the corresponding  $E$  isomer as a result of site chelation via the two ester groups only in the former isomer. The above-mentioned importance of steric effects, site chelation and solvent selectivity effects on silica makes it interesting to study similar separations on alumina, the other widely used adsorbent



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☆ For Part XI, see ref. 1.

in normal-phase liquid–solid chromatography (LSC). This paper deals with the TLC behaviour on alumina of the twenty diastereoisomers of type 1 studied previously [1] having two equal adsorbing groups COOR with an increasing volume of R. The choice of mobile phases was made by a microcomputer program [12] based on Snyder's theory [7–10] as an easier alternative [1,2,13,14] to the trial-and-error approach used in LSC separations of other *Z–E* diastereoisomers [15–45].

## 2. Experimental

Details of the synthesis and <sup>1</sup>H NMR spectra of compounds 1–20 in Table 2 are given in ref. 1.

TLC was done as in ref. 5 using three different aluminas, namely (1) aluminium oxide (Riedel-de Haën, Hannover, Germany), (2) acidic alu-

minium oxide (Merck, Darmstadt, Germany) and (3) neutral aluminium oxide (Merck). The adsorbent number corresponds to the adsorption activity (see below). A slurry of 60 g of adsorbent and 90 ml of distilled water was spread on four 20 × 20 cm plates by means of an apparatus according to Stahl. The samples were 2 μl of a solution prepared from 60 mg of each solute and 1.4 ml of toluene. The reproducibility of the *R<sub>F</sub>* values was ±0.03 unit, which is worse than that in ref. 1 because of some tailing in the most instances. *R<sub>F</sub>* values in Table 2 are arithmetic means of four to eight measurements.

## 3. Results and discussion

Table 1 lists the mobile phases used together with values of strength,  $\epsilon$ , localization, *m*, and polarity, *P'*. The values were calculated by

Table 1  
Mobile phases studied and the corresponding computer-calculated [12] values of strength,  $\epsilon$ , localization, *m*, and polarity *P'*

No.	Components	Composition (vol.-%)	$\epsilon$	<i>m</i>	<i>P'</i>
1	Hexane–diethyl ether	84.8:15.2	0.210	0.57	0.51
2	Hexane–toluene	63.24:36.76	0.220	–0.16	0.95
3	Hexane–diethyl ether	82.3:17.7	0.220	0.58	0.58
4	Hexane–acetone	99.03:0.97	0.220	0.90	0.15
5	Hexane–ethyl acetate	97.9:2.1	0.220	0.72	0.19
6	Hexane–tetrahydrofuran	97.0:3.0	0.220	0.77	0.22
7	Hexane–tetrachloromethane–methylene chloride	82.1:10.0:7.9	0.220	0.30	0.74
8	Hexane–toluene–diethyl ether	82.5:10.0:7.5	0.220	0.43	0.53
9	Hexane–chloroform–diethyl ether	84.8:10.0:5.2	0.220	0.42	0.64
10	Hexane–tetrachloromethane–diethyl ether	76.5:10.0:13.5	0.220	0.54	0.62
11	Hexane–tetrachloromethane–diethyl ether	69.0:20.0:11.0	0.220	0.50	0.70
12	Hexane–tetrachloromethane–diethyl ether	60.55:30.0:9.45	0.220	0.43	0.81
13	Hexane–tetrachloromethane–diethyl ether	51.65:40.0:8.35	0.220	0.35	0.93
14	Hexane–tetrachloromethane–diethyl ether	42.5:50.0:7.5	0.220	0.29	1.05
15	Hexane–tetrachloromethane–diethyl ether	14.3:80.0:5.7	0.220	0.13	1.45
16	Hexane–tetrachloromethane–diethyl ether	4.84:90.0:5.16	0.220	0.10	1.59
17	Hexane–diisopropyl ether–1,2-dichloroethane	74.9:20.0:5.1	0.220	–	0.73
18	Hexane–chloroform–ethyl acetate	89.5:10.0:0.5	0.220	0.46	0.52
19	Hexane–toluene–chloroform–diethyl ether	83.93:5.0:5.0:6.07	0.220	0.43	0.58
20	Hexane–tetrachloromethane–toluene–methylene chloride–ethyl acetate	89.3:3.33:3.33:3.33:0.7	0.220	0.47	0.36
21	Hexane–tetrachloromethane–diisopropyl ether–toluene–methylene chloride–diethyl ether	80.87:2.5:2.5:2.5:2.5:9.14	0.220	–	0.59
22	Hexane–diethyl ether	79.4:20.6	0.230	0.59	0.66
23	Hexane–diethyl ether	76.24:23.76	0.240	0.60	0.74
24	Hexane–diethyl ether	72.74:27.26	0.250	0.60	0.84

means of the above-mentioned microcomputer program [12]. The mobile phases are arranged in terms of increasing  $\epsilon$  and increasing number of solvents when  $\epsilon$  is constant. Ten different non-localizing and localizing solvents were used for the preparation of the mobile phases. The non-localizing or weakly localizing solvents were hexane, toluene, methylene chloride, chloroform, tetrachloromethane and 1,2-dichloroethane [9]. The mobile phases were composed of two to six solvents showing a limited variation in  $\epsilon$  (0.210–0.250) and greater variations in  $m$  and  $P'$ , *i.e.*, in solvent selectivity effects. Mobile phases 1, 3 and 22–24 are composed of hexane and diethyl ether in different ratios and have increasing  $\epsilon$ . Mobile phases 2–21 have constant  $\epsilon$  (0.220).

Table 2 summarizes the structure and the configuration of the compounds studied, their  $R_F$  values obtained on the three aluminas and the derived values of the separation factor,  $\alpha$ , of the diastereoisomeric pairs which were calculated by the following equation:

$$\log \alpha = R_{M(Z)} - R_{M(E)} \quad (1)$$

where the subscripts  $E$  and  $Z$  specify the isomer (see ref. 1 for the  $R_F$ – $R_M$  conversion). Fig. 1 shows the separations established.

According to Table 2,  $\log \alpha$  is positive in all cases studied, which corresponds to a stronger retention of the  $Z$  isomer than that of the corresponding  $E$  isomer taking into account Eq. 1. This relative retention, being the same as that found on silica [1], did not depend on the structure of the compounds, type of alumina or mobile phase used.

The discussions required some data about the adsorption of groups available in solute molecules. According to Snyder's theory, a group  $i$  is adsorbed if the mobile phase used has  $\epsilon$  less than a critical value,  $\epsilon_c$ , which is calculated on the basis of the free energy of adsorption of the group,  $Q_i^0$ , and its effective area under adsorption,  $a_i$  (see the contribution of Snyder in ref. 46 and also ref. 47). Table 3 summarizes the values according to Snyder [7] of the three parameters mentioned above for different groups of interest.

It also includes values of net free energy of adsorption ( $Q_i^0 - \epsilon a_i$ ) when  $\epsilon > 0$ . The values shown concern mobile phases 2–21 with  $\epsilon = 0.220$ .

### 3.1. Microcomputer-aided choice of the mobile phases used

LSC separations by means of TLC and high-performance liquid chromatography (HPLC) of diastereoisomeric substituted ethenes have been widely reported [7 (p. 315), 15–45] because of the importance of such compounds including vitamin A and terpenes. Most of the separations uses the normal-phase LSC on predominantly silica or alumina (*cf.*, ref. 10, p. 92). The selection of the mobile phases in these separations have been done only by the trial-and-error approach.

Recently [1,2,13,14], we chose the mobile phases for TLC separations on the basis of Snyder's theory [7–10] and the microcomputer program [12] which was applied also in this study. Thus, the choice of the mobile phases for alumina 1 began with mobile phase 6 showing  $R_F$  values of compounds 1–20 in a favourable range, 0.13–0.46. Using the microcomputer program, we calculated the strength  $\epsilon = 0.220$  of the mobile phase and selected the remaining mobile phases of the same or close  $\epsilon$ . Greater variation of  $\epsilon$  was not tried because some compounds could remain at the start line and other compounds could move to the front. Details of the microcomputer choice of the mobile phases are given in refs. 1, 2, 13 and 14.

A comparison of the  $R_F$  values of a given compound obtained with a given adsorbent and all mobile phases with  $\epsilon = 0.220$  showed a mean standard deviation (S.D.) for the three aluminas of 0.11. Consequently, Snyder's theory and the microcomputer program used permitted an easier choice of similar mobile phases.

### 3.2. Role of the alumina type on retention

The adsorbents used were of two types: neutral (aluminas 1 and 3) and acidic (alumina 2). Mobile phase 3 is the only mobile phase used

Table 2  
Experimental  $R_f$  values and derived values of  $\log \alpha$  for the diastereoisomeric compounds 1-20 of type 1

R	Solute	$R_f$ on alumina 1 for indicated mobile phase																	
		Configuration	No.	2	3	4	5	6	7	8	19								
CH <sub>3</sub>	Z	1	0.07	0.23	0.08	0.15	0.13	0.15	0.12	0.17									
	E	2	0.14	0.45	0.15	0.29	0.30	0.24	0.24	0.29									
CH <sub>2</sub> CH <sub>3</sub>	Z	3	0.08	0.31	0.09	0.15	0.18	0.16	0.14	0.20									
	E	4	0.17	0.58	0.20	0.36	0.36	0.26	0.34	0.37									
CH <sub>2</sub> CH <sub>2</sub> CH <sub>3</sub>	Z	5	0.09	0.34	0.09	0.20	0.20	0.15	0.16	0.20									
	E	6	0.18	0.58	0.19	0.39	0.38	0.25	0.35	0.38									
CH(CH <sub>3</sub> ) <sub>2</sub>	Z	7	0.08	0.39	0.09	0.22	0.22	0.16	0.17	0.21									
	E	8	0.18	0.64	0.21	0.39	0.42	0.26	0.39	0.41									
CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>3</sub>	Z	9	0.10	0.41	0.09	0.18	0.22	0.15	0.17	0.21									
	E	10	0.20	0.66	0.21	0.40	0.44	0.25	0.40	0.40									
CH(CH <sub>3</sub> )CH <sub>2</sub> CH <sub>3</sub>	Z	11	0.09	0.44	0.09	0.21	0.23	0.16	0.19	0.23									
	E	12	0.20	0.70	0.22	0.38	0.44	0.27	0.42	0.43									
CH <sub>2</sub> CH(CH <sub>3</sub> ) <sub>2</sub>	Z	13	0.09	0.42	0.08	0.21	0.23	0.18	0.19	0.23									
	E	14	0.19	0.68	0.22	0.38	0.43	0.28	0.42	0.43									
CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>3</sub>	Z	15	0.09	0.43	0.08	0.20	0.21	0.15	0.18	0.22									
	E	16	0.20	0.68	0.20	0.37	0.44	0.24	0.40	0.44									
CH <sub>2</sub> CH <sub>2</sub> CH(CH <sub>3</sub> ) <sub>2</sub>	Z	17	0.08	0.44	0.08	0.20	0.23	0.17	0.19	0.23									
	E	18	0.20	0.70	0.21	0.38	0.46	0.25	0.42	0.45									
Cyclohexyl	Z	19	0.07	0.44	0.07	0.18	0.23	0.16	0.17	0.21									
	E	20	0.17	0.69	0.18	0.34	0.44	0.21	0.40	0.43									

		Log $\alpha$ for indicated mobile phase																	
1-2		0.33	0.43	0.31	0.36	0.46	0.25	0.37	0.30										
3-4		0.37	0.49	0.40	0.50	0.41	0.27	0.50	0.37										
5-6		0.34	0.43	0.37	0.41	0.39	0.27	0.45	0.39										
7-8		0.40	0.44	0.42	0.36	0.41	0.27	0.50	0.42										
9-10		0.35	0.45	0.42	0.48	0.45	0.27	0.51	0.40										
11-12		0.40	0.47	0.45	0.37	0.42	0.31	0.49	0.40										
13-14		0.37	0.47	0.51	0.37	0.40	0.25	0.49	0.40										
15-16		0.40	0.45	0.46	0.37	0.48	0.25	0.48	0.45										
17-18		0.46	0.47	0.48	0.39	0.45	0.21	0.49	0.43										
19-20		0.43	0.45	0.46	0.37	0.42	0.14	0.51	0.46										

$R_F$  on alumina 2 for indicated mobile phase

	3	9	10	11	12	13	14	15	16	17	18	20	21	22	23	24
<b>1</b>	0.27	0.26	0.30	0.22	0.31	0.25	0.30	0.29	0.37	0.32	0.20	0.08	0.16	0.35	0.40	0.45
Z																
<b>2</b>	0.50	0.43	0.52	0.42	0.58	0.46	0.54	0.54	0.61	0.59	0.20	0.22	0.40	0.58	0.65	0.69
E																
<b>3</b>	0.36	0.29	0.37	0.29	0.39	0.31	0.34	0.33	0.42	0.43	0.22	0.12	0.23	0.45	0.51	0.56
Z																
<b>4</b>	0.63	0.58	0.71	0.57	0.72	0.60	0.65	0.65	0.73	0.71	0.45	0.25	0.50	0.74	0.80	0.83
E																
<b>5</b>	0.39	0.28	0.42	0.34	0.43	0.31	0.37	0.36	0.45	0.51	0.22	0.13	0.29	0.53	0.61	0.65
Z																
<b>6</b>	0.66	0.54	0.73	0.63	0.73	0.61	0.66	0.64	0.74	0.79	0.39	0.30	0.55	0.79	0.86	0.88
E																
<b>7</b>	0.41	0.30	0.44	0.36	0.45	0.33	0.37	0.38	0.47	0.53	0.22	0.13	0.31	0.56	0.63	0.68
Z																
<b>8</b>	0.70	0.57	0.76	0.66	0.74	0.63	0.67	0.64	0.75	0.81	0.40	0.31	0.57	0.80	0.88	0.90
E																
<b>9</b>	0.42	0.31	0.44	0.36	0.46	0.35	0.37	0.38	0.49	0.57	0.23	0.14	0.32	0.57	0.66	0.69
Z																
<b>10</b>	0.69	0.61	0.77	0.70	0.79	0.64	0.68	0.66	0.75	0.85	0.40	0.34	0.62	0.82	0.90	0.91
E																
<b>11</b>	0.43	0.35	0.50	0.39	0.49	0.34	0.40	0.48	0.53	0.61	0.23	0.14	0.34	0.62	0.67	0.70
Z																
<b>12</b>	0.69	0.63	0.82	0.72	0.79	0.64	0.69	0.75	0.83	0.85	0.44	0.31	0.60	0.87	0.90	0.91
E																
<b>13</b>	0.43	0.35	0.50	0.39	0.49	0.34	0.40	0.48	0.53	0.61	0.23	0.14	0.34	0.62	0.67	0.70
Z																
<b>14</b>	0.69	0.63	0.81	0.71	0.78	0.64	0.69	0.75	0.83	0.85	0.44	0.31	0.60	0.87	0.90	0.90
E																
<b>15</b>	0.42	0.33	0.48	0.37	0.49	0.35	0.38	0.49	0.53	0.60	0.23	0.13	0.33	0.62	0.68	0.70
E																
<b>16</b>	0.69	0.63	0.81	0.66	0.80	0.63	0.69	0.75	0.80	0.88	0.42	0.30	0.60	0.88	0.90	0.91
E																
<b>17</b>	0.44	0.34	0.50	0.37	0.50	0.36	0.39	0.49	0.53	0.61	0.23	0.13	0.35	0.62	0.68	0.71
Z																
<b>18</b>	0.71	0.63	0.82	0.68	0.78	0.66	0.69	0.75	0.82	0.88	0.44	0.29	0.62	0.88	0.90	0.90
E																
<b>19</b>	0.41	0.33	0.47	0.38	0.48	0.38	0.33	0.48	0.55	0.59	0.23	0.10	0.30	0.58	0.64	0.67
Z																
<b>20</b>	0.68	0.57	0.76	0.60	0.77	0.63	0.56	0.74	0.81	0.85	0.40	0.23	0.55	0.84	0.90	0.89
E																

Log  $\alpha$  for indicated mobile phase

<b>1-2</b>	0.43	0.33	0.40	0.41	0.49	0.41	0.44	0.46	0.42	0.49	0.35	0.51	0.54	0.41	0.45	0.44
<b>3-4</b>	0.48	0.53	0.62	0.51	0.60	0.53	0.56	0.58	0.57	0.51	0.46	0.39	0.52	0.54	0.58	0.59
<b>5-6</b>	0.48	0.48	0.57	0.52	0.55	0.54	0.52	0.50	0.54	0.56	0.36	0.46	0.48	0.53	0.60	0.60
<b>7-8</b>	0.53	0.49	0.60	0.54	0.54	0.54	0.54	0.46	0.53	0.58	0.37	0.47	0.47	0.50	0.64	0.62
<b>9-10</b>	0.49	0.54	0.62	0.62	0.62	0.52	0.56	0.50	0.50	0.63	0.34	0.50	0.54	0.54	0.66	0.65
<b>11-12</b>	0.47	0.50	0.66	0.60	0.60	0.54	0.53	0.51	0.55	0.56	0.42	0.44	0.47	0.62	0.64	0.63
<b>13-14</b>	0.47	0.50	0.63	0.58	0.57	0.54	0.53	0.51	0.55	0.56	0.42	0.44	0.47	0.62	0.64	0.58
<b>15-16</b>	0.49	0.54	0.66	0.52	0.62	0.50	0.56	0.50	0.55	0.69	0.38	0.46	0.49	0.66	0.62	0.63
<b>17-18</b>	0.49	0.52	0.66	0.56	0.55	0.54	0.54	0.50	0.61	0.68	0.42	0.44	0.48	0.66	0.62	0.56
<b>19-20</b>	0.49	0.43	0.55	0.39	0.55	0.44	0.41	0.48	0.54	0.59	0.34	0.43	0.46	0.58	0.70	0.60

(Continued on p. 186)

Table 2 (continued)

R	Solute	$R_F$ on alumina 3 for indicated mobile phase																							
		Configuration	No.	1	3	19	22	23	24																
CH <sub>3</sub>	Z	1	0.26	0.21	0.31	0.40	0.40	0.40	0.40																
	E	2	0.52	0.51	0.41	0.57	0.63	0.66	0.66																
CH <sub>2</sub> CH <sub>3</sub>	Z	3	0.35	0.35	0.27	0.41	0.49	0.51	0.51																
	E	4	0.64	0.65	0.52	0.71	0.77	0.78	0.78																
CH <sub>2</sub> CH <sub>2</sub> CH <sub>3</sub>	Z	5	0.44	0.43	0.31	0.49	0.54	0.60	0.60																
	E	6	0.73	0.73	0.59	0.77	0.83	0.85	0.85																
CH(CH <sub>3</sub> ) <sub>2</sub>	Z	7	0.45	0.46	0.33	0.50	0.57	0.63	0.63																
	E	8	0.74	0.76	0.61	0.79	0.85	0.87	0.87																
CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>3</sub>	Z	9	0.46	0.47	0.34	0.51	0.58	0.64	0.64																
	E	10	0.77	0.76	0.63	0.80	0.85	0.89	0.89																
CH(CH <sub>3</sub> )CH <sub>2</sub> CH <sub>3</sub>	Z	11	0.46	0.48	0.34	0.52	0.62	0.66	0.66																
	E	12	0.79	0.79	0.62	0.82	0.88	0.91	0.91																
CH <sub>2</sub> CH(CH <sub>3</sub> ) <sub>2</sub>	Z	13	0.47	0.48	0.34	0.52	0.62	0.66	0.66																
	E	14	0.78	0.78	0.62	0.81	0.88	0.91	0.91																
CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>3</sub>	Z	15	0.48	0.48	0.34	0.54	0.62	0.67	0.67																
	E	16	0.79	0.77	0.64	0.79	0.88	0.91	0.91																
CH <sub>2</sub> CH <sub>2</sub> CH(CH <sub>3</sub> ) <sub>2</sub>	Z	17	0.47	0.47	0.34	0.52	0.62	0.66	0.66																
	E	18	0.77	0.78	0.65	0.80	0.89	0.92	0.92																
Cyclohexyl	Z	19	0.45	0.45	0.34	0.49	0.59	0.65	0.65																
	E	20	0.75	0.74	0.61	0.74	0.85	0.91	0.91																

Log $\alpha$ for indicated mobile phase																							
1-2	0.48	0.47	0.42	0.47	0.41	0.47	0.47	0.47	0.47														
3-4	0.52	0.54	0.46	0.55	0.54	0.53	0.53	0.53	0.53														
5-6	0.53	0.55	0.51	0.54	0.62	0.57	0.57	0.57	0.57														
7-8	0.54	0.57	0.50	0.58	0.63	0.60	0.60	0.60	0.60														
9-10	0.59	0.55	0.52	0.58	0.61	0.66	0.66	0.66	0.66														
11-12	0.65	0.61	0.50	0.63	0.66	0.71	0.71	0.71	0.71														
13-14	0.60	0.58	0.54	0.60	0.66	0.71	0.71	0.71	0.71														
15-16	0.61	0.55	0.54	0.51	0.66	0.69	0.69	0.69	0.69														
17-18	0.57	0.60	0.56	0.57	0.70	0.77	0.77	0.77	0.77														
19-20	0.57	0.54	0.48	0.47	0.59	0.73	0.73	0.73	0.73														

For composition of mobile phases, see Table 1. The values of log  $\alpha$  were calculated from  $R_M$  values of the corresponding Z-E pair using Eq. 1.

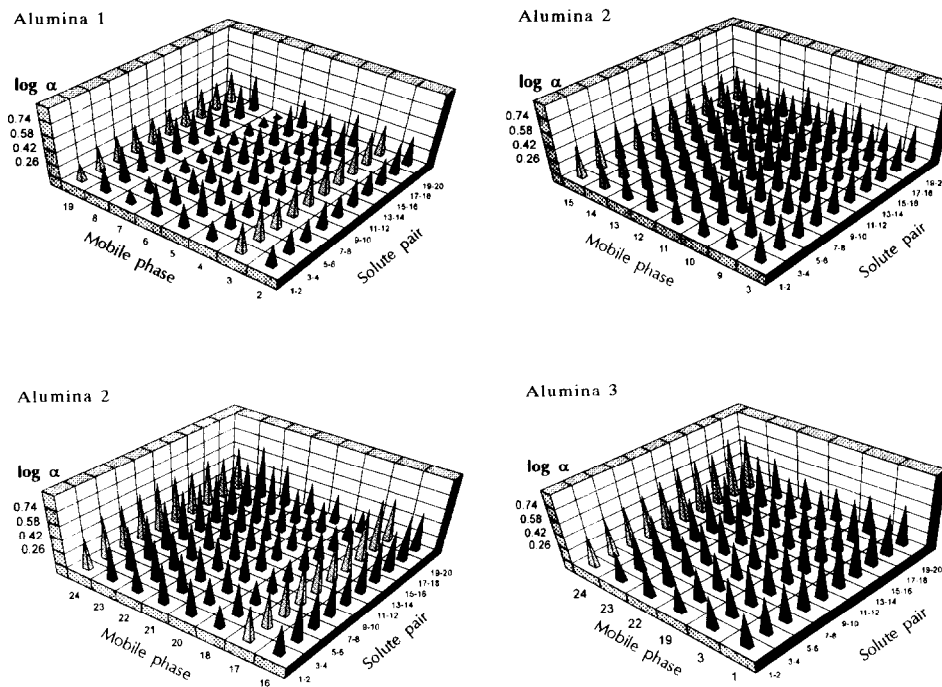


Fig. 1. Three-dimensional representation of all separations  $\alpha$  of diastereoisomeric pairs 1–20 obtained on aluminas 1–3 with mobile phases 1–24.

Table 3

Values of  $Q_i^0$ ,  $a_i$ , and derived values of  $\epsilon_{ci}$  and  $Q_i^0 - \epsilon a_i$  on alumina for groups  $i$  available in the compounds studied according to Snyder [7]

Group $i$	$Q_i^0$	$a_i$	$\epsilon_{ci} = Q_i^0/a_i$	$Q_i^0 - \epsilon a_i$ ( $\epsilon = 0.220$ )
C=C	0.31	2.0	0.16	-0.13
CO <sub>2</sub> CH <sub>3</sub>	4.02	3.0	1.34	3.36
CO <sub>2</sub> C <sub>2</sub> H <sub>5</sub>	4.04	3.4	1.19	3.29
CO <sub>2</sub> C <sub>3</sub> H <sub>7-n</sub>	4.06	3.7	1.10	3.25
CO <sub>2</sub> C <sub>3</sub> H <sub>7-iso</sub>	4.01	4.4	0.91	3.04
CO <sub>2</sub> C <sub>4</sub> H <sub>9-n</sub>	4.08	4.1	1.00	3.18
CO <sub>2</sub> C <sub>4</sub> H <sub>9-sec.</sub>	4.03	4.7	0.86	3.00
CO <sub>2</sub> C <sub>4</sub> H <sub>9-iso</sub>	4.03	4.7	0.86	3.00
CO <sub>2</sub> C <sub>5</sub> H <sub>11-n</sub>	4.10	—	—	—
CO <sub>2</sub> C <sub>5</sub> H <sub>11-iso</sub>	4.05	—	—	—
CO <sub>2</sub> cyclohexyl	4.12	4.6	0.90	3.11

The values of free energy of adsorption of group  $i$ ,  $Q_i^0$ , and its effective area under adsorption,  $a_i$ , are additive and are calculated on the bases of ref. 7, Tables 8-4 and 10-2. The values for Ar-CO<sub>2</sub>CH<sub>3</sub> are taken into account because the ester groups in compounds 1–20 are next to a double bond.  $\epsilon_{ci}$  is the critical value of  $\epsilon$  and  $Q_i^0 - \epsilon a_i$  is the net free energy of adsorption when  $\epsilon > 0$ .

with all three aluminas. The corresponding mean  $R_F$  values for compounds 1–20 were calculated, namely 0.51, 0.53 and 0.58 for adsorbent 1, 2 and 3, respectively. Consequently, the adsorption activities of the neutral alumina 1 and the acidic alumina 2 are virtually identical and that of the neutral alumina 3 is the lowest.

The retention of compounds 1–20 on any alumina depends on the size of the alkyl group R. Thus, the compounds with Z or E configuration show increasing  $R_F$  values (decreasing retention) with any mobile phase. The increase is distinct when R increases from methyl to sec-butyl and for larger groups the  $R_F$  values remain almost constant. This behaviour is in agreement with the decreasing values of net free energy of adsorption for the ester groups shown in Table 3.

Mobile phases 10–16 used with alumina 2 are composed of hexane, tetrachloromethane and diethyl ether in different ratios. All mobile phases have  $\epsilon = 0.220$ , decreasing  $m$  and increasing  $P'$ . However, the  $R_F$  values of a given

compound obtained with these mobile phases do not vary regularly with  $m$  or  $P'$ .

Mobile phases 1, 3 and 22–24 of increasing  $\epsilon$  (0.210–0.250) used with aluminas 2 and 3 give the expected increase in  $R_F$  values of compounds 1–20 having a given configuration. Thus, the corresponding  $R_F$  values of compound 6 increase from 0.73 to 0.85 on alumina 3.

### 3.3. Role of the alumina type on separation and comparisons with silica

The mobile phases used with alumina 1 have  $\epsilon = 0.220$  and the greatest variation of  $m$  from  $-0.2$  to  $0.9$ . However, the mean values of  $\log \alpha$  for compounds 1–20 and a given mobile phase except mobile phase 7 varied in the range  $0.39$ – $0.48$ , *i.e.*, the separations in this instance do not depend significantly on  $m$ .

Let us discuss the effect of the adsorbent on the separation  $\log \alpha$  of diastereoisomeric pairs studied. Fig. 1 shows that  $\log \alpha$  varies from  $0.14$  to  $0.77$ , *i.e.*, fair to excellent separations were obtained. The separations of the diastereoisomers on aluminas 2 and 3 are better than those on alumina 1. Relatively poorer but still good separations with  $\log \alpha \approx 0.3$  were obtained with mobile phases 2 and 7 composed of non-localizing and weakly localizing solvents. The same is valid for mobile phase 18, which contains the localizing solvent ethyl acetate in a very small amount (0.5 vol.-%). Very good separations having  $\log \alpha \approx 0.5$  were obtained with mobile phases 20 and 21, composed of five and six solvents, respectively.

In general, the best separation of diastereoisomers 1–20 ( $\log \alpha = 0.6$ – $0.7$ ) was obtained with alumina 2 using mobile phases 10, 12, 17 and 22–24 and alumina 3 using mobile phases 1, 3, 22–24, with both constant and increasing  $\epsilon$ .

As also seen from Fig. 1, the diastereoisomeric pairs with greater size of the group R and smaller retention usually show better separations. Thus, the diastereoisomeric pairs 17–18 and 19–20 with  $R = n - C_5H_{11}$  and cyclohexyl,

respectively, give the best separations with mobile phase 24 on alumina 3.

Concerning a comparison with silica, TLC of compounds 1–20 with hexane–ethyl acetate (98:2) (mobile phase 5 in this study and mobile phase 17 in ref. 1) shows mean values of  $\log \alpha$  of 0.40 and 0.38 for alumina 1 and silica, respectively, or virtually identical separations on the two adsorbents with this mobile phase.

The overall separation of a given adsorbent of the diastereoisomeric pairs can be expressed by the mean value of the individual  $\log \alpha$  found for this adsorbent. Calculated on the basis of ref. 1 and Table 2 in this paper, the corresponding values are 0.34 (silica), 0.41 (alumina 1), 0.53 (alumina 2) and 0.57 (alumina 3), taking into account that the mobile phases are very different in each instance. Consequently, alumina 3 shows the best overall separation of the diastereoisomeric pairs studied, irrespective of the fact that it has the lowest adsorption activity.

### 3.4. Expected model of adsorption

The values of  $\epsilon$  calculated permit a discussion of the model of adsorption for the cases studied. All mobile phases used have  $\epsilon$  greater than  $\epsilon_c$  for the double bond (see Table 3) and adsorption of this group is not expected. In contrast, all ester groups should adsorb because  $\epsilon < \epsilon_c$ . Complicating effects are not assumed because compounds 1–20 do not possess intramolecular hydrogen bonds and are conformational rigid compounds.

The retention of the *Z* isomer is favoured by the site chelation of the two close ester groups on an adsorbent site and hindered by their mutual steric hindrance. The site chelation on alumina is known to predominate over steric hindrance to adsorption (see ref. 7, p. 316). This appears to be true in the cases studied irrespective of the wide variation in the size of group R, explaining the greater retention of any *Z* isomer than that of the corresponding *E* isomer. Site chelation in the last isomer is not possible because of the significantly greater distance between the two ester groups than in the *Z* isomer.



This explains the relative retention  $Z > E$  found in all instances studied (*cf.*, ref. 1).

#### 4. Conclusions

The separations achieved showed the following unexpected features: (1) the best separations of the diastereoisomeric pairs studied were obtained on the neutral alumina 3 having the lowest adsorption activity; and (2) better separations were usually obtained for the diastereoisomeric pairs having lower retentions.

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