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Eingegangen am 8. Dezember 1969; geänderte Fassung am 3. Juni 1970

J. Chromatog., 51 (1970) 330-334

CHROM. 4847

Argentation thin-layer chromatography with silver oxide

I. Separation of pyridine homologues*

During the last few years argentation TLC, initially developed for lipid separation, has found extensive use in the separation of fatty acids, neutral lipids, phenylhydrazones of aldehydes and ketones, and several classes of unsaturated compounds, capable of complexing the silver ion (for a good review see ref. 1). Argentation chromatography has also been used for column and GLC separations. AgNO_3 is the main compound, but not the only one¹, used and the principle of true argentation chromatography is the complexation of the olefinic bond with silver ions².

We have tried to extend argentation TLC to pyridine and other nitrogen heterocyclics that are known to complex silver ions giving crystalline complexes³⁻⁵ with both AgNO_3 and AgClO_4 . Some nitrates^{4,6} are soluble in CHCl_3 and other organic solvents, and some of the heterocyclic bases give complexes with a 3:1 proportion of

* This work was supported by a grant from the Fundação de Amparo à Pesquisa do Estado de São Paulo.

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ligand to metal³⁻⁵, which could be explained by partially covalent properties of the $\text{NO}_3\text{-Ag}$ bond, giving tetrahedral sp^3 instead of digonal sp complexes⁴⁻⁶.

Chromatography was first tried with 5% AgNO_3 on SiO_2 plates, with several solvents, and some separation was obtained. But all the solvents in which there was some separation, leached some AgNO_3 , some of them removing it almost completely from the lower part of the plate.

This is why we decided to try Ag_2O on SiO_2 as the "adsorbent". Ag_2O has recently been shown to complex pyridine and its homologs⁷, when a sufficient excess of water is used, giving strong complex bases.

First, we tried an "activated" adsorbent, obtaining good separations, and then thin-layer plates equilibrated in a water saturated atmosphere, expecting to have true complexation chromatography with the participation of the water retained by the silica gel. Both methods gave good results, as can be seen below, and we are extending them to other classes of compounds. The activated adsorbent is of more general use, giving separations where the water equilibrated plates are useless.

Experimental

Preparation of the plates. The 5% AgNO_3 plates were prepared as usual¹. For Ag_2O plates, 5% AgNO_3 solution was added to the Silica Gel G, to give 5% Ag, in the total solids and enough 5% NaOH solution was slowly added to react stoichiometrically with all the silver ions, while mixing thoroughly. After drying 1 h, some of the plates were activated in an oven at $105\text{--}110^\circ$ for 1 h (activated Ag_2O plates) and the others were equilibrated for 24 h in a desiccator with water.

Activated Ag_2O on Silica Gel H plates were prepared by the same technique, giving some good separations. Ag_2O -on-alumina plates were prepared by the same method but preliminary results were bad, so we did not further study the possibility of their use.

Identification reagents. (1) Iodine vapour gives brown spots only with large amounts of the pyridines. (2) The Dragendorff reagent for alkaloids⁸ was the best reagent in our experience, giving red or orange spots on a light orange background. (3) Sulphuric acid did not reveal all the spots. (4) Formaldehyde gave black spots on a dark grey background with AgNO_3 plates, but with Ag_2O plates it did not give good results.

Solvents. Benzene, petroleum ether, and similar non-polar solvents did not elute the pyridines. Alcohols elute the pyridines near the front, but do not separate them. *tert.*-Butyl alcohol reacts with the Ag_2O and leaves a black band on the immersed part of the plate.

Discussion

We tried 36 solvent systems, of which 19 are given in Tables I and II, for activated and non activated plates, equilibrated in a water saturated atmosphere of Ag_2O on Silica Gel G.

For the last 5 of these solvents, comparison is made with Silica Gel G plates treated in the same way (activated or equilibrated with water), and the results are seen in Tables III and IV.

The R_F values are the mean of 3 runs, and the difference was less than 0.01 R_F units, for plates prepared from the same slurry. For plates prepared from different

TABLE I

 $R_F \times 100$ ON ACTIVATED SILICA GEL G + Ag_2O PLATES

Solvents: (1) $Me_2CO-C_6H_6(2:3)$; $Me_2CO-CHCl_3(2:3)$; (3) $Me_2CO-sec.-BuOH-C_6H_6(4:3:3)$; (4) $Me_2CO-n-BuOH-CHCl_3(4:3:3)$; (5) $Me_2CO-n-BuOH(3:2)$; (6) $CHCl_3-MeOH(3:2)$; (7) $MeCOEt-CHCl_3-n-BuOH(4:3:3)$; (8) $MeCOEt-n-PrOH(7:3)$; (9) $MeCOEt-iso-PrOH(4:1)$ (10) $AcOEt$; (11) $AcOEt-Me_2CO(1:1)$; (12) $tert.-BuOH-CHCl_3(3:2)$; (13) $Me_2CO-tert.-BuOH-CHCl_3(4:3:3)$; (14) $iso-PrOH$; (15) $Me_2CO-AcOEt-C_6H_6(4:3:3)$ (16) $AcOEt-MeCOEt(1:1)$; (17) $tert.-BuOH-AcOEt-C_6H_6(4:3:3)$; (18) $tert.-BuOH-CHCl_3-C_6H_6(4:3:3)$; (19) $Me_2CO-CHCl_3-C_6H_6(4:3:3)$. A preliminary selection of the solvents was made from the STAHL eluotropic series¹⁹ followed by combination of the more common solvents that gave good separation.

Compounds: (I) 2-picoline; (II) 3-picoline; (III) 4-picoline; (IV) 2,4-lutidine; (V) 3,5-lutidine; (VI) 2,4,6-collidine; (VII) 2-ethylpyridine; (VIII) 4-ethylpyridine; (IX) 4-propylpyridine; (X) 2,6-lutidine; (XI) 5-ethyl-2-methylpyridine; (XII) pyridine.

Solvent	Compound											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1	40	47	38	31	54	26	64	49	57	40	52	53
2	47	55	46	42	65	34	67	55	63	50	64	58
3	68	77	71	68	83	55	82	75	76	55	75	67
4	65	71	67	64	80	61	83	78	50	63	79	69
5	80	76	67	67	80	53	85	80	85	63	83	—
6	85	87	84	87	93	84	92	91	94	85	93	86
7	48	56	46	40	61	21	—	53	61	41	60	—
8	59	67	59	55	75	43	79	—	81	62	75	—
9	85	74	83	60	83	42	85	75	83	56	80	—
10	28	36	26	18	42	20	47	39	42	26	40	34
11	56	63	54	46	70	44	77	71	74	54	69	60
12	54	68	62	51	78	33	69	73	74	45	66	62
13	60	69	—	55	77	38	84	83	85	60	50	70
14	—	62	58	56	81	50	—	69	72	41	68	—
15	47	55	48	34	60	25	75	62	66	47	57	56
16	43	50	40	30	56	24	62	60	58	38	54	50
17	42	58	48	36	69	20	38	56	46	39	74	24
18	60	71	64	51	78	37	74	84	75	41	70	62
19	51	58	45	41	64	31	72	54	58	43	60	57

slurries with the same composition, we observed some larger differences in R_F (about 0.05 to even 0.1 units).

Comparing Tables I and III, and Tables II and IV, it can be seen immediately that the separations are better on Ag_2O -Silica Gel G plates than on pure Silica Gel G alone, both on the activated and on water-equilibrated plates, for the given solvents. On the plates containing Ag_2O , the R_F values are lower, because complexation slows down the pyridines.

We could not always find a simple correlation between the order of the R_F values and the basicity¹⁰ (inductive effect of substituents) of the pyridines, but on taking into account the dipole moments and stability constants, the picolines and lutidines travel up the plate in all our solvents in an order that can be explained.

That the dipole moments of the substituted pyridines are in good agreement with those expected from the polar effects of the substituents on the different positions in the pyridine ring can be seen well from the literature data^{10,12}. Dipole moments and pK_a values of some of the compounds of interest are given in Table V.

With respect to the picolines¹⁰ we have for the dipole moment $2 < 3 < 4$ as would be expected from the direction of the substituent moment vectors.

TABLE II

$R_F \times 100$ ON SILICA GEL G + Ag_2O PLATES EQUILIBRATED IN A WATER SATURATED ATMOSPHERE
For key to solvents and compounds see Table I.

Solvent	Compound											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1	57	68	60	54	65	41	75	63	71	57	67	65
2	72	35	77	71	90	65	84	72	79	68	80	69
3	66	74	69	68	78	48	77	69	77	60	77	70
4	70	79	77	78	87	72	87	85	90	76	89	75
5	—	82	71	74	86	51	89	86	91	80	80	—
6	84	85	83	84	89	82	87	85	88	80	88	82
7	47	55	45	43	65	31	62	52	63	43	59	—
8	67	78	73	72	85	60	84	79	64	70	89	—
9	—	88	62	68	87	47	88	82	88	58	83	60
10	21	32	24	17	46	19	53	44	49	25	45	28
11	69	70	72	73	87	71	88	85	91	66	88	65
12	66	79	63	65	88	45	79	83	87	60	85	72
13	63	75	68	62	82	49	78	81	82	56	77	64
14	—	69	—	72	88	74	—	77	90	55	85	—
15	50	59	47	41	60	33	65	58	71	55	68	62
16	27	41	29	20	44	13	60	47	42	24	33	36
17	30	50	32	25	55	14	57	56	53	21	37	38
18	50	70	60	48	75	23	81	82	86	47	71	62
19	44	51	42	33	55	27	66	63	58	41	48	47

TABLE III

$R_F \times 100$ ON SILICA GEL G ACTIVATED PLATES
For key to solvents and compounds see Table I.

Solvent	Compound											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
15	84	88	85	82	87	82	91	85	96	90	95	83
16	82	87	81	80	86	79	92	87	97	91	96	84
17	74	81	86	85	91	82	91	87	86	74	94	—
18	95	97	91	92	99	93	95	95	98	92	98	89
19	81	81	87	88	94	89	99	96	99	97	91	81

TABLE IV

$R_F \times 100$ ON SILICA GEL G PLATES EQUILIBRATED IN A WATER SATURATED ATMOSPHERE
For key to solvents and compounds see Table I.

Solvent	Compound											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
15	87	87	95	96	97	94	97	96	100	97	96	89
16	88	94	80	78	100	90	100	100	100	92	100	90
17	72	77	84	86	81	74	95	96	93	85	96	94
18	86	90	89	92	95	86	95	91	93	89	96	87
19	75	78	67	69	87	87	88	79	78	67	78	80

TABLE V

 pK_a VALUES⁹ AND DIPOLE MOMENTS¹⁰ OF ALKYLPIRIDINES

Compound	pK_a	μ (benzene)
Pyridine	5.17	2.21
2-Picoline	5.97	1.97
3-Picoline	5.68	2.40
4-Picoline	6.02	2.60
2-Ethylpyridine	5.97	—
4-Ethylpyridine	6.02	2.65
4-Isopropylpyridine	6.02	—
2,6-Lutidine	6.75	1.66
2,4-Lutidine	6.79	2.30
3,5-Lutidine	6.20	2.58
2,4,6-Collidine	7.59	—

The order of the pK_a values is $3 < 2 < 4$ and the order of R_F values is, in some of the solvents, $3 > 2 > 4$. The inverse order can be explained as stronger complexation of the more basic compounds, slowing down the rate of travel on the plate. In some other solvents the order of R_F values of the picolines is $3 > 4 > 2$, which could possibly be the result of steric hindrance making more difficult the release of 2-picoline from the complex and thus slowing it. The stability constants of Py_2AgNO_3 (ref. 3) and Py_2AgClO_4 (ref. 11) type complexes are in the order $2 > 4 > 3$.

For the lutidines, the order of dipole moments¹¹ is $2,6 < 2,4 < 3,5$ and pK_a values $2,4 < 2,6 < 3,5$; the order of the R_F values varies somewhat with the solvent, but is always the same as the pK_a values or as the dipole moments (polarity). The obvious conclusion is that basicity and polarity differences of pyridine and its homologues and, in some cases, the stability of the complexes play a major role in their separation in argentation TLC with silver oxide.

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Received May 21st, 1970

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