

CHROM. 6698

## Note

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### Separation of azulenes on mixed layers of silica gel and oxalic acid

E. C. KIRBY

*Balrobin, Pitlochry, Perthshire (Great Britain)*

(Received February 12th, 1973)

Chromatography has been widely used for the isolation and purification of azulenes, but comparatively little attention has been given to the separation of mixtures of hydrocarbons within this class.

A characteristic property of the azulenes is their reversible solubility in moderately strong acids<sup>1</sup>, and, since their basicity varies with the degree of alkylation<sup>2-4</sup>, this property can be exploited for their separation. Some of the more complex azulenes have been separated on oil-impregnated paper using strong acid as the mobile phase<sup>5-7</sup>.

Gas-liquid chromatography is useful<sup>8</sup>, but often a milder technique is preferable. Thin-layer chromatography (TLC) on alumina did not resolve azulene from 1-methylazulene<sup>9</sup>, although the separation of this pair from 4,6,8-trimethylazulene<sup>9</sup>, and of azulene from guaiazulene<sup>10</sup> on alumina or silica gel was successful.

We have found it convenient to use a stationary phase of silica gel impregnated with oxalic acid. Several azulenes, including azulene and 1-methylazulene, show an excellent separation on this medium.

## EXPERIMENTAL

### *Test materials*

Azulene<sup>11</sup>, 1-methylazulene<sup>12</sup>, 4,6,8-trimethylazulene<sup>13,14</sup>, 4,8-dimethyl-6-phenylazulene<sup>13</sup>, and 4,8-dimethyl-6-methoxyazulene<sup>13</sup> were prepared by described methods. 1,3-Dimethylazulene was obtained by the Wolff-Kishner reduction<sup>12</sup> of 1-formyl-3-methylazulene, derived from 1-methylazulene by the action of ethyl orthoformate in the presence of perchloric acid<sup>15</sup>. Guaiazulene was commercial material from Ralph N. Emanuel Ltd. All azulenes were purified before use by column chromatography and/or short-path distillation.

### *Thin-layer chromatography*

Plates impregnated with oxalic acid were prepared by substituting a solution of the acid for water in the slurry used to coat the plates. Other techniques, such as treating an ordinary silica gel plate by immersion, in whole or part, gave less satisfactory results. The plates were activated by allowing them to dry for several hours at room temperature over freshly baked silica gel desiccant. The plates and desiccant were housed in an air-tight polythene tent fitted with a fan to maintain

an internal air circulation. Activation of the plates by oven-drying gave similar but less reproducible results.

Oxalic acid was commercial grade (Evans Ltd.). Petroleum ether was May and Baker R grade, b.p. 40–60°, free from aromatic hydrocarbons, which had been redistilled to give a fraction of b.p. 40–45°. Toluene was May and Baker R grade, stored over sodium wire.

Test solutions were prepared in petroleum ether, and were about 0.01 *M* with respect to each azulene.

Glass plates 7.5 × 2.5 cm and 7.5 × 15 cm, spread with a 0.254-mm layer were used. The distance travelled by the solvent front being 5 and 10 cm, respectively. Development was carried out with an ambient temperature range of 10–14° in tanks lined with filter-paper. No detecting agent was necessary.

## RESULTS AND DISCUSSION

Under the conditions used the  $R_F$  values vary inversely with the extent of drying the plates have been subjected to. When the plates are too damp no resolution of azulene and 1-methylazulene is obtained. As they become too dry the separation they give continues to improve, but the 1-methylazulene spot loses its sharpness and exhibits pronounced tailing. The results shown in Table I all represent typical

TABLE I

### TYPICAL $R_F \times 100$ VALUES AND SPOT COLOURS FOR AZULENES

Thin layers\*: TL<sub>1</sub>=acid alumina (Woehlm); TL<sub>2</sub>=basic alumina (Woehlm); TL<sub>3</sub>=Silica Gel S (Hopkins & Williams); TL<sub>4</sub>=silica gel/0.19 *M* oxalic acid.

Solvents: S<sub>1</sub>=petroleum ether, b.p. 40–45°; S<sub>2</sub>=toluene. Solvent run: 10 cm.

Detecting agent: none.

Compound	$R_F \times 100$ value				Colour	$R_F \times 100$ value	Colour
	TL <sub>1</sub> S <sub>1</sub>	TL <sub>2</sub> S <sub>1</sub>	TL <sub>3</sub> S <sub>1</sub>	TL <sub>3</sub> S <sub>2</sub>	TL <sub>1-3</sub> S <sub>1</sub> , TL <sub>3</sub> S <sub>2</sub>	TL <sub>4</sub> S <sub>2</sub> ***	TL <sub>4</sub> S <sub>2</sub>
Azulene	35	50	28	70	blue**	67	violet-blue
1-Methylazulene	35	50	28	70	blue**	46	blue
1,3-Dimethylazulene	35	50	28	70	blue**	75	light blue
Guaiazulene (1,4-dimethyl-7- isopropyl azulene)	35	50	24	70	blue**	6	brown-green§
4,6,8-Trimethylazulene	24	40	15	70**	pink	8	turquoise§
4,8-Dimethyl-6-phenyl- azulene	16	24	10	70**	violet	24	turquoise§
4,8-Dimethyl-6- methoxyazulene	6	12	3	57	orange- pink	1	grey-green§

\* Activation conditions are discussed in the text.

\*\* It was apparent from the colour of many spots of mixtures, especially in transmitted light, that there are small differences of  $R_F$  value, but no useful separations occurred.

\*\*\* The reversal of order between guaiazulene and 4,8-dimethyl-6-phenylazulene on changing from TL<sub>3</sub>S<sub>1</sub> to TL<sub>4</sub>S<sub>2</sub>, was shown by further experiment to be due to the change of solvent rather than the change of layer.

§ Colours developed after several hours exposure at room temperature.

values for mixtures obtained under conditions where a plate prepared using about 0.2 M oxalic acid with silica gel showed an optimum resolution of azulene and 1-methylazulene. Usually when a batch of plates had reached optimum activity the rate of change of humidity by the desiccant had slowed, so that it was quite easy to keep the plates in a useful condition for several days.

A preliminary general search using small plates was made to locate conditions where azulene and 1-methylazulene would easily separate. Media which proved less satisfactory than silica gel/oxalic acid included silica gel impregnated with *sym.* trinitrobenzene<sup>16</sup>, magnesium hydroxide<sup>17</sup>, acidic and basic grades of alumina, and silica gel impregnated with citric acid. Kieselguhr, either alone or in the presence of oxalic acid gave no resolution under these conditions.

Several concentrations of oxalic acid were tried for the preparation of plates. The range 0.15–0.2 M appears to be best, although it is not critical. At higher concentrations the plates tend to be less even, while if the solution is too dilute the plates require more activation, and so have a greater sensitivity to atmospheric moisture during manipulation.

The seven azulenes studied fall into two distinct classes of behaviour during TLC. Those with no substituents in the seven-membered ring, azulene, 1-methylazulene, and 1,3-dimethylazulene, all retain their colour and are easily observed during development. After the plate has dried out these three gradually lose their definition, although the colours of the 1-methylazulene, and to some extent the azulene spots increase in intensity. The other azulenes are barely visible immediately after development, but after several hours the spots develop strong colours with improved definition. These colours are quite different from those of the original compounds.

Although silica or alumina adsorbents alone do not resolve the simple azulenes, the more highly alkylated ones separate, with more compact spots which retain their original colours. So TLC on silica gel in the presence and absence of oxalic acid provides useful and complementary information about a mixture of azulenes.

It appears from the colour changes of the spots on acid plates that the azulenes undergo reaction on this medium. Azulenic materials with unchanged colour and chromatographic behaviour can however be extracted from the developed plates within a few minutes. It therefore seems that preparative applications of the technique would be feasible.

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