288. *The Influence of Solvents and of Other Factors on the Rotation of Optically Active Compounds. Part XXXV.* Attractive Power and Solvent Effect on Rotation.*

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ALTHOUGH the rotation of optically active compounds often varies very greatly with the nature of inactive liquids used as solvents, no satisfactory suggestion has hitherto been made to correlate any property or properties of the solvent with the alteration thus produced. The following experiments had their origin in the idea that if an active compound, such as ethyl tartrate, were distributed between two, so-called immiscible, solvents, the relative attractive power, as it may be termed, of these two solvents for the ethyl tartrate might show some proportionality to the corresponding changes in rotation.

It is difficult, however, to find pairs of immiscible organic liquids, and it is therefore essential to attack the problem by using water as an intermediary. Moreover, it is not easy to find active substances which combine the properties of (1) being soluble in water, (2) being also soluble in organic solvents, and (3) showing considerable changes of rotation in different solvents; so that the field of experiment is somewhat limited.

Our method of procedure—to take a definite example—was to shake thoroughly together 50 c.c. of water, 50 c.c. of nitrobenzene, and 10 c.c. (12 g.) of ethyl tartrate, in a separating funnel, at room temperature, without any special precaution to maintain a definite temperature, since it was desired in the first place to obtain a general view in this particular field. After an hour the layers were run off, and the density of each determined by means of the Westphal balance, greater accuracy not being necessary in the circum-

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* Part XXXIV, this vol., p. 581.

stances; and the rotation of each layer was observed, in a 400-mm. tube, for sodium light, since many of the data upon which we had to rely are given in the literature only for sodium light. It was then possible, from results already published, to calculate the amount of ethyl tartrate in each layer. This quantity may be expressed either as percentage composition p or as concentration c (g. of active substance per 100 g. or 100 c.c. respectively of solution); and it is difficult to say which of these it is better to use.

In the example mentioned above, the rotation actually observed in the nitrobenzene layer was + 11°, the density was 1·157, whence $p = 7·2$, $c = 8·32$, and $[\alpha]_D = + 33°$. Similarly the data for the aqueous layer were α_D (400 mm.) = + 13·36°, the density 1·039, $p = 13·2$, $c = 13·68$, and $[\alpha]_D = 24·4°$. Of the 12 g. of ethyl tartrate added, 4·16 g. (half the value of c) had gone apparently into the nitrobenzene layer, and 6·84 g. into the aqueous layer, totalling 11·00 g., a discrepancy of 1 g.

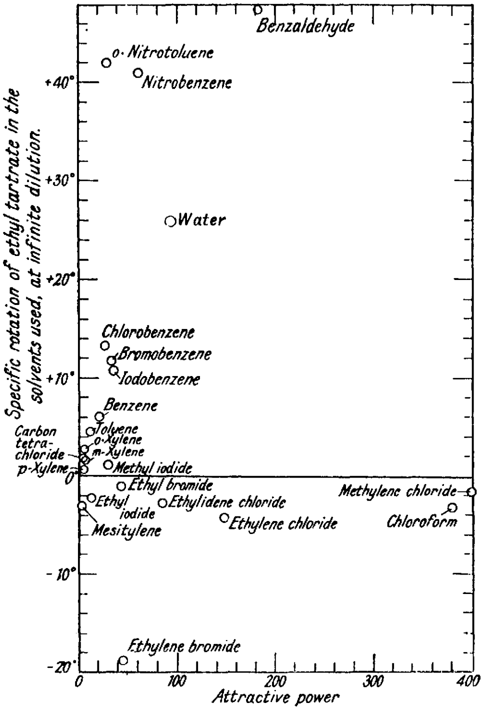
A.	*B.*	*C.*	*D.*	*E.*	*F.*	*G.*	*H.*	*K.*
	Concn. (c) of ethyl tartrate in		Attractive power of solvent (H_2O = 100).	$[\alpha]^{20°}$ at $v = \infty$.	α, obs. ($l = 4$), in		d, obs., in	
	Solvent.	H_2O.			Solvent.	H_2O.	Solvent.	H_2O.
Water	—	—	100·0	26·2° [2]	—	—	—	—
Benzene	3·52	16·84	20·9	6·1 [2]	0·98°	15·83°	0·880	1·04
Toluene	2·26	18·94	11·9	4·6 [2]	0·47	17·95	0·870	1·041
o-Xylene	1·06	19·76	5·36	2·7 [2]	0·15	19·00	0·883	1·043
m-Xylene	1·14	19·76	5·8	1·8 [2]	0·06	19·22	0·871	1·043
p-Xylene	0·95	19·76	4·8	0·7 [2]	0·01	19·15	0·867	1·043
Mesitylene	0·87	20·26	3·85	− 3·0 [2]	− 0·13	19·45	0·869	1·045
Chlorobenzene	4·44	16·66	26·65	13·3 [3]	2·31	15·60	1·113	1·035
Bromobenzene	6·10	17·64	34·6	11·7 [3]	3·50	16·72	1·49	1·038
Iodobenzene	6·24	17·44	35·8	11 [3]	3·37	17·59	1·623	1·171
Nitrobenzene	8·32	13·68	60·8	41 [4]	11	13·36	1·155	1·036
o-Nitrotoluene	4·74	16·74	28·3	42 [4]	7·98	15·79	1·160	1·033
Benzaldehyde	12·48	6·86	182·0	47·5 [5]	20·80	7·76	1·040	1·009
Carbon tetrachloride	0·78	20·28	3·85	1·9 [6]	0·09	19·02	1·592	1·040
	1·11 *	22·38 *	4·96 *	—	—	—	—	—
	1·34 †	22·66 †	5·91 †	—	—	—	—	—
Chloroform	20·88	5·54	377·0	− 3·2 [1]	2·85	5·18	1·454	1·009
	18·82 *	4·88 *	386 *	—	—	—	—	—
	18·00 †	6·00 †	300 †	—	—	—	—	—
Methylene chloride	19·83	4·90	405·0	− 1·60 [6]	− 2·61	5·25	1·304	1·011
	18·97 †	5·03 †	377·5 †	—	—	—	—	—
Ethyl bromide	6·50	15·68	41·5	− 0·95 [6]	− 0·66	14·74	1·415	1·032
	—	—	43·8 ‡	—	—	—	—	—
	—	—	43·7 ‡	—	—	—	—	—
Ethylene bromide	6·92	15·64	44·2	−18·8 [6]	− 4·52	14·88	1·98	1·03
Ethylene chloride	14·03 ‡	9·97 ‡	140·7 ‡	− 4·2 [6]	− 2·06	+ 8·55	—	—
	14·36 ‡	9·64 ‡	148·8 ‡	—	− 2·10	+ 8·60	—	—
Ethylidene chloride	11·00 ‡	13 ‡	84·6 ‡	− 1·7 [6]	− 1·38	+11·03	—	—
	11·17 ‡	12·83 ‡	87 ‡	—	− 1·44	11·32	—	—
Methyl iodide	5·67 ‡	18·33 ‡	30·8 ‡	+ 1·08 [6]	+ 0·16	+15·2	—	—
	5·84 ‡	18·18 ‡	32·1 ‡	—	+ 0·16	+14·98	—	—
Ethyl iodide	2·62 ‡	21·38 ‡	12·3 ‡	− 2·2 [6]	− 0·17	+17·23	—	—
	2·79 ‡	21·21 ‡	13·2 ‡	—	− 0·24	+17·20	—	—

[1] J., 1905, **87**, 320. [2] J., 1902, **81**, 1107. [3] J., 1908, **93**, 945. [4] J., 1908, **93**, 1856.
[5] J., 1909, **95**, 322. [6] J., 1908, **93**, 370—371.

It appears, therefore, that what may be called the attractive power (perhaps not necessarily the same as solubility) for ethyl tartrate of nitrobenzene is less than that of water approximately in the ratio 4·16 to 6·84; or, the attractive power of water being represented (for convenience) as 100, that of nitrobenzene is 61. When most of the data recorded in the table had been obtained, several of them were redetermined by a slightly different, and probably more accurate, process. In the case of water and chloroform, for example, 50 c.c. of water previously shaken with chloroform, 50 c.c. of chloroform previously shaken with water, and 10 c.c. of ethyl tartrate, were mixed and then examined as before, the temperature being noted. The density of each layer was determined by a pyknometer, and the rotation observed for sodium light, and mercury green light, a 400-mm. tube being used. From these data the approximate value of p for each layer was found. Several solutions were then made up of ethyl tartrate in the moist chloroform, and several in water saturated with chloroform, and examined polarimetrically. From concentration curves from these data, values of *p* were obtained. In the accompanying table, the results obtained by this method are marked with an asterisk.

The results for carbon tetrachloride, chloroform, and ethylene chloride were further checked as follows. To 50 c.c. of chloroform and 50 c.c. of water, 10 c.c. of ethyl tartrate were added and shaken as in the original experiments. The chloroform layer was run off in instalments, into a small distilling flask, and the chloroform distilled away. The last traces of solvent were then expelled by passing air, dried by bubbling slowly through concentrated sulphuric acid in a spiral, into the flask close to the surface of the liquid, the flask and contents being heated on the water-bath and weighed at intervals until of constant weight. In these cases the rotation was not examined. These experiments were carried out by Mr. A. J. Summers and are marked †. In some other experiments, carried out by Mr. J. Devine, the above procedure was followed, but since the solvent had not been included in the first set of experiments, the rotations of the solutions—but not the densities—were also determined. These experiments are marked ‡. This procedure could clearly be applied only to fairly volatile solvents.

The data obtained are given in the accompanying table. Cols. B and C show the weight of ethyl tartrate passing into the solvent and the aqueous layers respectively; the observed rotations are shown in cols. F and G; cols. H and K give the densities of the solvent and the aqueous layers; from these data, *p* and $[\alpha]_D$ of the various solutions examined can be calculated if desired. Col. E shows the rotation in the various solvents at *infinite dilution.* The methods adopted, from the nature of the case, cannot lay claim to any great accuracy. The experimental error is necessarily fairly large, and it is not easy to see how it could be greatly reduced. The results, however, are sufficient to give some general conspectus of the field, and since the differences in behaviour are, on the whole, striking, the experimental error has no undue influence. It should be noticed that in cols. B and C, the experimental error, which is already considerable, is doubled, since the data were obtained actually for 50 c.c. but are here given for 100 c.c. The numbers in these two columns ought to add up to 24; in the experiments marked † and ‡ they do add up to 24 since one of them is obtained by difference.



It is difficult to decide how comparison ought to be made amongst these data. It is quite obvious that much might depend on whether concentration were expressed as *c* or *p*. A solution of $p = 20$ in ethylene bromide is very different in constitution from one of $c = 20$, on account of the high specific gravity of the solvent.

It is also difficult to say how changes in rotation ought to be expressed. We do not know what is to be regarded as the rotation of an ethyl tartrate molecule free from external forces. In the homogeneous condition any molecule may be looked upon as under the solvent influence of that particular liquid. We cannot tell whether a given solvent raises or depresses the rotation of a *free* molecule of the active substance, we only know that in other solvents it has a greater or a less value than when dissolved in molecules identical with itself.

It seems, therefore, best, simply to compare the actual rotation in a given solvent with the attractive power of that solvent, and to express concentration as *c*, since this is easiest to visualise.

Our main results, namely, those of cols. D and E, are the most important, since they give a direct comparison of the attractive power of the solvent with the specific rotation which it produces in ethyl tartrate, at infinite dilution. They are represented also in the diagram, which makes them clearer than can any verbal description. The specific rotation at infinite dilution in a given solvent is plotted vertically, and the attractive power of the solvent, as compared with that of water set equal to 100, is plotted horizontally.

There is obviously no general relationship; but, to some extent, analogous solvents are grouped together.

The aromatic hydrocarbons have astonishingly little attractive power, but such as they have increases from mesitylene in a regular manner through *p*-xylene, *m*-xylene (which is slightly out of sequence), *o*-xylene, and toluene to benzene, whilst the rotation increases in a corresponding fashion. The introduction of methyl groups into the benzene molecule diminishes the attractive power of the solvent.

Chlorobenzene, bromobenzene, and iodobenzene show a behaviour opposite to that of the hydrocarbons; whilst the attractive power is least in chlorobenzene and greatest in iodobenzene, the rotations are in the opposite sequence. *o*-Nitrotoluene and nitrobenzene show a somewhat similar behaviour, the rotation being less as the attractive power increases, but, although the attractive power is not much different from that of chlorobenzene, the rotation is almost three times as great. Benzaldehyde, with a much greater attractive power, produces a higher, not a lower, rotation.

Perhaps our most interesting results concern the chloromethane derivatives. The attractive power of carbon tetrachloride is very slight, only 4; but the change to chloroform brings about an enormous change in attractive power, since that of chloroform is 375. On shaking an aqueous solution of ethyl tartrate with carbon tetrachloride, very little of the ester is extracted: about 20 times as much remains in the aqueous solution as passes into the carbon tetrachloride. Chloroform, on the other hand, extracts almost four times as much ester as remains in the water. There is, however, little change in rotation to correspond to this. The rotation in carbon tetrachloride has a small positive value, and in chloroform it has a small negative value. Methylene chloride has a somewhat greater attractive power than chloroform, but confers a rather higher rotation value.

It is interesting to notice that the nearer the solvent approaches to methane, the greater does the attractive power become, which is exactly the opposite to what seemed to be observed in the aromatic hydrocarbons, where the introduction of methyl groups very considerably diminishes the attractive power. Ethyl chloride and ethylene bromide have almost the same attractive power, but the rotation is considerably lower in the latter case than in the former. Ethylidene chloride has a fairly high attractive power, little less than that of water, whereas ethylene chloride has an attractive power considerably greater than that of water. Methyl iodide has an attractive power about $2\frac{1}{2}$ times as great as that of ethyl iodide, but the attractive powers of these last four solvents are not in the same order as the specific rotations at infinite dilution.

The foregoing experiments, whilst failing to discover any definite connection between the attractive power (as here defined) of various organic solvents for ethyl tartrate, and the rotation produced in ethyl tartrate, at infinite dilution, by these solvents, do reveal some interesting facts regarding the attractive power of the solvents used.

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