LXVI.—*Studies in Optical Superposition. Part III.*

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IN a recent paper (Trans., 1906, **89**, 1884) we described the preparation and optical behaviour of *l*-menthyl *l*-tartrate and its diacetyl derivative. We also gave reasons for supposing that van't Hoff's assumption regarding the summation of the rotations of several asymmetric atoms in one molecule is incorrect, and that, on the contrary, if, in a molecule which contains several asymmetric centres, the grouping about one of these be inverted, the corresponding change in the rotation may not be arrived at merely by altering the sign of the part of the total rotation due to that particular centre.

This conclusion was definitely expressed a number of years ago by Gadamer, whose work we have only recently had an opportunity of consulting. Gadamer (*Arch. Pharm.*, 1899, **237**, 92) prepared *d*-sec-butylthiocarbimide from *Cochleria officinalis*, and this compound on heating with water yielded *dd*-dibutylthiocarbamide, which was found to have a molecular rotation of $+77.08^\circ$ at 17° in 3.3 per cent. solution in alcohol.

By the action of *dl*-sec-butylamine on *d*-sec-butylthiocarbimide a *dr*-dibutylthiocarbamide was obtained the molecular rotation of which under the same conditions was $+34.84^\circ$, distinctly less than half that of the compound in which both butyl groups were dextrorotatory. Amplifying this in a later paper (*Arch. Pharm.*, 1901, **239**, 290), he says : "Fande eine einfache Addition der beiden optischen Effecte statt, so

müsste für den *dd*-Dibutylthioharnstoff $[M]_D$ das Doppelte von den für *dr*-Dibutylthioharnstoff gefundenen Werte betragen, also 69.68° ; statt dessen finden wir $[M]_D = 77.08^\circ$, also rund ein Zehntel mehr." The point is referred to again in a paper by Urban (at Gadamer's suggestion), who gives data for butylcarbamides and butylthiocarbamides in alcohol and chloroform solutions, and arrives at the conclusion: "Die Regel dass die optischen Wirkungen zweier asymmetrischen Kohlenstoffatome im Molekül sich summieren, bestätigte sich nicht" (*Arch. Pharm.*, 1904, 242, 85).

It appears to us, however, that this conclusion is not justified by the evidence, for it is clear that the compound which Gadamer names *dr*-dibutylthiocarbamide must consist of a mixture of molecules of *dd*-dibutylthiocarbamide and *dl*-dibutylthiocarbamide. Now the latter must be inactive, and therefore the principle of optical superposition is not really involved here, since the only comparison is between the rotation of pure *dd*-dibutylthiocarbamide on the one hand and of *dd*-dibutylthiocarbamide mixed with an inactive substance on the other. Gadamer, suggesting an alternative explanation of the fact that the rotation in the latter case is not exactly half of that in the former, says: "Allerdings ist dabei auf die Molekulargrösse noch keine Rücksicht genommen. Es ist vielleicht nicht ausgeschlossen dass dem *dr*-dibutylthioharnstoff als echte racemische Verbindung die doppelte Molekulargrösse zukommt und dadurch die beobachtete Verschiedenheit zu erklären ist" (*Arch. Pharm.*, 1901, 239, 290). This suggestion, although not impossible, seems to us improbable, since, so far as we are aware, racemic substances always dissociate in dilute solution into a mixture of the *d*- and *l*-isomerides. A much more likely explanation of the experimental numbers is that *d*-butylthiocarbimide, when acted on by *dl*-*sec*-butylamine combines preferentially with the *l*-isomeride, so that the resulting product contains a greater number of molecules of *dl*-dibutylthiocarbamide than of *dd*-dibutylthiocarbamide, in which case the rotation of the mixture would necessarily be less than half that of the pure active compound.

We are thus of opinion that Gadamer's results do not supply data whereby the question of optical superposition can be crucially tested. In our last communication we showed that this can best be done by comparing the specific or molecular rotations of sets of compounds, such, for instance, as *l*-menthyl *d*-tartrate, *l*-menthyl *l*-tartrate, and *l*-menthyl *i*-tartrate or their acetyl derivatives. If the rotation of the *i*-compounds be found equal to the mean of the rotations of the *d*- and *l*-compounds, van't Hoff's assumption is proved for those cases at least. If, on the other hand, the values found differ to an extent distinctly beyond the experimental error, van't Hoff's assumption must be regarded as disproved.

Our present communication gives data for the rotation of *l*-menthyl diacetyl-*i*-tartrate in the homogeneous condition as well as in solution in ethyl alcohol, benzene, and nitrobenzene, and, as is shown further on, these data, taken in conjunction with the others previously published, furnish, for the first time, conclusive evidence as to the untenability of van't Hoff's assumption regarding optical superposition.

Di-l-menthyl i-tartrate was prepared by mixing 10 grams of *i*-tartaric acid with 50 grams of menthol and passing dry hydrogen chloride through the mixture, first in the cold and then at a temperature of 110—130° for about twenty hours. The excess of menthol was then distilled off under reduced pressure. The viscid oil which remained was dissolved in ethyl alcohol and boiled with animal charcoal for two hours. On addition of water to the filtered solution the tartrate was precipitated as an oil, but although various methods were tried it did not crystallise. It was therefore converted directly into the diacetyl derivative.

Di-l-menthyl diacetyl-i-tartrate was readily obtained by boiling the menthyl tartrate with acetyl chloride. The solid which remained after the excess of acetyl chloride had been distilled off was washed with water and sodium carbonate solution and crystallised twice from methyl alcohol. The melting point was 129°, which is higher than that of either the corresponding *d*- (108°) or *l*- (102·5°) compound, although the melting point of *i*-tartaric acid (143°) is lower than that of *d*- or *l*-tartaric acid (172°). On analysis :

0·2186 gave 0·5272 CO₂ and 0·1746 H₂O. C = 65·77 ; H = 8·87.

C₂₈H₄₆O₈ requires C = 65·88 ; H = 9·02 per cent.

The composition of the ester was further verified by decomposing 0·3435 gram of the substance with 20 c.c. of 0·4021 *N*-ethyl-alcoholic potassium hydroxide solution. To neutralise the excess of alkali 14·6 c.c. of 0·3656 *N*-hydrochloric acid were necessary. Therefore 6·72 c.c. of the alkali had been utilised for saponification whilst theory requires 6·70 c.c.

When melted the ester was slightly opalescent, and as this greatly interfered with polarimetric measurements the preparation was boiled in ethereal solution with animal charcoal for four hours, and was then twice crystallised from absolute ethyl alcohol. The melting point was the same as before. The compound, thus purified, was then examined in the polarimeter with the following results, but owing to the readiness with which the ester solidifies on cooling, it was not found possible to obtain values for the rotation at such low temperatures as in the cases of the *d*- and *l*-compounds :

Rotation of l-Menthyl Diacetyl-i-tartrate.

t° .	α_D^c (30 mm.).	Density.	$[\alpha]_D^c$.	$[M]_D^c$.
145.6°	-15.888°	0.9540	-55.52°	-283.1°
122.6	16.145	0.9751	55.20	281.5
140.0	15.954	0.9592	55.44	282.7
130.1	16.060	0.9683	55.29	282.0
100.0 *	—	—	54.88 *	280.0 *
20.0 *	—	—	53.7 *	274.0 *

Densities determined :

Temperature.....	134°	139.6°	150.6°	161.4°
Density	0.9636	0.9596	0.9495	0.9395

* Extrapolated.

The results recorded in the first part of this investigation were obtained with an instrument which did not easily allow of observations at temperatures above 100°. Our rotation data for *l*-menthyl diacetyl-*d*-tartrate would therefore require to be extrapolated in order to allow of comparison with those given above, or vice versa. We therefore thought it worth while to re-examine *l*-menthyl diacetyl-*d*-tartrate at higher temperatures so that our data should be as definite as possible.* The values found were as follows :

Rotation of l-Menthyl Diacetyl-d-tartrate.

t° .	α_D^c (30 mm.).	Density.	$[\alpha]_D^c$.	$[M]_D^c$.
97.2°	-13.345°	0.9970	-44.63°	-227.6°
123.3	12.467	0.9758	42.59	217.2
134.4	12.171	0.9668	41.96	214.0

These numbers agree very closely with the values previously obtained. The molecular rotation formerly determined at 99.2° was -227.2°, which, allowing for the slight diminution of rotation due to rise of temperature, is practically identical with the number given above for 97.2°.

* We have also redetermined the density of this substance. Two series of observations were made with different pycnometers, the results being as follows :

Temperature	113°	134.5°	119°	146.5°
Density	0.9835	0.9660	0.9801	0.9577

These values agree closely with each other, but differ slightly from those given in *Trans.*, 1905, **87**, 40. All the rotation data for *l*-menthyl diacetyl-*d*-tartrate in the present paper are calculated by means of the new density determinations. This redetermination also affects the numbers for *l*-menthyl diacetyl-*d*-tartrate quoted in *Trans.*, 1906, **89**, 1897, but the necessary changes, which are small, do not affect the argument in any way.

*Rotation of 1-Menthyl Diacetyl-i-tartrate in Solution.**Solution in Ethyl Alcohol (d. 20°/4° : 0.7915).*

The ester is but slightly soluble in ethyl alcohol, and it was therefore only possible to examine a dilute solution.

p : 0.4547.

t° .	α_D^c (400 mm.).	Density.	$[\alpha]_D^c$.	$[M]_D^c$.
16.6°	- 0.827°	0.7954	- 57.2°	- 291°
35.5	0.828	0.7784	58.5	298
20.0 *	—	—	57.3 *	292 *

Densities determined :

Temperature	18.53°	23.2°
Density	0.79368	0.78964

Solution in Benzene (d. 20°/4° : 0.87749).

p : 5.20404.

t° .	α_D^c (100 mm.).	Density.	$[\alpha]_D^c$.	$[M]_D^c$.
17.2°	- 2.225°	0.8885	- 48.12°	- 245.4°
30.3	2.250	0.8746	49.43	252.1
37.7	2.291	0.8668	50.79	259.0
50.5	2.314	0.8535	52.10	265.7
20.0 *	—	—	48.59 *	247.8 *

Densities determined :

Temperature	19°	23°	28°
Density	0.88641	0.88233	0.87617

* Interpolated.

Solution in Nitrobenzene (d. 20°/4° : 1.20328).

p : 4.378.

t° .	α_D^c (100 mm.).	Density.	$[\alpha]_D^c$.	$[M]_D^c$.
17.2°	- 2.504°	1.1984	- 47.73°	- 243.4°
27.6	2.514	1.1883	48.32	246.4
37.4	2.574	1.1787	49.88	254.3
20 *	—	—	47.81 *	243.8 *

Densities determined :

Temperature	19.85°	22.1°	34.8°
Density	1.19603	1.19385	1.18158

* Interpolated.

Discussion of Results.

We may now consider these data in connexion with the corresponding values for the dextro- and lævo-compounds. The following table exhibits this comparison at different temperatures for the homogeneous substances :

Molecular Rotation of 1-Menthyl Diacetyl-d-tartrate, 1-Menthyl Diacetyl-l-tartrate and 1-Menthyl Diacetyl-i-tartrate.

	I.	II.	III.	IV.	
t°	1-Menthyl diacetyl- <i>d</i> -tartrate.	1-Menthyl diacetyl- <i>l</i> -tartrate.	Mean of I and II.	1-Menthyl diacetyl- <i>i</i> -tartrate.	Δ . IV—III.
20°	-255°	-360°	-307.5°	-274°	33.5°
100	226	382	304	280	24
130	215	390	302.5	282	20.5

In order to obtain a value for the molecular rotation of the *i*-tartrate at 20° extrapolation through 100° is necessary, and therefore the number given is subject to error. The values at 100° and 130° are more trustworthy, especially the latter, since it is found by interpolation. The values for the *d*- and *l*-esters are all interpolated.

It will be observed that at all three temperatures the molecular rotation of the *i*-tartrate is very distinctly—almost 10 per cent.—greater (that is, less negative) than the mean of the values for the *d*- and *l*-esters. This difference is greatest at low temperatures, so that the influence of rise of temperature, in this as in many other similar cases, is to diminish those forces which, acting between the atoms of a molecule, are evidenced by absence of additive regularities in the properties of the substance. The properties—rotation in this case—become more nearly additive at higher temperatures than they are at lower ones.

Solutions.—The next table gives a comparison of the values of molecular rotation which we have found for these esters in solution at 20°. The numbers given for the *d*- and *l*-tartrates are interpolated values for $p : 5$ solutions. Those for the *i*-tartrate are as stated. The slight difference in concentration of the benzene and nitrobenzene solutions would have no appreciable influence on the relationship, and this is also the case for the somewhat greater difference of concentration in ethyl alcohol.

	I.	II.	III.	IV.	
Solvent.	1-Menthyl diacetyl- <i>d</i> -tartrate.	1-Menthyl diacetyl- <i>l</i> -tartrate.	Mean of I and II.	1-Menthyl diacetyl- <i>i</i> -tartrate.	Δ . IV—III.
Ethyl alcohol.....	-268°	-367°	-317.5°	-292° ($p : 0.455$)	25.5°
Benzene	285	313	299	248 ($p : 5.2$)	51
Nitrobenzene	238	355	296.5	244 ($p : 4.38$)	52.5

It is apparent from these data that in solution also, as in the homogeneous state, the values for the rotation of the *i*-tartrate differ quite markedly—almost as much as 25 per cent.—from the means of the values for the *d*- and *l*-tartrates, and therefore that van't Hoff's conjecture regarding the summation of the rotations due to the different asymmetric carbon atoms in a compound containing several is incorrect,

The proof given is, we think, quite conclusive, since the differences upon which it depends are in all cases well beyond the limits of the experimental error, and the work is free from objections such as we have discussed in the previous part of this investigation.

It is of interest to compare our results with some obtained by Walden (*Zeitsch. physikal. Chem.*, 1896, 20, 377), which have been referred to by us already (Trans., 1906, 89, 1887).

His figures are :

	$[M]_D^{20^\circ}$.
Di- <i>l</i> -amyl <i>i</i> -tartrate	+13.83°
Di- <i>l</i> -amyl <i>dl</i> -tartrate	9.77

The rotation of di-*l*-amyl *dl*-tartrate should represent the mean of the rotations of di-*l*-amyl *d*-tartrate and di-*l*-amyl *l*-tartrate if it consisted—which is somewhat doubtful—of equal numbers of these molecules. It will be observed that the rotation of the *i*-tartrate is greater than that of the *dl*-tartrate, and the same relationship occurs in all our results; the rotation of the *i*-compound is always greater (less negative) than the mean value for the *d*- and *l*-derivatives, and therefore we must conclude that the rotation due to a given asymmetric atom in a compound of two or more asymmetric radicles is not independent of the configuration of the other group or groups with which it is combined.

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