271. *Supposed Rotational Isomerism in the Succinic Acid Series.*

By G. D. Buckley.

The existence (Duncanson, *J.*, 1952, 1753) of two solid forms of (±)-methylsuccinic acid has been confirmed and a third form has been discovered. The three are readily interconvertible and the differences between them disappear on dissolution or fusion. It is therefore concluded that these three forms are polymorphic modifications and not rotational isomers as claimed by Duncanson.

Duncanson (*J.*, 1952, 1753) reported that certain monosubstituted succinic acids exist in two forms, of which he obtained one by crystallisation and the other by sublimation. The two forms have different infra-red absorption spectra in the solid state and he considers that they are rotational isomers.

The discovery of a new form of isomerism is an event of some importance requiring support by irrefutable evidence. Very many carboxylic acids exist in two or more polymorphic modifications, but it has not so far been suggested that these are rotational isomers. Indeed acetic acid which is dimorphic, and malonic and anthranilic acids which are trimorphic, offer no possibility of isomerism, rotational or otherwise. Furthermore, according to Kendall (Amer. Chem. Soc. Meeting, Boston, Mass., April, 1951) the polymorphic modifications of a compound commonly have different infra-red absorption spectra, and Ebert and Gottlieb (*J. Amer. Chem. Soc.*, 1952, **74**, 2806) have shown that the differences in the spectra of the three forms of anthranilic acid are very marked. It therefore seems reasonable to suppose that the two forms of (±)-methylsuccinic and (±)-chlorosuccinic acid are also polymorphic modifications unless evidence to the contrary can be adduced.

Most of Duncanson's evidence relates to (±)-methylsuccinic acid. He states that the " crystallised acid " (modification A) is the normal form, which is recovered unchanged on crystallisation from water or from a mixture of chloroform and light petroleum, but is converted into the " sublimed acid " (modification B) by sublimation *in vacuo*. He found that B was recovered unchanged on crystallisation from benzene, but was reconverted into A when dissolved in water and boiled for several hours. He states, however, that he recovered B unchanged after 30 minutes' refluxing of its aqueous solution and evaporation at room temperature.

These observations, although suggestive of isomerism, do not rule out polymorphism. The essential distinction between these two is that the differences between polymorphic forms are confined to the solid state and disappear when the substances are melted or dissolved, whereas the differences between isomeric forms are also manifest, at least temporarily, in the liquid state. In order to prove that A and B are isomers it must therefore be demonstrated that both can exist in solution or in the liquid state, and this Duncanson purports to have done by showing that A and B have different dipole moments in benzene solution.

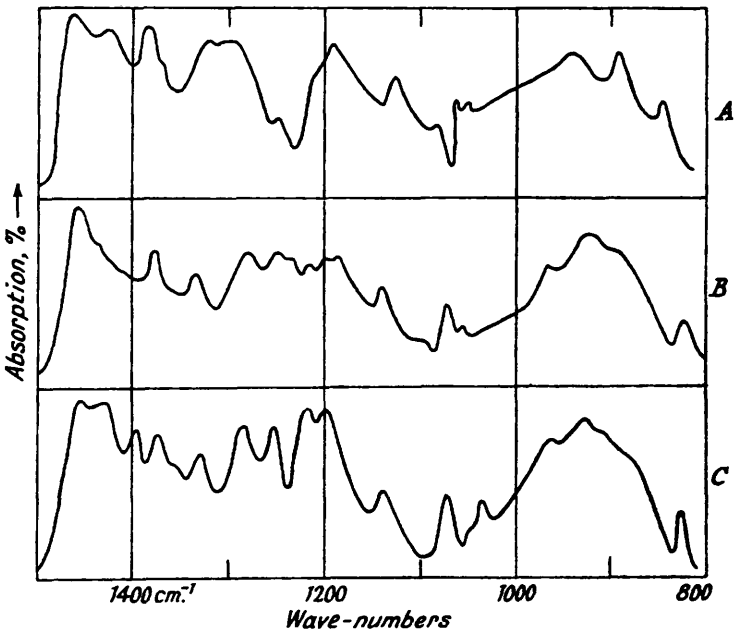
Modification A.						*Modification B.*					
10^3c.	ε_s	P_M	P_E	P_O	μ (D)	10^3c.	ε_s	P_M	P_E	P_O	μ (D)
6·092	2·2735	26·3	28·35	0	0	6·212	2·2742	45·1	28·35	16·75	0·90
6·169	2·2738	34·0	28·35	5·65	0·52	6·289	2·2745	52·5	28·35	24·15	1·08

However, his experimental results, which are reproduced above, will not stand up to critical examination. The determinations were carried out at such low concentrations that a slight error in the measurement of the dielectric constant would result in a large error in the dipole moment. That such errors must have occurred is evident from the large discrepancy between the two results for modification A and from the fact that this discrepancy is larger than the difference between the second value of the dipole moment for A and the first value for B. Furthermore the figure of 0 given for the dipole moment of A in the first determination is spurious: the true figure for P_0 is $-2·05$, and a dipole moment cannot be calculated from it. A further defect of these results is that the dipole

moments were calculated from a single dielectric-constant measurement in each case, whereas it is well known that the total polarisation and therefore the apparent dipole moment frequently varies with concentration; results should be obtained at several concentrations and extrapolated to infinite dilution. Bearing all these considerations in mind it must be concluded that the dipole-moment results are of little value and certainly cannot be adduced as evidence that A and B give different solutions.

Duncanson's theory cannot however be dismissed merely on the grounds that he has failed to provide evidence which supports it, and the different forms of (±)-methylsuccinic acid have therefore been prepared and studied. Modifications A and B were prepared according to Duncanson, and his observation that they had different infra-red absorption spectra in the solid state was confirmed (see Figure). They also had very different *X*-ray powder patterns. Form A was stable at room temperature, but B, after 2 months at room

Infra-red absorption spectra of three modifications of (±)-methylsuccinic acid, measured as a 20% suspension in Nujol. Cell thickness 0·025 mm.



temperature, had changed to a third modification (C) which had an infra-red absorption spectrum (see Figure) and an *X*-ray pattern which differed from those of both A and B. Form C was itself stable at room temperature.

All three forms when melted and cooled reverted to A, the highest-melting modification. It may therefore be assumed that the differences between them disappear on melting. All three invariably gave B when crystallised from benzene or ether and, except in one case, A when crystallised from water. In a single experiment, B was dissolved in a little hot water and seeded with B; the crystals obtained from the solution were pure C. When form A or B was dissolved in the minimum of cold water and evaporated *in vacuo* over phosphoric oxide at 20°, the product was pure A in both cases; Duncanson's statement that long boiling was necessary to effect the change from B to A could not be confirmed. In no case was B isolated from an aqueous solution. Crystallisation of any form from chloroform gave sometimes B and sometimes C, but C could always be obtained from solutions in chloroform by seeding with C.

These results show the characteristic behaviour of a trimorphic compound, but they do not rule out the possibility of labile isomerism. In order to eliminate this possibility it is necessary to prove that the three forms give identical solutions, and evidence bearing on this point was therefore sought.

Some difficulty was encountered in finding a suitable solvent for infra-red absorption measurements. The acid is very soluble in oxygen-containing solvents but these all absorb strongly in the infra-red in the same region as the acid itself, whereas the solubility in hydrocarbons and chlorinated hydrocarbons, which would otherwise be very suitable, is much too low. However, acetonitrile, in which methylsuccinic acid is very soluble, was fairly satisfactory since its absorption spectrum shows no bands in the region 1350—1090 cm.$^{-1}$ where the acid absorbs strongly and where the main differences between the three solid forms appear. 10% Solutions of the three modifications in this solvent had identical absorption spectra.

According to Sidgwick (*J.*, 1915, **107**, 672), when a substance is added to a saturated solution of another substance of the same molecular formula at constant temperature, then if they are isomers, the solid will dissolve, whereas if they are polymorphs the solid will not dissolve and the concentration of the solution will remain the same or decrease. Since Sidgwick demonstrated that this method distinguishes polymorphism from structural, geometrical, and optical isomerism it should be effective in detecting rotational isomerism. All three forms of (±)-methylsuccinic acid are readily soluble in ether and the concentration may be determined by titration with alkali. In this way it was shown that the addition of B or C to a saturated solution of A in ether produced no increase in the amount of acid in solution.

It is therefore proved beyond reasonable doubt that only one modification of (±)-methylsuccinic acid exists in solution or in the liquid state and that the three solid forms are polymorphic modifications and not rotational isomers.

Experimental

Microanalyses are by Dr. A. F. Colson. M. p.s are corrected.

Preparation of Polymorphic Modifications of (±)-Methylsuccinic Acid.—Modification A. (±)-Methylsuccinic acid, prepared according to *Org. Synth.*, 1946, **26**, 54 and crystallised from water, had m. p. 113—114°, and appeared to be identical with the " crystallised acid " described by Duncanson (*loc. cit.*) (Found : C, 45·5; H, 6·1. Calc. for $C_5H_8O_4$: C, 45·4; H, 6·1%).

Modification B. A specimen of A was sublimed at 95°/2 × 10^{-3} mm. The sublimate, m. p. 108—110°, was apparently identical with Duncanson's " sublimed acid " (Found : C, 45·3; H, 6·0%).

Modification C. This modification was first obtained fortuitously, but was later prepared by dissolving A in boiling chloroform, seeding the solution with a crystal of C, allowing it to cool, and collecting the crystals, m. p. 111—112° (Found : C, 45·4; H, 6·0%).

Infra-red Spectrography.—The infra-red absorption spectra were measured by Mr. L. H. Cross, using a Grubb-Parsons model S3 spectrometer, equipped with a rock-salt prism, thermal detector, A.C. amplifier, and pen recorder.

The spectra of the three forms in the solid state were measured on 20% suspensions in Nujol at a cell thickness of 0·025 mm. The spectra of A and B (see Figure) were similar in general form to those of Duncanson's " crystallised " and " sublimed " acids respectively, but differences in detail were noticeable.

X-*Ray Examination.*—The three modifications were examined by Mr. R. Brooks and Mr. T. C. Alcock by normal powder methods, using a 9-cm. Bradley–Jay type camera and nickel-filtered Cu-*Kα* radiation. The photographs indicated different crystal structures. A showed two characteristic reflections of equal strength at 4·34 and 4·11 Å; B showed a strong reflection at 4·81 Å, and C a strong reflection at 4·51 Å.

Interconversion of the Three Forms.—After various treatments, the products were characterised by infra-red spectrography. Some results are recorded on p. 1326. When kept for 2 months at 15—25°, A and C were unchanged, but B had been transformed into C; each form was unchanged after 6 hours at 60°. Form B was obtained when a solution of A or B in ether was evaporated at 20°.

One part of a solution of B in water was cooled, seeded with a crystal of A, and kept at 0—5° until crystallisation was complete; the crystals were pure A. The second part of the solution was similarly seeded with B; it gave pure C. In an attempt to repeat this result, both solutions gave pure A. Solutions of A in benzene, similarly seeded with A or B, gave only B. A solution of A in chloroform, when seeded with B, deposited B, but when seeded with A deposited C. When this experiment was repeated both solutions deposited only C.

Additive Solubilities in Ether.—Finely-powdered A (14 g.) was stirred in pure dry ether (80 c.c.) at 23° (thermostat). After 1 hour the undissolved solid was allowed to settle. 5 Ml. of the solution were withdrawn, run into distilled water, and titrated with 0·5N-sodium hydroxide (phenolphthalein). The stirrer was restarted and further 5-ml. portions were withdrawn at half-hourly intervals until no increase in titre occurred. Final titres: 20·55, 20·45 ml.; *i.e.*, 135·3 g. of acid per l. Finely-divided B (2 g.) was then added, stirring was continued for 30 minutes, and a 5-ml. portion was withdrawn. Titration required 20·55 ml. Finely-divided C (2 g.) was then added and the procedure repeated. Titration required 20·5 ml.

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