CLXXI.—*The Chemistry of the Glutaconic Acids.*
Part VIII. β -Phenylglutaconic Acid and the
 β -Phenyl- α -methylglutaconic Acids.

By JOCELYN FIELD THORPE and ARTHUR SAMUEL WOOD.

THE experiments described in the previous parts of this series have shown that a derivative of glutaconic acid containing the mobile hydrogen atom should, theoretically, exist in three forms, namely:

It has been proved, moreover, that the stability of the *cis*-labile acid, on which depends the possibility of converting it into the *trans*-isomeride, is determined by the weight of the groups attached to the carbon atoms of the three-carbon system. Thus it was found possible to isolate the *trans*-modification of α -benzyl- β -methylglutaconic acid, and to show that the *cis*-isomeride, whilst incapable of a separate existence, must be present in the form of its salts (T., 1912, **101**, 1739).

The great stability of the *cis*-labile modification of β -methylglutaconic acid (T., 1912, **101**, 858), compared with that of the corresponding acid derived from α -methylglutaconic acid, showed that increased stability is conferred by the presence of the substituting group on the β -carbon atom, and it might therefore be expected that the attachment of the phenyl group to the β -carbon atom would confer increased stability on the *cis*-form of the acid thus substituted.

Unfortunately, β -phenylglutaconic acid does not lend itself to direct comparison; the acid exists in one well-defined form, which melts at 154—155°, and yields an hydroxy-anhydride, which has the abnormally high melting point of 206°. The hydroxy-anhydride when boiled with water is converted into the acid melting at 154—155°, although the presence of another acid, stable only in the form of its salts, has been clearly proved (T., 1912, **101**, 861; Feist and Pomme, *Annalen*, 1909, **370**, 76).

We have assigned the normal structure to the acid melting at 154—155° instead of the *trans*-structure, as suggested by Feist:

because the acid is readily converted into the hydroxy-anhydride by cold acetyl chloride, and also because numerous experiments have failed to yield the normal anhydride, showing that the hydrogen atom is still mobile within the molecule of β -phenylglutaconic acid.

On the other hand, the acid melting at $154\text{--}155^\circ$ is unaltered by prolonged boiling with concentrated alkali hydroxide, and is not apparently converted under these conditions into the alkali salt of the *cis*-labile acid; in this respect, therefore, it differs markedly from the normal modification of β -methylglutaconic acid, which is completely converted into the salt of the *cis*-modification under the same experimental conditions.

It must be remembered, however, that the *cis*-labile forms of acids of this series are frequently so unstable that the mere act of liberating them from their salts by the aid of mineral acids is sufficient to transpose them into their more stable normal modifications. That this is actually the case with the *cis*-labile form of β -phenylglutaconic acid is shown by the fact that it is only possible to prove that the alkali salt of the unstable *cis*-labile modification is formed by the action of alkali on the hydroxy-anhydride in the presence of casein by decomposing the corresponding silver salt with hydrogen sulphide; if the alkali salt is acidified by mineral acids, the normal form, melting at $154\text{--}155^\circ$, is at once precipitated.

Indirect proof that the sodium salt of the unstable *cis*-labile modification of β -phenylglutaconic acid is formed by the action of aqueous sodium hydroxide on the normal acid is supplied by the following series of experiments.

When normal β -phenylglutaconic acid is boiled with dilute hydrochloric or sulphuric acids, it is rapidly transformed into carbon dioxide and two hydrocarbons, one of which is *isopropenyl*-benzene, and the other, with twice this molecular weight, which is probably 1:4-diphenylcyclohexane:

Boiling water is without action on β -phenylglutaconic acid, but in a sealed tube at 160° transformation into *isopropenyl*benzene is complete. β -Methylcinnamic acid can be isolated as an intermediate product in this reaction:

When, however, β -phenylglutaconic acid is heated with excess of aqueous alkali, even in a sealed tube at a high temperature, it is recovered unchanged on acidifying. It follows therefore that the alkali salt of the normal acid is transformed into the stable sodium salt of the *cis*-labile acid. This seems to be the only possible explanation, since it is well known that the presence of excess of alkali favours the elimination of carbon dioxide from acids of this type.

In the hope of throwing further light on this question, we have prepared β -phenyl- α -methylglutaconic acid, and have, for the first time, succeeded in isolating a derivative of glutaconic acid, containing the mobile hydrogen atom, in three distinct forms, which are without doubt the normal, *cis*-labile, and *trans*-labile modifications, formulated thus:

The ester from which these acids can be derived can be isolated in two forms by the action of methyl iodide on the sodium derived, which is produced in the condensation of ethyl phenylpropionate and ethyl sodiomalonate (T., 1912, 101, 868):

It is probable that, in this ester, the mobility of the hydrogen atom ceases, and that the two forms represent true *cis*- and *trans*-modifications, thus:

Support is given to this view from the fact that the solid ester yields the *trans*-labile acid only, under conditions of hydrolysis, which convert the liquid ester into a mixture of the normal and *cis*-labile acids. Neither form of the ester is converted into a sodium derivative by alcoholic sodium ethoxide.

The dibasic acids derived from these esters can be separated by means of the barium salts in the manner described in the experimental portion.

The *trans*-labile acid melts at 155°, and is quite unaltered, even on prolonged boiling, by acetyl chloride. The normal acid melts at 120°, and the *cis*-labile acid at 108°; both are readily converted into the hydroxy-anhydride (m. p. 94°) by acetyl chloride:

When the hydroxy-anhydride is boiled with water, it yields the normal acid melting at 120° ; when hydrolysed by strong alkali, it is transformed into an alkali salt, from which acids precipitate a mixture of the normal acid and the *cis*-labile acid. When hydrolysed by dilute alkali in the presence of casein, and the acid isolated through the silver salt and hydrogen sulphide, the *cis*-labile acid melting at 108° is the sole product.

All three forms eliminate carbon dioxide when boiled with dilute hydrochloric or sulphuric acids, and pass into *isobutenylbenzene*, but this decomposition evidently takes place through the normal form alone, because, if the reaction in the cases of the *trans*- and *cis*-labile acids is stopped before completion, the dibasic acid remaining unaltered is always the normal acid melting at 120° :

It was not found possible to convert either the *cis*-labile acid or the normal acid into the *trans*-labile acid, and it would appear as if this acid can only be produced by the hydrolysis of the *trans*-tricarboxylic ester in the manner already mentioned. This point is of some interest, because it follows that if similar esters could be isolated in the case of other members of the series, it should be possible to prepare other *trans*-acids of similar type. It shows, moreover, that the view expressed in an earlier communication, namely, that the isolation of the *trans*-forms is prevented by the fact that in order to prepare them it is necessary to pass through the more stable normal form is correct.

The *trans*-labile acid is converted into the alkali salt of the *cis*-labile acid on prolonged boiling with alkali hydroxide, and from this alkali salt a mixture of the normal acid and the *cis*-labile acid is obtained on acidifying.

EXPERIMENTAL.

(1) *The Decomposition of β -Phenylglutaconic Acid.*

(a) *isoPropenylbenzene*, $C_6H_5 \cdot CMe \cdot CH_2$, and 1:4-*Diphenylcyclohexane*.

These substances are formed when β -phenylglutaconic acid is boiled with either 10 per cent. aqueous sulphuric acid or 15 per cent. aqueous hydrochloric acid, and can be isolated by distillation in a current of steam; 10 grams of the acid, when boiled with 100 c.c. of the dilute mineral acid, are completely decomposed in the course of three hours.

The two hydrocarbons are then separated by fractional distillation. *isoPropenylbenzene* boils at $164^\circ/749$ mm.:

0.1362 gave 0.4543 CO_2 and 0.1048 H_2O . $C=91.18$; $H=8.55$.

C_9H_{10} requires $C=91.5$; $H=8.5$ per cent.

3.08 Grams decolorised 4.09 grams of bromine in chloroform solution. $C_9H_{10} + Br_2$ requires 4.17 grams.

Although no definite derivatives of this hydrocarbon could be prepared, there can be no doubt that it is identical with the substance obtained by Klages (*Ber.*, 1902, **35**, 2640), Tiffeneau (*Compt. rend.*, 1902, **135**, 845), and by Matsubara and Perkin (*T.*, 1905, **87**, 672) from phenyldimethylcarbinol.

1:4-*Diphenylcyclohexane* boils at $190^\circ/29$ mm. as a colourless, mobile liquid:

0.1523 gave 0.5115 CO_2 and 0.1154 H_2O . $C=91.58$; $H=8.42$.

$C_{18}H_{20}$ requires $C=91.5$; $H=8.5$ per cent.

Bromine in chloroform solution acts on the hydrocarbon at the ordinary temperature with the formation of hydrogen bromide; no definite derivatives have as yet been isolated, and the compound is still under investigation.

(b) *β -Methylcinnamic Acid*, $C_6H_5 \cdot CMe \cdot CH \cdot CO_2H$, and *isoPropenylbenzene*.

A mixture of these substances is produced when β -phenylglutaconic acid is heated in a sealed tube with water at 160° for six hours, although the amount of the hydrocarbon formed under these conditions is very small.

A larger yield of the unsaturated hydrocarbon unmixed with diphenylcyclopropane can be obtained by heating the sodium hydrogen salt with water at 160° for seven hours. In either case the hydrocarbon was isolated by distillation in steam, and the residual acid recrystallised from dilute alcohol. β -Methylcinnamic

acid melts at 97° . (Found, $C=73.69$; $H=6.19$. $C_{10}H_{10}O_2$ requires $C=74.1$; $H=6.2$ per cent.)

The acid has been prepared by G. Schroeter (*Ber.*, 1904, **37**, 1092; 1907, **40**, 1593). It was characterised by the formation of the dibromide of the dimethyl ester, $C_6H_5 \cdot CMeBr \cdot CHBr \cdot CO_2Me$, melting at $78-79^{\circ}$. (Found, $Br=47.53$. Calc., $Br=47.6$ per cent.)

(c) When the disodium salt of β -phenylglutaconic acid is heated with water in a sealed tube at 160° for ten hours, a small quantity of the unsaturated hydrocarbon and β -methylcinnamic acid can be isolated from the product. When an excess of sodium hydroxide is present, the sodium salt of β -phenylglutaconic acid can be heated for twenty hours at 160° , and the acid is recovered unaltered when the product is acidified.

(2) *The cis- and trans-forms of Ethyl α -Carbethoxy- β -phenyl- α -methylglutaconate, $CO_2Et \cdot CMe \cdot CPh \cdot CH(CO_2Et)_2$.*

The yellow sodium compound which is formed by the interaction of ethyl phenylpropionate and ethyl sodiomalonate (T., 1912, **101**, 868) is converted into a mixture of these esters when it is boiled, in alcoholic solution, with excess of methyl iodide. The reaction is finished when the yellow colour of the solution has been discharged, and the product is isolated in the usual way. The mixed esters boil at $225^{\circ}/18$ mm., and the distillate slowly deposits crystals. These were collected after some months, and recrystallised from light petroleum, when the large, colourless prisms of the *trans*-form, melting at 50° , were obtained:

0.1520 gave 0.3637 CO_2 and 0.0930 H_2O . $C=65.26$; $H=6.80$.

$C_{19}H_{24}O_6$ requires $C=65.5$; $H=6.9$ per cent.

For practical purposes the separation of the solid ester can be completed in the course of a day if the mixed esters are dissolved in an equal volume of light petroleum and the solution is placed in a mixture of ice and salt.

The *trans*-modification is readily soluble in all organic solvents excepting light petroleum. It boils at $225^{\circ}/18$ mm. as a viscous liquid, which quickly solidifies on cooling.

The *cis*-modification distils at the same temperature as its *trans*-isomeride, but cannot be obtained in the solid condition:

0.1507 gave 0.3626 CO_2 and 0.0913 H_2O . $C=65.61$; $H=6.73$.

$C_{19}H_{24}O_6$ requires $C=65.5$; $H=6.9$ per cent.

trans-Labile β -Phenyl- α -methylglutaconic Acid,
 $\text{CO}_2\text{H}\cdot\text{CMe}\cdot\text{CPh}\cdot\text{CH}_2\cdot\text{CO}_2\text{H}.$

This acid is formed by the hydrolysis of the *trans*-modification of the tricarboxylic ester by means of slightly more than the calculated quantity of alcoholic potassium hydroxide, and is precipitated on acidifying the aqueous solution freed from alcohol. Care must be taken to stop the hydrolysis so soon as completed, otherwise some of the *trans*-potassium salt will be converted into the potassium salt of the *cis*-labile acid by the excess of alkali present. In order to avoid this, it is advisable to remove the excess of alcohol, as far as possible, in a vacuum desiccator at the ordinary temperature, and not on the water-bath. The acid crystallises from hot water in well-defined needles, which melt at 155° :

0.1833 gave 0.4400 CO_2 and 0.0889 H_2O . $\text{C} = 65.46$; $\text{H} = 5.39$.

$\text{C}_{12}\text{H}_{12}\text{O}_4$ requires $\text{C} = 65.5$; $\text{H} = 5.5$ per cent.

The acid is unaltered on prolonged boiling with acetyl chloride, but is slowly converted into the hydroxy-anhydride (see next paragraph) when heated in a sealed tube at 100° with this reagent.

The barium salt is soluble in water, and in this way the acid can be readily distinguished from β -phenylglutaconic acid (m. p. 154 — 155°), the barium salt of which is insoluble in water.

Normal β -Phenyl- α -methylglutaconic Acid,
 $\text{CO}_2\text{H}\cdot\text{CMe}\cdot\text{CPh}\cdot\text{CH}\cdot\text{CO}_2\text{H}.$

This acid can be formed either by the action of aqueous alkali on the *trans*-labile acid (see later), or by the hydrolysis of the *cis*-tricarboxylic ester by means of alcoholic potassium hydroxide. In both cases a mixture of the normal acid and the *cis*-labile acid is precipitated when the product is acidified, and can be separated through the agency of the barium salts.

The separation is effected in the following manner. The mixed acids are converted into a neutral solution of the ammonium salts, and the solution is boiled with an aqueous solution containing a slight excess of barium chloride. The mixed barium salts, after being washed with boiling water, are repeatedly extracted with cold water. The *barium* salt of the normal acid is soluble in cold water, but is precipitated in the crystalline condition when the solution is boiled; it again dissolves when the liquid is cooled:

0.6247 gave 0.4090 BaSO_4 . $\text{Ba} = 38.49$.

$\text{C}_{12}\text{H}_{10}\text{O}_4\text{Ba}$ requires $\text{Ba} = 38.59$ per cent.

The acid is precipitated when the solution of the barium salt is acidified with excess of hydrochloric acid; it can be recrystallised

either from hot water or benzene, and forms small, colourless needles, which melt at 120° , and evolve water vapour at 130° :

0.2163 gave 0.5182 CO_2 and 0.1062 H_2O . $\text{C}=65.34$; $\text{H}=5.46$.

0.1685 „ 0.4044 CO_2 „ 0.0816 H_2O . $\text{C}=65.45$; $\text{H}=5.38$.

$\text{C}_{12}\text{H}_{12}\text{O}_4$ requires $\text{C}=65.5$; $\text{H}=5.5$ per cent.

The acid is at once attacked by acetyl chloride, yielding the hydroxy-anhydride.

A curious *barium hydrogen* salt is precipitated if the solution of the barium salt described above is acidified with dilute hydrochloric acid. It crystallises from hot water in feathery needles:

0.3073 gave 0.0893 BaSO_4 . $\text{Ba}=17.09$.

$(\text{C}_{12}\text{H}_{11}\text{O}_4)_2\text{Ba}, 12\text{H}_2\text{O}$ requires $\text{Ba}=17.1$ per cent.

The salt is stable at 100° , and, as heating at a higher temperature leads to decomposition, the presence of the water of crystallisation could not be proved. The aqueous solution of the salt is acid to litmus, and when treated with concentrated hydrochloric acid, the acid melting at 120° is precipitated.

cis-Labile β -Phenyl- α -methylglutaconic Acid,
 $\text{CO}_2\text{H} \cdot \text{CMe} : \text{CPh} \cdot \text{CH}_2 \cdot \text{CO}_2\text{H}.$

The *barium* salt of this acid is insoluble in cold water, and therefore remains after the barium salt of the normal acid has been extracted. It was purified by conversion into the acid, which was again transformed into the barium salt, only, in this case, the salt was precipitated in the cold:

0.3572 gave 0.2341 BaSO_4 . $\text{Ba}=38.54$.

$\text{C}_{12}\text{H}_{10}\text{O}_4\text{Ba}$ requires $\text{Ba}=38.6$ per cent.

The acid, formed from the barium salt by means of concentrated hydrochloric acid, separates from benzene in small, colourless prisms, which melt at 108° , passing into the hydroxy-anhydride at a few degrees above this temperature:

0.1702 gave 0.4084 CO_2 and 0.0825 H_2O . $\text{C}=65.44$; $\text{H}=5.39$.

$\text{C}_{12}\text{H}_{12}\text{O}_4$ requires $\text{C}=65.5$; $\text{H}=5.5$ per cent.

The acid is quickly attacked by acetyl chloride even at the ordinary temperature.

The Hydroxy-anhydride (6-Hydroxy-4-phenyl-3-methyl-2-pyrone),

This substance is formed by the action of acetyl chloride on either the normal acid or the *cis-labile* acid at the temperature of the boiling reagent, and can be obtained as a white solid on

evaporating the excess of chloride in an exhausted desiccator over potassium hydroxide.

The compound crystallises from a mixture of benzene and light petroleum in small, colourless needles, which melt at 94° :

0.1834 gave 0.4791 CO_2 and 0.0847 H_2O . $\text{C}=71.24$; $\text{H}=5.13$.

$\text{C}_{12}\text{H}_{10}\text{O}_3$ requires $\text{C}=71.3$; $\text{H}=5.0$ per cent.

The anhydride is readily soluble in benzene, and gives a blue colour in alcoholic solution with ferric chloride. It is soluble in aqueous solutions of alkali carbonate, forming a yellow solution:

0.2176 required 5.4 c.c. NaOH -solution (1 c.c. = 0.0079 gram NaOH).

$\text{C}_{12}\text{H}_{10}\text{O}_3$ (monobasic) requires 5.45 c.c.

The conversion of the hydroxy-anhydride into the acid melting at 120° is effected by boiling with water until complete solution is obtained. The pure acid separates on cooling. The conversion into a mixture of the acids melting at 120° and at 108° is effected by allowing a solution of the hydroxy-anhydride in concentrated alkali hydroxide to remain at the ordinary temperature until its yellow colour has been completely discharged. The mixed acids, precipitated on acidifying, can then be separated by means of their barium salts in the manner already described. The conversion into the acid melting at 108° can be brought about by the aid of casein and $N/10$ -sodium carbonate in the manner described for the hydroxy-anhydride of β -phenylglutaconic acid (Feist and Pomme, *Annalen*, 1909, **370**, 76), the acid being isolated through the silver salt, which was decomposed by hydrogen sulphide. The acid melting at 108° was the sole product.

The semianilide, $\text{NHPh}\cdot\text{CO}\cdot\text{CH}_2\cdot\text{CPh}\cdot\text{CMe}\cdot\text{CO}_2\text{H}$, from a benzene solution of the hydroxy-anhydride and aniline, crystallises from benzene in small, colourless prisms, which melt at 143° :

0.1923 gave 0.5155 CO_2 and 0.1016 H_2O . $\text{C}=73.10$; $\text{H}=5.87$.

$\text{C}_{18}\text{H}_{17}\text{O}_3\text{N}$ requires $\text{C}=73.2$; $\text{H}=5.8$ per cent.

The semianilide is soluble in alkali carbonates, and is transformed into the hydroxyanil at 160° .

The Hydroxyanil (3-Hydroxy-2:5-diphenyl-6-methyl-1:2-dihydro-pyridone), $\text{CPh}\begin{matrix} \text{CMe} & \text{CO} \\ \diagdown & \diagup \\ & \text{CH:C(OH)} \end{matrix} \text{NPh}$.

This compound can be prepared either by heating the above semianilide or from either one of the three isomeric acids, by heating it with a molecular amount of aniline at 170° for fifteen minutes. It can be isolated by rubbing the product with dry ether, and can be obtained in small, pale yellow needles, melting at 216° , by recrystallisation from alcohol:

0.1486 gave 0.4246 CO_2 and 0.0752 H_2O . $\text{C} = 77.93$; $\text{H} = 5.62$.

$\text{C}_{18}\text{H}_{15}\text{O}_2\text{N}$ requires $\text{C} = 78.0$; $\text{H} = 5.4$ per cent.

The compound dissolves in aqueous solutions of alkali carbonates, and is precipitated unchanged when the solution is acidified:

0.2872 required 5.2 c.c. NaOH -solution (1 c.c. = 0.0079 gram NaOH).

$\text{C}_{18}\text{H}_{15}\text{O}_2\text{N}$ (monobasic) requires 5.25 c.c.

The Decomposition of the β -Phenyl- α -methylglutaconic Acids.

(a) *isoButenylbenzene*, $\text{C}_6\text{H}_5\cdot\text{CMe}\cdot\text{CHMe}$.—This hydrocarbon is formed from either one of the three isomerides when it is boiled with dilute hydrochloric or sulphuric acids until carbon dioxide ceases to be evolved, and can be isolated by distillation in a current of steam. It is mobile liquid, having an odour resembling that of petroleum, and boils at $169^\circ/750$ mm.:

0.2013 gave 0.6702 CO_2 and 0.1668 H_2O . $\text{C} = 90.81$; $\text{H} = 9.21$.

$\text{C}_{10}\text{H}_{12}$ requires $\text{C} = 90.9$; $\text{H} = 9.1$ per cent.

Only a trace of a liquid of higher boiling point is formed in this reaction, which was too small for investigation. It is evident therefore that the hydrocarbon corresponding with diphenylcyclohexane is not formed under these conditions.

isoButenylbenzene readily forms a dibromide with bromine in chloroform solution, but the compound eliminates hydrogen bromide on distillation, and no definite boiling point could be obtained:

2.56 grams decolorised 3.11 grams of bromine.

$\text{C}_{10}\text{H}_{12} + \text{Br}_2$ requires 3.10 grams.

Experiments were made in which the action of the mineral acid was stopped before the conversion into the hydrocarbon was complete. In the case of the acids melting at 155° and at 108° , the unchanged acid was found to be the normal form, melting at 120° . The residue in the case of the normal acid was found to be unaltered acid. It follows therefore that the *trans*-labile acid and the *cis*-labile acid are converted into the normal acid prior to yielding the hydrocarbon.

(b) The disodium salt of the *cis*-labile acid, produced either by the action of alkali on the normal and *trans*-labile modifications or from the *cis*-labile acid itself, is unaltered when heated in a sealed tube with excess of alkali for ten hours at 170° . Attempts to prepare dimethylcinnamic acid from the sodium hydrogen salt have not as yet been successful.

THE SORBY RESEARCH LABORATORY,
THE UNIVERSITY, SHEFFIELD.