CXXXIII.—*Studies in Dicyclic Systems. Part I. The Chemistry of 2-Substituted* cis- *and* trans-*Hexahydrohydrindenes.*

By ARUPPILLAI KANDIAH.

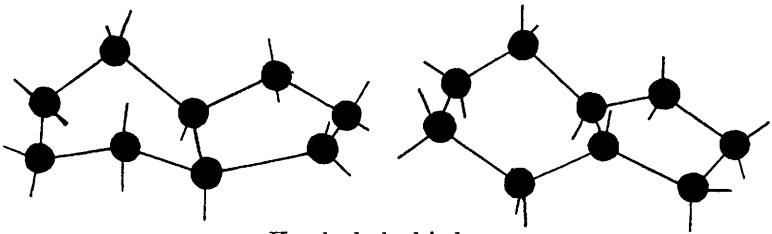
IN a series of papers of outstanding importance Ruzicka and his collaborators (*Helv. Chim. Acta*, 1926, **9**, 230, 249, 339, 499; 1928, **11**, 496, 670, 1174) conclusively demonstrated that large carbon rings are not only capable of existence but are as stable as the five- and six-membered rings. This discovery at once disposed of the theory of the uniplanar and consequently highly strained configurations of large rings, and is in harmony with Sachse's conception of strainless homocyclic systems (*Ber.*, 1890, **23**, 1363).

That the *cyclo*heptane ring departs considerably from the uniplanar form to relieve its strain was the conclusion reached by Baker and Ingold (J., 1923, **123**, 122) as a result of the examination of the products of hydrolysis of ethyl $\alpha\alpha'$-dibromo*cyclo*heptane-1 : 1-diacetate. For *cyclo*hexane, all the available evidence seems to indicate a normal planar structure which is probably a kind of equilibrium position between the strainless " cis " and " trans " forms (Aschan, " Lehrbuch der Alicyclischen Verbindungen," 1905, 327; Baker and Ingold, *loc. cit.*; Ingold and Thorpe, J., 1928, 1318).

The recent discovery of a comparatively large number of " cis " and " trans " fusions of saturated carbon rings (Windaus, Hückel, and Reverey, *Ber.*, 1923, **56**, 95; Hückel and Friedrich, *Annalen*, 1927, **451**, 132; Hückel, *Annalen*, 1927, **451**, 109; Gurney, Perkin, and Plant, J., 1927, 2676; etc.), taken in conjunction with the number and character of the stereoisomerides isolated, is satisfactorily accounted for either on the assumption that the two uniplanar strained component rings are inclined to each other (Haworth, *Ann. Reports*, 1927, **24**, 98) or on the basis of Mohr's ex-

tension to dicyclic systems (*J. pr. Chem.*, 1918, **98**, 315; 1922, **103**, 316) of Sachse's conception of strainless rings. *trans*-Decalin was the first substance to be studied with the view of determining which of these two hypotheses is the correct one. The researches of Rao (J., 1930, 1162) on the above compound, carried out in these laboratories, established beyond doubt that the system is practically strainless and thus lent considerable support to Mohr's theory.

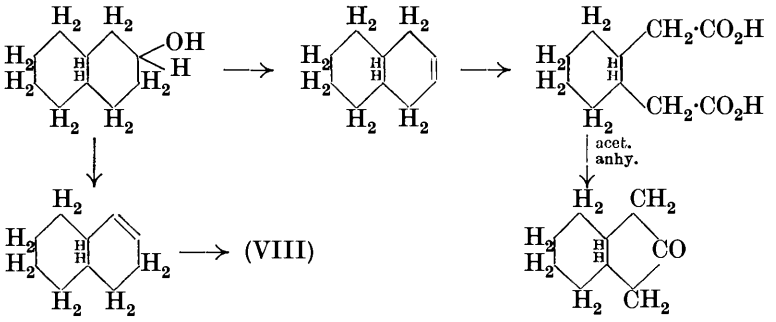
The purpose of the present investigation is to determine the condition of strain in *cis*- and *trans*-hexahydrohydrindenes, which are formed by the " cis " and " trans " fusions respectively of the *cyclo*hexane and *cyclo*pentane rings. This paper deals only with the chemistry of their derivatives, but in the following paper the matter is discussed from the standpoint of the Thorpe–Ingold valency deflexion hypothesis. Assuming for the moment that it is the strainless *cyclo*hexane ring that takes part in the dicyclic ring formation, consideration of the models indicates that *trans*-hexahydrohydrindene should exhibit an appreciable strain owing to the distortion of one of the carbon atoms of the *cyclo*pentane ring from the plane of the other four, but the *cis*-isomeride should be strainless.



Hexahydrohydrindenes

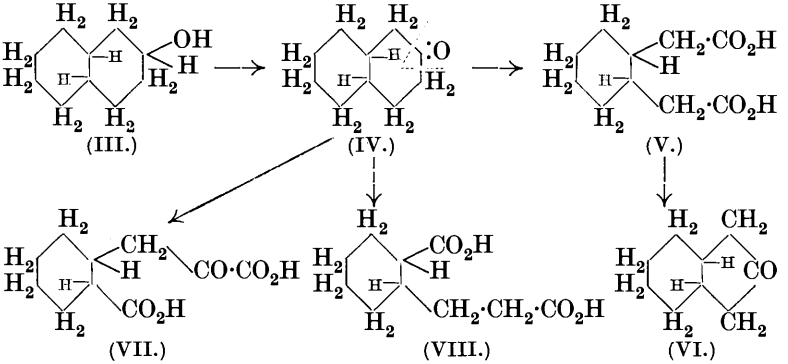
(I.) *cis*- (II.) *trans*-

Hückel and Friedrich (*Annalen*, 1927, **451**, 132), who were the first to study the new type of isomerism in this series, obtained pure *cis*- and *trans*-hexahydro-2-hydrindone from *cis*- and *trans*-β-decalol of m. p. 105° and 75° respectively by the following series of reactions :



Their method is unsatisfactory when considerable quantities of the pure ketones are required, because *cyclo*hexane-1 : 2-diacetic acid constitutes only 25% of the oxidation product; the remaining 75% consists of 1-carboxy*cyclo*hexane-2-propionic acid (VIII) and an oily acid whose identity has not been established. Moreover, the initial material is expensive and the authors give no details of the method of separation of the acids.

Many oxidising agents have now been tried. The best results were obtained by the oxidation of β-decalone (IV) with hot concentrated nitric acid under the conditions specified in the experimental portion. *trans-cyclo*Hexane-1 : 2-diacetic acid (V) was thus obtained in excellent yield and in a high state of purity, crystallising from the oxidation mixture as a lustrous solid, m. p. 167°.



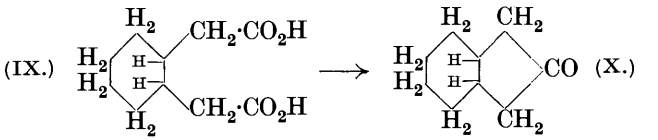
The by-products of the oxidation consisted of very small quantities of the acid (VIII) and an oily acid, probably (VII), which slowly solidified and the identity of which is still under investigation.

The process was less satisfactory, however, for the preparation of *cis-cyclo*hexane-1 : 2-diacetic acid (IX), which separated only to the extent of 30% owing, no doubt, to its greater solubility in the acid medium. This was particularly unfortunate, since it was only once possible to obtain pure *cis*-decalol from the Deutsche Hydrierwerke.

Further small quantities of the diacetic acids were obtained by alternately concentrating the mother-liquors slightly and keeping them at room temperature for a few weeks.

Both *cis-* and *trans-cyclo*hexane-1 : 2-diacetic acid are almost quantitatively converted into *cis-* and *trans*-hexahydro-2-hydrindone, (X) and (VI), respectively, on dry distillation with barium hydroxide. This method is superior to that of Hückel and Friedrich (*loc. cit.*) : it is more rapid and gives uniformly better yields of the ketones, even in small-scale preparations. The ease with which

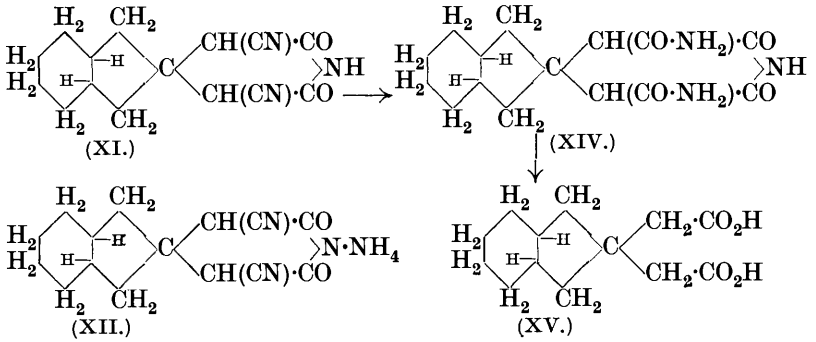
trans-hexahydro-2-hydrindone, a dicyclic system with *trans-ortho*-interlocking, is formed is remarkable.



The configurations of *cis*- and *trans*-hexahydro-2-hydrindone have been demonstrated by Hückel and Friedrich (*loc. cit.*), first by oxidation with sodium hypobromite, *cis*- and *trans*-1-carboxy*cyclo*hexane-2-acetic acid being produced, and secondly by reduction to the corresponding alcohol, the *trans*-compound yielding one (probably racemic) form, and the *cis*-isomeride two (*meso*) forms.

cis- and *trans*-Hexahydro-2-hydrindone display a remarkable difference in their tendency to condense with ethyl cyanoacetate and ethyl-alcoholic ammonia under the Guareschi conditions as modified by Kon and Thorpe (J., 1919, **115**, 686); for whereas the *trans*-compound gives a yield of about 60% of the *dicyano-imide* (XI), which separates as the crystalline ammonium salt (XII), the *cis*-compound gives scarcely 5% of the theoretical yield under the best experimental conditions. Possibly the strainless *cis*-hexahydrohydrindene ring in some way inhibits the formation of the pyridone ring.

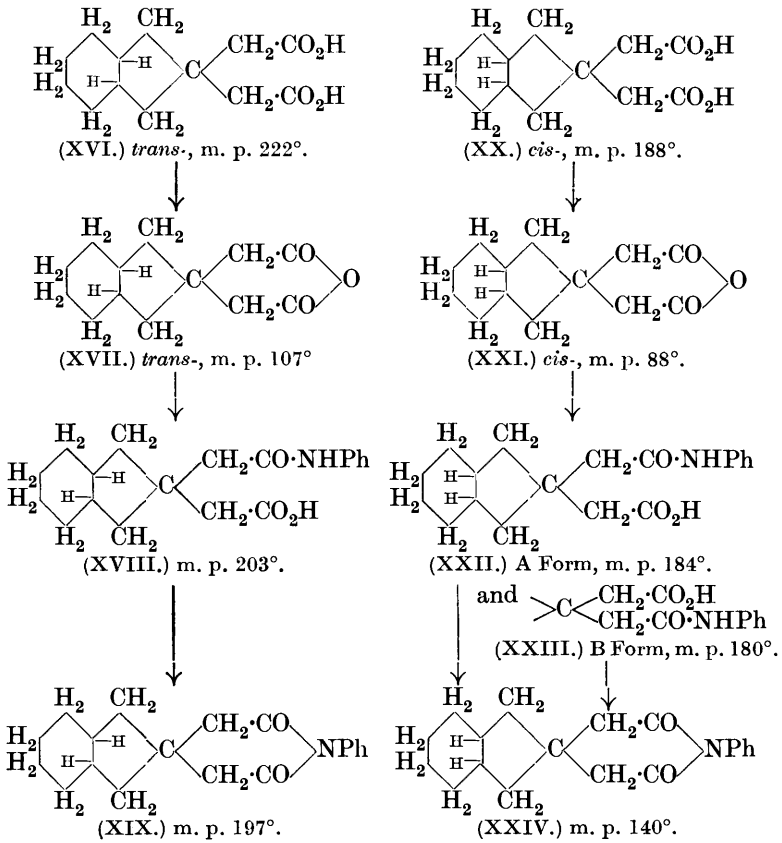
The dicarbamyl-imides, which are formed by the action of cold concentrated sulphuric acid on the dicyano-imides, char when heated with 60% sulphuric acid, but give almost colourless cis- and trans-



hexahydrohydrindene-2 : 2-*diacetic acid* (XX and XV) when the hydrolysis is effected by prolonged boiling under reflux with a large excess of 50% (volume) sulphuric acid. The two diacetic acids (XX and XV), though displaying similarity in solubility in various solvents, are distinct individuals, as is shown by the differences in melting point and chemical properties described below. There is,

therefore, no change of nuclear configuration during the hydrolysis of the dicyano-imides.

The *anhydride* (XVII) of *trans*-hexahydrohydrindene-2 : 2-diacetic acid gives only one *anilic acid* (XVIII), which on dehydration gives the *anil* (XIX).



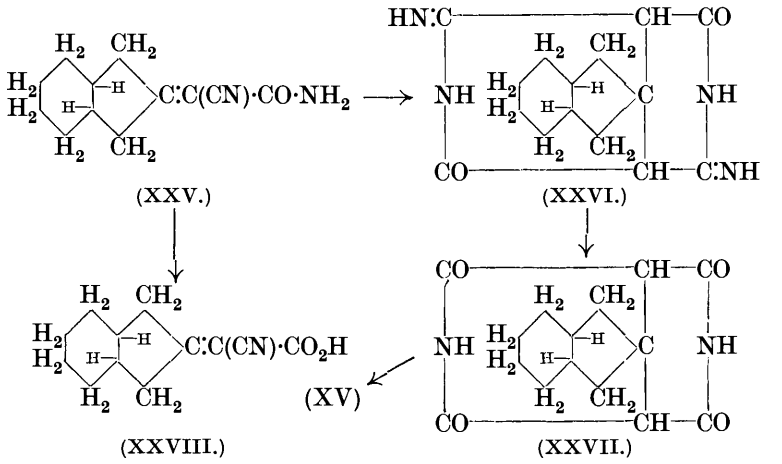
The anhydride (XXI) of *cis*-hexahydrohydrindene-2 : 2-diacetic acid, on the other hand, gives two *anilic acids* : one, to which formula (XXII) is ascribed, crystallises from benzene solution after two weeks; the other (XXIII) is obtained by evaporating the benzene mother-liquor and extracting an ethereal solution of the residue with aqueous sodium bicarbonate. The fact that both anilic acids give the same *anil* (XXIV) is satisfactory evidence of their being stereoisomerides.

If the mother-liquor of the ammonium salt of the *trans*-dicyano-imide (p. 925) is again saturated with ammonia at 0° and kept at

room temperature, it deposits a considerable quantity of a solid (m. p. 240—260°, softening at 148°), which consists mainly of the ωω'-*di-iminodi-imide* of trans-*hexahydrohydrindene*-2 : 2-*dimalonic acid* (XXVI), and a small quantity of the unsaturated *cyano-amide* (XXV). The separation of these two substances depends on the greater solubility of the latter in ethyl alcohol. As (XXVI) can be converted into *trans*-hexahydrohydrindene-2 : 2-diacetic acid, the above treatment results in a greater yield of the diacetic acid. It might be employed with advantage in all Guareschi reactions.

The presence of the product (XXV) indicates that in reactions of this kind the initial condensation leads to the formation of the unsaturated compound, which then reacts with cyanoacetamide, forming the glutaric acid derivative. The same two compounds are also obtained when *trans*-hexahydro-2-hydrindone and cyanoacetamide are condensed in aqueous-alcoholic solution in the presence of piperidine (Kon and Thorpe, J., 1919, **115**, 686) : the first crop of crystals obtained after ten hours consists entirely of the compound (XXV), and the subsequent crops exclusively of the di-iminodi-imide (XXVI).

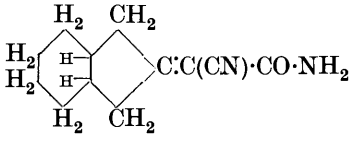
The constitution of the cyano-amide (XXV) was established by its oxidation to the parent ketone with permanganate and by its quantitative conversion into the unsaturated acid (XXVIII) on treatment with nitrous acid. The di-iminodi-imide (XXVI) is converted by hydrolysis first into the di-imide (XXVII) and then into *trans*-hexahydrohydrindene-2 : 2-diacetic acid (XV), its constitution thus being indicated.



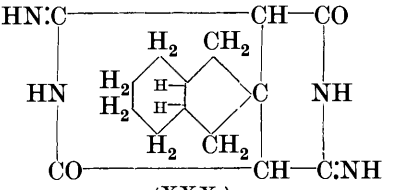
The di-iminodi-imide (XXVI) is also formed when an alcoholic

solution of cyanoacetamide, *trans*-hexahydrohydrindylidene-2-cyanoacetamide (XXV), and piperidine is kept at 40° for 2 hours.

cis-Hexahydro-2-hydrindone, on the other hand, gives only the unsaturated *cyano-amide* (XXIX) under these conditions, but the cis-*di-iminodi-imide* (XXX) is obtained by condensing this with another molecule of cyanoacetamide. The filtrate from the cyano-amide, on resaturation with ammonia, gives a mixture of the compound (XXIX) and cyanoacetamide and no trace of the di-imino-di-imide.

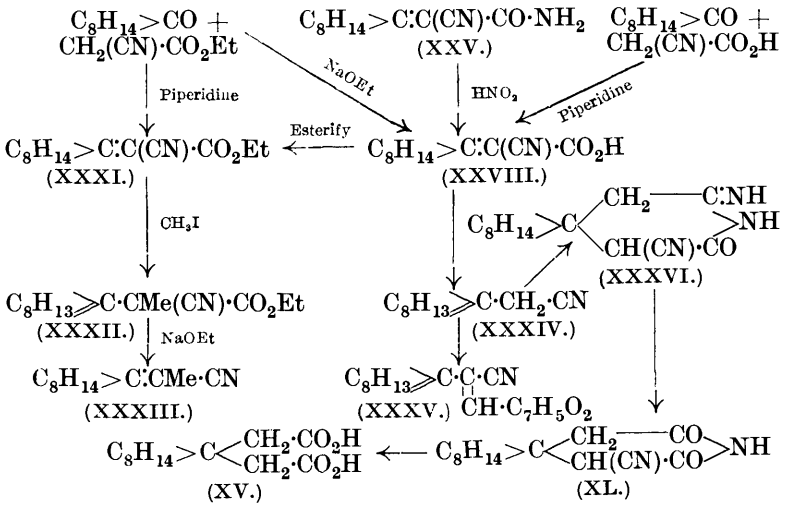


(XXIX.)



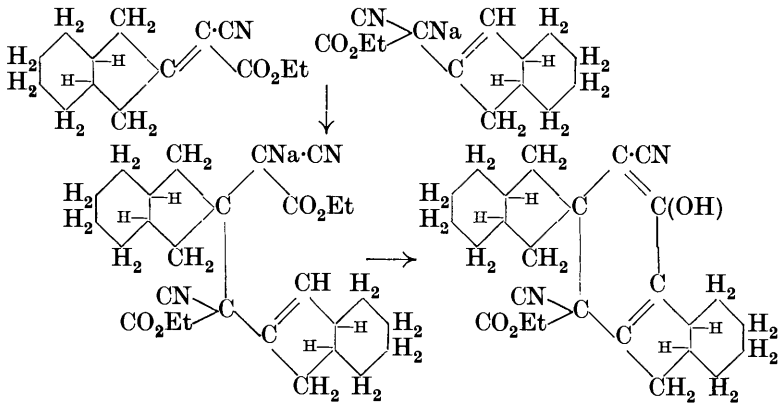
(XXX.)

trans-Hexahydro-2-hydrindone condenses readily with ethyl cyanoacetate in the presence of piperidine, giving *ethyl* trans-*hexahydrohydrindylidene*-2-*cyanoacetate* (XXXI). That the cyano-ester has the αβ-structure is shown both by its oxidation to *trans*-hexahydro-2-hydrindone with cold permanganate and by its inability to combine with bromine. It can, however, react both in the αβ- and in the βγ-form in the presence of alkaline catalysts (Birch, Kon, and Norris, J., 1923, **123**, 1369), for, on the one hand, it readily combines with potassium cyanide or with another molecule of ethyl cyanoacetate and, on the other, it is readily methylated, yielding *ethyl* α-*cyano*-α-trans-*hexahydroindenyl*-2-*propionate* (XXXII).



This methylated ester, which must have the βγ-structure from its mode of formation, loses ethyl carbonate on treatment with sodium ethoxide and gives α-*trans*-hexahydrohydrindylidene-2-propionitrile (XXXIII), which, because of the exaltation of its molecular refraction, and in the light of recent observations (Birch and Kon, J., 1923, **123**, 2442 ; Kandiah and Linstead, J., 1929, 2139), must be given the αβ-structure.

An attempt to prepare the cyano-acid (XXVIII) by the hydrolysis of the ester (XXXI) with sodium ethoxide resulted in the formation of a *compound*, m. p. 255°, which is sparingly soluble in benzene and ethyl alcohol—solvents in which the cyano-acid is readily soluble—and gives yellow solutions in alkalis. Its formation may be due to condensation of the cyano-ester (XXXI) with the sodio-derivative of the βγ-isomeride with the elimination of one molecule of alcohol (compare Birch and Kon, *loc. cit.*). The same compound, the nature of which is under investigation, occurs as a by-product in the condensation of the ketone and ethyl cyanoacetate in the presence of sodium ethoxide.



trans-*Hexahydrohydrindylidene*-2-*cyanoacetic acid* (XXVIII) is best prepared by the above method or by the action of nitrous acid on the corresponding cyano-amide (XXV) when this substance is available. The condensation of cyanoacetic acid with *trans*-hexahydro-2-hydrindone also gives the acid, pure but in rather poor yield. On distillation under reduced pressure, it is converted into trans-*hexahydroindenyl*-2-*acetonitrile* (XXXIV). Though this nitrile has undoubtedly the βγ-structure (Birch and Kon; Kandiah and Linstead, *locc. cit.*), as is shown by its physical properties and its condensation with piperonal, it can react under suitable conditions in the αβ-form, *e.g.*, with cyanoacetamide to form the imino-imide

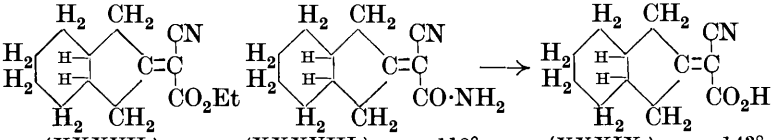
H H

(XXXVI), the constitution of which is established by its ultimate hydrolysis to *trans*-hexahydrohydrindene-2 : 2-diacetic acid (XV).

cis-Hexahydro-2-hydrindone gives a similar series of compounds, which are quite distinct from those of the *trans*-series. *Ethyl* cis-*hexahydrohydrindylidene*-2-*cyanoacetate* (XXXVII) is a liquid and is formed in much poorer yield than the *trans*-isomeride.

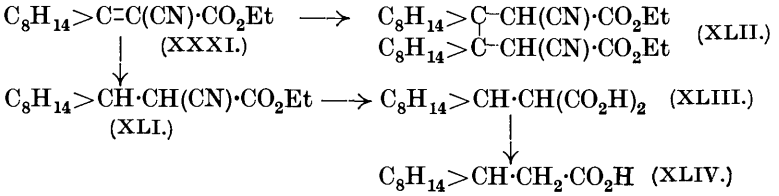
The product obtained by the condensation of the *cis*-ketone with either ethyl sodiocyanoacetate or cyanoacetic acid, with piperidine as the condensing agent, is a liquid from which a solid (m. p. 143°) crystallises in a vacuum after several days.

The same cyano-acid (XXXIX) is readily obtained in a pure state by the action of nitrous acid on the amide (XXXVIII).



(XXXVII.) (XXXVIII.) m. p. 118°. (XXXIX.) m. p. 143°.

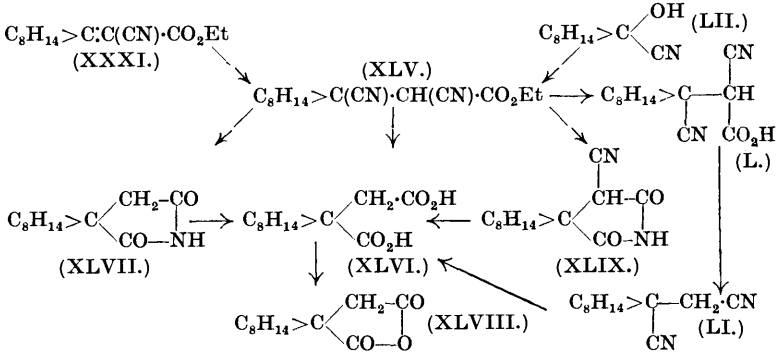
Ethyl *trans*-hexahydrohydrindylidene-2-cyanoacetate gives on reduction with moist aluminium amalgam in ether (Vogel, J., 1927, 594) *ethyl* r-trans-*hexahydrohydrindyl*-2-*cyanoacetate* (XLI) and a small quantity (18%) of the bimolecular compound (XLII). Attempts to establish the constitution of the latter by hydrolysis



to the corresponding adipic acid were unsuccessful. The constitution of the cyano-ester (XLI) was confirmed by its hydrolysis with aqueous-alcoholic potassium hydroxide to trans-*hexahydrohydrindyl*-2-*malonic acid* (XLIII). The latter, when heated above its melting point, was converted into trans-*hexahydrohydrindyl*-2-*acetic acid* (XLIV) with loss of carbon dioxide. The relative yields of the cyano-ester (82%) and the bimolecular compound (18%) closely correspond to those of the *cyclo*pentane analogues.

The unsaturated *trans*-cyano-ester (XXXI) condenses readily with potassium cyanide in aqueous-alcoholic solution, forming a crystalline potassio-salt which on prolonged boiling with concentrated hydrochloric acid is converted into a mixture of 2-*carboxy*-trans-*hexahydrohydrindene*-2-*acetic acid* (XLVI) and its *imide*

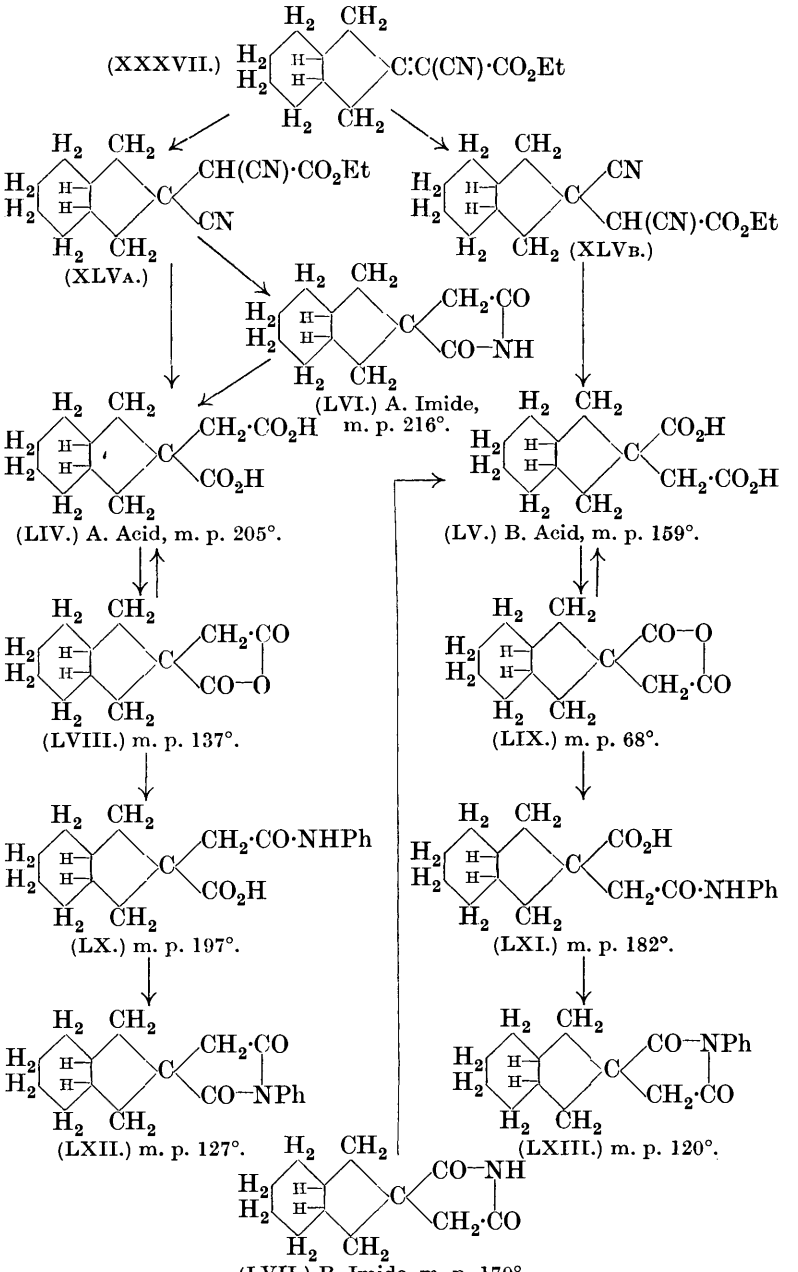
(XLVII). The latter is converted on hydrolysis with potassium hydroxide into the acid (XLVI).



It is impossible to isolate the *dicyano*-ester (XLV) formed in the reaction mentioned above, even by careful acidification of the potassio-addition compound with dilute hydrochloric acid, since it is converted into a mixture of the *dicyano*-acid (L) and the *imide* (XLIX). The latter on hydrolysis and decarboxylation is converted into the succinic acid derivative (XLVI). The dicyano-acid (L), when heated above its melting point, changes into the *dinitrile*, (LI), which sublimes in feathery needles. The dicyano-ester (XLV) is, however, obtained by the condensation of the *cyanohydrin* (LII) with ethyl sodiocyanoacetate (Higson and Thorpe, J., 1906, **89**, 1455). The *anhydride* (XLVIII) is formed when the acid (XLVI) is treated with acetyl chloride.

The unsaturated *cis*-cyano-ester (XXXVII) adds potassium cyanide, but to a much smaller extent than the *trans*-isomeride. The hydrolysis of the dicyano-esters (XLV A and B) with concentrated hydrochloric acid gives a mixture of acids and imides, which are separated by means of aqueous sodium bicarbonate.

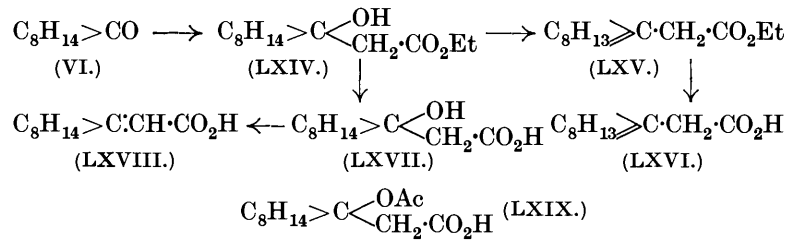
A partial separation of the two acids (LIV) and (LV) from the mixture (m. p. 140—160°) is effected by boiling with a limited quantity of acetone; a soluble fraction (m. p. 150—155°) and an insoluble one (m. p. 200—202°) are obtained. These are converted into their respective *anhydrides*, which are purified by fractional crystallisation and then decomposed with dilute alkali solution to the corresponding acids. Two isomeric 2-*carboxy*-cis-*hexahydrohydrindene*-2-*acetic acids*, m. p. 205° and 159° respectively, (LIV and LV), are thus obtained from the two isomeric anhydrides (LVIII and LIX), m. p. 137° and 68°. The two anhydrides give different *anilic acids* (LX) and (LXI), and these on dehydration give a pair of *anils* (LXII) and (LXIII).


(XXXVII.)
(XLVA.)
(XLVB.)
(LVI.) A. Imide, m. p. 216°.
(LIV.) A. Acid, m. p. 205°.
(LV.) B. Acid, m. p. 159°.
(LVIII.) m. p. 137°.
(LIX.) m. p. 68°.
(LX.) m. p. 197°.
(LXI.) m. p. 182°.
(LXII.) m. p. 127°.
(LXIII.) m. p. 120°.
(LVII.) B. Imide, m. p. 170°.

The stereoisomeric *imides* (LVI and LVII), which constituted the neutral fraction of the above hydrolysis, were separated by fractional crystallisation from acetone and converted into the corresponding succinic acids by hydrolysis with aqueous potassium hydroxide.

Corresponding members of the two series of compounds differ widely in melting point and considerably in solubility (the lower-melting members are much more soluble than the higher-melting ones).

trans-Hexahydro-2-hydrindone reacts with ethyl bromoacetate in presence of zinc to form the *hydroxy*-ester (LXIV), which on dehydration with phosphorus oxychloride is converted into *ethyl* trans-*hexahydroindenyl*-2-*acetate* (LXV): this on hydrolysis gives the corresponding $\beta\gamma$-unsaturated *acid* (LXVI).

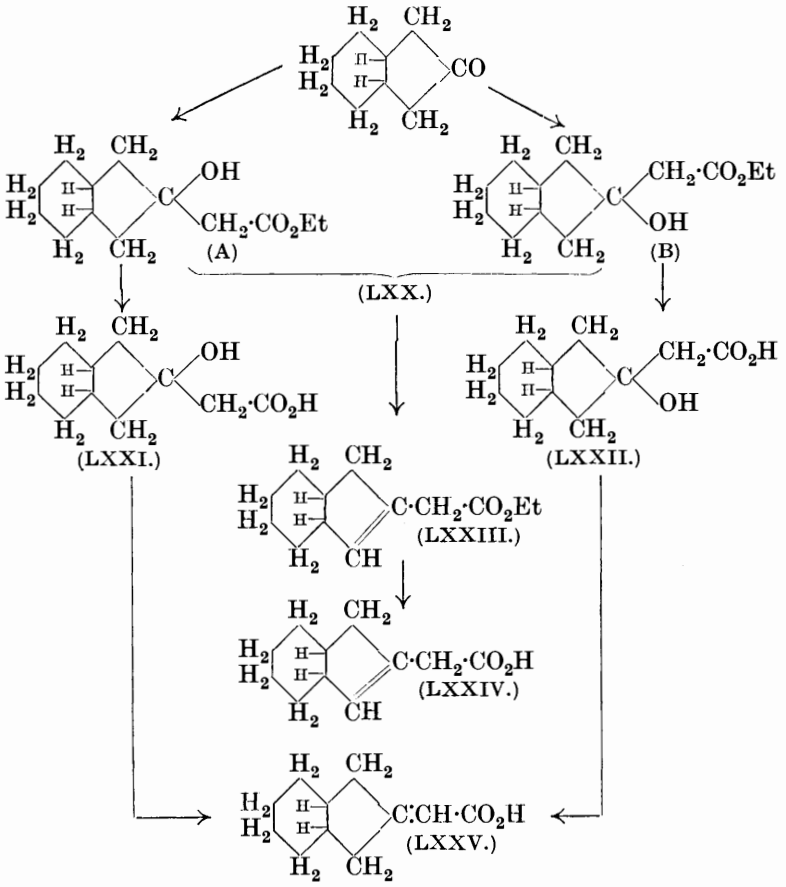


The dehydration of the hydroxy-ester with thionyl chloride by Darzens' method (*Compt. rend.*, 1911, **152**, 1601) gives a mixture of $\alpha\beta$- and $\beta\gamma$-esters in which there is a considerable proportion of the former, as shown by the ratio of $\alpha\beta$- to $\beta\gamma$-acid formed on hydrolysis. The *hydroxy-acid* (LXVII), when boiled under reflux with acetic anhydride for six hours, gives trans-*hexahydrohydrindylidene*-2-*acetic acid* (LXVIII). Gentle boiling with acetic anhydride produces the *acetyl* derivative (LXIX)—a result which suggests that acetylation precedes dehydration in this reaction. This substance on further boiling with acetic anhydride is converted into the acid (LXVIII).

cis-Hexahydro-2-hydrindone reacts similarly but less vigorously with ethyl bromoacetate.

In these condensations by the Reformatsky reaction the best yields of the hydroxy-ester are obtained when the reaction is allowed to proceed as vigorously as is consistent with safety, and the reaction mixture then heated on the steam-bath for 20 minutes. The unchanged ketone is easily recovered and may be again used for condensation with ethyl bromoacetate. The process, repeated twice, gives an excellent yield of the hydroxy-ester, even in the case of the *cis*-ketone. If, however, the reaction is checked by premature

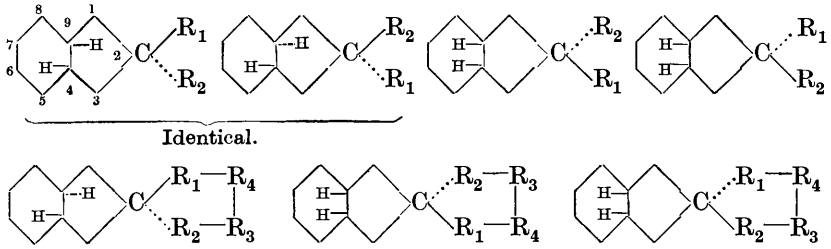
cooling during the early stages, and the mixture subsequently submitted to prolonged heating, the ketone undergoes self-condensation and a mixture of αβ- and βγ-hexahydrohydrindylidenehexahydro-2-hydrindones is formed in considerable quantity. This fraction of the distillate boils 20° higher than the hydroxy-ester under reduced pressure and is therefore easily separated therefrom.



Ethyl 2-*hydroxy*-cis-*hexahydrohydrindene*-2-*acetate*, which is probably a mixture of two stereoisomerides, gives on hydrolysis a solid, m. p. 70—75°, which is separated by repeated crystallisation from petrol into two isomerides, m. p. 84° and 130°. The αβ- and the βγ-unsaturated acid were obtained in the usual way.

With regard to the possibility of stereoisomerism in this series the following diagrams indicate that the asymmetric carbon atoms

4 and 9 in the *trans*-ketone possess equivalent rotation and consequently no new centre of asymmetry is created (Hückel and Friedrich, *loc. cit.*) by the replacement of the carbonyl oxygen by two dissimilar groups R_1 and R_2. Such a replacement should therefore give one racemic compound. On the other hand, in the *cis*-series, the presence of two unlike groups R_1 and R_2 would give rise to two *meso*-forms. The isolation of single individuals in the case of the succinic acid, anilic acid, and hydroxy-acid in the *trans*-series and of two isomerides of the corresponding *cis*-compounds is ample confirmation of Mohr's theory as regards isomerism. Further, Ingold (*Ann. Reports*, 1924, **21**, 92) has pointed out that Mohr's postulate allows no interconversion of the *cis*- and *trans*-forms unless brought about by the unlikely occurrence of temporary rupture of one of the bonds. In accordance with this, no conversion, under any of the experimental conditions employed, of a *trans*-compound into the *cis*- has been observed. Another remarkable feature (compare Rao, *loc. cit.*) is the persistence of isomerism even when the two dissimilar groups R_1 and R_2 form part of the ring, as exemplified in the formation of two anhydrides (LVIII and LIX) and two imides (LVI and LVII).



The resolution of 2-carboxy-*trans*-hexahydrohydrindene-2-acetic acid which is now in progress will form the subject of a future communication.

EXPERIMENTAL.

trans-*Series*.

trans-cyclo*Hexane*-1 : 2-*diacetic Acid* (V).—*trans*-β-Decalol (m. p. 75°) was converted into *trans*-β-decalone (b. p. 120°/18 mm.) by oxidation with chromic acid (Hückel, *Annalen*, 1925, **441**, 1; Rao, J., 1929, 1961). For the isolation of the ketone it was found advantageous to dilute the mixture with water (5 vols.), remove the precipitated decalone, and extract the aqueous solution twice with ether.

Concentrated nitric acid (1 l.), contained in a round-bottomed flask fitted with a reflux condenser and a dropping-funnel, was

heated to its boiling point. The heating was then stopped, and *trans*-β-decalone (500 g.) added dropwise at such a rate that the reaction proceeded sufficiently vigorously to ensure instantaneous oxidation of the ketone as it dropped into the reaction mixture. (If this procedure is not adopted, *trans-cyclo*hexane-1 : 2-diacetic acid resulting from the oxidation forms a solid scum which hinders further oxidation, and when the mixture is heated the accumulated ketone reacts with explosive violence.) The mixture was heated for 45 minutes after the *trans*-β-decalone had been added, and on the next day the crystalline deposit was removed and washed with a little ice-cold water. The filtrate continued to deposit crystals for a few weeks, and again after being concentrated to half its bulk and kept for several days. The later crops were contaminated with 1-carboxy-*trans-cyclo*hexane-2-propionic acid. Total yield, 420 g. The *trans-cyclo*hexane-1 : 2-diacetic acid crystallised from alcohol in plates, m. p. 167° (compare Hückel and Friedrich, *loc. cit.*).

Preparation of trans-*Hexahydro-2-hydrindone* (VI) *from* trans-cyclo*Hexane-1 : 2-diacetic Acid.*—When an intimate mixture of *trans-cyclo*hexane-1 : 2-diacetic acid (100 g.) and finely powdered, crystallised barium hydroxide (7 g.) was slowly heated, water distilled just above the melting point of the acid and a colourless mobile liquid at 260—270°. The aqueous layer in the distillate was twice extracted with ether and the extracts together with the ketone were washed with aqueous potassium carbonate, dried, and distilled. *trans*-Hexahydro-2-hydrindone boiled at 90°/11 mm. and had $n_D^{16°}$ 1·47692, $d_4^{16°}$ 0·9815; it readily gave a semicarbazone, which crystallised from alcohol in silvery plates, m. p. 243° (compare Hückel and Friedrich, *loc. cit.*).

Condensation of trans-*Hexahydro-2-hydrindone with Ethyl Cyanoacetate : Ethyl* trans-*Hexahydrohydrindylidene-2-cyanoacetate* (XXXI). —A mixture of *trans*-hexahydro-2-hydrindone (100 g.), ethyl cyanoacetate (82 g.), and piperidine (2 c.c.) was kept at room temperature for 48 hours, heated on the steam-bath for 3 hours, and poured into water. The oil produced was dissolved in ether, washed with dilute hydrochloric acid and with water, dried, and recovered. On distillation under diminished pressure, the unchanged ketone and ethyl cyanoacetate passed over first, and then the unsaturated cyano-ester (130 g.) at 190°/10 mm. The latter distillate solidified completely.

Ethyl trans-*hexahydrohydrindylidene-2-cyanoacetate* is extremely soluble in all solvents; it crystallises very slowly from light petroleum (b. p. 40—60°) in hard plates, m. p. 55° (Found : C, 71·8; H, 8·3. $C_{14}H_{19}O_2N$ requires C, 72·1; H, 8·2%). It is readily oxidised with cold 1% potassium permanganate solution to the

parent ketone, which is identified by its characteristic odour and by means of its semicarbazone.

Reduction with moist aluminium amalgam. Preparation of ethyl r-trans-*hexahydrohydrindyl-2-cyanoacetate* (XLI). The unsaturated cyano-ester (20 g.) was reduced with aluminium amalgam (40 g.) in moist ether (Vogel, *loc. cit.*). There was no induction period. The reaction, initially vigorous, slackened after 2 hours; a small quantity of water was then added to quicken it. The product was worked up in the usual manner after 20 hours and distilled: *ethyl* r-trans-*hexahydrohydrindyl-2-cyanoacetate* (XLI) (15 g.) passed over at 180—183°/18 mm. The residue (3 g.), which solidified to a transparent glassy mass, crystallised from aqueous alcohol in nodules, m. p. 104—106°. The unimolecular reduction product, on redistillation, boiled at 178°/15 mm. and had $n_D^{18\cdot0°}$ 1·4700, $d_4^{18\cdot0°}$ 1·021, whence $[R_L]_D$ 64·4 (calc., 63·91) (Found: C, 71·6; H, 9·2. $C_{14}H_{21}O_2N$ requires C, 71·5; H, 9·0%).

The *anilide* was prepared by heating a mixture of the ester and aniline at 180—185° for 6 hours. The cooled product, treated with dilute hydrochloric acid, yielded an oil which, after being triturated with concentrated hydrochloric acid, solidified and then crystallised from ethyl alcohol in bundles of needles, m. p. 150° (Found: C, 76·6; H, 7·9. $C_{18}H_{22}ON_2$ requires C, 76·6; H, 7·8%).

Hydrolysis of the Ester (XLI). *Preparation of* trans-*Hexahydrohydrindyl-2-malonic Acid* (XLIII).—A solution of the ester (15 g.) in rectified spirit (24 c.c.) was mixed with a solution of potassium hydroxide (30 g.) in water (60 c.c.) and refluxed until the evolution of ammonia practically ceased (30 hours). After removal of alcohol by evaporation, the residue was diluted with water, extracted once with ether to remove any unchanged ester, and acidified with dilute sulphuric acid. trans-*Hexahydrohydrindyl-2-malonic acid*, which then crystallised (12 g.), separated from anhydrous formic acid in long needles (plates when crystallisation is slow), m. p. 181—182° (decomp.) (Found: C, 63·6; H, 8·1; equiv., by titration, 113. $C_{12}H_{18}O_4$ requires C, 63·7; H, 8·0%; equiv., 113).

The *methyl* ester, prepared by the action of methyl-alcoholic hydrogen chloride on the acid, boiled at 138°/13 mm., and had $n_D^{19°}$ 1·4721, $d_4^{19·2°}$ 1·067, whence $[R_L]_D$ 66·71 (calc., 66·73) (Found: C, 65·9; H, 8·75. $C_{14}H_{22}O_4$ requires C, 66·1; H, 8·6%).

The *dianilide* is sparingly soluble in benzene and chloroform. It crystallised from a large volume of alcohol in silky needles, m. p. 296° (Found: C, 76·7; H, 7·6. $C_{24}H_{28}O_2N_2$ requires C, 76·6; H, 7·4%).

trans-*Hexahydrohydrindyl-2-acetic Acid* (XLIV).—The acid (XLIII) was kept at 190—195° for 2 hours. The hard cake obtained

on cooling was powdered and boiled with light petroleum (b. p. 60—80°). trans-*Hexahydrohydrindyl-2-acetic acid* crystallised from the filtered solution in lustrous plates, m. p. 120° (Found : C, 72·4; H, 9·9; equiv., by titration, 181·5. $C_{11}H_{18}O_2$ requires C, 72·5; H, 9·9%; equiv., 182).

The *ethyl* ester boiled at 138°/18 mm. and had $n_D^{19\cdot4°}$ 1·4643, $d_4^{19\cdot4°}$ 0·9627, whence $[R_L]_D$ 59·5 (calc., 60·0) (Found : C, 74·3; H, 10·4. $C_{13}H_{22}O_2$ requires C, 74·3; H, 10·5%).

The *anilide*, which could not be prepared from the ester but was readily formed when a mixture of the acid and aniline was heated at 160°, crystallised from alcohol in needles, m. p. 135° (Found : C, 79·6; H, 8·7. $C_{17}H_{23}ON$ requires C, 79·4; H, 8·9%).

Methylation of Ethyl trans-*Hexahydrohydrindylidene-2-cyanoacetate*.—Methyl iodide (18 c.c.) was added slowly to the red solution formed by the addition of the unsaturated cyano-ester (40 g.) to a solution of sodium (4 g.) in absolute ethyl alcohol (60 c.c.). When the vigour of the reaction had abated, the mixture was gently refluxed on the water-bath for 30 minutes and poured into water. The precipitated oil was extracted with ether, washed, dried, and distilled, *ethyl* α-*cyano*-α-trans-*hexahydroindenyl-2-propionate* (XXXII) passing over at 175°/16 mm. This reacted rapidly with bromine in chloroform solution (Found : C, 72·7; H, 8·6. $C_{15}H_{21}O_2N$ requires C, 72·9; H, 8·5%).

α-trans-*Hexahydrohydrindylidene-2-propionitrile* (XXXIII).—The above methylated ester was added to a solution of sodium in absolute methyl alcohol (30 c.c.), and the mixture kept at 35° for 4 hours. The oil precipitated on addition of water was extracted with ether, washed, dried, and distilled after the removal of the solvent. On redistillation, α-trans-*hexahydrohydrindylidene-2-propionitrile*, b. p. 153°/15 mm., was obtained as a colourless mobile liquid, which gradually solidified; it then crystallised from light petroleum (b. p. 40—60°) in long needles, m. p. 60° (Found : C, 82·0; H, 9·6. $C_{12}H_{17}N$ requires C, 82·3; H, 9·7%). Oxidised with potassium permanganate, it gave *trans*-hexahydro-2-hydrindone, identified by means of its semicarbazone.

trans-*Hexahydrohydrindylidene-2-cyanoacetic Acid* (XXVIII).—(1) *trans*-Hexahydro-2-hydrindone (20 c.c.) was mixed with ethyl sodiocyanoacetate (obtained from ethyl cyanoacetate, 17 c.c.; sodium, 2·5 g.; and absolute alcohol, 70 c.c.) and heated on the steam-bath for 2 hours. The mixture was diluted with water and extracted twice with ether to remove any unchanged ketone. The oil precipitated on acidification of the solution was extracted with ether, washed, and dried, and the solvent removed. The residue solidified almost completely and melted at 158—162° after removal

of a slight trace of oily impurity by spreading on a porous tile. trans-*Hexahydrohydrindylidene*-2-*cyanoacetic acid* crystallised from benzene in short silky needles, m. p. 179° (decomp.) (Found : C, 70·1; H, 7·5; equiv., by titration, 205. $C_{12}H_{15}O_2N$ requires C, 70·2; H, 7·3%; equiv., 205). It was readily oxidised by potassium permanganate.

(2) *Condensation of* trans-*hexahydro*-2-*hydrindone with cyanoacetic acid.* A mixture of the hydrindone (13 g.), cyanoacetic acid (7 g.), and piperidine (2 c.c.) was kept at room temperature for 2 hours, heated on the steam-bath for 4 hours, diluted with water, acidified, and extracted with ether. The unsaturated cyano-acid (XXVIII), purified by extraction with sodium bicarbonate solution, melted at 174—176°.

(3) *From* trans-*hexahydrohydrindylidene*-2-*cyanoacetamide* (XXV). A 20% solution of sodium nitrite (20 c.c.) was added very gradually and with constant stirring to a solution of the unsaturated cyano-amide (3 g.) in concentrated sulphuric acid (15 c.c.). After 2 hours, the mixture was heated on the steam-bath for ½ hour, cooled, and diluted with water. The unsaturated cyano-acid, thus obtained in almost quantitative yield, gave the ester (XXXI) on esterification with ethyl-alcoholic hydrogen chloride.

trans-*Hexahydroindenyl*-2-*acetonitrile* (XXXIV).—On distillation under reduced pressure, the unsaturated cyano-acid (XXVIII) lost carbon dioxide and was converted quantitatively into the nitrile (XXXIV). The distillate was dissolved in ether, washed with sodium bicarbonate solution, and dried, and the solvent removed. trans-*Hexahydroindenyl*-2-*acetonitrile* distilled at 136°/14 mm. as a colourless mobile liquid, having the characteristic odour of unsaturated nitriles; $n_D^{19°}$ 1·4956, $d_4^{19°}$ 0·9690, whence $[R_L]_D$ 47·98 (calc., 47·95) (Found : C, 82·0; H, 9·4. $C_{11}H_{15}N$ requires C, 82·0; H, 9·3%).

Condensation with piperonal. Piperonal (1·3 g.) and the nitrile (1 c.c.) were mixed with a solution of sodium (1·2 g.) in alcohol and kept at room temperature for 24 hours. The solid formed crystallised from dilute alcohol in clusters of needles, m. p. 225° (Found : C, 77·5; H, 6·7. $C_{19}H_{19}O_2N$ requires C, 77·8; H, 6·5%).

Condensation with cyanoacetamide. The nitrile (1 c.c.), mixed with the sodio-compound prepared from cyanoacetamide (1·6 g.), sodium (6 g.), and alcohol (15 c.c.), was heated on the steam-bath for 2 hours, ammonia being evolved. The solid formed on dilution of the solution melted at 308° and dissolved in dilute mineral acids. When it was boiled with concentrated hydrochloric acid for a short time, it was converted into the *imide* of α-*cyano*-trans-*hexahydrohydrindene*-2 : 2-*diacetic acid* (XL), which crystallised from dilute

alcohol in long slender needles, m. p. 224° (Found : C, 68·0; H, 7·4. $C_{14}H_{18}O_2N_2$ requires C, 68·3; H, 7·3%). This on hydrolysis with 60% sulphuric acid gave *trans*-hexahydrohydrindene-2 : 2-diacetic acid.

Action of Alcoholic Sodium Ethoxide on the Ester (XXXI).—The ester was refluxed for 2 hours with a solution of sodium (2·8 g.) in ethyl alcohol (80 c.c.). After evaporation of the alcohol, the product was diluted with water, the unchanged ester extracted in ether, and the aqueous liquid acidified. The semi-solid obtained was extracted with a large volume of ether, washed, dried, and recovered. Sparingly soluble in most solvents, it crystallised from much alcohol in shining plates, m. p. 265°. The constitution of the *substance* has not yet been established (see p. 929) (Found : C, 74·3; H, 7·5. $C_{26}H_{32}O_3N_2$ requires C, 74·3; H, 7·6%).

Condensation of Ethyl trans-*Hexahydrohydrindylidene-2-cyanoacetate with Alcoholic Potassium Cyanide. Preparation of 2-Carboxy-*trans-*hexahydrohydrindene-2-acetic Acid* (XLVI).—When solutions of potassium cyanide (65 g.) in water (170 c.c.) and of ethyl *trans*-hexahydrohydrindylidene-2-cyanoacetate (130 g.) in rectified spirit (650 c.c.) were mixed, considerable heat was developed and crystals of the addition compound soon separated. After 48 hours, alcohol was distilled off under diminished pressure, and the residue boiled with concentrated hydrochloric acid for 24 hours. The mixture was then freely diluted with water and extracted with ether. The acid was freed from the imide by extraction with aqueous sodium bicarbonate. On acidification of the alkaline extract, *2-carboxy-*trans-*hexahydrohydrindene-2-acetic acid* separated. It crystallised in plates from aqueous acetone and in feathery needles from much boiling water; m. p. 202° (decomp.) (Found : C, 63·8; H, 8·0; equiv., by titration, 113. $C_{12}H_{18}O_4$ requires C, 63·7; H, 7·9%; equiv., 113).

The *methyl* ester boils at 172°/30 mm. and has $n_D^{18\cdot2°}$ 1·47526, $d_{4°}^{18\cdot2°}$ 1·083, whence $[R_L]_D$ 66·0 (calc., 66·16) (Found : C, 66·2; H, 9·2. $C_{14}H_{22}O_4$ requires C, 66·1; H, 8·6%). The *ethyl* ester has b. p. 176°/14 mm. and $n_D^{18\cdot2°}$ 1·46876, $d_{4°}^{18\cdot2°}$ 1·043, whence $[R_L]_D$ 75·2 (calc., 75·0) (Found : C, 68·1; H, 9·2. $C_{16}H_{26}O_4$ requires C, 68·1; H, 9·2%). The p-*tolylimide* crystallised from alcohol in compact shining needles, m. p. 154° (Found : C, 76·9; H, 7·7. $C_{19}H_{23}O_2N$ requires C, 76·8; H, 7·7%).

The *anhydride* (XLVIII), prepared by refluxing the acid with acetic anhydride for 2 hours, distilled at 190°/15 mm. and solidified in the receiver. It crystallised from light petroleum (b. p. 60—80°) in clusters of silky needles, m. p. 181° (Found : C, 69·0; H, 8·0. $C_{12}H_{16}O_3$ requires C, 69·2; H, 7·7%).

The *anilic acid* was prepared by mixing the anhydride and aniline in benzene solution. The benzene was evaporated, the residue dissolved in ether, and the anilic acid extracted with sodium bicarbonate solution. It crystallised from hot water in silky needles, m. p. 185° (decomp.) (Found : C, 71·7; H, 7·9. $C_{18}H_{23}O_3N$ requires C, 71·8; H, 7·6%).

The *methyl hydrogen* ester of 2-*carboxy*-trans-*hexahydrohydrindene*-2-*acetic acid*, obtained by the action of the theoretical amount of alcoholic sodium methoxide on the anhydride and subsequent acidification, crystallised from petrol in clusters of needles, m. p. 124° (Found : C, 64·7; H, 8·1; equiv., by titration, 239·8. $C_{13}H_{20}O_4$ requires C, 65·0; H, 8·3%; equiv., 240). On distillation under reduced pressure, it was completely reconverted into the anhydride.

Imide of 2-*carboxy*-trans-*hexahydrohydrindene*-2-*acetic acid* (XLVII). The ethereal solution remaining after the extraction of the acid (XLVI) with aqueous sodium bicarbonate (above) gave the *imide* on evaporation of the solvent. This crystallised from alcohol in prismatic needles, m. p. 258° (Found : C, 69·8; H, 8·3. $C_{12}H_{17}O_2N$ requires C, 69·6; H, 8·2%).

trans-*Hexahydrohydrindene*-2-*cyanohydrin* (LII).—This was obtained from *trans*-hexahydro-2-hydrindone by Ultée's method (*Rec. trav. chim.*, 1909, **28**, 1). The separation of the bisulphite compound was very slow and took 2 days. The *cyanohydrin* was distilled under diminished pressure after the addition of two drops of concentrated sulphuric acid; b. p. 165°/15 mm. (slight decomp.) (Found : C, 73·1; H, 9·4. $C_{10}H_{15}ON$ requires C, 72·7; H, 9·1%). When boiled with concentrated hydrochloric acid, it was converted into 2-*hydroxy*-trans-*hexahydrohydrindene*-2-*formic acid*, which crystallised from light petroleum (b. p. 60—80°) in shimmering scales, m. p. 134° (Found : C, 65·0; H, 8·6. $C_{10}H_{16}O_3$ requires C, 65·2; H, 8·7%).

Ethyl 2-*Cyano*-trans-*hexahydrohydrindene*-2-*cyanoacetate* (XLV).—To a well-cooled solution of the cyanohydrin (16 g.) in absolute ethyl alcohol (16 c.c.) was gradually added with vigorous shaking a suspension of ethyl sodiocyanoacetate prepared from ethyl cyanoacetate (11·3 g.) and sodium (2·2 g.) dissolved in ethyl alcohol (30 c.c.). The mixture, after being kept at room temperature for 24 hours, was diluted freely with water and acidified with dilute hydrochloric acid and the precipitated oil was extracted with ether and distilled; the *dicyano-ester* boiled at 212°/15 mm. (Found : C, 69·3; H, 7·5. $C_{15}H_{20}O_2N_2$ requires C, 69·2; H, 7·7%). When hydrolysed with 50% sulphuric acid, the dicyano-ester is converted into the acid (XLVI), m. p. 202°.

2-*Cyano*-trans-*hexahydrohydrindene*-2-*cyanoacetic Acid* (L) *and*

the Imide of 2-*Carboxy*-trans-*hexahydrohydrindene*-2-*cyanoacetic Acid* (XLIX).—The addition compound of potassium cyanide and the cyano-ester (XXXI) was diluted with water and acidified with cold 2*N*-hydrochloric acid, and the precipitated oil shaken with ether. The solid insoluble in this solvent was identified as the cyano-imide (XLIX). The substances in the ethereal extract were separated into acid and neutral fractions by extraction with a solution of sodium bicarbonate. 2-*Cyano*-trans-*hexahydrohydrindene*-2-*cyanoacetic acid* crystallised from aqueous alcohol in needles, m. p. 154° (Found : C, 67·0; H, 6·7; equiv., by titration, 231. $C_{13}H_{16}O_2N_2$ requires C, 67·2; H, 6·9%; equiv., 232).

The dicyano-acid (L), when heated at 160° for 2 hours, was converted with loss of carbon dioxide into 2-*cyano*-trans-*hexahydrohydrindene*-2-*acetonitrile* (LI), which partly sublimed in needles. It crystallised from light petroleum (b. p. 60—80°) in soft needles, m. p. 179° (sintering at 175°) (Found : C, 76·8; H, 8·4. $C_{12}H_{16}N_2$ requires C, 76·6; H, 8·5%).

The ethereal extract, after the removal of the acid fraction, was washed and dried and the solvent removed. The solid residue, which proved to be the *imide* (XLIX), crystallised from water in prisms, m. p. 173° (Found : C, 67·3; H, 7·1. $C_{13}H_{16}O_2N_2$ requires C, 67·2; H, 6·9%).

Condensation of trans-*Hexahydro*-2-*hydrindone with Ethyl Cyanoacetate. Preparation of the* ω-*Imide of* trans-*Hexahydrohydrindene*-2 : 2-*dicyanoacetic Acid* (XI).—Absolute ethyl alcohol (1 l.), cooled in a freezing mixture and saturated with dry ammonia, was mixed with ethyl cyanoacetate (4 mols.) and *trans*-hexahydro-2-hydrindone (276 g.) and kept at room temperature for 2 weeks. The ammonium salt produced was washed with a little alcohol and with ether, and decomposed with boiling dilute hydrochloric acid. The imide obtained was washed with boiling water and dried. The alcoholic filtrate, partly freed from ammonia by a current of air, was largely diluted, extracted with ether to remove unchanged ketone, and acidified, a further quantity of the imide being precipitated (total yield, 60%). The ω-*imide* of trans-*hexahydrohydrindene*-2 : 2-*dicyanoacetic acid* was sparingly soluble in all organic solvents and crystallised from ethyl alcohol in pearly plates, m. p. 291° (Found : C, 66·3; H, 6·4; N, 15·2. $C_{15}H_{17}O_2N_3$ requires C, 66·4; H, 6·3; N, 15·5%).

ω-*Imide of* αα′-*Dicarbamyl*-trans-*hexahydrohydrindene*-2 : 2-*diacetic Acid* (XIV).—When a solution of the dicyano-imide in ten times its weight of cold concentrated sulphuric acid was kept at room temperature for 24 hours and poured on ice, the *dicarbamyl* compound separated as a fine solid which crystallised from hot water

in silvery scales, m. p. 260° (Found : C, 58·4; H, 6·9. $C_{15}H_{21}O_4N_3$ requires C, 58·6; H, 6·8%).

Hydrolysis of the Dicyano-imide : Preparation of trans-*Hexahydrohydrindene*-2 : 2-*diacetic Acid* (XV).—The dicyano-imide (100 g.), dissolved in concentrated sulphuric acid (500 c.c.), was kept at room temperature for 24 hours, diluted with water (450 c.c.), and boiled under reflux for 30 hours. The mixture was then cooled and diluted, and the precipitated solid filtered off. The acid was separated from a small quantity of the imide present by extraction with a dilute solution of sodium bicarbonate.

trans-*Hexahydrohydrindene*-2 : 2-*diacetic acid*, which is sparingly soluble in ether, benzene, and chloroform, crystallises from acetone in lustrous stellate clusters of short needles, m. p. 224° (decomp.). It is unchanged on being boiled with alkali or concentrated hydrochloric or hydrobromic acid (Found : C, 65·1; H, 8·4; equiv., by titration, 127. $C_{13}H_{20}O_4$ requires C, 65·0; H, 8·3%; equiv., 120).

The *methyl* ester boils at 172°/15 mm. and has $n_D^{19\cdot0°}$ 1·4769 and $d_4^{19\cdot0°}$ 1·074, whence $[R_L]_D$ 70·40 (calc., 70·38) (Found : C, 67·3; H, 9·1. $C_{15}H_{24}O_4$ requires C, 67·1; H, 8·9%). The *ethyl* ester distils at 182°/16 mm. and has $n_D^{19\cdot0°}$ 1·4687 and $d_4^{19\cdot0°}$ 1·043, whence $[R_L]_D$ 75·20 (calc., 75·0) (Found : C, 68·7; H, 9·3. $C_{17}H_{28}O_4$ requires C, 68·9; H, 9·5%). The *di*-p-*toluidide* crystallises from alcohol in slender needles, m. p. 197° (Found : C, 77·3; H, 8·2. $C_{27}H_{34}O_2N_2$ requires C, 77·5; H, 8·1%).

The *anhydride* (XVII) was obtained by boiling the acid with acetic anhydride (2 mols.) for 3 hours and distilling the excess of the latter under diminished pressure. The residue solidified in a vacuum over caustic potash. The *anhydride* crystallised from light petroleum (b. p. 60—80°) in rosettes of flat needles, m. p. 107° (Found : C, 70·4; H, 8·3. $C_{13}H_{18}O_3$ requires C, 70·3; H, 8·1%).

The *anilic acid* (XVIII) crystallised in a few minutes when benzene solutions of the anhydride and aniline were mixed. Sparingly soluble in cold benzene, it crystallised from hot benzene in short needles, m. p. 203° (Found : C, 72·2; H, 8·0. $C_{19}H_{25}O_3N$ requires C, 72·4; H, 7·9%).

The *anil* (XIX) was obtained by keeping the anilic acid at 210° until the evolution of water vapour ceased and triturating the residue with dilute aqueous ammonia to remove any unchanged acid. It crystallised from alcohol in lustrous scales, m. p. 197° (Found : C, 76·6; H, 7·8. $C_{19}H_{23}O_2N$ requires C, 76·8; H, 7·7%).

Methyl Hydrogen trans-*Hexahydrohydrindene*-2 : 2-*diacetate*.—To an ice-cold solution of the anhydride (20 g.) in absolute methyl alcohol (15 c.c.) was gradually added a solution of sodium (2·3 g.) in methyl alcohol (30 c.c.). After the removal of alcohol, the residue

was diluted and extracted with ether to remove any unchanged anhydride. The heavy oil precipitated from the aqueous solution on acidification was extracted with ether, washed, dried, and recovered. The *methyl hydrogen* ester, which partly solidified in a vacuum after 1 week, was dried on a porous tile and crystallised from petrol, separating slowly in prisms, m. p. 73° (Found : C, 66·2; H, 8·6; equiv., by titration, 253·5. $C_{14}H_{22}O_4$ requires C, 66·1; H, 8·6%; equiv., 254).

Preparation of the ωω′*-Di-iminodi-imide of* trans*-Hexahydrohydrindene-*2 : 2*-dimalonic Acid* (XXVI) *and of* α*-Cyano-*trans*-hexahydrohydrindylidene-*2*-acetamide* (XXV).—The filtrate after the separation of the ammonium salt (XII), on resaturation with ammonia at 0° and keeping for one week, deposited a considerable quantity of solid (40 g. from 1 g.-mol. of ketone). This was boiled with a limited quantity (150 c.c.) of absolute ethyl alcohol. The filtered solution, on concentration to a small bulk, deposited lustrous plates, m. p. 149° (slow crystallisation from aqueous methyl alcohol gives rise to stellate clusters of prismatic needles), of the unsaturated cyano-amide (XXV) (see below).

The solid, m. p. 284°, insoluble in alcohol formed the main bulk of the mixture and was practically insoluble in all organic solvents. It, however, dissolved in dilute mineral acids and was reprecipitated by sodium acetate solution. It was converted by boiling dilute hydrochloric acid into the ωω′*-di-imide* (XXVII) of trans*-hexahydrohydrindene-*2 : 2*-dimalonic acid*, which was sparingly soluble in all the usual solvents and crystallised from glacial acetic acid in short needles, m. p. 308° (Found : C, 62·3; H, 6·1. $C_{15}H_{18}O_4N_2$ requires C, 62·1; H, 6·2%).

Condensation of trans*-Hexahydro-*2*-hydrindone with Cyanoacetamide.*—To a solution of cyanoacetamide (16 g.) in the minimum amount of water was added *trans*-hexahydro-2-hydrindone, together with sufficient alcohol to ensure solution. Piperidine (1 c.c.) having been added, crystals began to be deposited after 4 hours. α*-Cyano-*trans*-hexahydrohydrindylidene-*2*-acetamide* (6 g.), which had separated after 10 hours, crystallised from alcohol in needles, m. p. 149° (Found : C, 70·5; H, 7·9. $C_{12}H_{16}ON_2$ requires C, 70·6; H, 7·8%). More piperidine was added to the filtrate and the crystals which separated were collected at intervals of 24 hours (8 g.). These were identical with the di-iminodi-imide (XXVI) obtained above.

Condensation of trans*-Hexahydro-*2*-hydrindone with Ethyl Bromoacetate : Preparation of Ethyl* 2*-Hydroxy-*trans*-hexahydrohydrindene-*2*-acetate* (LXIV).—A mixture of *trans*-hexahydro-2-hydrindone (69 g.), ethyl bromoacetate (53 g.), zinc filings (35 g.), and dry

benzene (175 c.c.) was warmed on the steam-bath. When reaction subsided, the mixture was heated on the water-bath for 20 minutes, cooled, and decomposed with ice and dilute sulphuric acid, the benzene layer was separated, and the aqueous solution extracted once with ether. The combined benzene and ethereal solutions were washed successively with 20% sulphuric acid, 10% caustic soda solution, and water and dried and the solvents were removed. On distillation of the residue under diminished pressure, unreacted ketone passed over first (110°/15 mm.), then *ethyl 2-hydroxy-trans-hexahydrohydrindene-2-acetate* at 160°/16 mm. (Found: C, 68·7; H, 9·8. $C_{13}H_{22}O_3$ requires C, 69·0; H, 9·7%), and finally a small fraction (5 g.) at 190°/16 mm. The hydroxy-acetate had $n_D^{19°}$ 1·47279 and $d_4^{19°}$ 1·038, whence $[R_L]_D$ 61·0 (calc., 61·12).

The last fraction of the distillate, which partly solidified, was triturated with a little light petroleum (b. p. 40—60°) and crystallised several times from petrol, needles, m. p. 126°, being finally obtained. This substance was identified as trans-*hexahydrohydindylidenehexahydro-2-hydrindone* (Found: C, 83·8; H, 10·0. $C_{18}H_{26}O$ requires C, 83·7; H, 10·1%). The mother-liquors, when concentrated and kept in a vacuum, deposited small cubes, m. p. 86—87°, more soluble than the first solid. The pure $\beta\gamma$-isomeride has not been isolated.

The ketone of m. p. 126° readily gave a *semicarbazone*, which crystallised from alcohol in prismatic needles, m. p. 140° (Found: C, 71·0; H, 9·5. $C_{18}H_{29}ON_3$ requires C, 71·3; H, 9·6%).

2-Hydroxy-trans-*hexahydrohydrindene-2-acetic acid* (LXVII) was produced when its ester was mixed with aqueous-alcoholic potassium hydroxide (20% excess) and kept for 3 days. After distillation of the alcohol in a vacuum, the residue was diluted with water, extracted with ether to remove any unchanged ester, and acidified. The hydroxy-acid, precipitated as a heavy oil and isolated by means of ether, crystallised from light petroleum (b. p. 60—80°) in stellate clusters of flat needles, m. p. 91° (Found: C, 66·5; H, 9·1; equiv., 198. $C_{11}H_{18}O_3$ requires C, 66·7; H, 9·1%; equiv., 198).

Dehydration of the Hydroxy-acid.—(1) *Preparation of* trans-*hexahydrohydrindylidene-2-acetic acid* (LXVIII). The hydroxy-acid was mixed with acetic anhydride (5 mols.) and boiled under reflux for 6 hours. The excess of acetic anhydride was removed under diminished pressure, and the residue steam-distilled until a litre of distillate had been collected. As the $\alpha\beta$-acid was not very volatile in steam, the residual acid, which completely solidified on cooling, was freed from water and crystallised from light petroleum (b. p. 60—80°), trans-*hexahydrohydrindylidene-2-acetic acid* separating in stellate clusters of prismatic needles, m. p. 155° (Found: C, 73·2; H,

9·0; equiv., by titration, 180. $C_{11}H_{16}O_2$ requires C, 73·3; H, 8·9%; equiv., 180).

A solution of the αβ-acid (LXVIII) in sodium carbonate is readily oxidised by a solution of potassium permanganate (1%) in the cold to the parent ketone, which is identified by its odour and by means of its semicarbazone, m. p. 242°.

The *acetyl* derivative (LXIX) was obtained when the hydroxy-acid was gently boiled with acetic anhydride for 3 hours and the excess of the latter distilled under reduced pressure. After steam-distillation to remove acetic acid, the residual oil solidified and then crystallised from light petroleum (b. p. 60—80°) in rosettes of silky needles, m. p. 106° (Found: C, 64·8; H, 8·4; equiv., 240. $C_{13}H_{20}O_4$ requires C, 65·0; H, 8·3%; equiv., 240).

The *dibromide*, $C_8H_{14}>CBr\cdot CHBr\cdot CO_2H$, was formed when a chloroform solution of the αβ-acid and bromine was kept for 24 hours. After spontaneous evaporation of the solvent, it was dried on a porous tile and crystallised from benzene–light petroleum (b. p. 60—80°), forming well-defined cubes, m. p. 150° (Found: Br, 47·5. $C_{11}H_{16}O_2Br_2$ requires Br, 47·1%).

(2) *Preparation of* trans-*hexahydroindenyl-2-acetic acid* (LXVI). (i) *With phosphorus oxychloride.* Phosphorus oxychloride (20 g.) and a solution of the hydroxy-ester (56 g.) in benzene (75 c.c.) were heated together on the steam-bath until the evolution of hydrogen chloride ceased. The oil thrown out on dilution of the solution was extracted with ether, washed with a solution of sodium carbonate, and recovered. The βγ-*ester* (LXV) boiled at 152°/15 mm. (Found: C, 75·1; H, 9·4. $C_{13}H_{20}O_2$ requires C, 75·0; H, 9·6%).

(ii) *With thionyl chloride* (Darzens' method, *loc. cit.*). Thionyl chloride (1 mol.) was added dropwise to an ice-cold solution of the hydroxy-ester (45 g.; 1 mol.) in pyridine (1 mol.). After being kept in ice for 2 hours, the reaction mixture was poured into water and acidified with dilute hydrochloric acid and the oil precipitated was extracted with ether, washed successively with hydrochloric acid, sodium carbonate and water, dried, and recovered (35 g.); it had b. p. 144°/11 mm.

The unsaturated ester, hydrolysed with 15% aqueous-alcoholic potash at room temperature, gave the βγ-*acid*, which crystallised from light petroleum in rhombic prisms, m. p. 144° (Found: C, 73·5; H, 8·8; equiv., by titration, 190·1. $C_{11}H_{16}O_2$ requires C, 73·3; H, 8·9%; equiv., 180).

Partial esterification. The acid from the above ester, which solidified only to a small extent, was partially esterified by the method of Eccott and Linstead (J., 1929, 2153): 30 g. of liquid acid gave 20 g. of ester, b. p. 144°/15 mm., and 10 g. of solid αβ-acid. The former

had $n_D^{19\cdot5°}$ 1·47741, $d_{4°}^{19\cdot5°}$ 0·9970, whence $[R_L]_D$ 59·69 (calc., 59·0). The *dibromide*, $C_8H_{13}Br{>}CBr{\cdot}CH_2{\cdot}CO_2H$, obtained from the βγ-acid crystallised from light petroleum in prisms, m. p. 146° (Found : Br, 47·6. $C_{11}H_{16}O_2Br_2$ requires Br, 47·1%).

The *hydrobromide* was obtained by saturating an ice-cold solution of the αβ- or the βγ-acid in chloroform with dry hydrogen bromide; it crystallised from light petroleum in prisms, m. p. 97° (Found : Br, 30·1. $C_{11}H_{17}O_2Br$ requires Br, 30·6%).

cis-*Series.*

cis-cyclo*Hexane*-1 : 2-*diacetic Acid* (IX).—*cis*-β-Decalone (b. p. 116°/14 mm.), obtained by the oxidation of *cis*-β-decalol (m. p. 105°) with chromic acid, was oxidised with concentrated nitric acid to *cis-cyclo*hexane-1 : 2-diacetic acid (m. p. 160°) in about 30% yield. More of the acid (5%) was obtained by concentrating the filtrate and keeping it at room temperature for a few weeks.

cis-*Hexahydro*-2-*hydrindone* (X).—*cis-cyclo*Hexane-1 : 2-diacetic acid (100 g.), intimately mixed with powdered baryta (7 g.) and distilled from an air-bath, gave *cis*-hexahydro-2-hydrindone (55 g.), b. p. 110°/20 mm., $n_D^{20\cdot2°}$ 1·0021, $d_{4°}^{20\cdot2°}$ 0·997 (compare Hückel and Friedrich, *loc. cit.*); the semicarbazone had m. p. 215°.

ω-*Imide of* cis-*Hexahydrohydrindene*-2 : 2-*dicyanoacetic Acid.*—*cis*-Hexahydro-2-hydrindone (69 g.) was condensed with ethyl cyanoacetate (113 g.) and alcoholic ammonia, as described in the case of the *trans*-ketone. After 4 weeks, the precipitate (15 g.) was removed and the filtrate diluted with water and extracted with ether to remove the unchanged ketone. The solution, after acidification with dilute hydrochloric acid, slowly deposited a solid (5 g.). Use of methyl in place of ethyl alcohol did not materially alter the yield. The cis-*dicyano-imide* crystallised from alcohol in small plates, m. p. 262° (Found: C, 65·9; H, 6·4. $C_{15}H_{17}O_2N_3$ requires C, 66·2; H, 6·3%).

cis-*Hexahydrohydrindene*-2 : 2-*diacetic acid* (XX) was obtained by the hydrolysis of the *cis*-dicyano-imide with 50% sulphuric acid (yield, 50%). It was sparingly soluble in benzene and chloroform, crystallised from aqueous acetone in prisms, m. p. 188° (Found : C, 65·2; H, 8·1; equiv., by titration, 126·5. $C_{13}H_{20}O_4$ requires C, 65·0; H, 8·3%; equiv., 120), and was not attacked by boiling dilute alkali solution or concentrated hydrochloric or hydrobromic acid.

The *anhydride* (XXI) crystallised from light petroleum (b. p. 60—80°) in lustrous short plates, m. p. 88° (Found : C, 70·3; H, 8·2. $C_{13}H_{18}O_3$ requires C, 70·3; H, 8·1%). On decomposition with dilute alkali solution it was converted into the acid (XX).

Anilic acids. When the anhydride was treated with aniline in benzene solution, a mixture of *anilic acids* was formed, one of which

separated from the solution after 1 week and crystallised from alcohol in rhombic prisms, m. p. 184° (Found : C, 72·3 ; H, 8·1. $C_{19}H_{25}O_3N$ requires C, 72·4 ; H, 7·9%). The more soluble anilic acid was isolated by extraction with dilute sodium carbonate solution after evaporation of the benzene : after two crystallisations from aqueous acetone it melted at 180° (Found : C, 72·4 ; H, 8·0%).

A mixture of the two anilic acids melted at 175—178°.

The *anil* (XXIV), formed when either anilic acid was heated above its melting point, crystallised from dilute alcohol in plates, m. p. 140° (Found : C, 76·9 ; H, 7·8. $C_{19}H_{23}O_2N$ requires C, 76·8 ; H, 7·7%).

Condensation of cis-*Hexahydro-2-hydrindone with Cyanoacetamide.* —This was carried out according to the method described earlier. The crystalline solids filtered off at intervals of 24 hours were found to be identical. α-*Cyano*-cis-*hexahydrohydrindylidene-2-acetamide* (XXIX) thus obtained crystallised from alcohol in light scales, m. p. 118° (Found : C, 70·5 ; H, 7·9. $C_{12}H_{16}ON_2$ requires C, 70·6 ; H, 7·8%).

This unsaturated cyano-amide (XXIX) (5 g.), when condensed with cyanoacetamide (3 g.) in presence of piperidine at 40°, deposited a solid (4 g.), m. p. 310°, which was converted by boiling mineral acid into the ω-*di-iminodi-imide* of cis-*hexahydrohydrindene-2 : 2-dimalonic acid* (XXX), m. p. above 325°. This dissolved slowly in sodium carbonate solution but was sparingly soluble in all organic solvents (Found : C, 61·5 ; H, 6·3. $C_{15}H_{20}O_2N_4$ requires C, 62·0 ; H, 6·2%). If larger quantities are used in the above preparations, poor yields of the condensation product are obtained.

Condensation of cis-*Hexahydro-2-hydrindone with Ethyl Cyanoacetate. Ethyl* cis-*Hexahydrohydrindylidene-2-cyanoacetate* (XXXVII).—A mixture of *cis*-hexahydro-2-hydrindone (69 g.), ethyl cyanoacetate (53 g.), and piperidine (1 c.c.), after being kept for 3 days, was heated on the steam-bath for 4 hours. The unsaturated *cyano-ester* boiled at 200°/19 mm. (a mixture of the unchanged ketone and ethyl cyanoacetate having passed over at 110—120°/18 mm.) and had $n_D^{21\cdot4°}$ 1·5126, $d_4^{21\cdot4°}$ 1·064, whence $[R_L]_D$ 65·7 (calc., 63·5) (Found : C, 72·0 ; H, 8·4. $C_{14}H_{19}O_2N$ requires C, 72·1 ; H, 8·2%). Oxidised with 1% potassium permanganate solution, it gave *cis*-hexahydro-2-hydrindone, identified by means of its semicarbazone.

Condensation of Ethyl cis-*Hexahydrohydrindylidene-2-cyanoacetate with Alcoholic Potassium Cyanide. Preparation of Isomeric 2-Carboxy*-cis-*hexahydrohydrindene-2-acetic Acids.*—The reaction was carried out as described for the *trans*-compound : the quantities employed were 20 g. of the unsaturated ester, 160 g. of rectified spirit, 12 g. of potassium cyanide, and 25 c.c. of water. The addi-

tion product was boiled with concentrated hydrochloric acid and the solid which separated on cooling was filtered off, dissolved in ether, and separated into acid (*A*) and neutral (*B*) portions by means of cold dilute sodium bicarbonate solution.

(*A*) The acid product (14 g.), m. p. 140—180°, was boiled with acetone (100 c.c.), and the solution filtered.

(1) The insoluble portion (9 g.), m. p. 198—202°, heated with acetyl chloride (2 mols.) for 4 hours and kept over-night, deposited a certain amount (3 g.) of the *anhydride* (LVIII) as rhombic prisms : the remainder was obtained after evaporation of the excess of acetyl chloride. The anhydride crystallised from light petroleum in pearly plates, m. p. 137° (Found : C, 68·9; H, 7·9. $C_{12}H_{16}O_3$ requires C, 69·2; H, 7·7%).

When decomposed with dilute alkali solution, it gave 2-*carboxy*-cis-*hexahydrohydrindene*-2-*acetic acid* (LIV), which crystallised from water in prisms, m. p. 205° (decomp.) (Found : C, 63·7; H, 7·8; equiv., by titration, 112·8. $C_{12}H_{18}O_4$ requires C, 63·7; H, 7·9%; equiv., 113). The *ethyl* ester boiled at 170°/15 mm. and had $n_D^{19\cdot4°}$ 1·4720, $d_4^{19\cdot4°}$ 1·1045, whence $[R_L]_D$ 75·5 (calc., 75·0) (Found : C, 68·0; H, 9·0%). The *anilic acid* (LX) was precipitated in a few minutes when the anhydride and aniline were mixed in benzene solution. It crystallised from alcohol in rectangular prisms, m. p. 197° (Found : C, 71·6; H, 7·8. $C_{18}H_{23}O_3N$ requires C, 71·8; H, 7·6%). The *anil* (LXII), obtained by heating the acid above its melting point for a few minutes, crystallised from alcohol in rectangular slabs, m. p. 127° (Found : C, 76·2; H, 7·5. $C_{18}H_{21}O_2N$ requires C, 76·3; H, 7·4%).

(2) The acetone-soluble fraction, m. p. 150—155°, was heated with acetyl chloride, the excess of the latter removed, and the residue distilled. The *anhydride* (LIX), b. p. 186°/18 mm., was a colourless liquid which solidified in a few minutes. After two crystallisations from petroleum (b. p. 60—80°), from which it separated as rhombic plates, it melted at 68° (mixed m. p. with the other anhydride, 63—66°) (Found : C, 69·1; H, 7·8%). When this anhydride was decomposed with dilute potassium hydroxide solution it gave 2-carboxy-*cis*-hexahydrohydrindene-2-acetic acid (LV), which was crystallised from aqueous alcohol; m. p. 159° (mixed m. p. with the other acid, 148—155°).

The *anilic acid* (LXI) separated in needles, m. p. 182° (decomp.), from alcohol, in which it was more soluble than the *trans*-isomeride (Found : C, 71·5; H, 7·6%). The *anil* (LXIII) obtained from this anilic acid crystallised from aqueous alcohol in bundles of needles, m. p. 120° (mixed m. p. with the other anil, 115—116°) (Found : C, 76·5; H, 7·5%).

(*B*) *The imides of* 2-*carboxy*-cis-*hexahydrohydrindene*-2-*acetic acids* (LVI and LVII). When the ethereal solution containing the neutral products of the hydrolysis (p. 949) was evaporated, a residue was obtained which solidified completely (m. p. 150—165°). It was separated by fractional crystallisation from acetone into a less soluble *imide* (LVI), m. p. 208—210°, and a more soluble *imide* (LVII), m. p. 150—152°. The former crystallised from acetone in plates, m. p. 216° (Found : C, 69·5; H, 8·3%), and the latter from aqueous acetone in plates, m. p. 170° (Found : C, 69·8; H, 8·2%).

cis-*Hexahydrohydrindylidene*-2-*cyanoacetic Acid* (XXXIX).—(A) *From* cis-*hexahydrohydrindylidene*-2-*cyanoacetamide*. The unsaturated cyano-amide (8 g.), dissolved in a mixture of chloroform (160 c.c.) and water (4 c.c.), was treated with a rapid current of nitrous fumes until a permanent bluish-green colour was obtained (6 hours). After 24 hours, the chloroform was evaporated, the residue dissolved in ether, and the acid separated from the unchanged amide by extraction with sodium carbonate solution. The extract on acidification with dilute hydrochloric acid yielded a heavy oil (7 g.) which solidified. cis-*Hexahydrohydrindylidene*-2-*cyanoacetic acid* crystallised from benzene in rosettes of rhombic prisms, m. p. 143° (Found : C, 70·2; H, 7·4; equiv., by titration, 204·6. $C_{12}H_{15}O_2N$ requires C, 70·2; H, 7·3%; equiv., 205).

(B) *By the condensation of* cis-*hexahydro*-2-*hydrindone with ethyl sodiocyanoacetate*. The reaction was carried out as described in the case of the *trans*-acid, the quantities being as follows : the ketone, 10 c.c.; ethyl cyanoacetate, 8·5 g.; sodium, 1·3 g., and alcohol, 35 c.c. The acid (9 g.) thus obtained was a mobile liquid which partly crystallised in needles, m. p. 142°, when kept in a vacuum for 3 weeks.

cis-*Hexahydroindenyl*-2-*acetonitrile* was obtained by the distillation of the cyano-acid under reduced pressure. It boiled at 140°/15 mm. and had $n_D^{19·5°}$ 1·49680, $d_4^{19·5°}$ 0·9750, whence $[R_L]_D$ 47·97 (calc., 47·94) (Found : C, 81·9; H, 9·1. $C_{11}H_{15}ON$ requires C, 82·0; H, 9·3%). It is a mobile colourless liquid and has the characteristic odour of unsaturated nitriles.

Ethyl α-*cyano*-α-cis-*hexahydroindenyl*-2-*propionate*, obtained by methylation of the unsaturated ester, boiled at 165°/15 mm. and had $n_D^{18·1°}$ 1·4843, $d_4^{18·1°}$ 1·028, whence $[R_L]_D$ 68·39 (calc., 68·0) (Found : C, 72·7; H, 8·4. $C_{15}H_{21}O_2N$ requires C, 72·9; H, 8·5%). When heated with alcoholic sodium ethoxide (1 mol.) at 40°, it was converted into cis-*hexahydrohydrindylidene*-2-*propionitrile*, which distilled at 154°/15 mm. as a colourless mobile liquid and had $n_D^{18·4°}$ 1·51010, $d_4^{18·4°}$ 0·9703, whence $[R_L]_D$ 53·94 (calc., 52·57) (Found : C, 82·1; H, 9·8. $C_{12}H_{17}N$ requires C, 82·3; H, 9·7%).

Condensation of cis-*Hexahydro-2-hydrindone with Ethyl Bromoacetate.*—The reaction was carried out as described in the case of the *trans*-ketone, the quantities used being 68 g. of ketone, 32 g. of zinc filings, 53 g. of ethyl bromoacetate, and 150 c.c. of benzene. The reaction, which began after 30 minutes, was less vigorous than in the case of the *trans*-ketone. The unchanged ketone (20 g.) distilled at 112°/10 mm., and *ethyl 2-hydroxy*-cis-*hexahydrohydrindene-2-acetate* (40 g.) at 158°/10 mm. The latter had $n_D^{15\cdot5°}$ 1·48170, $d_4^{15\cdot5°}$ 1·043, whence $[R_L]_D$ 61·6 (calc., 61·01) (Found : C, 68·9; H, 9·7. $C_{13}H_{22}O_3$ requires C, 69·0; H, 9·7%). The high fraction (5 g.) boiled at 180°/10 mm., and gradually solidified in the receiver. Subjected to the same process, the recovered ketone gave 20 g. of hydroxy-ester.

Hydrolysis of the hydroxy-ester. Stereoisomeric 2-hydroxy-cis-*hexahydrohydrindene-2-acetic acids* (LXXI and LXXII). The hydroxy-ester (28 g.), hydrolysed with 15% aqueous-alcoholic potash, gave a solid (20 g.), m. p. 74—78° to a turbid liquid which cleared at 100°. This was boiled with light petroleum (b. p. 60—80°), and the solution filtered.

(A) The insoluble portion, on recrystallisation from much light petroleum (b. p. 40—60°), separated in short needles, m. p. 130°. It also crystallised from chloroform in rhombic prisms (Found : C, 66·6; H, 9·3; equiv., 198. $C_{11}H_{18}O_3$ requires C, 66·7; H, 9·1%; equiv., 198).

(B) The second crop of crystals obtained from the petroleum solution (b. p. 60—80°) separated as hexagonal plates, m. p. 84°, mixed m. p. with the other acid, 72—75° (Found : C, 66·8; H, 9·2; equiv., 197·5).

Dehydration of the hydroxy-acid. A mixture of the two hydroxy-acids was dehydrated with acetic anhydride, and the product steam-distilled. The first two litres of distillate contained oily material and were worked up separately. The snow-white solid which separated from the remaining (7 litres) distillate was collected (total yield, 9 g.). cis-*Hexahydrohydrindylidene-2-acetic acid* crystallised from light petroleum (b. p. 60—80°) in elongated rhombic prisms, m. p. 140° (Found : C, 73·2; H, 8·9; equiv., 180. $C_{11}H_{16}O_2$ requires C, 73·3; H, 8·9%; equiv., 180).

Dehydration of the hydroxy-ester. The hydroxy-ester (20 g.), dehydrated with phosphorus oxychloride in benzene solution, gave *ethyl* cis-*hexahydroindenyl-2-acetate* (15 g.), which boiled at 143°/10 mm. and had $n_D^{15\cdot6°}$ 1·48917, $d_4^{15\cdot6°}$ 1·007, whence $[R_L]_D$ 59·53 (calc., 59·01) (Found : C, 75·1; H, 9·5. $C_{13}H_{20}O_2$ requires C, 75·0; H, 9·6%). The unsaturated ester when hydrolysed with 20% aqueous-alcoholic potash gave cis-*hexahydroindenyl-2-acetic acid*, which distilled at 180°/18 mm. and partly solidified in the receiver. The

$\beta\gamma$-acid crystallised from petroleum (b. p. 60—80°) in plates, m. p. 138° (Found : C, 73·1 ; H, 8·9% ; equiv., 180).

The author's thanks are due to Professor J. F. Thorpe, C.B.E., F.R.S., for his interest in this investigation, and to the Chemical Society for generous grants which have partly defrayed the heavy cost.

IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY,
LONDON, S.W.7. [*Received, February 19th*, 1931.]