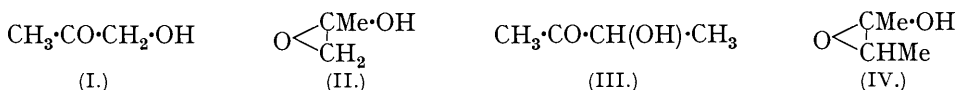**156.** *The Rotatory Dispersion of Organic Compounds. Part XXVI. Acetoin.*

By T. M. LOWRY and W. C. G. BALDWIN.

ACETYLMETHYLCARBINOL, or acetoin (Bouveault and Locquin, *Bull. Soc. chim.*, 1906, **35**, 629), $CH_3 \cdot CH(OH) \cdot CO \cdot CH_3$, the aliphatic analogue of benzoin, is one of the simplest unsaturated optically active compounds. The racemic form has been known since 1890, when Pechmann and Dahl (*Ber.*, **23**, 2421) obtained it as a reduction product of diacetyl, whereas Vladesco in 1891 (*Bull. Soc. chim.*, **6**, 810) prepared it by chlorinating methyl ethyl ketone and hydrolysing the product. The optically active form was first described in 1904 by Desmots (*Compt. rend.*, **138**, 581; cf. Grimbert, *ibid.*, 1901, **132**, 706; Browne, *J. Amer. Chem. Soc.*, 1906, **28**, 467) as a product of the action of various bacteria on polyhydric alcohols and carbohydrates.

The dynamic isomerism of acetoin was studied in 1905 by Kling (*Compt. rend.*, 1905, **140**, 1457), in comparison with that of acetol (I), which had been shown (i) to yield reduction products (propylene glycol and *iso*propyl alcohol) derivable most readily from the isomeric oxide (II) (*ibid.*, 1902, **135**, 970; *Bull. Soc. chim.*, 1903, **29**, 92), (ii) to exhibit in aqueous solutions the behaviour of a pseudo-acid (*Compt. rend.*, 1905, **140**, 1256; *Bull. Soc. chim.*, 1905, **33**, 755), although (iii) the refraction and magnetic rotation of the anhydrous liquid agreed with the ketonic formula. From measurements of refraction, Kling concluded that the monomeric liquid form of acetoin (obtained by distillation of the solid polymeride) was an equilibrium mixture of the ketone (III) with the oxide (IV).

$$CH_3 \cdot CO \cdot CH_2 \cdot OH \qquad O{<}^{CMe \cdot OH}_{CH_2} \qquad CH_3 \cdot CO \cdot CH(OH) \cdot CH_3 \qquad O{<}^{CMe \cdot OH}_{CHMe}$$

(I.)   (II.)   (III.)   (IV.)

Pechmann and Dahl (*loc. cit.*) obtained two solid forms, m. p. 126—128° and 94—98°, the former being deposited on long standing, and the latter on freezing in presence of zinc. These were subsequently described by Diels and Stephan (*Ber.*, 1907, **40**, 4336) as melting

at 95·5° and 85·5°. Both forms could be recrystallised from boiling acetone, in which solvent they were shown to be dimeric; but they were depolymerised by contact with ether and could not then be recrystallised. The existence of two forms of the solid was also confirmed by Dirscherl and Braun (*Ber.*, 1930, **63**, 416), who found that they melted at 95° and 85° when heated very slowly, but at 125° and 95° (compare Pechmann and Dahl) when heated rapidly.

Acetoin was recently described by Professor A. J. Kluyver ("Symposium on Bread and Milk," *J. Soc. Chem. Ind.*, 1933, **52**, 373T) as a precursor of diacetyl in butter. Through his kind introduction, we obtained three specimens from the " N. V. Nederlandsche Gist en Spiritusfabriek " of Delft. The following details of the preparation were supplied by the firm : " A mash containing carbohydrates, nitrogen, and phosphorus compounds was treated with a certain strain of bacteria. These bacteria are capable of partly transforming the carbohydrates into 2 : 3-butylene glycol, $CH_3 \cdot CH(OH) \cdot CH(OH) \cdot CH_3$. When, however, the fermenting liquor is aerated, acetylmethylcarbinol is produced. The substance obtained in this way is lævorotatory, but soon polymerises to the solid, which is the commercial product." Two of the specimens were pale yellow, crystalline solids; the other was a yellow liquid, from which some crystalline material had separated. The yellow liquid was lævorotatory, but both samples of solid were inactive.

Properties of the Solid.—The samples of inactive solid were identical with that which had separated from the active liquid. Thus, the inactive solid, when washed three times with alcohol and dried, melted at 101—102° when heated in the ordinary way, but at 126° when heated rapidly from 115°. The same m. p. was given by the inactive solid deposited from the optically active liquid, after it had been recrystallised quickly from ethyl acetate. When, however, a small quantity of this solid was left over-night in contact with the mother-liquor (ethyl acetate or acetone and chloroform) from which it had separated, it redissolved in the " saturated " solution, owing to depolymerisation. Similarly, an almost unlimited quantity of the solid could be dissolved in warm water, but none was deposited on cooling.

Freezing-point determinations of dilute aqueous solutions of the solid gave a normal molecular weight, $M = 90$ ($C_4H_8O_2 = 88$); but higher values were obtained by determinations of boiling point in non-aqueous solvents, *e.g.*, chloroform, $M = 134$; acetone, $M = 143$; freezing-point determinations in acetic acid gave an intermediate value, $M = 112$. It is therefore clear, in agreement with Diels and Stephan (*Ber.*, 1907, **40**, 4338), that the solid is a dimeric compound, which readily depolymerises on distillation or on dissolution in water.   Since, however, solutions prepared by gently warming the solid with ethyl acetate gave *no trace of selective absorption*, it is clear that this polymeride contains no carbonyl groups. We have therefore formulated it as a derivative of *cyclo*butane (V), comparable with the dimeric form of cinnamic acid.

(V.)

(VI.)
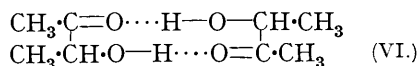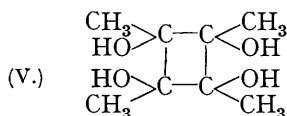
These results are directly opposed to those of Dirscherl and Braun (*loc. cit.*), who found that alcoholic solutions, in which the solids were still dimeric ($M = 170$ falling to 100 in 15 mins.) and from which they could be recovered after some hours, gave the same absorption spectrum, $\varepsilon_{max.} = 17·8$ at 2800 Å.U., as the monomeride. They therefore concluded that the molecules were united only by secondary valencies as in (VI); but, since our solutions in ethyl acetate were completely transparent in this region, we conclude that their alcoholic solutions must have been partially depolymerised, and that their argument is therefore invalid.
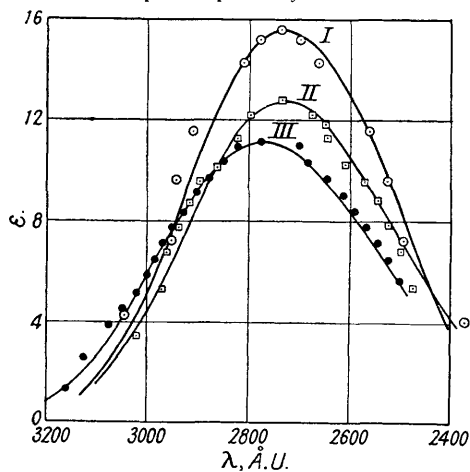
Properties of the Liquid.—On distillation of the yellowish optically active liquid in air, the first runnings were strongly coloured owing to oxidation to diacetyl, but a sample almost free from yellow colour, and of b. p. 142·7—143·2°/760 mm., was obtained by fractionation in a stream of carbon dioxide.

(i) The *absorption spectrum* was examined in the homogeneous state and in solutions in water, ethyl acetate, and *cyclo*hexane. In each case, the ketonic band at 2750 Å.U. was well developed. The data for the three solutions are plotted in Fig. 1. The curves are not symmetrical on a scale of wave-lengths, but can be expressed by Hudson's general equation (see preceding paper, p. 699). The concordance of the observed extinction coefficients with those calculated from Hudson's equation ($n = 2$) can be seen clearly in the data for the homogeneous compound, which are plotted in Fig. 2, from readings taken with a calibrated cell of thickness 0·10 mm.

It is remarkable that the absorption band of acetoin is strongest in aqueous solutions, whereas that of other carbonyl compounds is weakened by hydration. This affords support to the conclusion of Kling (*loc. cit.*) and of Bergmann and Ludwig (*Annalen*, 1924, **436**, 173), that acetoin is a mixture of the ketonic and the oxidic form, (III) and (IV), and that the equilibrium between them is displaced by the action of water; but this solvent appears to favour the ketonic form, and not the oxidic form, as Kling supposed.
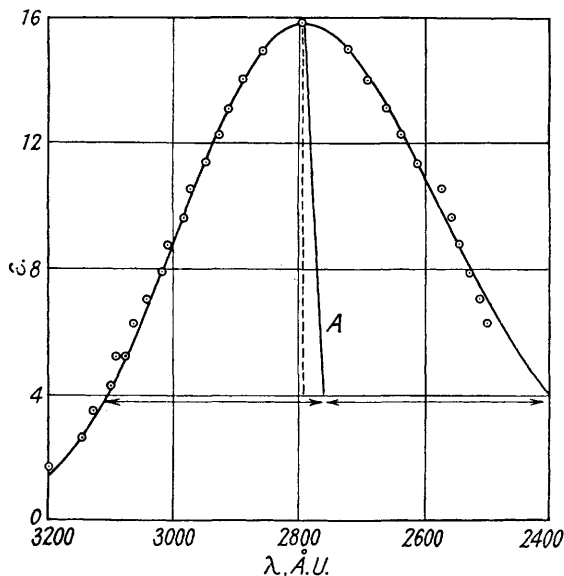
FIG. 2.

Absorption Spectrum of Acetoin (no solvent) with calculated curve deduced from Hudson's equation (n = 2).

FIG. 1.

Absorption Spectra of Acetoin.

I. *In water.*
II. *In* cyclo*hexane.*
III. *In ethyl acetate.*
} with calculated curves deduced from Hudson's equation (n = 2).

The line A *shows the slope of the rectilinear diameter.*

(ii) The *circular dichroism* was too small to be measured, and it was therefore not possible to compare the position of the maximum with that of the maximum of absorption.

(iii) The *rotatory power* of the liquid (d 1·000) was $[\alpha]_{5461} = 6\cdot60°$, but this was increased to 8·04° by fractionation.

(iv) The *rotatory dispersion* of the redistilled liquid (b. p. 142·7—143·2°/760 mm.) was determined without a solvent over the range 6708—3395 Å.U., but could not be followed into the region of absorption. The results are shown in Table I.

Over the whole range of observation the rotations could be expressed by a Drude equation with three constants

$$[\alpha] = -\ 2\cdot1644/(\lambda^2 - 0\cdot084049) + 0\cdot62666/\lambda^2.$$

The dispersion constant of the low-frequency term, $\lambda_0{}^2 = 0\cdot084049$, $\lambda_0 = 2900$ Å.U., corresponds with the frequency of maximum absorption in the ketonic band, $\lambda_a = 2794$ Å.U. The introduction of a dispersion constant into the high-frequency term was unnecessary at wave-lengths down to about 3600 Å.U., but would be necessary to express the rotations at shorter wave-lengths.

TABLE I.

Specific Rotations of Acetoin at 20°.

No solvent; $l = 2$ dm. except where otherwise noted; $d_{4°}^{20°} = 1·000$; all rotations are negative.
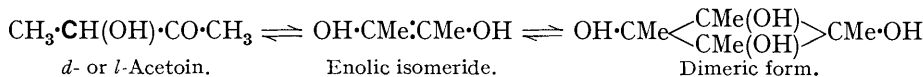
	Visual readings.				Photographic readings.		
	λ.	$[\alpha]$.	O–C.			λ.	$[\alpha]$.	O–C.
Li	6708	4·47°	0·06°	Fe	5002	10·67°	−0·17°
Ba	6497	4·95	−0·04	Fe	4590	13·95 †	0·18
Cd	6438	5·07	−0·03	Fe	4500	14·95 †	0·22
Li	6104	5·87	−0·05	Fe	4432	15·95 †	0·11
Na	5893	6·42	−0·01	Fe	4368	17·14 *	−0·14
Cu	5782	6·77	±0	Fe	4320	18·20 *	−0·46
Hg	5780	6·76	0·01	Fe	4310	17·95 †	−0·05
Cu	5700	7·07	−0·02	Fe	4266	19·25 *	−0·60
Ba	5536	7·62	0·07	Fe	4178	20·31 *	±0
Ag	5468	7·97	−0·01	Fe	4144	21·39 *	−0·36
Hg	5461	8·04	−0·04	Fe	4101	22·42 *	−0·44
Cu	5219	9·16	0·03	Fe	4060	22·95 †	0·05
Ag	5209	9·12	0·12	Fe	3968	25·45 †	0·07
Cu	5153	9·62	−0·07	Fe	3928	27·20 *	−0·46
Cu	5106	9·86	−0·02	Fe	3872	27·95 †	0·67
Cd	5086	9·97	0·01	Fe	3839	30·29 *	−0·38
Ba	4934	10·93	0·07	Fe	3738	34·40 *	±0
Zn	4811	11·98	−0·01	Fe	3653	38·52 *	0·58
Cd	4800	12·22	−0·15	Fe	3585	42·70 *	0·92
Zn	4722	12·77	0·01	Fe	3521	47·00 *	2·04
Zn	4680	13·20	−0·02	Fe	3478	51·10 *	2·22
Cd	4678	13·14	0·05	Fe	3395	57·33 *	6·62
Li	4602	13·89	0·09				
Ba	4554	14·52	−0·01				
Hg	4358	17·60 *	−0·49				

* $l = 0·4725$ dm.   † $l = 1$ dm.

The activity of the compound is due mainly to the low-frequency lævorotation of the carbonyl group, which is about 5 times as great as the high-frequency dextrorotation of the asymmetric carbon atom.

Racemisation of Acetoin.—The specific rotatory power of acetoin is increased by fractional distillation. Its optical activity is therefore resistant to the effects of vaporisation. On the other hand, at the end of a day, the liquid had deposited a considerable proportion of the inactive solid polymeride, from which the inactive monomeride could be prepared by distillation. The rotatory power of the liquid remained very nearly constant during the process of racemisation, as would be expected if the liquid were saturated with the inactive polymeride, so that its concentration in the saturated solution remained constant.

The preceding observations suggest that the racemisation of acetoin is dependent on *reversible polymerisation* rather than on the more usual process of *reversible isomeric change.* It is, however, quite possible that an enolic isomeride is first produced, *e.g.*, by alkaline catalysis in glass vessels, but is converted immediately into the polymeride :

$$CH_3 \cdot CH(OH) \cdot CO \cdot CH_3 \rightleftharpoons OH \cdot CMe \colon CMe \cdot OH \rightleftharpoons OH \cdot CMe {<}^{CMe(OH)}_{CMe(OH)}{>} CMe \cdot OH$$

d- or l-Acetoin.   Enolic isomeride.   Dimeric form.

The fact that the formation of the dimeric form is accompanied by a complete loss of optical activity is in harmony with the formula (V), but is not explained by Dirscherl and Braun's formula (VI).

Acetylation of the Solid.—After observations of absorption had shown that the dimeric form of acetoin did not contain any carbonyl groups, an attempt was made to establish the presence of four hydroxyl groups. The solid was therefore acetylated with pyridine and acetic anhydride (Bergmann and Ludwig, *Annalen,* 1924, **436**, 173). The product was identical in odour, in b. p. (168—171°), and in composition (Found : OAc, 45·7. Calc. for $C_6H_{10}O_3$: OAc, 45·4%) with the acetate which they obtained from the mono-meride, so acetylation had evidently been accompanied by depolymerisation. The absorption curve of the monomeride is reproduced in Fig. 3. The maximum extinction coefficient of the ketonic absorption band is about 30% stronger than in acetoin, but is

supplemented by a much stronger absorption, rising towards an unreached maximum on the edge of the Schumann region, which can be attributed to the acetate radical.

Acetylation of the Liquid.—The optically active liquid was dissolved in acetic anhydride (11·90 g./100 c.c.). It gave an initial specific rotation, $[\alpha]_D$ − 12·10°, about twice as large as that of the pure liquid. This rose during about 3 hours at 18—19°, then fell according to a linear law during the period 91—200 hours, and then more slowly to a negligible value after 578 hours :

t, hrs. ...	0	$\frac{1}{4}$	1	$2\frac{3}{4}$	$19\frac{1}{2}$	72	91	115	145
$[\alpha]_D$	12·10°	12·35°	12·44°	12·60°	11·68°	10·60°	10·41°	9·58°	8·99°
t, hrs. ...	190	235	262	290	331	402	451	477	578
$[\alpha]_D$	7·48°	6·21°	5·37°	4·54°	3·70°	2·52°	1·68°	1·18°	0·17° ($a = 0·02°$)

These changes of rotatory power are attributed to a rapid initial acetylation of the active ketol, followed by a slower racemisation of the acetate; but the mutarotation curve is

FIG. 3.
Absorption Spectrum of Acetoin Acetate.
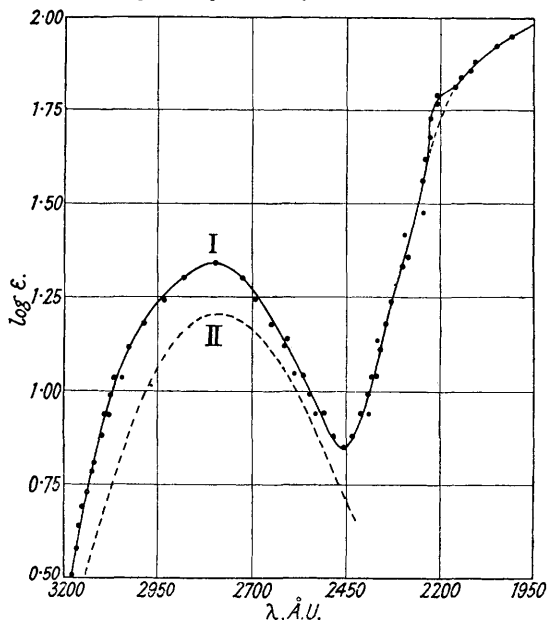
I. *Acetate in cyclohexane (logarithmic scale).*
II. *Acetoin (no solvent) on same logarithmic scale.*

too complex to be readily analysed, and we are unable to express an opinion as to the mechanism of the racemisation.

SUMMARY.

1. Acetoin, or acetylmethylcarbinol, exists as an optically active liquid, $[\alpha]_{5461} = -6·6°$, from which an optically inactive solid polymeride separates slowly without altering the rotatory power of the saturated solution. The rotatory power can, however, be increased to $[\alpha]_{5461} = -8·0°$ by fractional distillation.

2. The liquid shows a well-developed ketonic band, but this is absent from freshly prepared solutions of the polymeride.

3. Acetylation of the polymeride yields a monomeric acetate, in which the ketonic band is again fully developed.