177. " *Leaf Alcohol* " *and the Stereochemistry of the* cis- *and the* trans-n-*Hex*-3-*en*-1-*ols and* -n-*Pent*-3-*en*-1-*ols*.

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The stereochemistry of " leaf alcohol " is examined. The compound is shown to be *cis*-hex-3-enol, thus confirming the suggestion of Stoll and Rouvé. Takei's assignment of the *trans*-configuration to it is mistakenly based on the properties of a synthetic hexenol, which is not the true stereoisomer of " leaf alcohol " and is probably not homogeneous. Authentic *trans*-hex-3-enol is described and certain melting-point anomalies are removed.

The infra-red absorption spectra of *cis*- and *trans*-hex-3-enol are examined and the preparation of *cis*- and *trans*-pent-3-enol is described.

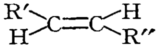
In connection with our investigations of the sterochemistry of cinerone (Harper, *J.*, 1946, 892; Crombie and Harper, *Nature*, 1949, **164**, 534), jasmone (Crombie and Harper, forthcoming publication), and related compounds, it became necessary to have available specimens of the *cis*- and the *trans*-form of pent-3-enol and of hex-3-enol. One stereochemical form of hex-3-enol is widely distrubuted in nature as " leaf alcohol " (Walbaum, *J. pr. Chem.*, 1917, [ii], **96**, 245; Takei, Sakato, Ono, and Kuroiwa, *J. Agric. Chem. Soc. Japan*, 1938, **14**, 709; Bohnsack, *Ber.*, 1941, **74**, 1575; 1942, **75**, 72; 1943, **76**, 564). It is usually isolated from green-tea oil or from the tailings of Japanese peppermint oil, in which it occurs as the phenylacetate, and is used in perfumery since it possesses the characteristic smell of green grass and leaves. Although its structure as a hex-3-enol is fully established, its stereochemical configuration has been the subject of dispute (Takei, *ibid.*, 1940, **73**, 950; Stoll and Rouvé, *ibid.*, p. 1358). The synthesis of "leaf alcohol" by Stoll and Rouvé (*Helv. Chim. Acta*, 1938, **21**, 1542), through the semihydrogenation of hex-3-ynol with a colloidal palladium catalyst, strongly favoured the *cis*-configuration. This was further supported by the presence of bands at 1267 and 1655 cm.$^{-1}$ in its Raman spectrum (Ruzicka, Schinz, and Susz, *ibid.*, 1944, **27**, 1561; cf. Grédy, *Bull. Soc. chim.*, 1935, [v], **3**, 1101). However an isomeric sharper-smelling hexenol had been prepared by Ruzicka and Schinz (*Helv. Chim. Acta*, 1934, **17**, 1602) and by Takei, Imaki, and Tada (*Ber.*, 1935, **68**, 953) by Bouveault–Blanc reduction of ethyl sorbate, which was accepted as the stereoisomer of "leaf alcohol." The derivatives of this hexenol melted at lower temperatures than those of "leaf alcohol" (see the table; but for a more comprehensive list see Takei, Sakato, Ono, and Kuroiwa, *loc. cit.*), a fact which led Takei to reject the *trans*-configuration for the former and to regard it as the *cis*-, "leaf alcohol" becoming the *trans*-isomer.

Since the Bouveault–Blanc reduction of ethyl sorbate gave a poor yield we have prepared trans-*hex*-3-*enol* by the lithium aluminium hydride reduction of *trans*-hex-2-enoic acid.* This acid was made by the Knoevenagel condensation of *n*-butaldehyde with malonic acid, using triethanolamine as catalyst (Boxer and Linstead, *J.*, 1931, 740; Linstead, Noble, and Boorman, *J.*, 1933, 557). It is reasonable to assume that this reaction gives a *trans*-acid since Lane, Fentress, and Sherwood (*J. Amer. Chem. Soc.*, 1944, **66**, 545) prepared a pent-2-enoic acid from crotyl chloride, which from the conditions of its formation has the *trans*-configuration, and this was identical with the pent-2-enoic acid prepared by the Knoevenagel condensation of propaldehyde (Linstead, Noble, and Boorman, *loc. cit.*). It is therefore considered that this hex-2-enoic acid and the hex-3-enol prepared from it have the *trans*-configuration. This conclusion has been confirmed by Dr. F. Sondheimer (private communication; succeeding paper) who has obtained an identical hexenol by the reduction of hex-3-ynol with sodium in liquid ammonia, a process that is known to give the pure *trans*-ethenoid product (Campbell and Eby, *ibid.*, 1941, **63**, 216, 2683; Campbell and Campbell, *Chem. Reviews*, 1942, **31**, 90; Greenlee and Fernelius, *J. Amer. Chem. Soc.*, 1942, **64**, 2505).

This *trans*-hex-3-enol was clearly different from Ruzicka and Schinz's hexenol for it had a powerful but pleasant chrysanthemum-like odour and its derivatives melted at higher temperatures (see the table). The 1-naphthylurethane of the alcohol prepared by the Bouveault–Blanc reduction depressed both the melting point of the 1-*naphthylurethane* of our *trans*-hex-3-enol and that of "leaf alcohol." The identity of Ruzicka and Schinz's hexenol is not certain, but it may be a mixture of hex-3-enols and hex-4-enols, for the derivative melted rather unsharply. It is relevant that Goldberg and Linstead (*J.*, 1928, 2343) showed that sodium amalgam reduction of sorbic acid gave a mixture of hex-2-enoic and hex-3-enoic acids ("hydrosorbic acid"), which had previously been regarded as a homogeneous substance. Furthermore, Fischer and Wiedmann (*Annalen*, 1936, **522**, 1) state that reduction of sorbaldehyde with sodium in ethanol gives a mixture of hex-3-enol (~66%) and hex-4-enol (~33%).

Although the melting points of the 1-naphthylurethane and 3 : 5-*dinitrobenzoate* of *trans*-hex-3-enol were very close to those of the corresponding derivatives of "leaf alcohol," on admixture large depressions were observed. The p-*nitrophenylurethane* and the p-*diphenylylurethane* of *trans*-hex-3-enol, however, melted at higher temperatures than the corresponding derivatives of "leaf alcohol." "Leaf alcohol" is clearly not *trans*-hex-3-enol. Furthermore these melting points invalidate Takei's argument and there is no doubt that from the method of synthesis, the Raman spectrum, and by exclusion "leaf alcohol" is *cis*-hex-3-enol.

We have examined the tailings from the distillation of Brazilian peppermint oil (*Mentha Arvensis*) as a likely source of "leaf alcohol," although we are not aware of its presence having been previously recorded. Distillation gave fractions containing ester and the richest was hydrolysed to yield an exceptionally pure specimen of "leaf alcohol." The steam-volatile oily acid failed to crystallise when seeded with phenylacetic acid, from which it would appear as if "leaf alcohol" is not present as the phenylacetate in Brazilian peppermint oil.

The infra-red spectra of few *cis–trans* pairs of olefinic hydrocarbons have been measured, but it is now generally accepted that an absorption band at 10·3 μ. is due to the flapping vibrations of the hydrogen atoms about a *trans*-double bond of the type  $\overset{\mathrm{R'}}{\underset{\mathrm{H}}{>}}\mathrm{C{=}C}\overset{\mathrm{H}}{\underset{\mathrm{R''}}{<}}$

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* Following current Journal practice the carboxyl group is not numbered in this and other acids.

Properties of cis- *and* trans-*hex*-3-*enol and* -*pent*-3-*enol*.

		" Leaf Alcohol." *cis*-.	Product from $LiAlH_4$ reduction. *trans*-.	Product from Bouveault–Blanc reduction.
Hex-3-enol	B. p.	66—67°/19 mm.	52—53°/9 mm.	59—60°/12 mm.*
	n_D^{20}	1·4384	1·4374	1·4376
1-Naphthylurethane	M. p.	69—70°	69—70°	61—63°
3 : 5-Dinitrobenzoate	M. p.	49°	47—48°	28°
p-Nitrophenylurethane ...	M. p.	72·5—73·5°	84—85°	—
p-Diphenylylurethane ...	M. p.	91·0—91·5°	99·0—99·5°	—

		cis-.	*trans*-.
Pent-3-enol	B. p.	139—141°	136—137·5°
	n_D^{20}	1·4386	1·4340
1-Naphthylurethane	M. p.	88—89°	93°

* Data taken from Ruzicka, Schinz, and Susz (*loc. cit.*) and from Takei, Imaki, and Tada (*loc. cit.*).

(cf. Rasmussen, Brattain, and Zucco, *J. Chem. Physics*, 1947, **15**, 135). There is some evidence too that an absorption maximum at 14 μ. in an olefinic hydrocarbon is to be associated with a *cis*-double bond of the type $\begin{smallmatrix}R'\\H\end{smallmatrix}\!>\!C{=}C\!<\!\begin{smallmatrix}R''\\H\end{smallmatrix}$ (Anderson and Seyfried, *Analyt. Chem.*, 1948, **20**, 998; Hall and Mikos, *ibid.*, 1949, **21**, 422; Hampton, *ibid.*, p. 923). However, information on the infra-red spectra of olefinic *cis–trans* pairs other than hydrocarbons is very sparse. Elaidic acid (*trans*-) has a strong band at 10·3 μ. which is almost absent in oleic acid (*cis*-), and this band is also present in the spectrum of vaccenic acid (*trans*-). Both oleic and elaidic acid show absorption at 13·8—13·9 μ. (Rao and Daubert, *J. Amer. Chem. Soc.*, 1948, **70**, 1102). The infra-red spectra of *cis*- and *trans*-hex-3-enol therefore seemed of interest and were kindly determined by Miss I. M. Friedmann (see Figs. 1 and 2). The hydroxyl band at 9·5 μ. is strongly in evidence in both spectra, but the *trans*-alcohol shows a strong band at 10·3 μ. which is of very low intensity in the spectrum of the *cis*-alcohol, whereas the intensity of absorption at 13·9 μ. is markedly higher for the latter. These observations fall into line with the results quoted above and provide further evidence that " leaf alcohol " has the *cis*-configuration. Corresponding with the disappearance of the 10·3 μ. band characteristic of the *trans*-alcohol we find that a new band appears at 11·5 μ. in the spectrum of the *cis*-alcohol. There are also other minor differences between the two spectra. Observation of the bands at 10·3 μ., 11·5 μ., and 13·9 μ. may therefore be of considerable assistance in the assignment of geometrical configurations to compounds of the type $CH_2R\cdot CH{:}CH\cdot CH_2R'$, where R and R' may be other than alkyl groups.

Fig. 1.

cis-*Hex*-3-*enol* (*natural*).

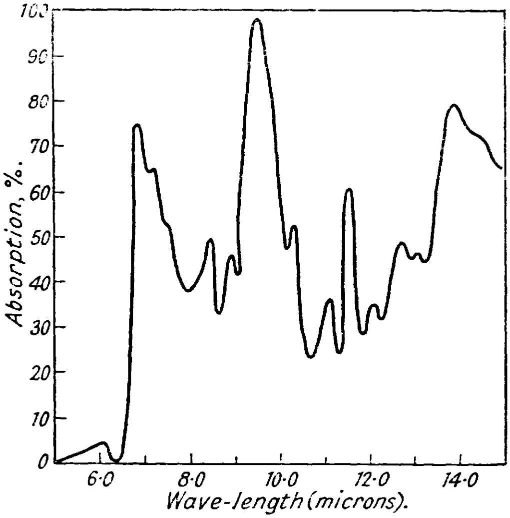
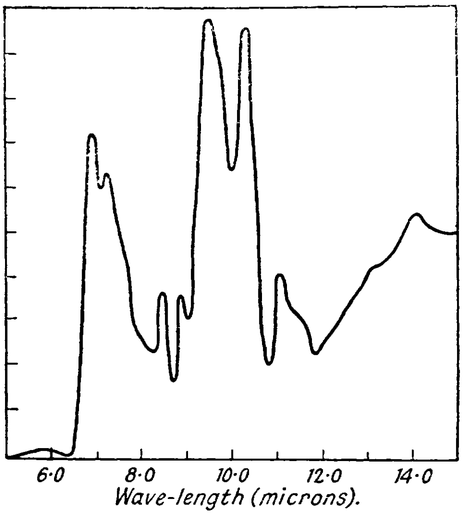


Fig. 2.

trans-*Hex*-3-*enol*.



Three preparations of pent-3-enol have been described in the literature. Goethals (*Natuurwetensch. Tijds.*, 1937, **19**, 184; *Bull. Acad. roy. Belg.*, 1937, [v], **23**, 721; *Bull. Soc. chim. Belg.*, 1937, **46**, 409) attempted to prepare pent-3-enol by the Bouveault–Blanc reduction of ethyl pent-2-enoate but even under the best conditions the product was a mixture containing some 25% of *n*-amyl alcohol. From the Raman data given by Goethals the unsaturated component appears to be *trans*. Goering, Cristol, and Dittmer (*J. Amer. Chem. Soc.*, 1948, **70**, 3314) have described the preparation of a pent-3-enol of unspecified configuration by the lithium aluminium hydride reduction of methyl pent-2-enoate. Unfortunately these workers failed to characterise their product by crystalline derivatives, but from the method of preparation of the pent-2-enoic acid (hydrolysis of but-2-enyl cyanide, derived from crotyl chloride) we consider that it is largely or entirely *trans*. Finally Normant (*Compt. rend.*, 1948, **226**, 733), by ring fission of 3-chloro-2-methyltetrahydrofuran with sodium, prepared a pent-3-enol which was not homogeneous. We had independently explored this route and shown that the product is a mixture of *cis*- and *trans*-pent-3-enol, and the evidence for this will be reported shortly. The mixed pent-3-enols were brominated in ether, and the dibromide dehydrobrominated by sodamide in liquid ammonia to give pent-3-ynol. From this, authentic pure *cis*- and *trans*-pent-3-enol have been prepared. *trans*-Pent-3-enol was made by reduction with sodium in liquid ammonia (cf. Sondheimer, *loc. cit.*), while the *cis*-isomer was obtained when the pentynol was hydrogenated over a palladium–calcium carbonate catalyst at room temperature. The two pent-3-enols had closely similar physical constants (see the table), but the 1-*naphthylurethane* of the *trans*-alcohol was a little higher-melting than the *cis*-derivative. The possibility that the *cis*-pent-3-enol contained a minor proportion of *trans*-isomer was considered, since it has been reported that semi-hydrogenation over Raney nickel or a supported nickel catalyst did not cause 100% *cis*-reduction (Henne and Greenlee, *J. Amer. Chem. Soc.*, 1943, **65**, 2020). However, the proportion must be quite small, for the *cis*-hex-3-enoic acid derived from it was pure and we have found that the *trans*-acid is readily detected in derivatives of the *cis*-acid.

EXPERIMENTAL.

Microanalyses are by Drs. Weiler and Strauss, Oxford. M. p.s are uncorrected. The infra-red absorption spectra were determined with a Grubb Parsons spectrometer using the pure liquids in a cell of 30—50 μ. thickness.

cis-*Hex-3-enol* (*"Leaf Alcohol"*).—The "leaf alcohol" used and a sample of its 3 : 5-dinitrobenzoate were generously presented to us by Dr. M. Stoll and had been isolated from Japanese peppermint oil. On redistillation the main portion of the alcohol had b. p. 65—67°/19 mm., n_D^{20} 1·4384. We prepared the 1-naphthylurethane, m. p. 69—70°, which crystallised as colourless needles from light petroleum (b. p. 60—80°), in which it was rather more soluble than the *trans*-derivative. In a search for derivatives differing in m. p. from those of *trans*-hex-3-enol we prepared also the p-*nitrophenylurethane* as colourless crystals of uncertain shape [from light petroleum (b. p. 40—60°)], m. p. 72·5—73·5° (Found: C, 59·0; H, 6·1; N, 11·1. $C_{13}H_{16}O_4N_2$ requires C, 59·1; H, 6·1; N, 10·6%), and the p-*diphenylylurethane* as colourless prisms [from light petroleum (b. p. 80—100°)], m. p. 91·0—91·5° (Found: C, 77·2; H, 7·25. $C_{19}H_{21}O_2N$ requires C, 77·25; H, 7·2%).

The sample of the high-boiling fraction of Brazilian *Mentha Arvensis* oil, kindly supplied by Messrs. W. J. Bush & Co., had b. p. above 200° and a portion (220 g.) was therefore roughly fractionated in vacuum to give: (i) b. p. up to 100°/20 mm. (11 g.), (ii) b. p. 100—120°/18 mm. (85 g.), (iii) b. p. 135—150°/18 mm. (54 g.), and (iv) b. p. 150—165°/18 mm. (52 g.). Fractions (iii) and (iv) gave saponification equivalents corresponding to 31 and 45% of ester respectively, calculated as hexenyl phenylacetate. Fraction (iv) was hydrolysed by adding it in portions to a warm solution of potassium hydroxide (20 g.) in water (75 ml.) and completing the hydrolysis by heating the mixture on the steam-bath for 2 hours. Next day the hydrolysate was steam-distilled and the first 400 ml. of distillate were extracted with ether. The extract was dried (K_2CO_3) and distilled through a short column to give "leaf alcohol" (6·2 g.), b. p. 154—157°, n_D^{20} 1·4383. The 1-naphthylurethane, m. p. 71·0—71·5°, was slightly purer than that prepared from Dr. Stoll's hexenol, crystallising more readily in superior form, but gave no m. p. depression on admixture. Continued steam-distillation yielded a yellow oil, b. p. above 200°, evidently a neutral constituent of the original oil. The alkaline solution was then acidified and again steam-distilled, to yield an oily acid which did not crystallise when seeded with phenylacetic acid. It has not been further examined.

trans-*Hex-3-enol*.—*trans*-Hex-2-enoic acid was prepared by the method of Linstead, Noble, and Boorman (*loc. cit.*) and purified by partial freezing and rejection of the liquid layer. An ethereal solution of the acid (2·80 g.) was added slowly to lithium aluminium hydride (0·95 g.) dissolved in anhydrous ether (50 ml.). The reaction was completed by refluxing for one hour, cooling, and addition of water to destroy the excess of lithium aluminium hydride. The ethereal layer was washed with dilute acid and alkali, and on distillation gave trans-*hex-3-enol* (1·61 g.), b. p. 51—53°/9 mm., n_D^{20} 1·4374 (Found: C, 72·0; H, 12·2. $C_6H_{12}O$ requires C, 71·9; H, 12·1%). The 1-*naphthylurethane* formed needles (from light petroleum), m. p. 69—70° (Found: C, 75·8; H, 7·2; N, 5·6. $C_{17}H_{19}O_2N$ requires C, 75·8; H, 7·1; N, 5·2%), and when admixed with the 1-naphthylurethane of *cis*-hex-3-enol (1 : 1) melted at once when placed in a bath at 58°. The 3 : 5-*dinitrobenzoate* crystallised from light petroleum (b. p. 40—60°) in a freezing mixture and after one crystallisation had m. p. 43—46°; four recrystallisations raised this to m. p. 47—48° (Found : C, 53·6 ; H, 4·95 ; N, 9·5. $C_{13}H_{14}O_6N_2$ requires C, 53·05 ; H, 4·8 ; N, 9·5%). The p-*nitrophenylurethane* had m. p. 84—85° (Found : C, 59·0 ; H, 6·15 ; N, 11·0%), and the p-*diphenylylurethane* had m. p. 99·5° (Found : C, 77·3 ; H, 7·15%) [these derivatives were prepared from *trans*-hex-3-enol made by a new method (to be published) which gave a 1-naphthylurethane and 3 : 5-dinitrobenzoate identical with those described above]. The anthraquinone-2-carboxylate, in our hands, proved an unsatisfactory derivative ; it was formed in low yield, was difficult to obtain crystalline, was photosensitive, and often showed a double m. p. (49—50° and 68—70°).

Hexenol from the Bouveault–Blanc Reduction of Ethyl Sorbate.—We are indebted to Prof. L. Ruzicka for the gift of a small specimen of the 1-naphthylurethane of this hexenol (cf. Ruzicka, Schinz, and Susz, *loc. cit.*). It sintered at 59—60°, melted to a turbid yellow melt at 61—63·5°, which became clear at 64·5°.

Pent-3-*ynol.*—The *cis-trans*-mixture of pent-3-enols (74 g.), prepared by the ring fission of 3-chloro-2-methyltetrahydrofuran, was diluted with ether (75 ml.), and bromine (141 g.) added dropwise, the temperature being kept below 25°. The ether was then sucked off by a water pump. If the temperature is allowed to rise much above 25° there is a tendency for hydrogen bromide to be eliminated with the formation of 3-bromo-2-methyltetrahydrofuran. Meanwhile sodamide was prepared by dissolving sodium (70 g.) in liquid ammonia (1·5 l.) in the presence of an iron catalyst (Vaughn, Vogt, and Nieuwland, *J. Amer. Chem. Soc.*, 1934, **56**, 2120). The 3 : 4-dibromopentanol was then added rapidly to the stirred solution of sodamide in liquid ammonia and stirred for 4 hours. A layer of ether was then added and the ammonia allowed to evaporate overnight. Next morning ammonia solution (*d* 0·880) and then water were added ; the aqueous layer was thoroughly extracted with ether, and the bulked extracts were washed and dried. Fractional distillation gave pent-3-ynol (24·3 g.), b. p. 154—157°, n_D^{20} 1·4554 (Found : C, 69·5 ; 69·4 ; H, 9·95, 9·7. Calc. for C_5H_8O : C, 71·4 ; H, 9·6%). The 1-*naphthylurethane* formed needles [from light petroleum (b. p. 60—80°)], m. p. 119° (Found : C, 76·0 ; H, 6·1. $C_{16}H_{15}O_2N$ requires C, 75·9 ; H, 6·0%). A considerable quantity of a bromopentenol (3- or 4-bromopent-3-enol), containing vinyl bromide, was recovered from the higher-boiling fractions, b. p. 99°/14 mm., n_D^{20} 1·4897.

cis-*Pent*-3-*enol.*—Pent-3-ynol (52·5 g.) was hydrogenated at room temperature and atmospheric pressure in the presence of a palladium–calcium carbonate catalyst (1·5 g. ; 10% of Pd) without use of a solvent. When 13·5 l. had been absorbed (Calc. for reduction to pentenol : 14·0 l.), filter cel was added, and the catalyst removed by filtration and washed with a little ether. Careful distillation of the filtrate gave cis-*pent*-3-*enol* (39·8 g.), b. p. 139—142°, n_D^{20} 1·4387 (Found : C, 69·4 ; H, 11·8. $C_5H_{10}O$ requires C, 69·7 ; H, 11·7%). The 1-*naphthylurethane* formed needles [from light petroleum (b. p. 60—80°)], m. p. 88—89° (Found : C, 75·2 ; H, 6·4. $C_{16}H_{17}O_2N$ requires C, 75·3 ; H, 6·7 ; N, 5·4%).

trans-*Pent*-3-*enol.*—Sodium (10 g.) was added to liquid ammonia (300 ml.) and then pent-3-ynol (5·0 g.) was added to the blue solution with stirring during 15 minutes. After stirring for a further 90 minutes ammonia solution (*d* 0·880) was added cautiously and the product set aside overnight to allow as much as possible of the ammonia to evaporate. Thorough extraction of the residue with ether, followed by washing, drying, and distillation, gave *trans*-pent-3-enol (3·0 g.), b. p. 136—137°, n_D^{20} 1·4340 (Found : C, 69·45 ; H, 11·6%). The 1-*naphthylurethane* formed needles, m. p. 93° (Found : C, 75·55 ; H, 6·55 ; N, 5·6%). A 1 : 1 mixture with the *cis*-1-naphthylurethane melted at 75—80°.

We gratefully acknowledge grants from the Agricultural Research Council, the Central Research Fund of the University of London, the Royal Society, and the Chemical Society which have defrayed the expenses of this investigation. We are also indebted to Prof. L. Ruzicka, Dr. M. Stoll, and Messrs. W. J. Bush and Co. for gifts of materials.

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